Personalised Immersive Soundscapes Supporting Children with Attention Deficit Hyperactivity Disorder (ADHD)

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Abstract

This thesis investigates the application of personalized, immersive soundscapes as a novel intervention strategy for Attention Deficit Hyperactivity Disorder (ADHD) in children. Employing advanced audio technologies and cognitive psychology, the research explores four sound conditions across two studies to discern the impact on cognitive and behavioural aspects of ADHD. Initial exploration involved pink noise, leading to personalised soundscapes presented in mono and binaural 3^{rd} order Ambisonic and concluding with the integration of auditory indicators as interactive, immersive soundscapes. Results indicate that pink noise demonstrated modest yet significant improvements in impulsivity control among ADHD participants. Personalized soundscapes, mirroring pink noise characteristics, further enhanced cognitive functions, notably attention, as evidenced by improved Hit Response Time (HRT) consistency and variability and reduced hand movement, indicating controlled hyperactivity. Binaural sound reproduction significantly influenced cognitive and behavioural control, with observed improvements in attention and impulsivity metrics. However, mixed interactions, especially regarding HRT variability and preservation errors, highlighted a complex relationship between binaural audio and ADHD cognitive processes. Binaural audio outperformed mono reproduction, particularly in the control group, showcasing its wider utility. The integration of auditory cues within soundscapes maintains controlled hyperactivity, evidenced by reduced hand movement. Simultaneously, increased head movement, coupled with improved impulsive control, suggests a potential enhancement of alertness. While these cues offer benefits, occasional distractions, more pronounced in the control group, underscore the need for careful design. These findings highlight the promising potential of personalized, immersive soundscapes as a non-invasive tool for children with ADHD, while underscoring the need for careful design to balance engagement and potential distraction. This research also paves the way for future explorations in psychoacoustic research for neurodevelopmental disorders.

to Emily & Myrto

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Declaration of Authorship

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as references.

1 Introduction

The prevalence and impact of Attention Deficit Hyperactivity Disorder (ADHD) in children worldwide has been a topic of much debate and interest in recent years. Characterised by persistent patterns of inattention, impulsivity, and hyperactivity, ADHD is not a uniform disorder; it presents heterogeneously across individuals. This variability is seen in its three primary sub-types: predominantly inattentive, predominantly hyperactive-impulsive, and combined. Each sub-type manifests distinct symptoms, affecting a child's cognitive and behavioural performance in unique ways, often impairing their academic achievement and social interactions. Moreover, ADHD is frequently accompanied by a range of comorbidities, including but not limited to learning disabilities, anxiety disorders, depression, and oppositional defiant disorder. These comorbid conditions can significantly influence the course and management of ADHD, adding layers of complexity to both diagnosis and treatment. Importantly, the manifestations of ADHD and its associated comorbidities can evolve over time, underscoring the need for dynamic and personalized intervention strategies.

Among various treatment modalities, non-pharmacological interventions have gained substantial attention, particularly those utilizing sensory stimulation to modulate cognitive and behavioural responses. This thesis explores the potential benefits of an innovative, non-invasive sensory intervention: personalized, immersive soundscapes and their effects on cognitive and behavioural performance in children with ADHD. The heterogeneity of ADHD suggests that personalized approaches might be particularly effective, catering to the specific needs and symptom profiles of individual children.

There is an ever-growing body of literature supporting the use of various auditory stimuli to enhance cognitive performance within the realm of ADHD. However, the application of these auditory elements, specifically personalised to the individual's preferences and spatially presenting these auditory elements, remains underexplored. This research aims to fill this gap, carving a niche in the intersection of ADHD interventions, immersive auditory stimulation, and personalisation. With a focus on the creation of immersive, personalised soundscapes as potential tools for cognitive and behavioural modulation, valuable insights into their effects on children with ADHD are provided.

This research provides the potential for personalised soundscapes to augment conventional treatment modalities for ADHD. With a shift towards personalised interventions in healthcare, the potential for this research to influence ADHD management is high. By providing a better understanding of how to optimise the use of sound in improving the cognitive and behavioural performance of children with ADHD, this work can contribute to developing more effective, personalised non-pharmacological interventions.

Several key contributions are made through this research. Firstly, a new, nuanced understanding of how soundscapes can influence cognitive and behavioural outcomes in children with ADHD is established. Secondly, the cognitive and behavioural benefits of personalising these soundscapes are illuminated. Thirdly, the differential impacts of mono and binaural sound reproduction are demonstrated, thereby advancing our understanding of how different modes of delivery can affect outcomes. Collectively, these contributions position this work as a significant step towards the next generation of non-pharmacological interventions for ADHD, underpinned by the power of personalised, immersive soundscapes.

1.1 Statement of Hypothesis

The principal hypothesis that forms the primary motivation of the research presented in this thesis is as follows:

Personalised, immersive soundscape therapy
will positively affect the cognitive and behavioural performance
of children with Attention Deficit Hyperactivity Disorder.

The primary terms of this hypothesis and how they relate to the thesis are explained as follows:

- **Soundscape**: The combination of all sounds originating from or contributing to a sonic environment, constructed on the principle of acoustic communication. Soundscapes emphasise the relationship between an individual's or a society's perception, comprehension, and engagement with the auditory surroundings.

- **Personalised Soundscape**: An auditory environment that has been specifically tailored or customized to an individual's preferences or needs.

- **Immersive Soundscape**: An auditory environment that surrounds a listener, fostering a sense of immersion and giving the impression of being enveloped or surrounded by sound. Immersive soundscapes employ 3D audio technology for capturing and reproducing spatialized sounds, which are then disseminated through a multi-speaker setup or delivered binaurally using headphones.

- **Attention Deficit Hyperactivity Disorder**: A common neurodevelopmental disorder that typically starts in childhood and can continue into adulthood, characterized by persistent patterns of inattention, hyperactivity, and impulsivity that interfere with functioning or development.

- **Cognitive and Behavioural Performance**: Two aspects of an individual's function and behaviour that are commonly assessed in psychology and neuroscience.

  Cognitive Performance refers to an individual's mental capabilities, including memory, attention, perception, and other skills that are necessary for acquiring, processing, and understanding information. Cognitive performance can be measured using various cognitive assessments or tests that evaluate these abilities.

  Behavioural Performance refers to an individual's observable actions, responses, and conduct in various situations. It involves the way an individual interacts with their environment, responds to stimuli, engages in various tasks, and exhibits emotional responses. This can be measured through direct observation, self-reports, and other assessment tools that track and evaluate an individual's behaviour.

1.2 Novel Contributions

The main aim of this research was to investigate how a controllable sonic environment can sensory stimulate individuals with ADHD.

The research presented in this thesis has produced the following novel contributions to the field:

- **A Scoping Review investigating the role of soundscape in Therapeutic Immersive Environments**: This provides an in-depth analysis of the soundscape contribution to therapeutic practices and identifies three main elements of therapeutic immersive soundscape referring to the sound content, spatial audio rendering and interactivity. Through the analysis, a mapping topology emerges that associates the therapeutic practice, the sound contribution, and sound components emerges. Also a validation of personalised experience in the interactive structures is also discussed.

- **Soundscape content integrating method**: A method has been developed for integrating soundscape content based on Noise Therapy to facilitate therapeutic practice for individuals with ADHD. This approach combines three natural soundscape samples, preserving the Noise Therapy therapeutic benefits while introducing an element of personal preference to the treatment, leading to the creation of a personalised rendition of the practice. Evaluation of this method involves a comparison of three sound conditions: silence, serving as the baseline, pink noise, introduced as a standardised content, and personalised soundscapes.

- **Headphone calibration method for dual mono and binaural 3^{rd} order Ambisonics**: A calibration method has been developed to ensure precise reproduction of sound level at the listener's ear for both dual mono and binaural 3rd order Ambisonics rendering, emphasizing the significance of detailed sound level reproduction in Noise Therapy. This method has been devised to facilitate the accurate delivery of sound level irrespective of the reproduction method utilized.

- **Evaluation of personalised soundscape content**: The prevalent approach in the studies examining sound-supported interventions for individuals with ADHD has been the application of predetermined sound content for all participants. This study shifts focus to exploring the possibility of tailoring sound content to individual preferences via the creation of a personalised soundscape. This is achieved through the application of a novel process termed as the *soundscape-content integration method*, which was developed within the scope of this research.

- **Evaluation of efficacy spatial audio reproduction method**: An evaluation has been conducted to assess the efficacy of spatial audio reproduction methods in enhancing cognitive and behavioural attributes in children with ADHD. The influence of stimulant exposure has been compared between dual-mono and binaural 3^{rd} order Ambisonic rendering in order to determine any potential additional benefits.

- **Evaluation of interactive auditory cues**: A method is designed to incorporate dynamic spatialised auditory cues into the personalised soundscape, with the objective of providing spatial guidance and additional stimulation for participants with ADHD. The aim of this approach is to enhance attention levels and mitigate hyperactivity.

- **Pink Noise assessment to children with ADHD**: Although the use of white noise is prevalent in ADHD support practices, pink noise has only been examined in two studies, yielding no positive outcomes. The objective of this research is not only to delve deeper into the potential advantages of pink noise, but also to employ it as a standardised point of reference for comparison.

1.3 Statement of Ethical Approval

The procedures and management of data used in this thesis have received approval from the Physical Sciences Ethics Committee at the University of York with reference number "Tsagkarakis270522". The application form is included in Appendix C.

1.4 Thesis Structure

The thesis starts by setting the theoretical framework, which expands over Chapters 2 & 3, aiming to give the reader a base of knowledge for the material covered in the remains of the thesis.

Chapter 2 delves into the complex origins of ADHD, discussing its neurological and structural brain characteristics linked with executive function traits. This segues into its association with the Go-NoGo paradigm, a common cognitive task in ADHD research, used to evaluate inhibitory control and attention levels. Subsequently, the chapter introduces the *fixed deficit model* and the *dynamic/contextual model*, two critical theoretical frameworks with diverging views on the nature of executive dysfunction in ADHD individuals. The chapter highlights the potential benefits of tailoring interventions to specific contexts via environmental stimulation, aiding ADHD individuals in symptom management and functional improvement. In support of this contextual-dependency approach, the chapter explores Noise Therapy, a method to adjust external stimulation to counterbalance underarousal. Finally, the chapter wraps up with an introduction to the moderate brain arousal (MBA) model and the stochastic resonance (SR) effect, providing the theoretical grounding for noise therapy.

Chapter 3 expands on the idea of environmental stimulation by highlighting *soundscapes*, which serve as a crucial element in this research. It presents a comprehensive view of soundscapes, detailing the various types, structural components, and their role in shaping sonic environments. It also illustrates their psychophysiological impact on humans through examples, thereby shedding light on the current state of *therapeutic soundscapes*. Additionally, the chapter introduces technological facets of soundscapes, including the principles of *interactivity* and *spatial audio*. It discusses immersive soundscapes, linking them to the broader concept of *immersion*. This discussion includes an understanding of human localization techniques and the use of *head related transfer functions* (HRTFs) for sound simulation in open environments.

Chapter 4 presents a Scoping Review that examines the existing body of literature on the therapeutic advantages of soundscape creation within Therapeutic Immersive Environments (TIE). It explores both the technological developments in immersive and interactive audio and the physiological and emotional characteristics of the soundscape content. It introduces the concept of Therapeutic Immersive Soundscape (TIS), a unified form of soundscape encompassing both therapeutic content and presentation technology. The chapter establishes a mapping topology for sound components used in health practices and categorizes the interactive structures based on their level of personalization. The therapeutic benefits of combining individual soundscapes into a purposeful TIS composition are also highlighted. It concludes by calling for novel strategies for constructing soundscapes and investigating the impact of spatial audio on the ADHD population, setting the stage for the methodology detailed in the following chapters.

Building on the observations of Chapter 4, Chapter 5 outlines the methodologies implemented in this research and is segmented into two parts. The first section details the techniques used to measure the dependent variables, initially focusing on cognitive and behavioural characteristics and their metrics. These metrics, derived from the collected measurements, facilitate the generation of additional metrics, collectively constituting the dependent variables of the study. Subsequently, these methodologies transform the data collection process into an engaging, game-oriented experience for participants. The games include a gamified version of Conner's CPT [1], called "Save the Mushroom", and a "spatial audio evaluation game", intended to familiarise participants to spatial audio and assess their spatial perception. Summaries of both dependent and independent variables are included for clarity regarding measurement metrics and sound conditions. The second section of the chapter shifts focus to the sound conditions of the experiment, which serve as the independent variables. It offers an overview of the methods employed to structure these variables, which involve selecting and post-processing sound content, executing the soundscape Auto-Mix algorithm, and crafting personalised soundscapes. A significant aspect of the experimental procedure is the assurance of accurate playback audio levels. To address this pivotal element, thorough calibration procedures for both mono and spatial audio formats have been laid out.

Chapter 6 presents a small-scale pilot test that took place to examine the technical consistency of the methods in real-life cases. The aim of the pilot tests is to collect feedback from participants on the technical and practical issues, usability, and fluidity of the processes.

Chapter 7 presents the main experiment undertaken in this research. The experimental framework comprises two distinct studies, each formulated to address specific hypotheses. Study I investigates the impact of personalised content over a span of three sessions, while Study II investigates the potential role of spatial audio and dynamic auditory cues as stimuli or distractors across two sessions. Common aspects evident in both studies are discussed, encompassing participant demographics, the experimental procedures deployed across two nations, and the soundscape content that underpins the individual study designs and procedures. Subsequently, thorough descriptions and analyses of both Study I and Study II are put forth, culminating in the disclosure of the findings and a discussion of the results.

Chapter 8 provides a conclusion to this thesis, encapsulating the principal findings of the presented work and recapitulating the hypothesis. The objectives of the thesis are re-evaluated, and a determination is made as to whether they have been fulfilled. Potential areas for future research, identified throughout the course of this thesis, are examined in further depth. Lastly, the scope of this thesis and its implications within the larger research context are deliberated upon.

2

Literature Review - Part I: Attention Deficit Hyperactivity Disorder

2.1 Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a prevalent neurodevelopmental disorder significantly affecting children and adolescents around the globe. In 2005, the American Psychiatric Association (APA) reported a global prevalence rate of about 5% in children and 2.5% in adolescents with ADHD [2]. Recent systematic research reveals that the global prevalence of ADHD is 7.6% in children aged 3 to 12 years and 5.6% in teenagers aged 12 to 18 years, indicating a notable incidence of ADHD diagnoses in these age groups [3].

ADHD is a heterogeneous disorder that presents in various forms and intensities, affecting individuals differently. It is characterized by persistent and age-inappropriate levels of inattention, hyperactivity, and impulsivity that interfere with functioning or development [2]. Additionally, ADHD is not only a behavioural disorder but also an emotional one, causing significant impairment in relationships and academic functioning, often persisting into young adulthood [4, 5].

The condition is commonly categorized into three distinct subtypes: predominantly inattentive presentation (ADHD-I), predominantly hyperactive-impulsive presentation (ADHD-H), and combined presentation (ADHD-C) [6]. ADHD-I is characterized by significant inattention and distractibility without the notable presence of hyperactivity or impulsivity. In contrast, ADHD-H is marked by predominant hyperactivity and impulsivity but less pronounced inattention. The combined presentation, ADHD-C, is where both inattention and hyperactivity-impulsivity are equally predominant. Each subtype presents unique challenges and may require tailored approaches for effective management [7, 8]. The recognition of these subtypes underscores ADHD's complexity and the need for individualized diagnostic and therapeutic strategies.

ADHD frequently co-occurs with other neurodevelopmental and psychiatric conditions, adding to its complexity. Common comorbidities include learning disabilities, anxiety disorders, depression, oppositional defiant disorder (ODD), and conduct disorder (CD) [9]. The presence of these comorbidities can significantly influence the course and treatment of ADHD. For instance, children with ADHD and comorbid anxiety may exhibit heightened inattentiveness due to increased worry or fearfulness. Similarly, the presence of ODD or CD can exacerbate the challenges in behaviour management [10]. It is also observed that the expression of ADHD symptoms and comorbidities can evolve over time. For example, hyperactivity symptoms often decrease with age, while inattentiveness tends to persist into adulthood [11]. The evolving nature of ADHD and its comorbidities necessitates a dynamic approach to treatment and support, which considers the changing needs of individuals over time.

For the purpose of this research, the objective is to establish a comprehensive understanding of the unique neurological and structural brain characteristics present in individuals with ADHD, and to explore their functional implications. Such understanding allows for a correlation of aetiologies with symptoms, and with the support of the theoretical framework, underscores the importance of external environmental stimulation. This is a key aspect of this research, as it explores the potential of soundscapes as a therapeutic form of stimulation.

Considering this, the following sections begin with an examination of the neurological characteristics of ADHD. It is important to identify the neurotransmitters involved in ADHD pathophysiology and explain the structural changes and abnormalities that influence the maintenance of optimal arousal and alertness levels. These alterations often result in *functional impairments*, particularly in areas such as *executive functioning* and *inhibitory control* [12, 13]. The Go-NoGo paradigm is frequently utilized as a cognitive task to probe these functionalities [14, 15, 16]. Following that, two primary contrasting theoretical frameworks are introduced: the *fixed deficit model* and the *dynamic/contextual model*. These frameworks provide insights into the nature of executive dysfunction in ADHD. Particularly, the dynamic/contextual model emphasizes that executive dysfunction is a dynamic process, varying based on context, circumstances, and environment. The model leads to the conclusion that personalised interventions, tailored specifically to contexts and enhanced by environmental support, can effectively manage ADHD symptoms. Noise therapy supports the contextual-dependency approach by manipulating external stimuli in the environment to compensate for under-arousal. It targets auditory stimulation to help regulate and amplify neural activity in the brain, thereby enhancing attention and cognitive performance. The chapter concludes with the Moderate Brain Arousal (MBA) model and Stochastic Resonance (SR) effect, providing the theoretical framework behind noise therapy.

2.1.1 Neurological Characteristics

Although ADHD is extensively researched, its precise aetiology remains unknown [17, 18]. The development of ADHD is believed to involve a combination of biological and environmental factors. Tarver et al. [19] provided an overview of the complex interplay between genetic and non-genetic factors, including gene-environment interactions.

In ADHD-related genetic research, particular attention has been given to genes involved in the regulation of dopamine, serotonin, and noradrenaline transmission, as these neurotransmitter systems are implicated in the pathophysiology of ADHD [20]. Dopamine, in particular, has received significant focus in ADHD research [21]. Genes encoding dopamine receptors (DRD4, DRD5), dopamine transporters (DAT1), and enzymes involved in dopamine synthesis have been extensively studied [22, 20]. Similarly, genes encoding serotonin and noradrenaline receptors (e.g., 5-HTT), transporters (SERT), and enzymes involved in serotonin synthesis and metabolism have been investigated [12, 20]. Furthermore, genes related to noradrenaline synthesis and transport (e.g., NET, DBH) have been explored [20, 22]. Variations in these genes have been associated with altered neurotransmitter signalling, which may contribute to the core symptoms of ADHD, such as inattention, hyperactivity, and impulsivity. The primary aim of these genetic studies is to identify specific genetic variations, such as single nucleotide polymorphisms (SNPs), that could impact susceptibility to ADHD or influence its severity and symptomatology [20]. Although the genetic variations associated with dopaminergic, serotonergic, and noradrenergic systems [1] are complex and their interactions are

[1] The noradrenergic, dopaminergic, and serotonergic systems enclose distinct neurons that produce the neurotransmitters noradrenaline, dopamine, and serotonin respectively, as well as their specific receptors to which these neurotransmitters bind.

not fully understood, some associations have been observed. The noradrenergic system plays a role in sensory alertness and the regulation of attentional processes. The release of noradrenaline enhances sensory processing and promotes a heightened state of arousal, enabling individuals to be more responsive to stimuli in their environment [23, 24]. On the other hand, dopaminergic systems are often associated with motor activation, executive control, motivation, and various functions of the prefrontal cortex [25, 26]. In the case of serotonin, neurons involved in its production are associated with the control of inhibition. Serotonin can have both inhibitory and excitatory effects, depending on the specific receptor subtype and brain region involved [12].

2.1.2 Structural Characteristics

ADHD is linked to structural abnormalities in several brain regions. Some of the key brain regions affected by ADHD include the prefrontal cortex (PFC), basal ganglia, and cerebellum [27], illustrated in Figure 2.1. The prefrontal cortex, responsible for executive functions such as decision-making, self-control, and working memory, often exhibits reduced volume and abnormal connectivity in individuals with ADHD [28]. Additionally, the basal ganglia, which play a role in motor control and reward processing, show alterations in volume and function [29]. The cerebellum, involved in motor coordination and timing, may also display structural and functional abnormalities [30]. Nakao et al. [30] provide evidence of differences in cortical thickness and delayed maturation in various brain regions among children and adolescents with ADHD compared to typically developing individuals.

The PFC is a fundamental region for attention, inhibition, emotion, and motivation, and disruptions in its functioning can contribute to the symptoms observed

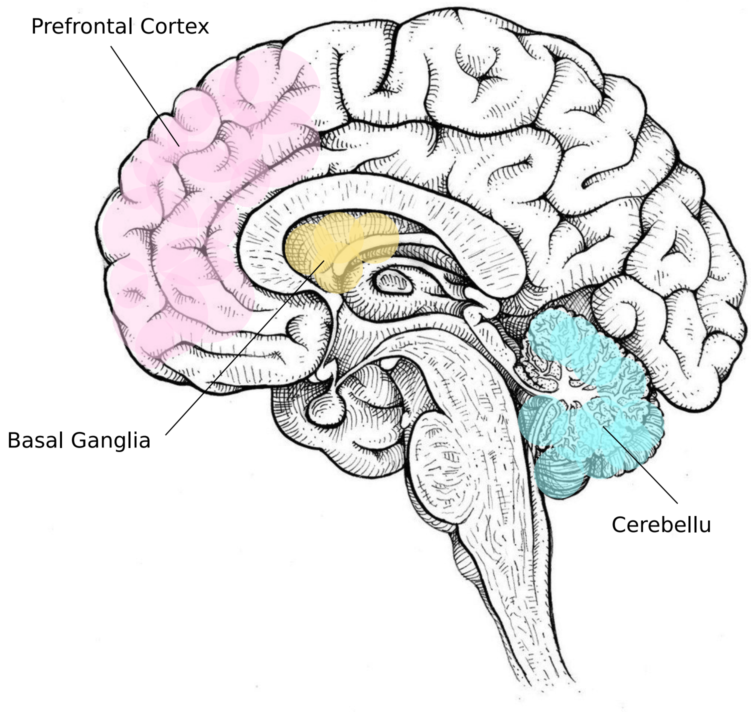


Figure 2.1: Key brain regions affected by ADHD: Illustration of human brain regions of the cerebellum, basal ganglia, and prefrontal cortex.

in individuals with ADHD. The functioning of the PFC is closely intertwined with the levels of noradrenaline and dopamine playing crucial roles maintaining an optimal level of arousal and alertness. Imbalances in these neurotransmitters, particularly in the PFC, can impact cognitive functioning and contribute to the symptoms of ADHD [31].

2.1.3 Functional Impairments

ADHD is characterized by considerable impairments in attention regulation, working memory, and inhibitory control. The cognitive processes, collectively known as Executive Functioning (EF), play a crucial role in goal-directed behaviour and cognitive adaptability [13]. The term 'Executive Functioning' encompasses a range of higher-order cognitive processes involved in planning, organizing, problem-solving, self-monitoring, and self-regulation. Individuals with ADHD often experience difficulties in these processes, which can have a significant impact on their daily functioning, behaviour, and academic performance [32]. A deficiency in inhibition often manifesting in impulsivity, primarily targets the neural circuits responsible for regulating actions and delaying gratification. It encompasses the challenges faced by individuals with ADHD in restraining impulsive behaviours, managing their behavioural responses, and resisting distractions or temptations [33, 24]. Individuals with ADHD frequently encounter difficulties in suppressing immediate or automatic responses, leading to impulsive behaviours and struggles with self-control.

The Go-NoGo paradigm is a frequently used cognitive task in ADHD research to assess inhibitory control and response inhibition [14, 15, 16]. In this task, participants are presented with a series of stimuli (e.g., letters or shapes) and are instructed to respond ('Go' response) when a specific stimulus appears while withholding their response ('NoGo' response) when a different specific stimulus appears. The task requires participants to inhibit their automatic response during the NoGo trials.

In individuals with ADHD, deficits in inhibitory control can be observed in the form of commission errors. Commission errors occur when individuals mistakenly respond to the NoGo stimulus, indicating a failure to inhibit their response. These errors suggest difficulties in suppressing or withholding impulsive responses, which is a characteristic feature of ADHD [12]. Furthermore, some studies have also reported higher reaction time variations and more omission errors compared to control groups, demonstrating that the Go-NoGo task is an appropriate test for examining inattention and impulsivity [1]. Several brain functions and regions are involved in the Go-NoGo task and the underlying inhibitory control processes [34]. Neuroimaging studies have identified the involvement of the PFC, particularly the anterior cingulate cortex (ACC), and the orbitofrontal cortex (OFC), in response inhibition [35]. The ACC is associated with error monitoring and detecting conflicts between response tendencies, while the OFC is involved in evaluating the motivational significance of stimuli and inhibitory control [36, 12]. Other brain regions implicated in response inhibition include the basal ganglia and the parietal cortex, which is involved in attentional processes. Additionally, the dopaminergic system, including the neurotransmitter dopamine, has been implicated in modulating inhibitory control and response inhibition [24].

Understanding the brain functions involved in the Go-NoGo task and their dysregulation in ADHD can provide insights into the neural mechanisms underlying inhibitory control and attention deficits in this disorder.

2.1.4 Theoretical Models of ADHD

Two theoretical frameworks represent contrasting perspectives on the nature of executive dysfunction and performance in individuals with ADHD: *the fixed deficit model* [37] and *the dynamic/contextual model*.

The *fixed deficit model*, applicable not only to ADHD but also to other cognitive and psychiatric disorders, embodies various theoretical frameworks such as Barkley's 'Model of Executive (Self-Regulatory) Functions' [33] and Sonuga-Barke's 'Dual Pathway Model' [38]. This model states that executive dysfunction in ADHD is a core, fixed cognitive deficit that remains relatively stable across various contexts and states and proposes that cognitive performance can be understood in terms of three parameters:

Energetic Factors: These include factors such as arousal and activation, which can impact the efficiency of cognitive processing [38, 39].

Effort: The model suggests that people with ADHD may be less willing to expend cognitive effort compared to those without the disorder [38, 39].

Cognitive Strategy: This refers to how an individual approaches a task, including their use of working memory and attention resources [33, 37].
In the context of ADHD, the fixed deficit model proposes that these three parameters are ‘fixed’ or relatively consistent for each individual and relatively stable across different contexts and states. This means that a person with ADHD may consistently demonstrate lower arousal, less willingness to expend effort, or less efficient cognitive strategies compared to someone without the disorder associated with the characteristic symptoms of ADHD. The focus is on identifying and addressing the underlying cognitive impairments that are assumed to be stable and independent of contextual factors [37]. However, this approach tends to overlook contextual factors like the variability in symptoms; an individual with ADHD may exhibit better attention and self-regulation during one-on-one interactions but struggle in a busy classroom environment or in the case of contextual influence where ADHD case may display heightened hyperactivity and impulsivity during unstructured recess time but exhibit better self-control and attention during structured academic tasks [37].

On the other hand, the *dynamic/contextual model* challenges the notion of executive dysfunction as a fixed deficit in ADHD. Instead, it emphasizes that executive functions are dynamic processes that can vary from state to state and setting to setting. This model suggests that performance on executive tasks can fluctuate depending on context, circumstances, and environment. It implies that symptoms of ADHD are not simply the result of a static neurological deficit but can be exacerbated or mitigated by various environmental factors. For example, an individual might be able to maintain focus well in a stimulating, high-interest situation but struggle in a less engaging setting. By acknowledging the role of context and state factors, the dynamic/contextual model provides a more comprehensive understanding of cognitive and performance deficits in ADHD [40, 37]. The dynamic/contextual model is in line with theories that describe neuropsychological impairment in ADHD as a secondary outcome, primarily stemming from issues within the foundational systems related to motivation and energy [37]. These theories highlight the dynamic nature of ADHD and emphasize the influence of contextual and state factors on cognitive functioning and performance. There is an increasing interest in these dynamic/contextual models due to the limitations of fixed deficit models. The recognition of ADHD symptoms as context-dependent and influenced by motivational and energetic processes provides a more comprehensive understanding of the condition [37]. Various contextual factors can influence the expression of ADHD symptoms, including task demands (the complexity, novelty, and structure of tasks), environmental stimuli (such as distractions), social context (social interactions and social expectations), emotional states (difficulties in emotional regulation), reinforcement and motivation (availability and immediacy of rewards or consequences) [40].

Understanding the context-dependency of ADHD symptoms has implications for treatment and intervention strategies. Tailoring interventions to specific contexts and providing environmental support, structure, and accommodations can help individuals with ADHD better manage their symptoms and improve their functioning in various situations.

2.2 Contextual Stimulation

The contextual-dependency approach suggests that ADHD symptoms can be influenced by external stimulation in the environment to compensate for under-arousal. Zentall et al. [41] state that the restless and hyperactive behaviour of children with ADHD can be seen as attempts to increase sensory and arousal input, as a type of self-stimulation, to reach their optimal level and, consequently, improve performance. According to this theory, individuals seek an optimal level of stimulation or arousal to perform their best on tasks. In line with the optimal stimulation theory, the hypoarousal model [42, 43] suggests that hyperactivity observed in individuals with ADHD is a self-regulatory mechanism used to counteract drowsiness and maintain an optimal level of arousal, attempting to stay awake, increase stimulation, and sustain attention. Similarly, the vigilance regulation model [44] highlights the role of vigilance fluctuations and arousal regulation in understanding ADHD symptoms, particularly inattention and hyperactivity as an attempt to increase stimulation and maintain arousal. While these models share the assumption that hyperactivity serves as a self-regulatory mechanism to improve hypoarousal in ADHD individuals, there is limited substantial evidence to support this assumption [45].

2.3 Noise Therapy

Noise therapy in ADHD correlates with the theory of contextual dependency, proposing that ADHD symptoms are not fixed deficits, but rather, they fluctuate depending on different contexts and settings. Within the scope of noise therapy, the objective is to provide individuals with ADHD with supplementary sensory stimulation or environmental noise. The rationale behind this approach is that increased stimulation may optimize their attention and performance. It is hypothesized that the infusion of extra noise or sensory input could intensify arousal levels, thereby enhancing cognitive function in individuals with ADHD [46]. Noise therapy, alternatively known as auditory stimulation therapy, is a non-pharmacological intervention which utilizes specific auditory stimuli to mitigate ADHD symptoms [46]. This therapy exposes individuals with ADHD to carefully calibrated auditory stimuli such as white noise, pink noise, or nature sounds [47]. The auditory stimulation is believed to help regulate and enhance neural activity in the brain, leading to improvements in attention and cognitive performance [48, 49]. While the precise mechanism responsible for the benefits remains unclear [50], it is the moderate brain arousal (MBA) model [51] and stochastic resonance (SR) effect [51] that offer the theoretical foundation for noise therapy. These models explain that auditory stimulation increases overall neural activation in the brain, promoting optimal arousal and enhancing attentional processes. Noise therapy offers a consistent and predictable sensory input that helps individuals with ADHD filter out irrelevant stimuli and maintain focus on relevant tasks. By incorporating noise therapy into treatment, it aims to create an environment that supports attention and cognitive functioning in individuals with ADHD.

2.3.1 Moderate Brain Arousal - Stochastic Resonance

The Moderate Brain Arousal (MBA) model is a recent theory that supports the beneficial effects of noise [52]. It postulates a connection between atten-

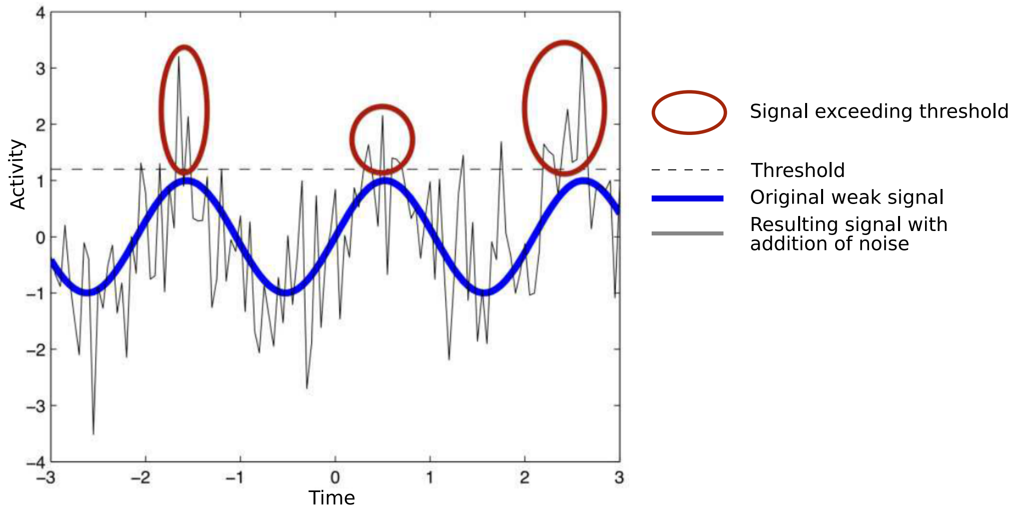


Figure 2.2: Stochastic resonance where a weak sinusoidal signal goes undetected as it does not bring the neuron over its activation threshold. With added noise, the same signal results in action potentials. Graph borrowed from [51]

tion, dopamine transmission, and the stimulation from external auditory noise, specifically white noise. The MBA model suggests that a low level of extracellular dopamine (DA) in individuals with ADHD leads to inadequate neural noise levels, causing suboptimal signal transmission. This conclusion aligns with the hypoarousal model for ADHD, which suggests that ADHD is associated with lower-than-average arousal levels. In order to counterbalance the low internal neural noise, the model suggests that individuals with lower arousal, such as children with ADHD, require more stimulation, i.e. external noise, for optimal cognitive functioning compared to their typically developing peers. It underscores the notion that the need for additional task stimulation is proportional to the hypoarousal of the dopamine system.

The MBA model utilizes the principle of Stochastic Resonance (SR) to explain why external noise stimuli play a crucial role in enhancing the attentional performance of children with ADHD [22, 52]. SR is a concept borrowed from psychophysics and occurs in nonlinear systems wherein the addition of random noise assists weak signals to surpass a threshold, thereby improving the detection of these weak signals or enhancing the system's response to them [51], as depicted in Figure 2.2.

Within the realm of cognitive functioning, SR has been examined in relation to sensory perception, signal processing, and information processing in the brain. It proposes that introducing optimal levels of noise can improve cognitive performance and heighten the detectability of weak signals or stimuli. The SR concept suggests that an optimal level of noise exists that can enhance neural processing and boost cognitive function. Insufficient noise may lead to diminished sensitivity or suboptimal performance, while excessive noise may interfere with information processing [53, 54]. SR has been demonstrated in multiple neural systems, where thresholds are present due to the all-or-nothing (bistable) nature of action potentials and can be modelled by a nonlinear activation function [55]. Action potentials, alternatively known as nerve impulses or spikes, are electrical signals generated by excitable cells, predominantly neurons, for information transmission within the nervous system. They play an integral role in cell-to-cell communication and are fundamental for transmitting sensory information, coordinating motor movements, and processing cognitive functions. Action potentials remain in a resting state (typically around -70 millivolts), and if a stimulus is strong enough to reach the threshold level (generally around -55 to -50 mV), it triggers the depolarization process leading to the peak of the action potential. Action potentials operate on an all-or-nothing principle, implying that they occur at full strength once the threshold is met. Furthermore, the frequency of action potentials can communicate the intensity or strength of the stimulus. SR can impact DA in the brain, not directly via dopamine release, but indirectly through an increase in neural noise.

The SR phenomenon asserts that moderate noise can enhance performance in systems that incorporate threshold levels in their process. Empirical studies indicate that individuals with ADHD tend to perform better in environments containing various types of auditory noise, such as classroom sounds, speech noise, rain sounds, and white noise [49, 56, 57, 58, 51] and require more noise to achieve optimal cognitive performance.

Examples of SR have been observed across multiple sensory modalities. For instance, random tactile stimulation was found to increase the sensitivity of skin receptors [59]. In auditory processing, white noise has been reported to enhance auditory detection in groups with normal hearing [50, 60, 61]. In the visual field, flickering noise improved the detection of weak signals [62]. It is crucial to highlight the cross-modal nature of SR, wherein weak visual signals became more detectable when participants were exposed to loud auditory white noise [53].

The novel aspect of the MBA model is that it proposes individual differences in the SR effect. The model proposes that cognitive performance in children with ADHD and inattentive children could benefit from additional noise stimulation in the environments, which increases noise levels within the neural system via the perceptual system. The model suggests that individual variations in the SR effect are related to attentional capacity, while individuals with ADHD require more external noise stimulation than typically developing children (TDC) to perform at their full potential [22]. This relationship is graphically represented in Figure 2.3 as inverted U-shaped curves, where cognitive or perceptual performance is plotted against noise intensity. Notably, the response from the sub-attentive group is shifted to the right, indicating a higher requirement for external noise.

MBA suggestions have been put to the test and validated in numerous contexts with different participant groups and tasks. Such tasks have included the verbal episodic recall test demonstrating the differential impact of auditory white noise on attentive versus inattentive children [63]. It found that inattentive children showed improved performance in the presence of white noise, while attentive children experienced a decline. This aligns with the MBA models proposition that neural noise levels associated with dopamine tone in inattentive individuals (like those with ADHD) are sub-optimal. According to the model, external noise can compensate for this low neural noise, leading to improved cognitive performance, or conversely, it can overload an already optimal system. However, its narrow focus on a specific type of cognitive task (memory performance) suggests the need for further research across different cognitive domains. This study provides practical evidence for the MBA models suggestion that SR can enhance cognitive performance by introducing optimal levels of noise into the neural system through the perceptual system. In a different study, the same author examined the effects of white noise on low-performing school children [52]. The findings underscore that the endogenous neural noise level in these groups is often sub-optimal, and optimal cognitive performance is achieved with a specific level of external noise, particularly for individuals with low dopamine levels. This study consolidates the MBA model's explanation that the beneficial effects of noise are mediated by SR. Moreover, it highlights that individuals with hypo-dopaminergic conditions like ADHD require more external noise for optimal cognitive functioning. The model was also validated by Helps et al. [50] in a verbal recognition and visuo-spatial working memory test in children with different attention capabilities. The results showed differential effects where children with sub-attentive capabilities benefited more from the white noise compared to their peers with normal or super-attentive capabilities. The study validated that a moderate sound level of 75 dB, relative to 65 dB and 85 dB, achieves optimal performance. One limitation of this study was its focus on a specific age group, suggesting the need for research across different developmental stages.

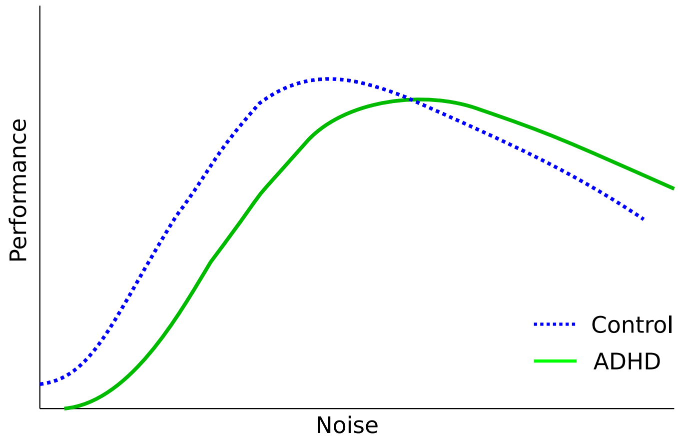


Figure 2.3: Individuals with ADHD require increased levels of noise for optimal performance compared to the control group. The figure depicts the occurrence of stochastic resonance phenomena, wherein cognitive test performance (y-axis) reaches its peak at moderate noise levels (x-axis). Performance declines at noise levels that are either too low or too high. In low dopamine (ADHD) neural systems, more noise is necessary to achieve optimal performance as compared to high dopamine (control) neural systems.

2.4 Summary

This chapter presents a detailed examination of the neurophysiological and structural brain differences associated with ADHD, emphasizing their impact on executive functions. It highlights the dysregulation of neurotransmitters such as dopamine, noradrenaline, and serotonin, each associated with specific cognitive functions. Structural brain disparities are primarily evident in the prefrontal cortex, basal ganglia, and cerebellum and can result in functional impairments, especially in executive functioning and inhibitory control.

The chapter discusses the utility of the Go/No-go paradigm in ADHD research for assessing key symptoms like response characteristics and inhibitory control. Two major theoretical approaches to understanding executive dysfunction in ADHD are presented: *the fixed-deficit model*, which sees ADHD cognitive deficits as fairly consistent, and *the dynamic/contextual model*, which suggests that behaviours and symptoms can vary based on context and environment.

Noise therapy adapts a variety of noise content for environmental stimulation. The MBA model utilizes the principle of SR to explain how external noise stimuli can critically enhance attentional performance in children with ADHD. The MBA model underlines individual differences in the SR effect and specifically notes that the ADHD population require additional noise stimulation in the environment for optimal performance.

From a different standpoint, optimal external sound stimulation can positively affect the three primary neurotransmitters, subsequently improving executive function in ADHD. This comprehension is crucial for this research, as it suggests the creation of auditory environments as potential interventions to enhance cognitive performance in individuals with ADHD. Therefore, building on the understanding of neurophysiological characteristics and theoretical frameworks of ADHD, the following chapter will delve into the theoretical, technical, and therapeutic aspects of soundscapes as consciously constructed sonic environments designed for stimulation.

3 Literature review - Part II: Soundscapes

3.1 Introduction

ADHD functional impairments emerge as symptoms which, according to the dynamic/contextual model, are influenced by changes in the environment and context. This research proposes the utilization of soundscapes as environmental stimulation, serving as a direct therapeutic intervention for children with ADHD. Soundscapes reflect the auditory information shared between the sonic environment and the individuals who experience it. In this research, soundscapes are presented as an integration of sound content and the technologies involved in structuring this content, facilitating real-time customization, and employing reproduction methods to deliver it to the participants. This integrated, holistic approach to the formation and delivery of soundscapes, designed specifically for therapeutic purposes, gives rise to the concept of *Therapeutic Immersive Soundscapes* (TIS), further elaborated in chapter 4.

Initially, a theoretical understanding of soundscapes is essential to establish a framework that incorporates key concepts of *acoustic ecology* and *acoustic communication* with the types and structural elements of sonic environments created through compositional means. Attention is given to distinguishing between 'noise' and 'sound' within the soundscape context. Subsequently, the concept of *therapeutic soundscapes* is introduced, highlighting the physiological effects of soundscapes on human autonomic functions and extending to psychological benefits.

The technological aspects of soundscapes are then discussed, beginning with *interactivity* and concluding by discussing *immersive soundscapes.* Immersive soundscapes, grounded in the broader concept of *immersion* and the technical field of *spatial audio*, encompass the fundamental understanding of human sound localization.

3.2 Soundscape Theory

The theory of soundscapes, first proposed by Canadian composer and environmentalist Murray Schafer, examines the acoustic environment as a holistic entity, incorporating not only the aesthetic or musical aspects but also the ecological and sociocultural perspectives [64]. As the pioneer of 'Acoustic Ecology', Schafer investigates the relationships between humans and their environments, mediated by sound. He introduced the term 'soundscape,' which represents the combination of all sounds within a specific area, akin to how a landscape portrays an area's visual characteristics [65]. In his book 'Acoustic Communication,' Barry Truax delves into individual perception, defining a soundscape as a sonic environment with an emphasis on its perception and comprehension by an individual or society [66]. Davis et al. [67] summarizing from the World Soundscape Project [66], define soundscapes as "the totality of all sounds within a location with an emphasis on the relationship between individuals or society's perception of, understanding of and interaction with the sonic environment." Bernie Krause, co-founder of "Soundscape Ecology" or 'Ecoacoustics,' developed a taxonomy for sounds within a soundscape. He coined the terms ‘geophony’ for sounds originating from the natural environment, such as wind or water, ‘biophony’ for sounds created by biological entities, including birds and insects, and ‘anthrophony’ for sounds produced by humans, both intentionally (as in music or speech) and unintentionally (like the noise from machines or traffic) [68].

In addition to these soundscape descriptions, it is crucial to consider how they are perceived by individuals. Human perception of soundscapes is a subjective experience that varies greatly depending on one’s cultural background, personal experiences, and current psychological state [67, 64]. For instance, the sound of a passing train may be perceived as a stressful cacophony to some, while others might find a rhythmic, almost musical quality in the same sounds. Furthermore, the context in which a soundscape is experienced plays a significant role in its perception [69, 70]. The acoustic environment of an area can change dramatically based on factors such as its physical characteristics (urban vs. rural), the time of day, and the prevailing cultural and social atmosphere. For example, the daytime city park soundscape buzzes with children’s laughter and birdsong, while its nighttime counterpart, with rustling leaves and distant urban sounds, evokes solitude and contemplation.

3.2.1 Types of Sonic Environments

Schafer introduces several characteristics to differentiate various types of environments based on their acoustic qualities. He formulated the concepts of ‘hi-fi’ and ‘lo-fi; soundscapes, an analogy reflecting acoustic ecology’s inclination towards cacophony [65]. A ‘hi-fi’ (high fidelity) soundscape features a high signal to noise ratio (SNR), allowing noteworthy sounds to be easily distinguished amidst a relatively low level of background noise. Conversely, a ‘lo-fi’ (low fidelity) soundscape exhibits a low SNR, where high background noise levels tend to mask individual sounds, typically associated with urban environments. The ‘temporal aspects’ of a soundscape, as Schafer suggested, are characteristics that shift depending on the time of day, season, or year. These temporal changes can interact with each other, as Krause observes: “When a bird sings or a mammal or amphibian vocalizes, their voices appear to fit in relation to all of the natural sounds of the immediate environment in terms of frequency and rhythm” [69]. Similarly, the ‘acoustic quality’ of soundscapes denotes physical properties such as the propagation nature of sound in a given environment, background noise masking other sounds, or the absorption or echo of a sound. Finally, ‘cultural aspects’ and ‘emotional and psychological effects’ serve to categorize soundscapes by identifying sounds with cultural significance and noting their societal and historical contexts. This includes the understanding of how different soundscapes impact people’s moods, feelings, and behaviours. It is important to note that other taxonomies and frameworks for classifying soundscapes are also possible and recognized in the field. Different researchers and theorists have proposed alternative ways to understand and categorize sonic environments. These might include classifications based on functional uses of soundscapes (e.g., communication, aesthetic, informational) [71, 72], or even based on the listener’s subjective experience and interpretation [73]. Acknowledging these various approaches underscores the multifaceted nature of soundscape studies and the evolving understanding of how we interact with our acoustic environments.

3.2.2 Noise (Pollution)

Schafer characterizes noise as an *unwanted, unmusical, and loud sound that causes disturbance* [64]. While he does not explicitly differentiate between 'good' and 'bad' noise, one can argue that natural types of noise can have beneficial effects, a notion backed by various studies that compare the contrasting impacts of natural and urban noise. In the context of soundscapes, Schafer differentiates between 'sound' and 'noise'. He considers 'sound' as any auditory phenomenon, whereas he defines 'noise' as an unwanted sound. Consequently, a 'good' noise might be a subjective concept, largely dependent on the context and the listener's perspective. For instance, the sound of birds chirping could be enjoyable (good) for a person in a park but may be considered noise (bad) by someone attempting to concentrate on work at home.

Schafer's approach to noise pollution extends beyond sheer quantity (loudness) and delves into the quality (informational content). In his explorations of acoustic ecology, he underlines that noise pollution extends beyond mere volume of a sound. The 'quality' of the noise, its timbre, and the information it conveys significantly influence its impact. For example, a loud but musical performance might not be considered noise pollution because it has a pleasing quality and carries meaningful information (the music). Conversely, a consistent, loud, and discordant sound, even if not as loud as the music, might be perceived as noise pollution due to its disruptive quality and lack of useful information for the listener.

3.2.3 Soundscape Structure

The structure of a soundscape comprises several sonic categories, forming its fundamental components. Krause's taxonomy of sound sources, categorized into geophony, biophony, and anthrophony, helps classify these sounds based on their origin of the sound source. Schafer identifies three salient characteristics relating to these sources and their role within the soundscape [64]. Firstly, 'keynote sounds' serve as the background of a soundscape, often perceived subconsciously. They provide the base layer of a soundscape and can be likened to the hum of an air conditioner in an office or the rustling of waves at a beach. Secondly, 'sound signals' are consciously noticed foreground sounds. They are usually brief yet prominent, akin to the ringing of a phone or a specific bird's chirping. Third, 'soundmarks' represent the sonic equivalent of visual landmarks. These are unique sounds inherently linked to a specific location or community, such as the chime of a town clock or the ringing of a church bell. Drawing inspiration from Pierre Schaeffer's electroacoustic concept of the 'sound object' [74], Schafer introduced "sound events" as the smallest independent units in soundscape composition, each possessing a beginning, middle, and end structure.

3.2.4 Soundscape Composition

According to Truax, the real goal of the 'soundscape composition' is ".. the reintegration of the listener with the environment in a balanced ecological relationship" [75]. This form of composition employs environmental sounds to represent, recreate, or abstractly express a specific sonic environment. It entails more than merely utilizing field recordings as raw material; it necessitates the composer's engagement with the context and significance of the sounds. Schafer and Truax broadened the conceptual framework for understanding and creating soundscapes. Their approach to soundscape composition incorporates previously mentioned elements and characteristics while introducing further considerations specifically related to composing with environmental sounds. Schafer promotes the idea of 'ear cleaning' and 'soundwalks,' essential steps for listeners to enhance their listening skills and awareness of the sonic environment. Enhanced sound perception can guide the compositional process. Truax emphasizes the concept of 'acoustic communication', which focuses on ways sounds in a soundscape context communicate information, whether that information is about the physical environment, the activities within it, or the cultural context. Soundscape compositions can be designed to highlight or explore these communicative aspects [66]. Both Schafer and Truax highlight the necessity of considering the 'context and meaning' of sounds in soundscape composition. This includes both the original context in which the sounds were recorded, as well as the new context created by the composition. Regarding the 'transformation of sounds,' Truax also explores the use of digital signal processing techniques to alter environmental sounds [75]. While Schafer's methodology leans more towards 'found sound' and the preservation of original sounds' integrity [64], Truax advocates for the transformational process as a means to uncover novel facets of familiar sounds or to craft entirely unique sounds.

While there is a correlation between the general characteristics of soundscapes and the compositional elements emphasized by Schafer and Truax, the latter concentrates specifically on how these elements can be applied and understood in the context of crafting new art from environmental sounds.

3.3 Therapeutic Soundscapes

Schafer's concept of acoustic ecology, along with his introduction of 'lo-fi' and 'hi-fi' soundscapes, underlines his commitment to preserving the well-being of listeners and society at large. Therapeutic soundscapes utilize the restorative qualities of sound environments, contributing positively to human health and well-being.

Two prominent theories have emerged since the 1980s, explaining how certain environments, particularly natural ones, can facilitate psychological restoration. Rachel and Stephen Kaplan's Attention Restoration Theory (ART) suggests that interaction with natural environments can restore mental functioning and attention capacities, which often get depleted in everyday life [76]. ART distinguishes between two types of attention: directed attention, which requires effort and can fatigue over time, leading to cognitive performance decline, and involuntary attention, which is effortlessly engaged by inherently fascinating stimuli such as those found in nature. The theory asserts that spending time in natural environments can refresh cognitive functioning by engaging involuntary attention and allowing directed attention to rest. Roger Ulrich's Stress Reduction Theory (SRT) argues that natural environments can have a restorative effect on individuals under stress [77]. SRT postulates that exposure to nature or natural elements, either directly or through representations like images or sounds, can elicit a positive affective response, reduce negative emotions, and facilitate physiological stress recovery.

Recent studies have explored the psychological and physiological impacts of soundscapes, shifting focus towards their positive aspects and therapeutic applications [78, 79, 80]. Medvedev et al. [78] demonstrated that subjective responses to the acoustic environment could influence autonomic function, both during stress recovery and at rest. They found that the least eventful soundscapes resulted in a lower heart rate, while soundscapes perceived as pleasant produced lower skin resistance compared to those perceived as unpleasant. Similarly, Hume et al. [79] showed that listeners exposed to sounds judged as pleasant experienced a significant rise in respiratory rate (RR), while sounds deemed unpleasant tended to raise electromyography (EMG) levels. However, not all studies found a connection between physiological responses to soundscapes and their perceptual attributes. Erfanian et al. [81], for instance, reported wide variability and inconsistency in physiological responses associated with perceptual attributes.

Clinical environments have also tested soundscapes as a means to reduce procedural anxiety and pain. Diette et al. [82] found that presenting nature sights and sounds as a distraction significantly reduced discomfort associated with pain in patients. Similarly, Cutshall et al. [83] showed that music and nature soundscapes played during postoperative cardiac surgery significantly reduced symptoms of pain and anxiety, while also improving patient relaxation levels. A comparable effect was reported in a healthcare waiting room study by Watts et al. [84]. The psychological impacts of soundscapes have been explored in various studies. For example, a study found that a positive soundscape within a hospital environment, including natural sounds and occupational noises like tea trolleys, elicited positive feelings and emotions from patients and staff. Even so, subjective responses to the soundscape revealed both positive and negative views [85]. Nature sounds and human noises, such as voices or footsteps, often invoked soft fascination and stimulated encouraging, positive memories in patients with stress-related mental disorders [86]. Conversely, technological noises like traffic were generally perceived as negative and annoying.

Soundscapes have been demonstrated to support cognitive performance by enhancing focus, concentration, and information processing. Ratcliffe's review [87] noted that, despite some inconsistencies, nature sounds and soundscapes can subjectively and objectively improve mood and cognitive performance, as well as reduce arousal, especially after stress or fatigue. However, the impact of soundscapes on mood improvement has shown mixed results. Luton's experimental study [88] found that nature soundscapes did not increase positive mood or cognitive arousal. Furthermore, a nature soundscape with high acoustic variation negatively impacted performance in a mental arithmetic task when compared to a soundscape with low acoustic variation. Similarly, Newbold et al. [89] found that soundscapes with high acoustic variation could disrupt serial recall tasks and had no impact on mood. Despite these findings, students reported perceiving these soundscapes as beneficial for focus, calmness, stress management, and noise masking. On a positive note, natural bird sounds were found to rejuvenate perceived attention restoration and stress recovery in adults [90]. Additionally, Shu and Ma [91] found that exposing children to music, birdsong, and sounds of water features improved their reaction time and short-term memory, thereby confirming the restorative effects of soundscapes on children's cognitive performance.

Lastly, soundscapes are often used in environmental design to mask distractions, especially in office environments. Soft, unobtrusive background noises, such as white noise or nature sounds, are used to decrease speech intelligibility and thus limit distractions. Hongisto's model [92] suggests that masking speech in this way can enhance work performance in open-plan offices. In support of this, Abdalrahman et al. [93] found that using water feature soundscapes for masking resulted in increased levels of subjective satisfaction in the assessment of the open-plan office soundscape.

It is important to note that individual preferences, task requirements, and the specific characteristics of the soundscape can influence its effectiveness in supporting cognitive performance. Furthermore, soundscapes can evoke varying responses in different individuals. What might constitute an optimal soundscape for one person may not hold true for another [86, 94]. This underscores the significance of personal selection and customization.

3.4 Interactive Soundscapes

Interactivity significantly enhances the user experience by transitioning the user from a passive observer to an active participant, thus offering a more extensive range of therapeutic interactions [95, 96, 97]. In digital environments, interactivity refers to the real-time alterations of the content and the narrative it frames. Truax describes an "interactive system when the user provides data to control the algorithmic processes of the machine and is constantly evaluating and optimizing the results" [66, p. 222]. Rubio-Tamayo et al. [98] define it as the ability to receive information from all our senses and to construct and configure an alternate reality or simulate reality. Bianchi-Berthouze et al. [99] highlight the correlation between body movements and players' affective states, positing that these movements can significantly enhance player engagement. They identify interactivity as the crucial element linking body movement and engagement, suggesting that experiences become more engaging as the level of interactivity increases. Interactivity levels range from basic responsive systems to more complex and improvisational systems. Gifford and Brown [100] clarify that in a truly interactive system, both human and technological parties should be able to improvise rather than merely respond, hence defining interaction as mutual adaptation.

Interactive soundscapes pertain to auditory environments that the listener can manipulate [66]. These soundscapes consist of dynamic, adaptive audio content that changes based on user input or environmental factors. This can include physical movement, gestural interaction, touch-based interfaces, or other forms of user input that modify the auditory experience. Interactive soundscapes strive to emulate the natural acoustic environment, where the soundscape dynamically adjusts in response to the participant's actions and surrounding noises. This feedback loop is crucial for therapeutic practice as it provides feedback on the participant's current state in response to the methodology. An essential element of therapeutic practice is personalizing the experience; this is accomplished by adapting and customizing the interactive system's responses relative to the participant's state and personal characteristics. A comprehensive analysis of the personalization in the interactive structure has been conducted and is presented in the scoping review Section 4.4.3.

3.5 Immersive Soundscapes

An immersive soundscape envelops the listener in a multi-directional auditory environment, generating perceptions of direction, distance, and motion of sound sources. This design cultivates a sense of three-dimensional auditory space, enhancing the listener's feeling of 'presence' or 'immersion' within the audio environment (discussed in the following Section 3.5.1). The term often arises in contexts such as virtual reality, gaming, and spatial audio production, wherein audio elements originate from specific locations within a three-dimensional space [101, 102]. Immersive soundscapes are crafted using a blend of natural and artificial sounds, carefully placed in space to convey depth, movement, and realism. Listeners can experience these soundscapes through various audio systems, including headphones or loudspeaker-based surround sound systems. Complementary visual stimuli, such as projections or virtual reality and interactive technology, can augment the auditory experience.

Spatial audio technology underpins immersive soundscapes. The spatialization process, essential in creating an immersive soundscape, involves replicating acoustic cues realistically. This includes employing binaural or Ambisonic recording techniques [103, 104], as well as channel-based audio systems and object-based audio formats to accurately simulate human auditory perception [105, 106]. Another advanced technique, Wave Field Synthesis (WFS) [107, 108], also contributes to creating virtual acoustic environments, offering a different approach to auditory immersion. Hendrix and Barfield [109] demonstrated that spatial sound dramatically heightens individuals' sense of presence in virtual reality. In this light, any configuration of sound sources in a virtual environment, whether through binaural, Ambisonic, channel-based, or object-based audio systems, can be regarded as an element of an immersive soundscape. The design approach to immersive soundscapes often employs a landscape architecture model, allowing the designer to outfit a virtual space with a range of sound objects, thereby synthesizing 3D sonic topologies [110, p.259-273], [111, 112].

3.5.1 Immersion

Immersion is a term frequently associated with the development of extended reality (XR) technologies applied across various fields, ranging from gaming [113] and entertainment [114] to education [115] and healthcare [116, 117]. The definition of immersion often varies based on the specific application and frequently overlaps with terms such as 'presence' and 'engagement'. 'Presence' is commonly viewed as a perceptual dimension associated with the feeling of being physically surrounded by a virtual environment [118, 119, 120]. In contrast, 'engagement' is usually referred to as a cognitive dimension, indicating the level of involvement in a task, activity, or narrative [121, 122]. For example, Slater [123] associates presence with immersion, clarifying that it is less about belief and more about the illusion of "being there". It is a perceptual, rather than cognitive, illusion where the perceptual system identifies potential targets or threats, triggering an automatic and rapid response from the brain-body system, while the cognitive system acknowledges that this is not real. Brown and Cairns [124] suggest engagement as the initial phase of immersion, where the participant has to overcome the challenges of learning control and reconciling with other gamer preferences. Bianchi-Berthouze et al. [99] emphasize the role of body movements in determining the players affective state and hence consequently, enhancing their level of engagement. According to Witmer and Singer [125], immersion is defined as a perceptual experience wherein one perceives themselves to be enveloped by, included in, and interacting with a stream of stimuli and experiences. Conversely, Agrawal et al. [126] emphasize the cognitive process, suggesting that immersion can occur regardless of sensory stimulation, driven solely by a state of deep mental involvement.

The above approaches look at the psychological state of immersion. Agrawal et al. [126] express the uncommon opinion on immersion being the objective property of a technology or system and a set of system characteristics that can be objectively determined and quantified. As the system provides higher levels of multi-modal stimuli or displays, the higher the sense of immersion, without taking into consideration the individual's psychological state or mood [127].

Many interpretations of immersion tend to highlight a single aspect of the concept, missing the holistic multidimensional nature by focusing primarily on perceptual or cognitive elements [122].

Hyunkook Lee's work provides key clarifications and introduces a conceptual model of the immersive experience [122]. Lee suggests standardizing terminology to differentiate between ‘immersive experience’ (the psychological aspect) and ‘immersive system’ (the technological aspect), aiming to explain the cause-and-effect relationship between the system (approached as an independent variable) and the experience (approached as a dependent variable).

Lee’s model offers a four-tier conceptual hierarchy that constructs an immersive experience, as illustrated in Figure 3.1. The model starts from the individual and his/her ‘subjective factors’ such as internal reference, personal preference, and skills/knowledge, indicating that immersive experience is a personal construct. When an individual is introduced to an ‘immersive system’ with relevant ‘content’, the subjective factors form and influence three properties: These properties are ‘plausibility’ (the believability of a scenario), ‘interactivity’ (promoting task or motor engagement), and ‘interestingness’ (how engaging or meaningful the content is to the user).

Lee then constructs three core dimensions that constitute an immersive experience:

‘Physical Presence’ is associated with the feeling of ‘being there’ in a virtual environment, primarily driven by sensory stimulation and cognitive processes.

‘Social/Self Presence’ corresponds to the sensation of interacting with other virtual beings or objects, or experiencing oneself as a virtual entity within the virtual environment.

‘Involvement’ describes the extent to which a user engages with the content’s narrative or a specific task or activity within the immersive environment.

The top of the hierarchy is the “overall level of immersive experience”, which can be quantified and is determined by the combination of the three core di-

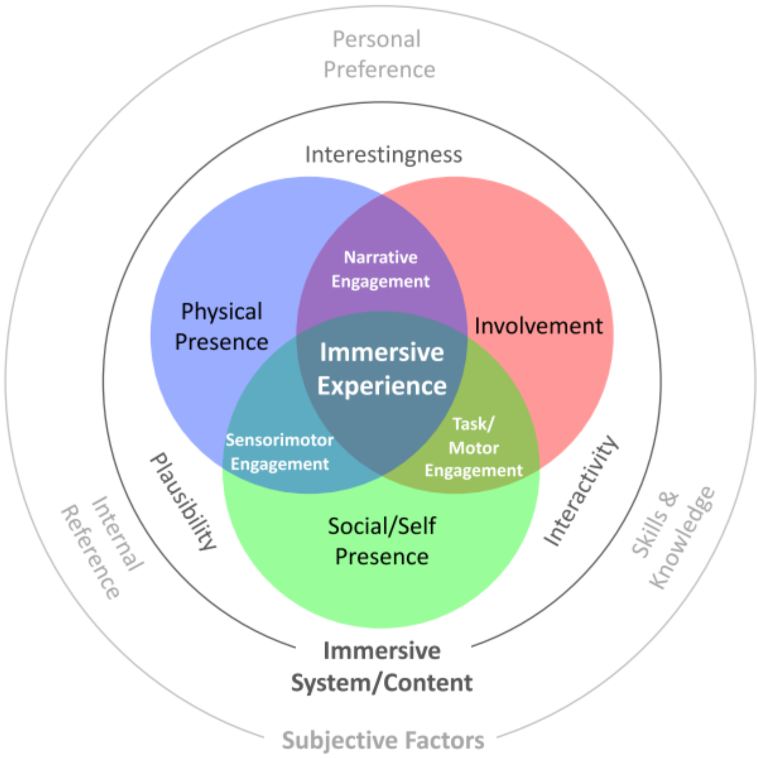


Figure 3.1: Hyunkook Lee's conceptual model of immersive experience in extended reality applications. [122, p-11]

mensions. The relative importance of each dimension may vary based on the application context.

In this research, a cross-modal paradigm is utilized, wherein immersive soundscapes are employed to foster a partial immersive experience in accordance with the requirements of the therapeutic process detailed in the ADHD theory, see Sections 2.2 and 2.3. These soundscapes are introduced as participants engage in a cognitive visual task, the Continuous Performance Task (CPT), further explained in Chapter 3.6.1. According to Lee [122], not all three core dimensions of an immersive environment need to coexist for an immersive experience to take place. Each dimension can independently create an immersive environment, while with a less powerful impact, but potentially yielding more targeted results, as is the case in this research. The objective is to transport participants into an immersive soundscape environment while maintaining their focus on the visual task.

This was pursued by enhancing the “interestingness” of the content, allowing participants to select it personally, and augmenting “plausibility” through the provision of realistic natural environments delivered via highly descriptive, binaural high-order Ambisonic [103] audio (referred to as the “immersive system”), which is described in detail in the following Section 3.6.1. At a higher level, soundscapes were employed to provide a sense of “physical presence” resulting from sensory stimulation offered by the immersive system [128].

The remaining two cardinal dimensions in Lee’s model, namely “involvement” and “Social/self-presence” (Figure 3.1), are not intentionally reinforced, adhering to this research’s therapeutic framework.

CPT results in limited involvement. Drawing from Calleja’s dimensions of involvement [129], CPT is identified as a cognitively demanding yet predominantly monotonous task. Minimal *decision-making* and *performative demand* are involved, and *narrative involvement* is not actively encouraged. In contrast, during the execution of the CPT cognitive task, an *affective involvement* is adopted by participants. This involvement pertains to the mood and emotional state evoked by the design and aesthetics of the personalised, immersive soundscape environment. Such an observation is consistent with the concept of passive immersion, as articulated by Eaton et al. [130], emerging from sensory simulation technology.

“Social/self-presence,” the sense of being in and interacting with another intelligent entity or object, is considered to constitute both perceptual and cognitive experiences [131]. Therefore, such elements are not reinforced in this experiment as they can be perceived as distractors.

3.6 Spatial Audio Psychoacoustics

3.6.1 Spatialization

Spatial sound reproduction crafts the illusion of a three-dimensional auditory environment, which can contribute to the participants sense of immersion. Despite the crucial role of audio, visual elements have been prioritized and more developed in the creation of immersive virtual environments (VE), as highlighted in the scoping review in Chapter 4. In the context of this research, spatialization refers to the techniques employed to binaurally reproduce personalized soundscapes.

As a common assumption, spatial sound could be said to have three main dimensional attributes: Firstly, the sense of spatial 'presence' versus 'absence' relates to the space or width the source occupies in the spatial field, reflecting the 'spaciousness' of the source. This attribute is referred to as Apparent Source Width (ASW) [132]. Secondly, it involves the specific angular direction on a plane or within a 360-degree sphere surrounding a listener. The localization direction refers to both horizontal and vertical planes [133]. Azimuth represents the horizontal angle measured from a reference direction, usually straight ahead of the listener (azimuth=0). Elevation indicates the vertical angle from the listener's horizontal plane to the sound source, denoting the source's height. For instance, an elevation angle of 90 degrees implies the sound is directly above the listener, while 180 degrees indicates below the listener's feet, and 0 degrees represents the horizontal plane. Lastly, it encompasses the perceived distance of the sound source, ranging from near to far from the listener.

3.6.2 Binaural Hearing

Binaural audio aims to replicate the natural perceptual cues inherent in normal listening to render 3D soundscapes perceived at the listener's eardrums. The achievement of immersive 3D audio depends on accurately reproducing the localization cues of the human auditory system. Digital technologies play a pivotal role in enhancing binaural audio's accuracy, flexibility, and spatial fidelity. Enhancements in binaural audio through digital technologies encompass a spectrum of methods. Digital Signal Processing (DSP) algorithms such as convolution reverb optimize sound reproduction for realism. Moreover, digital advancements extend beyond faithful reproduction to precisely position sound sources within a 3D space. Encoders employing Higher Order Ambisonics (HOA) or Vector-Based Amplitude Panning (VBAP) utilize sophisticated algorithms to manipulate audio signals, allowing for precise localization and movement of sound sources within spatial environments. Despite these digital advancements, analogue methods remain relevant in capturing spatial sound. Classic binaural recording techniques, such as the use of dummy head microphones or stereo microphone setups, exemplify the analogue approach to capturing spatial nuances. Baumgarte and Faller [134] refer to the applicability of binaural principles in both digital and analogue domains, highlighting the enduring significance of analogue techniques alongside digital innovations in binaural audio.

Binaural hearing refers to the ability of humans to perceive and locate sounds using both ears. This capability enhances our understanding of the surrounding auditory environment, providing a detailed interpretation of the world around us.

Understanding the basic psychoacoustic principles concerning how a sound wave, produced by an external source, interacts with the head and outer ears is crucial. This interaction alters the timing and intensity of the sound in both ears. These modifications in the acoustical stimulus provide valuable information about the position of a sound source relative to the listener's head [135].

Our perception of directional sound is guided by three primary mechanisms: the interaural time difference (ITD), the interaural level difference (ILD), and spectral cues. They involve detecting disparities in timing or phase, amplitude and spectral aspects between the ears. Each of these mechanisms contributes uniquely to our ability to localize sound. The essence of spatial perception lies in the brain's ability to integrate these differential signals received by both ears. This integration enables us to form a cohesive and accurate understanding of the spatial environment based on auditory cues [133].

This section will describe the vital role of binaural cues in identifying the origin of a sound. It will also explain how these binaural cues can be captured in the form of a Head Related Transfer Function (HRTF), which can be used to recreate the sensation of hearing with two ears using headphones.

3.6.3 Interaural Time Difference (ITD)

The physiological characteristics of the two ears situated on opposite sides of the head, along with the physical attributes of the head and torso, enable the brain to discern subtle differences in the arrival times of sound waves at each ear. This is referred to as the interaural time difference (ITD), the variance in a sound's arrival time between two ears. Take, for instance, a scenario where a sound source is positioned at a 45-degree angle off-centre axis (front-right) of the listener, the sound reaches the ipsilateral ear slightly sooner than the contralateral ear. The brain perceives this subtle disparity in arrival times, linked to the *angle of inci-*

dence θ, and utilizes this information to ascertain the sound source's direction (see Figure 3.2). The time difference reaches a maximum for sources directly at the side of the head, producing the maximum delay between the two ears at 0.65ms, termed 'binaural delay' [132, 136]. While humans can discern the direction of a sound source with a resolution of a few degrees on the horizontal plane, differentiating between front and rear sources presents a more complex challenge. This is because ITD and ILD are often similar for sounds coming from directly in front and directly behind the listener. To accurately identify whether a sound is coming from the front or the back, the auditory system relies more heavily on spectral cues provided by the shape of the outer ears (pinnae). These cues, resulting from the unique way our ears interact with sound waves, help in resolving the front-back ambiguity that ITD and ILD alone cannot distinguish. However, this front-back localization can be less straightforward and may not be as precise as horizontal localization. Equation 3.1 presents the ITD relative to the angle of incidence θ [137]. It incorporates the additional distance the wave travels around the head to reach the contralateral ear. This equation also assumes a spherical head shape and an approximate inter-aural distance of 18cm. ITD's effectiveness is frequency-dependent and is most pronounced for low-frequency sounds, typically below 1500 Hz. Specifically, ITD and the phase of the incoming wave are directly correlated. For a given frequency, a longer path to the contralateral ear results in increased phase lag for the sound wave reaching that ear compared to the ipsilateral ear. The auditory system detects this phase difference, using it as a localization cue. For frequencies below 1.5 kHz, where the sound's wavelength is larger than the listener's head, these phase differences offer reliable localization cues. However, as frequency increases (and wavelength decreases), the phase difference becomes less reliable for localization, and the Interaural Level Difference (ILD) becomes more important in sound localization.

$$\mathbf{ITD} = \frac{r(\theta + \sin(\theta))}{c} \tag{3.1}$$

where r = half the distance between ears (m)

θ = angle of arrival of sound from median plane (radians)

c = speed of sound ($340\,ms^{-1}$)

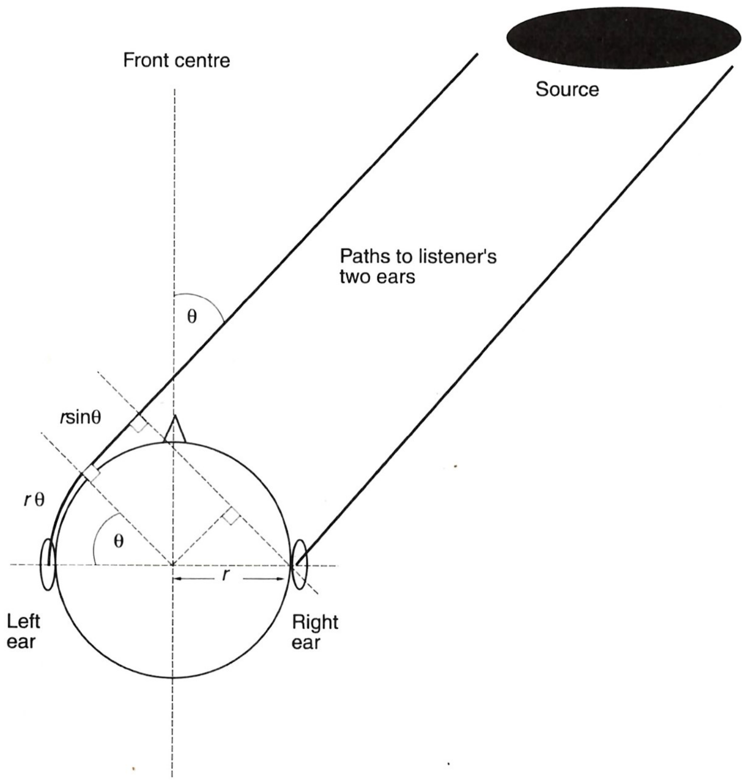


Figure 3.2: The Interaural Time Difference (ITD) for a listener depends on the angle on incident θ of the source, as this affects that additional distance that the sound wave has to travel to the more distant ear. [133]

3.6.4 Interaural Level Difference (ILD)

ILD refers to the difference in the intensity of the sound reaching each ear. When a sound source is located off axis of the listener, the presence of physical barriers such as the listener's shoulders, head, and outer ears causes the sound to be attenuated at the contralateral ear [138, 132]. The auditory system recognizes this difference in intensity between the ears and uses it as a cue to determine the sound source's direction. It is noteworthy that the utility of ILD as a localization cue is frequency-dependent, as seen in Figure 3.3. High-frequency sounds, with wavelengths shorter than the head's width, get obstructed by the head more easily, leading to greater ILDs. Therefore, ILDs serve as a more reliable cue for higher frequencies, as the head acts as a barrier, creating a sound shadow for these high-frequency waves. This obstruction leads to more significant intensity differences between the ears, which the auditory system uses to determine the sound source's direction. Conversely, low-frequency sounds, with their longer wavelengths, can diffract around the head more easily. This results in smaller ILDs, making ILD less effective for determining the direction of low-frequency sounds. Additionally, an object doesn't begin significantly scattering or shading sound until its size reaches about two-thirds of a wavelength. Hence, a minimum frequency exists beneath which the effect of intensity on localization becomes less meaningful. This frequency corresponds to when the head's size equals about a third of the wavelength ($\frac{1}{3}\lambda$). For a head diameter of 18 cm, this equates to a minimum frequency of approximately 637 Hz, as per formula 3.2. This factor is particularly significant when considering the differences in head size between adults and children, as it affects the frequency at which ILD becomes an effective cue for sound localization.

$$\mathbf{f}_{\mathbf{min}(\theta=\pi/\mathbf{2})} = \frac{1}{3} \quad \frac{c}{d} \tag{3.2}$$

where c = speed of sound ($340\, ms^{-1}$)

d = head diameter (0.18m)

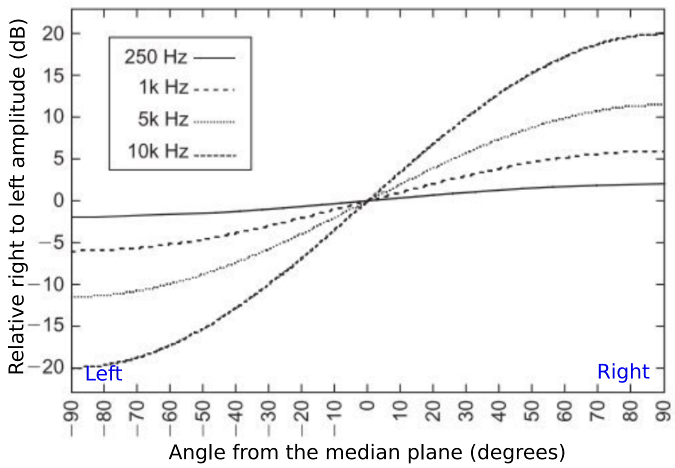


Figure 3.3: Interaural Level Difference - Function of angle and frequency [137]

3.6.5 Spectral Cues

The human auditory system integrates spectral cues with ITD and ILD to determine the direction of a sound source. Spectral cues are especially vital for vertical localization, determining whether a sound is coming from above or below, and differentiating front from back. Spectral cues refer to the changes in a sound's frequency content caused by its interaction with the listener's body. The pinna can induce complex reflections, resonances, and diffractions, leading to the amplification or attenuation of certain frequencies based on the direction of the sound [139, 140]. The combined interaction of spectral cues, ITD and ILD make up the 'Head-Related Transfer Function,' which is unique for any given sound source position and angle of incidence [132]. Empirical studies have shown that certain parts of the frequency spectrum may be enhanced or attenuated for particular source positions in the median plane. When the sound originates from in front of the listener, there is a peak in amplitude for low frequencies (250-500Hz) and high frequencies (above 13kHz). However, as the sound appears to move overhead, the prominent frequency shifts to around 8kHz. When the sound source is positioned behind the listener, the frequency peaks occur around 1.5kHz and 10kHz [141] Interestingly, familiarity with the sound content influences the spectral perception of the sound. Listeners typically perceive unknown sources as coming from behind [138].

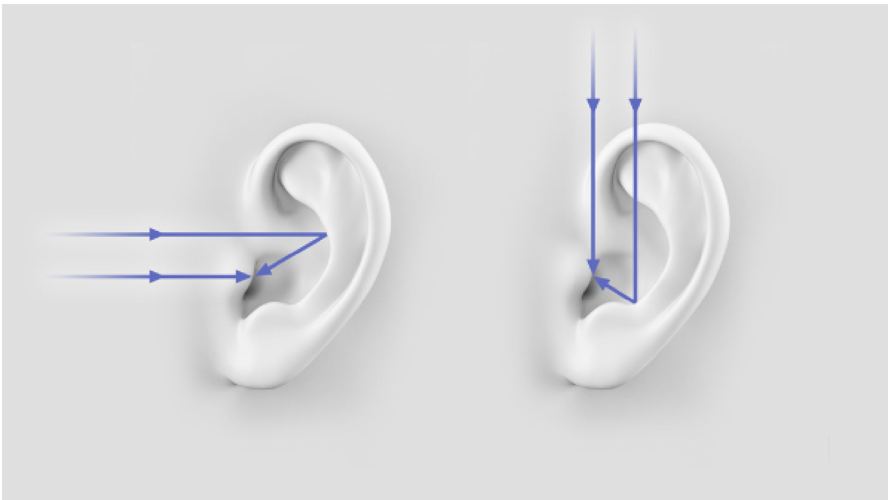


Figure 3.4: Spectral Cues - Elevation cues from pinna reflections [142]

3.6.6 Head-Related Transfer Function (HRTF)

Head-Related Transfer Function (HRTF) refers to the unique acoustic filtering effects that occur as sound waves travel around the human head and interact with the anatomy of the outer ears (pinnae), head, torso, and shoulders before reaching the eardrums [143]. In essence, HRTFs encapsulate how a human ear perceives a sound originating from a certain point in space, accounting for frequency-dependent variations in amplitude and time delay. These variations provide providing unique binaural information that the brain interprets as spatial cues [132, 144]. The modification of sound captured by the HRTF is crucial for pinpointing sound locations in our environment. Typically, HRTFs are characterized as a set of filters, one for each ear, for each sound incidence direction expressed in azimuth and elevation.

The individual's anthropometric features, especially the shape and size of the pinnae, vary significantly among humans, forming a unique 'acoustic fingerprint.' These individual features influence the spectral perception, resulting in highly individualized HRTFs.

Individualized HRTFs, measured directly from a person's ears, offer the most precise spatial sound reproduction for that specific individual, reflecting the unique acoustical properties of their head and ears. However, the processes of obtaining these individualized HRTFs can be both time-consuming and costly, thereby limiting their practical application in certain contexts [145].

Generalized HRTFs, on the other hand, derive from averages across numerous individual HRTFs or from an artificial head, also referred to as a dummy head or mannequin. Examples include the KEMAR or Neumann KU100 (Figure 3.5) [146, 147]. These HRTFs are not tailored to any specific individual. The main advantage of generalized HRTFs lies in their ease of measurement and their universal applicability. However, this comes at the cost of reduced spatial accuracy compared to individualized or personalized HRTFs [145]. Available generalized HRTF measurement datasets included in the SADIE-II database [148] provide spatial audio cues that are reasonably effective for most listeners.

Lastly, personalized HRTFs aim to bridge the gap between generalized and individualized HRTFs. They take a generalized HRTF as a basis and refine it to more closely align with an individual's acoustical characteristics. Various methods, including morphological measurements of an individual's head and ears or subjective listening tests, can be employed to personalize HRTFs. The aim of personalized HRTFs is to deliver a higher level of spatial accuracy than generalized HRTFs, without incurring the time and costs associated with measuring individualized HRTFs [149]

Figure 3.5: Binaural Microphones. Left: KEMAR dummy head[150]; Centre: Neumann KU 100 dummy head [151]; Right: Human Ear with locked-ear-canal measurement with miniature microphone [144].

Every HRTF measurement corresponding to a specific spatial position is associated with a *Head-Related Impulse Response* (HRIR). While the HRTF provides a frequency-domain representation of how sound is modified by the head and ears, the HRIR represents the alterations in the time-domain [144]. It captures how a sudden burst of sound (a 'sound impulse') from a given direction is transformed before reaching the ear. This transformation includes the time delays and level variations caused by both interaural differences and the spectral shaping effects of the pinnae and head. Thus, the HRIR is a temporal snapshot of the HRTF's impact on sound. The conversion between HRTF and HRIR (and vice versa) is achieved through Fourier transformations [144], allowing for a comprehensive understanding of spatial hearing from both frequency and time perspectives. A comparative illustration of this can be seen in Figure 3.6.

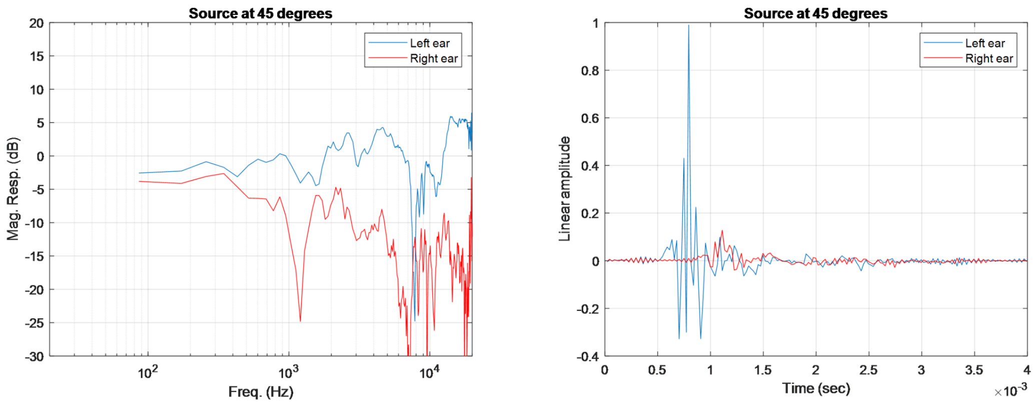


Figure 3.6: Left: HRTF represented in the frequency domain, displaying the amplitude and frequency differences between the left and right ears for a signal recorded at an azimuth of 45^o and an elevation of 0^o. Right, we see the HRIR representation of the same sound, but in the time domain. Both images were sourced from the Spatial Audio for Domestic Interactive Entertainment (SADIE) II database [148].

To capture these measurements, an individual typically sits with microphones placed in their ears, as illustrated in Figure 3.5 on the right. Ideally, these measurements should be conducted in an anechoic chamber to prevent the influence of room acoustics on the response [152]. A known signal (commonly an exponential sine sweep for HRTF) is emitted from a speaker arranged at a fixed radius and at various predefined positions around the listener, as shown in Figure 3.7 on the left. The sound reaching the ear microphones is recorded and later analyzed to derive the HRIR and HRTF [144]. Each recording yields a pair of HRIRs associated with the source position described in terms of azimuth and elevation angles.

HRTFs play a significant role in headphone-based spatial audio reproduction systems. When they are convolved with a monaural sound [1] the sound adopts the spatial characteristics of the HRTF. As a result, the listener perceives the sound as originating from a specific free-space position (azimuth and elevation), thus creating a sense of spatial sound location [144].

For the delivery of spatialized binaural audio in the experiments of this research, the personalised HRTF dataset produced by Braren et al. [153] was utilized [154]. This dataset measured the HRTFs of children aged 5-10 years old, which closely approximated the age group of the participants in the current study. The HRTFs were captured in a hemi-anechoic chamber with a resolution of 5 degrees in both azimuth and elevation, as seen in Figure 3.7 on the right. This dataset was employed both to spatialize the soundscape content and to localise the audio indicators during the interactive soundscape trials, as further discussed in Chapters 5.3.1, 5.2.4, and 5.2.3.

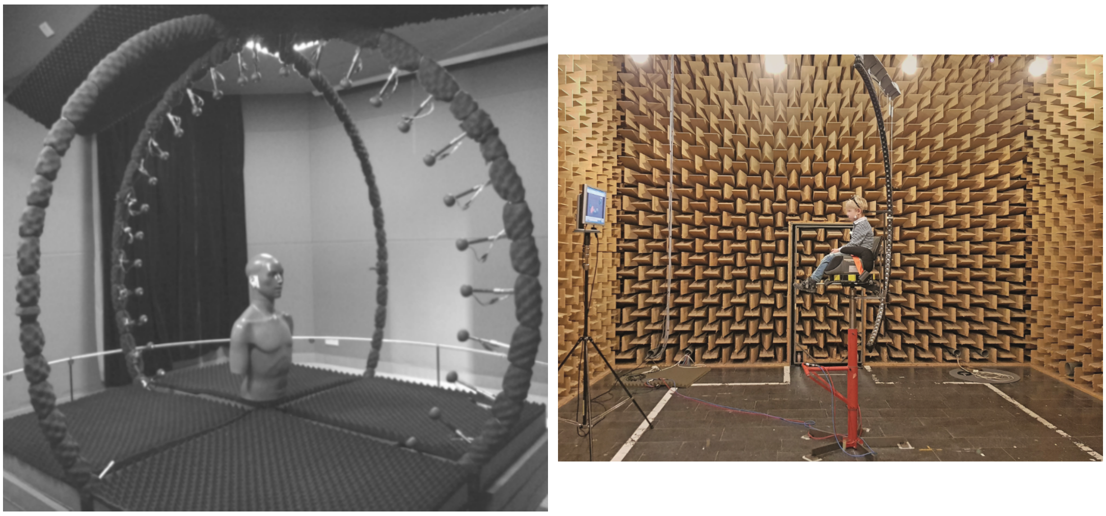


Figure 3.7: HRTF measurements: On the left, KEMAR in a listening room [144]. On the right, a child in a hemi-anechoic chamber [153].

[1]sound intended to be perceived as emanating from a single position

3.7 Summary

Schafer highlighted the sociocultural necessity for acoustic ecology, seeing the concept of the soundscape as a means to observe and induce a positive impact in society. In the context of this research, soundscape creation is an act of enhancing well-being. By tailoring this research to a well-defined group of listeners within a therapeutic framework defined by ADHD psychophysiological characteristics, a soundscape composition with therapeutic intent is designed. This theoretical framework serves as the basis for the current design of therapeutic soundscapes.

Schafer stresses the significance of 'information transfer' through sonic content as a key factor distinguishing 'noise' from 'sound'. Applying this notion to the sonic content of this study, the natural sound elements, although they might be characterized as noisy, convey specific information to the listener, such as pleasant experiences or memories. The act of personally selecting and combining these natural sound elements further qualifies these experimental stimuli as 'sounds' (or 'good noise' for purposes of discussion). Hence, even though these natural elements might inherently possess noise-like characteristics, they are still classified as 'hi-fi' soundscapes. As discussed in the previous Chapter 2.3, Noise Therapy primarily employs white noise in therapeutic practice. Combining different natural noise elements, such as a river, wind, fire, etc., to construct a soundscape introduces random variations in spectral and temporal attributes.

Schafer underscores the significance of the cultural and emotional connection between the listener and the soundscape. Participants in this thesis work were drawn from the UK and Greece, thus necessitating consideration of 'cultural aspects'. It is reasonable to assume that the sonic representation of natural elements is perceived differently according to the cultural origin of the participant.

The compositional strategy for the later experimental work, Chapter 5, adheres to specific rules rooted in the psychophysiological characteristics of the ADHD population and the context-dependent framework, particularly the practices associated with noise therapy. The resultant composition forms a soundscape consisting of 'keynote' sonic material, purposely avoiding foreground 'sound signals' that could attract unnecessary attention and act as distractors. The composition aims to acoustically communicate the experience and information of a physical environment shaped by personal choice. The Therapeutic Soundscape is informed by three primary influences: firstly, noise therapy, which endorses a rich, random spectrum while avoiding sudden dynamics; secondly, the sound archetype, which relies on emotional connections with the natural environment; and finally, the creation of immersion through the spatial representation of content. These components collectively enhance the therapeutic qualities of the composed soundscape.

With the ADHD therapeutic framework, soundscape content, structure, and associated technologies now established, the subsequent chapter 4 presents a Scoping Review that delves into the contribution of soundscapes explicit within *Therapeutic Immersive Environments* (TIE). The review examines the aspects of the soundscape previously described in terms of *content*, *immersiveness*, and *interactivity*. It also thoroughly investigates the association between *sound components*, *sound contribution*, and *therapeutic practices*.

4 The Role of Soundscapes in Therapeutic Immersive Environments: Scoping Review

4.1 Introduction

This scoping review undertakes an exploratory journey, investigating the existence of soundscapes within therapeutic practices implemented in immersive environments. The review focuses not specifically on ADHD but instead, it explores a broad spectrum of therapeutic practices. The aim is to determine the emergent qualities of soundscapes as they occur from their applications in therapeutic immersive processes.

As articulated in section 3.5.1 on *immersion*, the distinct strength of immersive environments lies in their capability to invoke sensations of *presence* and *engagement*. Hyunkook Lee makes a significant contribution by refining terminologies, specifically by differentiating an ‘immersive experience’ from an ‘immersive system’ [122]. Furthermore, he develops a model that originates from the participant’s characteristics, leading to a combined level of immersion. All immersive technologies expand upon reality, either by merging the *virtual* and *real* environments or by fostering a fully immersive experience that excludes the *real* environment. These technologies presuppose the existence of a Virtual Environment (VE), inviting the participant to explore and interact within it.

From the studies examined in this review, the applications applying extended reality (XR) technologies for health and well-being purposes follow a general framework that describes the therapeutic task with the applied methodology and the content that supports the VE. This collaborative framework of VEs, immersive and interactive technologies, sets a condition where all system components synergize to enhance human health and well-being. This perceptual identity of such a unified system, however, remains uncharted in literature. For the purpose of this review, this framework is termed a *Therapeutic Immersive Environment* (TIE). TIE denotes the fusion of therapeutic techniques (which provide methodology, content and context for the VEs) and extended reality technologies (which heighten the sense of immersion) to assist health and well-being practices. In essence, it refers to immersive environments that employ interactive audiovisual techniques to apply therapeutic methods.

This scoping review explores the potential benefits of creating soundscapes within TIE and their contributions to the therapeutic process. The concept of *Therapeutic Immersive Soundscapes* (TIS) is introduced, a term that encapsulates several key facets of human experience and technology, including physiological and emotional responses to sound, soundscape content creation, and the benefits of interactivity and spatial audio. Not yet referenced in existing literature, TIS is defined as the intentional composition of a virtual sonic space employing natural or abstract sounds reproduced via spatial audio techniques with the intention of enhancing participants' physical, mental, or emotional well-being. TIS consists of three primary components: content, immersive processes, and interactive structure. The subsequent analysis in this review delves into the therapeutic attributes associated with each of these components.

The scope of this review broadens to assess the impact of variations in the interactive structure of therapeutic practices on interactive soundscapes. In the studies examined for this review, a noticeable differentiation was observed in TIEs between the therapeutic methodology employed and the interactive structures. In all instances, the subject maintains a minimal level of interactivity, involving navigation and experiencing the VE. In many cases, this interaction extends to modifying the content as well. However, there are instances where the subject does not directly interact with the system but merely navigates the VE without influencing its content. In these scenarios, the observer overseeing the process evaluates and customizes the interactive structure and content to offer appropriate feedback for the treatment, thus completing the feedback loop. Miller [155], who adopts a bio-feedback approach, links this scenario to protect the subject and the challenge of self-regulation. Bandyopadhyay and Dalvi [156] refer to variations in the interactive structures associated with the therapist or observer's role and the adaptiveness of the system, employing manual, semi-automatic, or automatic supervision. This review relates the studies evaluated to identify variations in interactive structures relative to therapeutic practices. These variations gave rise to four interactive models, namely *Manual, Responsive, Semi-Auto,* and *Auto Supervision*, which are further analyzed in terms of their *personalized effects.* Furthermore, the influence of these interactive models on both interactive and passive soundscapes is also evaluated.

4.2 Objectives and Research Questions

This review aims to investigate the current application of soundscapes in TIEs. It compares immersive reproduction techniques applied to soundscapes and the visual modality, analyses the soundscape content as part of the sound contributions in the therapeutic practice, and examines the association between soundscapes and interactive structures. This analysis creates an overview of the soundscape therapeutic characteristics and concludes with associations to the more complex form that of TIS.

Relevant works in the field have outlined the concept of this scoping review looking at soundscape applications in TIE. The systematic review by Erfanian et al. [81] investigated the link between physiological manifestations of soundscape and the perceptual attributes, emphasizing the quantification of autonomous nervous systems (ANS) reactivity to environmental sounds. On the same trajectory, the systematic review by Aletta et al. [157] supports the claim that the positive perception of acoustic environments might be beneficial for human health. Both reviews refer to the physiological responses that acoustic environments produce in humans and their relationship with the perceptual attributes created. The scoping review of Kitson et al. [158] approached the idea of 'positive change' from a technical perspective. They investigated the interactive strategies and immersive technologies used to implement positive change and improve well-being, generally referred to as the interconnected dimensions of an individual's physical, mental, and social health. The above reviews investigate the relative fields of the psychophysiological impact of soundscapes and how interactive and immersive technologies have been used to improve well-being. To the best of the authors' knowledge, no review has been conducted covering the scope of soundscape char-

acteristics associated with virtual environments and immersive and interactive technologies applied to support health and well-being practices.
To assess the current state of soundscape implementation, sound contribution categories, and interactive methodologies relative to TIE, this scoping review addresses three research questions:

RQ1: What are the immersive and non-immersive technologies used to support soundscape for therapeutic purposes?

RQ2: How does soundscape content contribute to TIEs?

RQ3: How do variations in the interactive methodologies affect the interactive soundscapes?

4.3 Materials and Methods

4.3.1 Scoping Review Protocol

A scoping review is an evidence synthesis approach. Arksey and O'Malley [159] proposed an original framework, and improvements and clarifications occurred in later years by Levac and colleagues [160, 161]. This scoping review methodology has followed the corresponding guidance developed by the JBI Collaboration (JBIC) [162, 163] and complied with the extended Preferred Reporting Items for Scoping Reviews, the PRISMA-ScR [164]. The methodology prioritizes a broad coverage of the scientific landscape rather than solely focusing on peer-reviewed journal articles. In addition to peer-reviewed literature, this review encompasses conference proceedings, technical reports, and diverse documents from various disciplines and sources. This review focuses on identifying and mapping the range of evidence and key characteristics of the concept rather than evaluating the bias effect and the judgment of the trustworthiness of studies.

4.3.2 Information Sources

The search strategies for this scoping review were a collaborative effort involving an experienced librarian from Solent University in Southampton, who specialized in information retrieval and database searching. Their expertise played an important role in designing and executing the search strategies. Given the interdisciplinary nature of this research, a team approach was adopted to refine the search strategies and select the most relevant databases. Through extensive discussions with the librarian, I provided context about the multidisciplinary field encompassing soundscapes, therapy, and audio-visual immersive technologies. Drawing upon their knowledge, the librarian and I optimized the selection of databases and the arrangement of keywords within the search engine. Furthermore, the search strategy and database selection underwent thorough discussions with the research supervisor to ensure alignment with the study's objectives and to refine the inclusion and exclusion criteria for study selection.

An organized search was performed in electronic databases, weighted towards medical literature: Science Direct, IEEE Xplore, ACM Digital Library, MedLine, and PubMed. Also, the Audio Engineering Society (AES) E-Library was manually scanned, which specialises in spatial audio and applied acoustics. The search included studies from January 1980 to the present, with the last search performed in April 2020. Although the standard practice in systematic/scoping reviews involves searching two to three databases,.the multidisciplinary of this review led to the inclusion of five databases and one E-Library.

The selected keywords were chosen to ensure the consistency of the search

Keywords
('Abstract': 'soundscape' OR 'immersiv*' OR 'interactiv*')
AND
('Abstract': 'well-being' OR 'well-being' OR 'positive change' OR 'physiolog*' OR 'health' OR 'psycholog*')
AND
('Full Text Only': 'virtual reality' OR 'augmented reality' OR 'mixed reality' OR 'extended reality' OR 'VR' OR 'MR' OR 'XR' OR 'affect*' OR 'audio' OR 'sound')
AND
('Full Text Only': 'autonomy' OR 'engag*' OR 'meaning' OR 'happiness' OR 'joy' OR 'excitement' OR 'satisfaction' OR 'pride' OR 'awe' OR 'flow' OR 'relationship' OR 'purpose' OR 'success' OR 'emotion')

Table 4.1: Example of the keywords and their syntax that were used in the IEEE database

results by using Boolean operators (as shown below) to carefully reduce the amount of the results without rejecting relevant studies. The first part of the search index describes the technical terms of the research (applied to the title and abstract). The second part introduces terms relative to physiological and psychological health and well-being (applied to the title and abstract). Finally, terms included in the third and fourth parts are explanatory and originate from the above fields and their general principles, see e.g. at table 4.1.

4.3.3 Study Selection

A total of 1678 published articles resulted from the literature search. The references were imported into the Mendeley reference manager, and subsequently, duplicates (n =72) were removed. Initiating the screening process, titles and, when necessary, abstracts of the studies were evaluated based on relevance and selection criteria. The examined studies consisted of journals, conference articles, pilot studies, proof of concept papers, position papers, and feasibility studies. Standards and book chapters were excluded due to a lack of implemented practices. There were also excluded theoretical and more generic studies and studies related to education, social cognition, art, video games, and robotics. Only studies published in English were included. The specific inclusion criteria were: (1) Key research fields under study: soundscape, immersive and interactive technology; (2) support to health or well-being related practices. The studies that used only interactivity or not virtual environments were excluded. In the cases where different publications by the same authors developing the same study, only the more detailed versions were included (e.g., [165] and [166], [167] and [168], [169] and [170], [171] and [172]).

The excluded studies were (n = 1113). In the remaining 493 studies, the full text was assessed, and the eligibility criteria, following the method outlined in PRISMA-Scr [164], were applied. All the steps of the process can be viewed in Figure 4.1. The resulting 118 studies were categorised according to their applied therapeutic contribution: a) Physiological Health, b) Psychological Health, and c) Well-being practice and presented in the supplementary material Tables S1, S2, S3.

The selection up to this point provided adequate information to identify the soundscape usage and the tendencies between immersive and non-immersive technologies in TIE, referenced to RQ1. Out of the 118 studies, the final 74 studies made some form of reference to application of sound in their process. This final selection aims to collect evidence to answer RQ2 and RQ3.

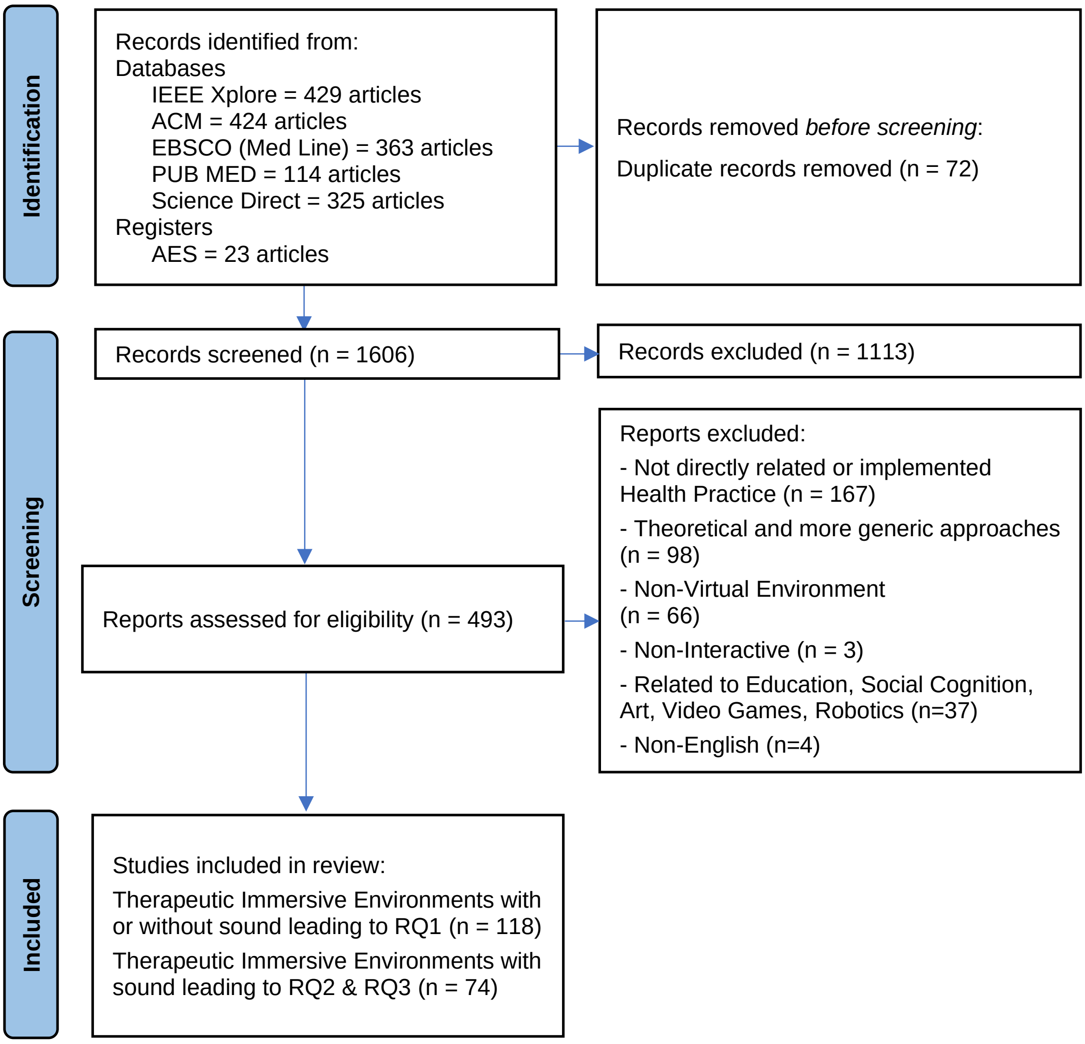


Figure 4.1: PRISMA-Scr flow diagram representing the steps of study selection.

4.3.4 Data Charting

From the studies included in the review, information was extracted to inform the charting categories. Adequate information was collected for the reader to obtain an overview of the study and allow comparison among selected evidence. Data charting was set and iteratively updated based on new findings and arguments elicited from the studies (see supplementary material Tables S1, S2, S3). With consensus among the reviewing team, the process continued to the data extraction.

Associating the charting categories (Fig. 4.2) to the relevant research question, the following combinations occur:

- RQ1 derives information from the information about the health treatment and its intervention associated with soundscapes as part of immersive technologies and other technologies used, charting categories (1), (2) and (3) respectively in Fig. 4.2.

- RQ2 focuses on the correlation of therapeutic interventions with the required sound components as an assistive therapeutic process and elicits the relevant information from the Health (1) and Sound (4) categories.

- RQ3 examines the variations in the interactive methodology relative to therapeutic practices, categories Health (1) and Interactivity (5).

1. INFORMATION		2. IMMERSION		3. TECHNOLOGY USED				4. SOUND		5. INTERACTIVITY	
Citation	Health practice Description	Soundscape	XR	Details	Bio Sensor	Wear-ables	Machine Learning	Sound Contribution	Sound Elements	Supervision Type	Interactive Methodology

Figure 4.2: Charting categories: The image above represents the header in the analysis tables in the supplementary material.

Clarifying the variables within the charting categories supports extracting the data from the studies. Starting from the first category, 'Information', the citation along with a short description helps the reader to familiarize themself with the general idea of the study. The category 'Immersion' includes the different types of extended reality technologies used in therapeutic practices. The category 'technology' gathers details on equipment and accessories used, giving the reader an overview of the implementation. Similarly, the 'Sound' category brings together details on how sound is employed to deliver within the therapeutic process. It is crucial to identify and map the variety of sound components, auditory feedback, stimuli, and auditory display, to name but a few, and correlate them with the relative therapeutic assistance or cure. Details on technology and sound were extracted from the studies, and on some occasions, I had to trace back to previous publications for the same writers. Finally, the information regarding variations in interactive methodology is gathered in category (5). I examined the implementation methods of the studies to identify the roles within the system by asking the following questions: Who is evaluating the process? How does the system adapt to the evaluation? What is the ability/variety to customize the output? The answers provided insights into the roles and responsibilities between roles. The role of the observer is not always clear since it could be employed by the therapist/caregiver or the machine on some occasions.

To handle a multitude of studies, three categories were selected according to their targeted practice: 'Physiological Health' based on bio-physiological issues which might require medication support, 'Psychological Health' referring to mental health issues focused on emotional, behavioural, and social issues, supported by a specialist without medication support and finally 'well-being', which covers cases dealing with wellness, happiness and obtaining a healthy way of life without the support of a specialist nor medication. This made it easier to manage the studies and revealed relevant tendencies.

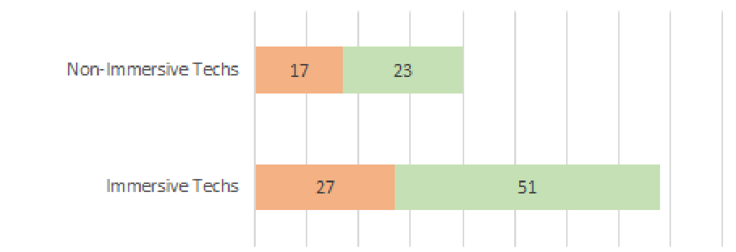
4.4 Results

The analysis follows the three therapeutic immersive soundscapes (TIS) characteristics:

- Immersive technologies
- Content
- Interactivity

4.4.1 Immersive and non-immersive technologies used for therapeutic purposes

VEs recruit both visual and auditory modalities for their implementations. Here, the modalities are analysed separately according to the immersive and non-immersive technologies used (see Fig 4.3). From the 118 studies that passed the eligibility criteria, only 74 studies made some reference to sound. Some were very detailed, and others made short references like ‘audio-visual stimulus’ or ‘sound feedback’.



	Immersive Techs	Non-Immersive Techs
Studies with no reference to Sound	27	17
Studies with reference to sound	51	23

Figure 4.3: The number of studies is presented according to immersive and non-immersive technologies used and the reference to sound or not as part of their process.

Technologies for Visual Environments

VEs consist of the content built-in as a 3D space and the reproduction technology used, immersive or non-immersive. The extended reality technologies used in the studies were categorized according to their immersiveness in the 'reality to virtual continuum'. The categories follow Milgram's 'virtuality continuum' approach [173], with the addition of the 'interactive installation' as described in Kitson's et al. review [158]. In our approach, Mixed Reality (MR) is not treated as a separate extended reality type, but it represents the continuum from the *Real World* to the *Virtual World*. It is the blending of digital elements with the physical world. Even so, two cases arose where the authors referred to MR practices. Crowell et al. [165] used motion capture and required a much more extended physical condition in space from the participant to follow the virtual game on a floor projection, which I consider to be closer to an interactive installation type. Similarly, Salva et al. [174] created the MR rehabilitation system (MRRS), which uses a video see-through head mount display (VST-HMD), which could be nicely fitted in the AR category. The following characteristics describe this 'reality to virtual continuum' starting from the non-immersive and leading to full immersive technology VR with the use of HMD as presented in Table 4.2:

- **non-immersive technologies**: They include practices with immersive content and are performed via non-immersive technologies like screens and mobile phones.

- **interactive installations**: They represent a creative way to activate a physical space through interactive technology, sound, and light that respond to the participant's actions. It implies some level of physicality in the real world, with VE content performed via projectors (not immersive surround-screen displays such as Cave).

- **augmented reality (AR)**: Refers to the experiences of overlaying virtual objects onto physical objects in the physical world. The applications use some form of a recognition system that provides the ability to superimpose information in sound, video, and graphics and, hence, augment the surroundings.

- **augmented virtuality (AV)**: An opposite approach to AR. It presupposes the existence of a VE where 'real' objects are inserted in a virtual world.

- **virtual reality (VR)**: It presents an entirely digital experience that engages the user's sensory system. Most of the time, the content consists of a 3D virtual environment within which the participant can interact and navigate freely or 3D movies with a predefined movement path. The participants can experience the environment surrounding them in 360°.

Technologies for Auditory Environments

The 'immersiveness continuum' is reviewed based on the reproduction techniques used to represent soundscape content. Starting from mono, stereo, surround, and finally to fully immersive spatial audio, reproduced via multiple speakers or binaurally over headphones. Content creation is directly related to this process since the methods of recording (e.g., stereo, binaural, Ambisonics) and mixing (e.g., stereo, surround, or Ambisonic encoding and decoding) predefines the outcome. Spatial audio over closed-back headphones isolates the participant from the 'real' world in the same manner as VR over an HMD. One can raise the question as to which offers the greatest immersion - VR without sound or a Spatial Audio environment without visual. A joint agreement, though, might conclude that the combination of both is a powerful tool for immersiveness. Table 4.3 presents an overview of

Levels of Immersion	XR Type	Immersive Techn/gies	References
Fully Immersive	Virtual Reality	HMD	[**175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 102, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207**] [96, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220]*
		HMD Mob.	[**221**] [222]*
		CAVE	[**167, 223**] [224, 225, 226]*
	Augmented Virtuality	HMD	[**227**]
	Augmented Reality	HMD	[**228**] [229, 230, 174]*
		Mobile	[231, 232]*
		Tablet	[**233**] [234]*
		Screen	[**235**]
		Projector	[**236, 237, 238**] [239]*
Less Immersive	Interactive Installation	Projectors	[**166, 240, 241, 242, 243, 97**] [244, 245]*
Non Immersive		Screen	[**246, 171, 247, 248, 249, 250, 170, 251, 252, 253, 254, 156, 255, 256, 257, 258, 259, 95, 260, 261, 262, 263, 264**] [265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281]*

Table 4.2: Visual modality - The figure lists the distribution of studies according to the extended reality technologies, ranging from low to high levels of immersion. The references in **bold** indicate the studies that used sound and * refers to studies that did not make any reference to sound or audio.

the soundscape cases categorized according to their levels of immersion, which are classified as ‘Fully Immersive’ and ‘Less Immersive.’ To provide clarity, these terms are explained below:

Fully Immersive: In the context of this review, ‘Fully Immersive’ refers to sound reproduction techniques that aim to create an auditory environment that fully surrounds and engulfs the listener, providing a high level of realism and spatial fidelity. It includes technologies such as Spatial Audio, Ambisonics, Binaural audio, and multi-channel surround sound systems that aim to replicate the auditory experience in a way that closely mimics real-world soundscapes.

Less Immersive: Conversely, ‘Less Immersive’ technologies represent sound reproduction techniques that provide a lower degree of auditory immersion compared to fully immersive approaches. These technologies include stereo audio, headphone-based audio, and conventional speaker/screen setups. While these technologies can offer engaging auditory experiences, they may not fully envelop the listener in a 360-degree sound environment.

Discussion: VE technologies and soundscapes in therapeutic practices

To identify the soundscape applications in the studies examined, it was necessary to acknowledge the combination of therapeutic techniques based on the content-context and reproduction technologies. *Content* is built in 3D environments and the *Context* relates to the therapeutic psychophysiological health and well-being aims to be achieved. The implementation of these therapeutic techniques led me to use two main categories relative to reproduction technologies: ‘Immersive Technologies’, based on 3D content and immersive reproduction and ‘Non-Immersive Technologies’, based on 3D content and non-immersive reproduction, represented in Fig. 4.4.

‘Immersive Technologies’ include Immersive Soundscape, Interactive Installa-

Levels of Immersion	Types: Audio Reproduction	Reproduction Technologies	References
Fully Immersive	Spatial Audio	Ambisonics/ Binaural	[167, 91, 261, 185, 177]
	Surround Sound	8 Speakers	[240]
		5.1 Systems	[223]
		4 Speakers	[97]
Less Immersive	Stereo	HMD	[200, 228, 203, 182] [191] [188] [192] [196]
		Headphones	[195] [205]
		Speakers/Screen Projector	[102] [178] [171] [175] [242] [248] [251]

Table 4.3: Soundscape Immersion Continuum: The studies that used soundscapes arranged according to the level of immersion.

tion, AR, AV and VR. Here, the emphasis falls on the reproduction techniques aiming to encapsulate and surround the participant within the VE by engaging the participant's senses and cognitive abilities. Examples consist mainly of psychological practices that aim to increase realism, such as drug dependencies [192, 185, 177], Post Traumatic Stress Disorder (PTSD) [187, 258], and social anxiety; for example, Lc and Fukuoka [188] used VR with systematic desensitization to control the amount of distraction to train stutterers to cope with imminent episodes of public and social speaking. Similarly, in well-being cases promoting self-awareness and restorative experiences [203, 202].

'Non-immersive technologies', on the other hand, rely mainly on 3D visual content represented by non-immersive technology such as a screen or a single projector or stereo representation in the case of audio. Many studies on physical rehabilitation prefer using this setup where space for body movement is required [171]. There are also psychological cases using Exposure Therapy where the participant identifies with the virtual content not necessarily immersively presented [242, 245]. For instance, a person with Acrophobia will still experience vertigo through a virtual bridge or flying simulation seen on a screen [282].

Fig.4.4 summarises the combination of visual immersive (grey) and non-immersive (blue) technologies with immersive (purple) and non-immersive (green) soundscapes. Forty studies of non-immersive visual technologies (blue, centre) incorporate three non-immersive soundscapes and one immersive soundscape. Similarly, 78 studies used immersive visual technologies (grey, centre), where a total of 14 non-immersive and seven immersive soundscapes were presented alongside VR (12, 5), AR (1) and interactive installation (1, 1). The Immersive Soundscape (right) is the only case that used only sound for the therapeutic practice.

VR was the most commonly used technology (55 studies). This was expected due to VR's strong influence on the excitation of both senses and cognitive processes. VEs presented via screen were the next preferred option, showing that virtual content successfully retains participants' engagement and capability to identify with the content despite being less physically immersed in the technology. Gordon et al. [175] demonstrated the same effectiveness on pain reduction with patients playing video games with an HMD and a simple audiovisual display. AR was not the preferred method due to the high cost of the limited selection of technology, such as Hololens [283] or Magicleap [284], which cost between 2000-3000 US dollars in 2018. This situation has only slightly improved in recent years. Interactive installations were used when physical movement used key factors like in the cases of physical rehabilitation [248], or when the aim was to create an

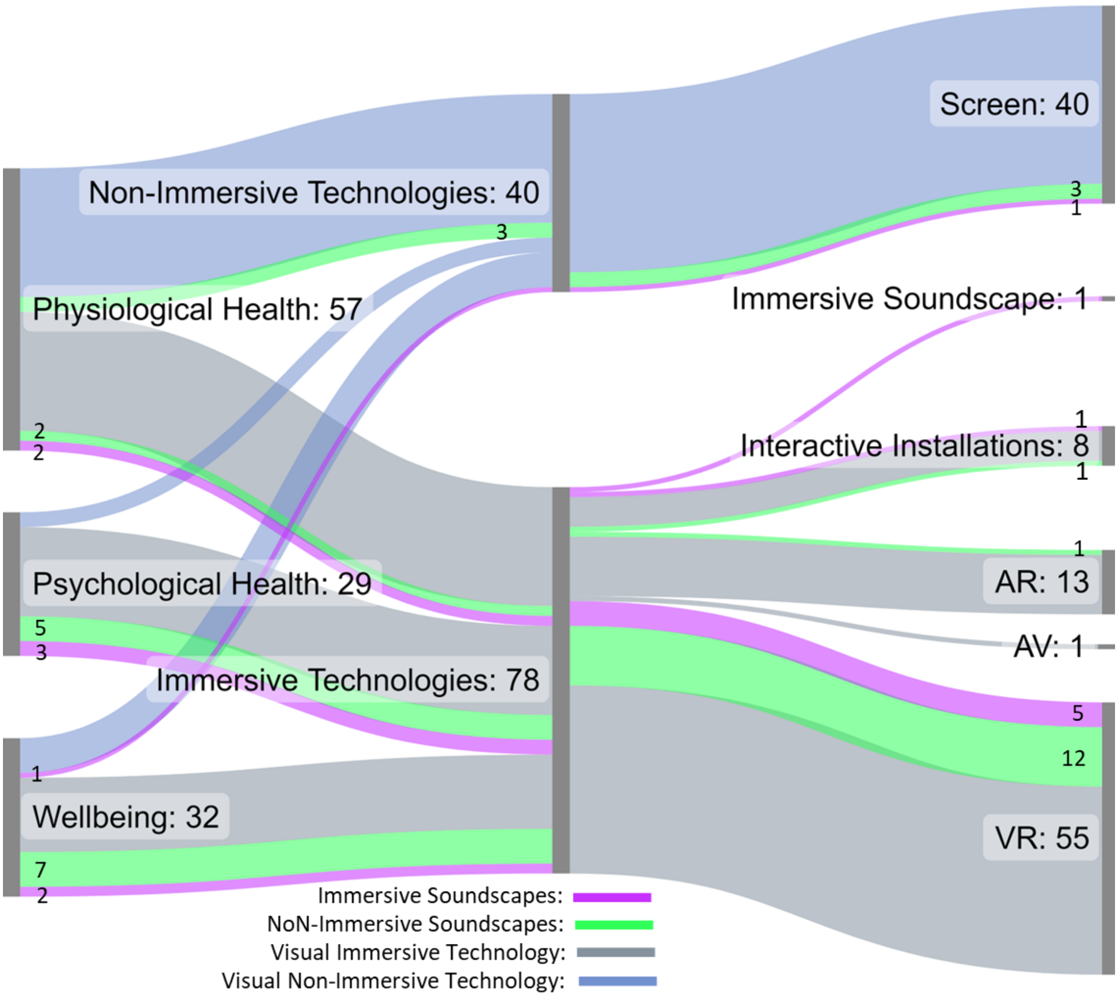


Figure 4.4: Describes how the immersive soundscapes (purple) and non-immersive soundscapes (green) are combined with visually immersive (grey) and visually non-immersive (blue) techniques. Starting from the left side, the physiological, psychological, and well-being VEs are separated according to the non-immersive and immersive reproduction technologies in the centre. The right side shows the different technologies used for reproduction methods for non-immersive (screen, stereo soundscapes) and immersive (immersive soundscapes, interactive installations, AR, AV, VR). The numbers refer to the number of studies included in each category. See Table 4.2 for references.

extended experience in the real world, including interactive objects/walls/floors, for example, with children with ASD [169, 166]. Finally, some cases enhanced an existing space by adding visuals, light, and sound [97, 243].

Citation	Therapeutic Practice	Repr/ction Technique	Soundscape Details
[167]	Children with autism	3rd order Ambisonics	Soundscape creation with moving sound objects.
[91]	Restorative Effects on Childrens Cognitive Performance	Bin. H/P	Soundscape of natural envs.
[185]	Methamphetamine use disorders	Bin. H/P	People played with paraphernalia smoked and talked about the quality of MA crystals; neutral env.
[177]	Methamphetamine dependence	Bin. H/P	Atmosphere and voices to lure/invite participants to take drugs.
[261]	Assisting blind individuals with spatial knowledge	2nd ord. Amb. Bin.	Enrich the soundscape with additional sound sources to help VIP.
[240]	Children with severe autism	8 skps	Interactive soundscape based on vocalizations and sounds of the participant.
[97]	Support well-being and productivity	4 spks	Interactive Soundscape affecting natural environmental.
[223]	Inducing physiological stress	5.1	Interactive Soundscape: changing dynamic sounds of nature.

Table 4.4: Presents the details of Immersive Soundscapes defined in the studies. The table correlates the therapeutic practice of each study to soundscape content.
H/P: Headphones, spk: Speakers, St: Stereo, Bin: Binaural, Amb=Ambisonics

As a response to RQ1, soundscapes were infrequently introduced in the therapeutic processes, with a total of 25 cases, presented in Tables 4.4-4.5 and in the supplementary material Table S4. In most of them, soundscapes co-existed alongside visual content except for Shu and Mas [91] study, which introduced immersive

Citation	Therapeutic Practice	Repr/ction Techniques	Soundscape Details
[228]	Self-awareness and relaxation	HMD	User's brain activity conveyed to ambient sounds.
[203]	Self-awareness, mood restoration	HMD	Urban and forest soundscapes.
[200]	Stress treatment	HMD	Soundscape underwater sounds.
[196]	Stress treatment	HMD	Interactive natural soundscape.
[243]	Self-regulation and behaviour change	HMD	Interactive soundscape: nature sounds
[192]	Nicotine dependence	HMD	Nature or party scene.
[188]	Helping stutterers cope with public speaking	HMD	Soundscape-relaxation: forest or beach.
[191]	Distraction interventions to alleviate anxiety	HMD	Soundscape of natural envs.
[195]	Restorative experiences: coherence, being away	St. H/P	Ambient forest sounds: wind and birds singing.
[182]	Preoperative anxiety	St. H/P	Soundscape of natural envs.
[171]	Stroke rehabilitation	St. spks	Alternating soundscapes to reduce auditory repetition.
[242]	Cope with anxiety situations	St. spks	Interactive soundscape with destructive background noises
[248]	Cognitive rehabilitation for elderly with dementia	St spks	Relaxation-Soundscapes: nature sounds
[102]	Rehabilitation exercise for older adults	St.spks	Interactive Soundscape : 4 natural scenes.
[175]	Pain reduction	St. spks	Interactive soundscape: underwater sounds
[178]	Motor-imagery rehabilitation training	St. spks	Ambient realistic sounds.
[251]	Amnestic and Alzheimer's disease	St. spks	Soundscape of typical city noises.

Table 4.5: Presents the details of Non-Immersive Soundscapes defined in the studies. The table correlates the therapeutic practice of each study to soundscape content. H/P: Headphones, spk: Speakers, St: Stereo

soundscapes as an independent therapeutic process, as can be seen as the single category 'immersive soundscapes' at the right of Fig. 4.4. Immersive technologies have been lightly introduced to soundscape reproduction. Immersive soundscapes are an extended reality technology by themselves that can be applied as a standalone practice or in conjunction with another extended reality technology. It is the only modality that retains the descriptive characteristics of narration without the accuracy of the visual content. The soundscape provides all the conscious stimulus and sonic archetypes (recognizable sound icons like a door closing, a baby crying etc.) for the listener to create a personal narration. So, it is on the edge of abstraction and concrete description.

The few studies that used spatial reproduction techniques exploited the capabilities and impact of sound immersion as part of the therapeutic process and to enhance immersion, Table 4.4. Shu and Ma [91] used binaural reproduction to immerse the student in a natural environment. At the same time, Zhao et al. [97] showed that dynamic spatialized soundscapes positively affected well-being and productivity. Johnston et al. [167] as well as Picinali et al. [261] used spatialized sound sources supporting the social interaction for children with ASD and constructing coherent spatial mental maps for visually impaired people (VIP), respectively. Annerstedt et al. [223] demonstrated the importance of sound in stress recovery compared to no sound while using surround sound systems to make both natural environments and high anxiety occasions like public speaking more realistic. Similarly, Wang et al. [177] used surround sound to increase realism in a reduced drug craving treatment.

The primary soundscape reproduction technique was non-immersive, mainly over HMD and stereo speakers (qv. Table 4.5). While most of these studies focused on enhancing immersion, the reproduction methods primarily used a limited number of loudspeakers (often only 2), restricting the sound's ability to surround and envelop the listeners. It is essential not to correlate the reproduction techniques with the soundscape content. Spatial audio is a tool that communicates the meaning and empowers the purpose of the treatment by increasing the sense of presence and engaging the senses. A detailed soundscape design from Bruun-Pedersen [102] presented over a 2.1 system failed to motivate older adults. The participants described the restorative VE, consisting of both visual and soundscape content, as a convincing experience and a believable environment representation, but they overlooked the significance of the soundscape. This response raises questions regarding how the therapeutic soundscape effectiveness can be reduced due to the physical boundaries of the reproduction methods.

4.4.2 Sound content contribution to health and well-being practices

A general observation from the studies highlights the disproportionate focus on visual aspects compared to sound. Only 49% of Physiological, 65% of Psychological and 69.5% of well-being applications made some reference to the implementation of sound, from the most straightforward audio feedback to complex sound analysis and multilayer mapping. To state an example, Burdea and colleagues [248] studied an immersive cognitive rehabilitation system for the elderly with Dementia. They presented a detailed sound description using expressions such as "the sound of waves was added to help the participants relax ... corresponding sound to image for memory... Musical Drums was the third game to train focus... rewards were auditory (applause, cheering), provided positive reinforcement and were meant as morale boosters." This made obvious the relationship between the health issue (Dementia), the need for sound contribution (e.g., providing a reward and offering positive reinforcement for achievement) and the sound components (applause, cheering).

In other cases, the description was limited such as "audio-visual feedback, like in a balloon shooting game for physiological rehabilitation from stroke [252] or "a dynamic 3D visual content and associated auditory stimuli" used in a pain reduction technique [247], or "sound of fire" used in a VERT simulation [190]. Others were more descriptive like Faith et al. [253] provided a "continuous, real time auditory and visual feedback .. for the subject to become accustomed .. the desired reach trajectory, hand velocity, and wrist rotation". Similarly, Yu et al. [243] provided "an immersive, engaging user experience for relaxation training," using "an interactive soundscape of various nature sounds with controllable audio parameters."

Each study was examined to retrieve all references to sound and audio as an output modality. The analysis starts by identifying the "sound components" that constitute the means that sound supports therapeutic practices. The investigation continues by looking at the sound contribution" categories. I trace why specific sound implementations were required and how that was associated with the overall therapeutic practice/cure. I ask the question, "what is required by the sound components to assist?"; "how does sound implement each contribution?."

Components of Sound Content and Processes

Sound components constitute the building block of this review, revealing the variety of sound content types and audio processes used, hence underpinning the role of sound in therapeutic practices. Four of the sound component categories belong to the sound content: Sound Stimulus, Music Stimulus, Speech and Soundscape content. Another three are related to the audio processes: Auditory Display, Auditory Feedback and Spatial Sound. If a study required more than one sound component to implement the requested contribution, they were all included. For example, Potts et al. [228] examine a system of self-regulation that requires an emotional shift of 'relaxation and engagement' (sound contribution) using two sound components, *music stimulus* (ambient music) and *soundscape* of ambient sounds creating a spatial sonic environment. The sound component categories are presented all together in the supplementary material Table S5 and described in detail below:

Soundscape Component: Here, soundscapes cover the sonic outcomes from any form of environmental sounds, real or fictional, including audio cues and sound sources describing a VE or just a sound environment. Soundscape as a discipline has a relatively recent increase in popularity, and many studies did not use the term; instead, they describe the use of natural sounds most of the time for relaxation purposes. I consider these cases as soundscapes even though the soundscape composition is not structured and targeted. Cases presented a quick reference to natural sounds like the beach, forest, birds singing, urban, crowd, traffic [191, 251, 203, 196, 91, 178, 285, 188, 97], and underwater environment [175, 200, 195]. Other cases described scenes like "four persons played with paraphernalia, smoked and talked about the quality of MA crystals" [185] (p. 511), "participants heard the voices with a black screen to lure/invite participants to take drugs" [177](p.382388) and similar cases [242, 192]. There were occasions where soundscapes were composed with greater detail [171, 243, 167, 228, 240, 248] targeted for restorative purposes [102] or enriched with additional sound sources to help Visually Impaired People (VIP) to navigate [261]. Tables 4.5-4.4 and in the supplementary material Table S4 provide details on the studies that include soundscapes.

Music Stimulus: In the context of this review, this is specified as "... organized, structured rhythmic successions and superposition of tones..." [286](p.13) employed to create an emotional effect. In most cases, it is referred to with general and short descriptions with a lack of information and one-word descriptions like relaxing [263], soft [221], neutral [186], background soundtrack-music [201, 180, 260], music sequence [235], or with a brief few word clarification like instrumental musical score [199], calm ambient music [95, 228], relaxing and louder music during the refreshment stage [196], soundtracks selected from the international affective digital sounds (IADS) database [262], Christmas scenery music [206] or classical piano music [91]. Some studies used music in a more targeted way but still with a limited description like Music Therapy [254, 191], or to create a personalized experience like a symbolic representation of a particular period of the patient [258, 236].

Sound Stimuli: This component refers to the cases which produce a sonic outcome that adapts a more abstract form [240, 166, 197], compared to music, for example, and may also include well descriptive and recognizable sounds from everyday life, like animal sounds [233, 204, 248], the sound of fire [190], noise level, people speaking, phone ringing [188]. A distinctive characteristic of Sound Stimuli is the use of metaphors to describe sounding content [262] like Gutierrez-Maldonado and colleagues [257] told "a range from unpleasant pain sensation to a pleasant and quiet environment". Again, the aim is to emotionally shift the listener positively or negatively, like crying and moaning stimuli [179], applause and cheering [248], transforming sounds emitted by the child, vocalizations and clapping [240], or "an auditory summary for an emotional connection between audio feedback and movement performance" [171, p-1828]. Finally, Sound Stimuli have been used to emotionally underline other output modalities like visual content [247, 206, 183].

Speech: It was introduced to cover the cases where verbal, recorded or not, communication was used for Instructions [260, 256], guidance [176, 156, 264], dialogue [207, 184] and narration [202, 221, 263, 186, 181, 170].

Auditory Display: This presents information in an audible form [287] and offers a relay between the information source and the receiver [288]. It transforms external parameters into musical relevant parameters [240]. The most common representations relate to physical movements such as hand velocity, rotation, path [171, 237, 253, 250], the speed of a posture to complete [156], stepping/gait characteristics [256], the quality of the movement [249], and also biometric representations (biofeedback) [198, 260, 193, 243, 259, 194], leading to the most simplified version of alarming indications [189].

Auditory Feedback: This is used in the context of a closed-loop interactive process, focusing on the action that produces the sonic outcome. The reactive relationship 'cause and effect' defines this category. Hence, comparing it to Auditory Display, the latter has as its primary aim to sonically describe the continuum of the action as descriptive information. Extending the comparison with the Sound and Music stimulus component (discussed below) emphasises the content of the sonic outcome and the emotional imprint it leaves. The Auditory Feedback component is commonly used in game situations [181, 175, 250, 95], like hitting targets [180, 227, 201, 249], or as sound effects [263, 196, 255], or reactions to body movements [246, 285, 252, 178, 256, 241]. There are also studies describing musical actions, like swinging virtual balls and dynamically creating abstract musical elements with their bodies [289, 240], playing notes or drums [238, 248].

Spatial Audio: This component refers to any spatial audio reproduction, such as Ambisonics or Binaural reproduction [167, 91, 97, 261, 199], object-based or channel-based audio [240, 223, 177].

Sound Contribution Categories

This section focuses on identifying the necessity and role of sound being introduced to contribute to the therapeutic processes. Emphasis was given on sentences or even words describing this contribution. The supplementary material, Table S5 presents all categories together. Below are described the details on each of the sound contribution categories separately:

Body and Mind: This covers characteristics related to the circular condition of the mind-control-body paradigm, Appendix Table A.1. By providing stimuli to increase self-awareness, self-regulation is activated to influence a physiological response. Most of the cases included project respiration characteristics attempting to control breathing [260, 194, 259, 203] or other biometric responses [198]. Villani and Riva, [202] use a guided narrative imagery experience as a relaxation exercise.

Emotions: This is a general category including all attempts to create an emotional shift with the use of a sound element (cf. Appendix Table A.2). These include decreasing stress/anxiety [221, 196, 95, 228, 188, 200, 248, 263], eliciting awe [199], provoking emotions [262, 179], create an emotional connection [171], emotional stimulation [223, 175], create a sense of craving [185, 177], and change in vitality and mood [195].

Encouragement and motivation: These are tightly related by mentally supporting and stimulating someones interest in an activity (cf. Appendix Table A.3). Interactive and immersive practices (both process and resulting content) value their effectiveness on motivation/encouragement, so the participant will continue to interact. Several studies required sound contribution for motivation [256, 249, 250, 102, 235], for encouragement [201] and positive reinforcement [248].

Exposure: The central behavioural element in virtual reality exposure therapy (VRET) supports that experiencing feared situations without avoidance will teach the client that the experienced anxiety will eventually decrease and that feared outcomes would not occur [207]. The amount of sensitive content exposed to the patient is controlled in real time by the therapist [184, 242, 190] or an adaptation process based on biofeedback [188] or both [183] or it is standardized by the procedure itself[192, 176]. Details are available in Appendix Table A.4.

Focus / Concentration: It refers to the need for sound supporting the improvement of focus [248, 97], concentration [260], and attention [102, 186, 91, 246], remove worries and possible distractions and enrapture users in the present moment [197, 191, 180] (cf. Appendix Table A.5).

Immersion: The characteristics emerged from the studies requiring sound assistance to increase immersion [243, 196, 241, 200, 251, 177, 167, 240], realism [178], or presence [102, 180, 181], and escapism [206] (cf. Appendix Table A.6).

Informative: This category reflects sound implementations providing information related to the therapeutic process. Studies referred to guidance throughout by the virtual coach asking questions and setting tasks with greater difficulty in training phobia of heights[176], performing an exercise with the help of an audio guide for physical rehabilitation [156, 264], or navigating through on-screen menu [256]. Picinali et al. [261] used realistic 3D acoustic information to guide visually impaired people (cf. Appendix Table A.7).

Memory: It relates to practices that support and improve sort memory [91, 220] or auditory memories [248] and also symbolic representation [258] (cf. Appendix Table A.8).

Social Skills: They refer to practices aiming to improve social communication skills [170], natural communication and cooperation between users [167, 166, 254] (cf. Appendix Table A.9).

Interactivity: This gathers the categories using sound components as the feedback process to achieve engagement [250, 95, 178, 257, 252, 240, 233, 171, 248, 223, 228, 243, 102], response to movement [249, 156, 237, 227, 252, 255, 189, 263, 196, 242, 175, 188], guidance through a process [253, 256, 236], divert attention/distraction/isolation [247, 175, 182] and cognitive stimulation [238, 97] (cf. Appendix Table A.10).

Discussion: Soundscape Content within TIEs

In this discussion, I explore the role of soundscape content within TIEs. The historical roots of the term ‘soundscape’ were introduced by M. Schafer in the 1960s, but its contemporary significance and application within TIEs require a nuanced perspective. While environmental sounds have frequently been used in various contexts within TIEs, often describing natural, relaxing environments, this was typically done without explicit reference to the term ‘soundscape’, implying that designers approached soundscapes primarily as sound content accompanying visual material. However, this review emphasizes the argument that soundscape composition can reach its full potential when intentionally created, not solely based on sound contents but also by harnessing its compositional techniques and technical advantages. This concept is encapsulated in the proposed concept of therapeutic immersive soundscapes (TIS). Recognizing the significance of TIS underscores the intricate interplay between sound, environment, and therapeutic outcomes within contemporary TIEs.

In this review, a notable contribution is encapsulated by the bidirectional template, as depicted in Figures 4.5 and 4.6. This template elucidates the associations between the therapeutic practice and the sound components via the intermediary sound contribution. The comprehensive data, presented in Appendix Tables A.1-A.10 and further combined in a single table (supplementary material Table S5), cohesively unveils current trends regarding crucial sound contributions formulated by an assortment of sound components to enhance health and well-being practices in TIE.

The sound contribution *Immersion* is observed to utilize all types of sound components. In studies aiming to enhance *Immersion*, only a third employed *Spatial Audio*, opting for *Soundscapes* and *Auditory Feedback* instead. *Music Stimulus* is found to support mainly *Focus/Concentration* and *Emotions*. On the other hand, while *Sound Stimulus* is employed in numerous contributions, it's predominantly used for *Interactivity, Emotions*, and *Exposure*. *Auditory Feedback* is noted to be utilized in *Interactivity*, predictably, and also in *Immersion, Encouragement, and Focus*. These correlations are indicative of the prevailing design methodologies and can provide guidance for future designs.

The findings can be interpreted in different ways depending on the approach chosen. When viewed from the perspective of the **therapeutic task**, the sound contribution and the sound components utilized to achieve it can be assessed, Figure 4.6) (qv. supplementary material in Table S6 and Appendix Table A.11s). For instance, in order to enhance *Mood Repair and Restorative Experience*, sound contributes to the cyclical association between *Body and Mind*, influencing the *Emotional state*, amplifying *Immersion*, and enhancing *Interactivity*. This was accomplished through the deployment of *Musical Stimuli* or *soundscapes*, presented as *Auditory Feedback* or *Auditory Display*. Similarly, when the focus is shifted to **sound contribution**, the impact and contribution can be identified in the supplementary material in Table S5. An example can be discerned where *Encouragement* facilitates mainly *Physical Rehabilitation*, *Concentration/Attention*, and support for *People with Dementia (PwD)*. This is realized by employing *Musical and Auditory Stimuli* and *soundscapes*, which are presented as either *Auditory Display or Auditory Feedback*. Lastly, by observing the results from the **sound component** point, one can identify relevant sound contribution and therapeutic impact, as can be observed in detail within Table 7 of the supplementary materials. The information presented in the tables is flexibly approached based on therapeutic, technical, and creative requirements, making this template a valuable tool across various disciplines.

Soundscapes were included in most sound contribution categories, indicating their versatility and importance in VEs. Regardless of their common use, their content was not equally developed-composed. On one end and in most cases, the content supported the visuals by adding a complementary realistic sound environment. On the other, more sophisticated compositions combined layers of sound stimuli, both natural and abstract sounds, to build a dynamic and complex soundscape. Approaching the distinction between sound assisting a therapeutic practice

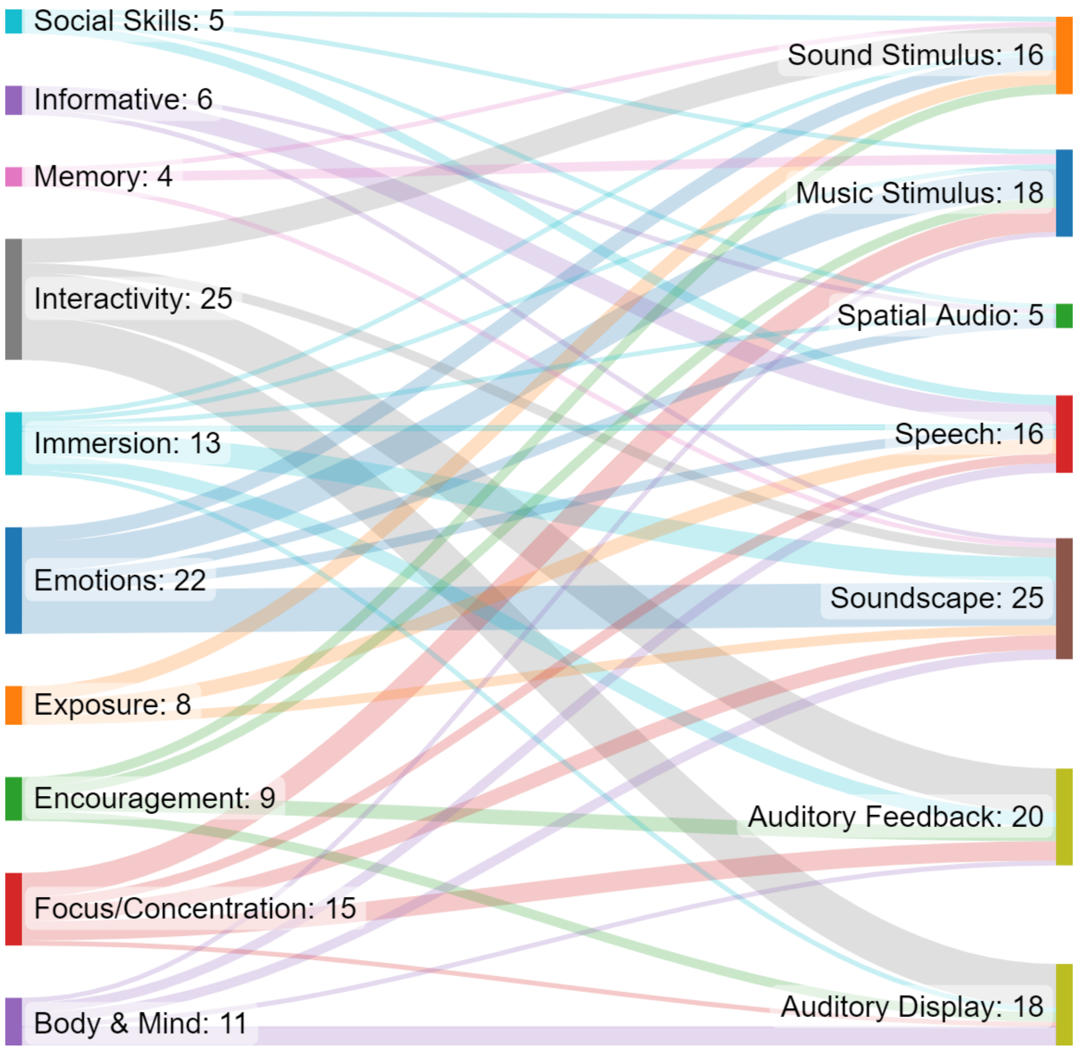


Figure 4.5: Describes the relationship between the sound contribution categories (left) and the sound components (right)

and therapeutic sound was investigated, i.e. how sound as an intervention can improve health and well-being. Nazemi [94] described the difference between music in therapy and Music Therapy (MT) as “the use of music as a means of enabling rapport building to work further toward the therapeutic goals” as opposed “a registered music therapist takes all aspects of the music, including all musical elements

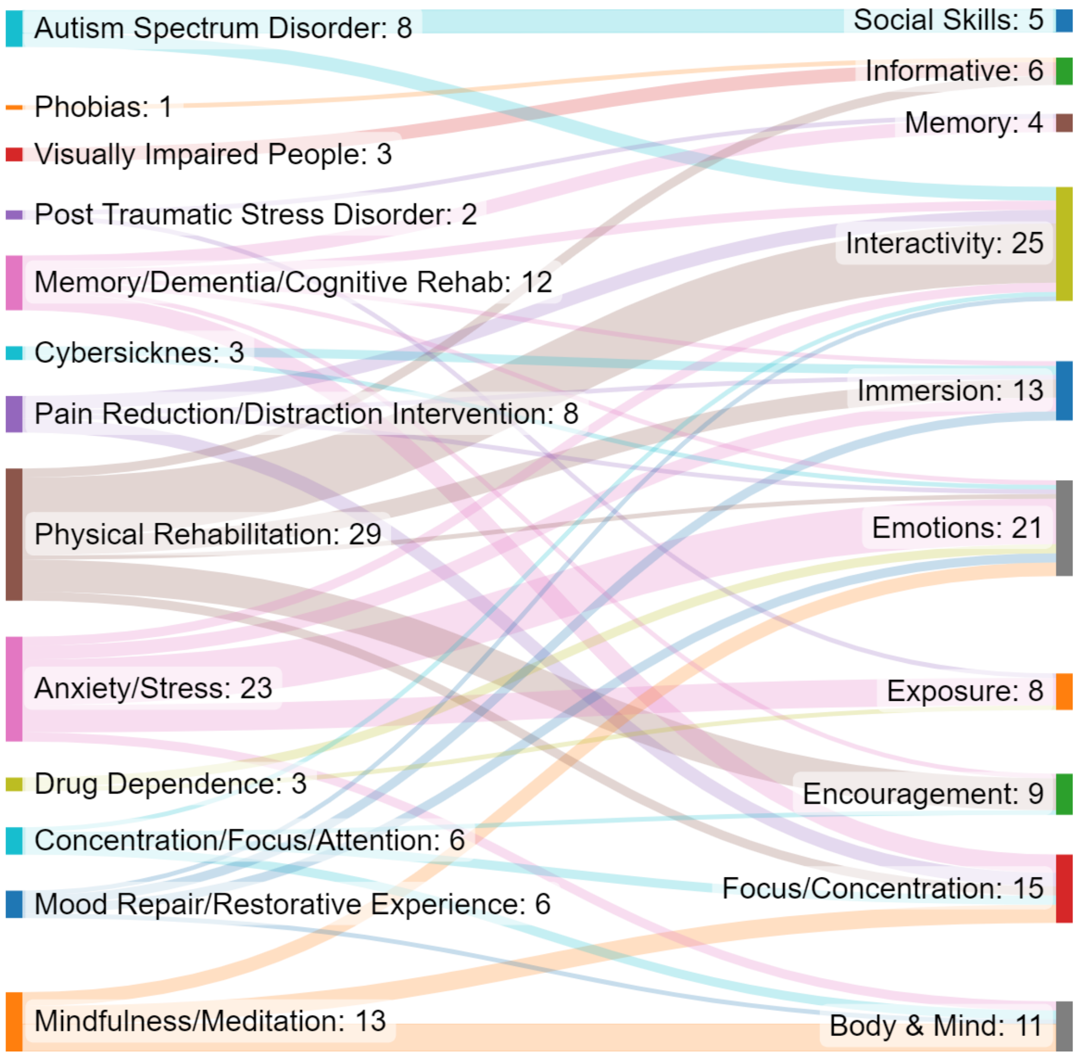


Figure 4.6: Describes the association between the therapeutic practice (left) and sound components categories (right)

into consideration in working towards a patient's goals".

The therapeutic qualities of natural environments vary according to the tasks, the sound components, and the technologies involved. Shu and Ma [91] showed that the simplest form of immersive natural soundscape (e.g., birdsong, fountain sound, ambient noise, etc) improved the different aspects of children's cognitive perfor-

mance like reaction time and working memory. A similar approach is adopted by many studies that introduce a relaxing natural VE (e.g., trees, forest, island, etc.) as a restorative environment before a stressful task, such as social speaking support [223]. Chirico et al. [191] compared music therapy (relaxation music selected by the therapist) and VR (natural VE with the relevant soundscape built-in "Second Life" [290]) as distraction interventions to alleviate anxiety and improve mood states in breast cancer patients during chemotherapy. They reported that VR had a significant impact on post-interventional anxiety, with MT having a lower impact. Also, predefined realistic soundscape content was used to increase the sense of presence in cases of drug dependency. Sounds from a drug abuse scene, such as party atmosphere or house gathering, were used to increase participants' tolerance in a controlled manner [192, 185, 177]. In the cases of VRET like Lc and Fukuoka [188], supporting stutters in social speaking provided a general soundscape of a park with the therapist controlling the amount of exposing destructive sounds as sound stimuli such as people talking, cars passing or a phone ringing. Another case of VRET introduced only the sound of fire as an auditory stimulus without the ambient soundscape, thus resulting in a much less immersive experience [190]. Gordon et al. [175] used a combination of natural underwater soundscape and a mix of synthesized auditory feedback sounds as part of the same sonic environment for pain distraction.
Under this scope, the soundscape content contributions to therapeutic practices were identified:

- Provide a positive emotional shift for relaxation, mood restoration, and anxiety reduction.

- As part of building self-confidence, the soundscape was used to produce negative emotions by adding noisy elements in the environment to distract people with social anxiety or introduce sound cues that increase the craving for drug abuse.

- Supporting biofeedback in a self-awareness process using a direct representation of measurement (e.g., heart rate (HR), respiration) with a natural element (e.g., wind, waves), or applying a metaphor, e.g., the higher level of meditation, the more realistic and richer the soundscape became.

- Introducing spatial sound cues encourages gamification and improves social interaction for children with ASD.

- Maintain active engagement by alternating the soundscapes and reducing auditory repetition.

- Assisting Visually Impaired People (VIP) in self-navigation and improving spatial knowledge.

- Accompanying the visual content.

Abstract sound elements are introduced in many practices mainly associated with audio processes (e.g., auditory feedback, auditory display, spatial sound). This field of incorporating abstract sonic elements in immersive soundscapes for therapeutic purposes is at its very beginning. In a stroke rehabilitation application, Chen et al. [171] aim to "create an emotional connection between audio feedback and movement performance". Synthesized sounds are used with harmonic intervals and sound attributes mapped to the participant's movement. The sound layers created provided an alternating soundscape to avoid auditory repetition and maintain active engagement. Similarly, the same study creates rewarding sounds by introducing variations between dissonant and non-dissonant pleasing sound synthesis with fast-moving, high-density, tin-sounding notes instead of slower sounds of a gentle, rolling ocean. Pares et al. [240] provide a dynamic environment that encourages children with Autism to express themselves and establish a sense of agency. The abstract sound stimuli originated from the participant's voice, vocalizations, and clapping. The stimuli were transformed by adapting forms of formant synthesis to simulate singing voices.

Another example of a real time audio process for therapeutic purposes was Person et al. [197], which aimed to remove distraction and focus participants' attention. They create an installation transporting the user to a musical wonderland where their bodies become the instrument to produce a harmonious symphony of sounds.

Miller [155] provides guidance on the use of biofeedback technology to enable an insight into how music or sound cues can change the status of a patient's responses in real time. Most of the studies introduced biofeedback to improve self-awareness. Dar et al. [194] and Plessis [198] used synthesized, non-verbal instructions to bring the participants breathing behaviour to a rhythm that allowed them to feel more relaxed. Yu et al. [243] and Prpa et al. [193] preferred transforming biofeedback data into nature sounds instead of audio tones or a melody.

In the VE, all sound components are intended to coexist and collaboratively shape the virtual experience. Given that sound components, particularly the soundscape content, have been linked to both types of contributions and therapeutic practices, a cohesive form can be pursued within the TIS framework. TIS encompasses the purposeful integration of these sound components. It was observed that for a particular therapeutic task, a synthesis of sound components is necessary. When designing TIS, it is imperative to incorporate various sound components to preserve these established associations. For instance, sound stimuli such as abstract, animal, or everyday sounds should be crafted to seamlessly fit within the soundscape in terms of content and VE acoustics. This ensures that coherence is consistently maintained. The provided descriptions delineate potential variations TIS might exhibit, grounded in the therapeutic correlations of the sound components.

4.4.3 Interactivity

Variations in Interactive Structures

Interactivity adds a personal feeling to the soundscape creation, helping the participants familiarise themselves and engage with the VE. Adapting the system to the participants characteristics and customising its content are significant steps for personalising the therapeutic experience. According to the therapeutic practice, there are variations in the interactive structure of the agents. The analysis of these variations aims to explore their correlation with interactive-passive soundscapes. The rest of the studies that didn't use soundscapes respond to the interactive process using a mixture of all the content-based sound components, i.e. sound and music stimuli and speech.

The roles of the different agents in the interactive structure, defined by the subject, the observer and the processes of evaluation, content creation and customization, interconnect and sometimes overlap in investigating a specific method or case. In an immersive environment, the subject always retains the primary form of interactivity by navigating in the VE and, in most cases, modifying the content. The observer supervises the process according to the therapeutic tasks, retains the physical and mental safety precautions, provides information and instructs when necessary. The adapting process supports the personalization of the therapeutic process towards the subjects characteristics. It consists of the

Evaluation and the *Customization* tasks controlled by either the observer or the machine/computational process.

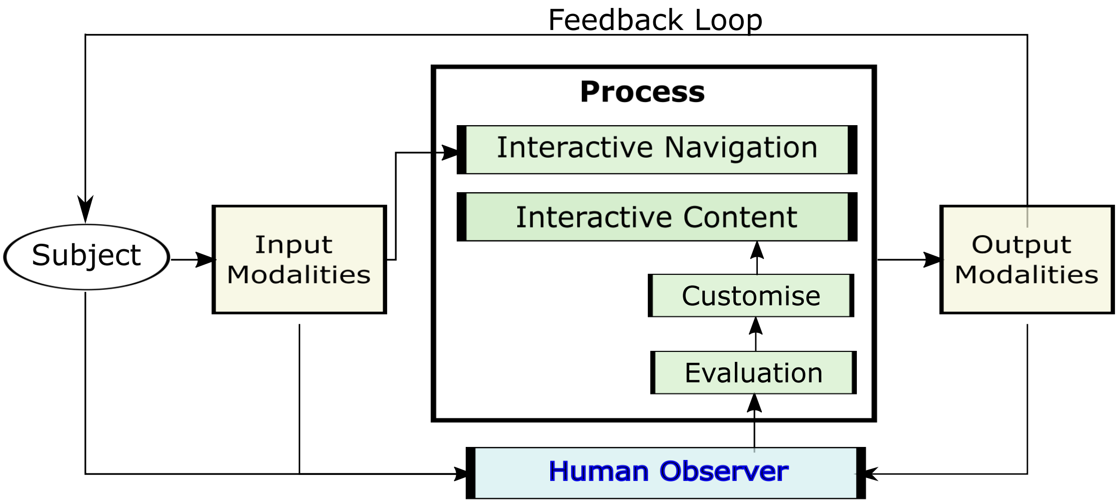


Figure 4.7: Diagram presenting the Manual Supervision configuration. The subject does not affect the content and the observer completes the feedback.

Manual Supervision: This is highly dependent on the role of the observer. The participant navigates in the VE, but there is no further interaction with the content. The observer or therapist, on the other hand, completes the feedback loop by observing, evaluating the process, and customizing the content, as shown in Fig.4.7. In this case, the system does not exist without the observer. This unique case is mainly used by studies involving VRET where stimulus exposure is crucial. Also, an overall evaluation of the emotional state of the subject is required [223, 242, 184, 207, 190, 91].

In the Manual Supervision Claudio et al. [242] and Annerstedt et al. [223] used interactive soundscapes. Aligned with the above structure presented in Fig. 4.7, the observer controls the sound exposure of the content. Both studies applied

VRET by adjusting the sound level and occurrence of distractive sounds in the VE and, hence, the amount of annoyance, according to the participant's distress.

Responsive System: The subject navigates and interacts with the content. The system applies a 'staged progression' structure with predefined difficulty and steps of development; see also Fig. 4.8. Like most video games, the process does not distinguish between player's characteristics, needs, or personal expressions [243, 285, 201, 199, 196, 264, 197, 227, 205, 206, 195, 200, 261, 202, 228, 198, 259, 204, 252, 257, 178, 166, 251, 238, 189, 191, 192, 182, 262]. There is no personalized experience. There is a variation that comes with the existence of the observer who supervises the process and provides assistance when required but does not affect the content [179, 247, 181, 180, 246, 175, 186, 258].

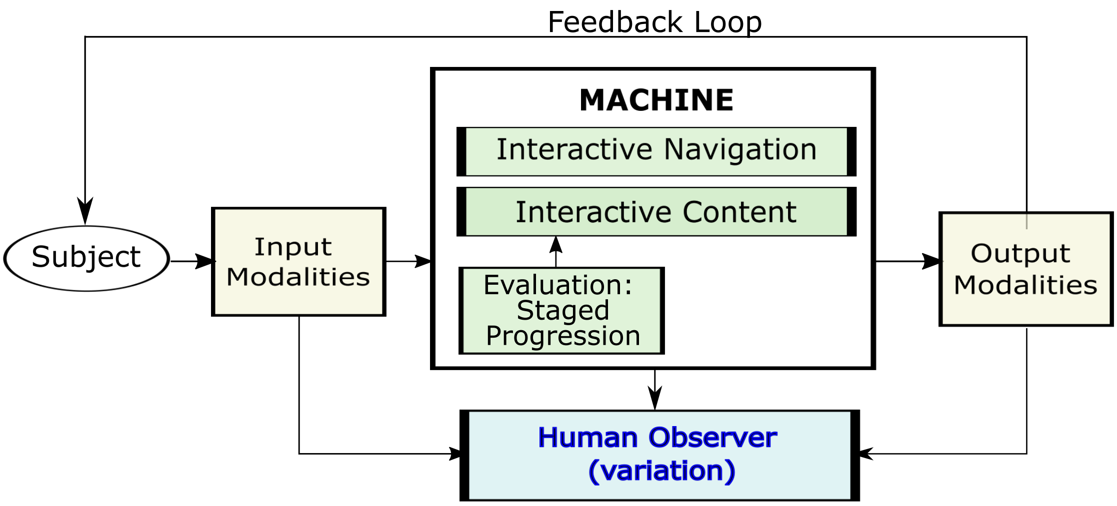


Figure 4.8: Diagram presenting the interactive process in the Responsive Supervision case where there is staged progression of the development of the tasks without any personalized modification.

There are several passive soundscapes where therapies expose the participants to predefined natural sound environments [251, 205, 195, 191, 182] and examine levels of relaxation via physiological measures or questionnaires. Similarly, realistic scenarios of drug use environments may be provided to improve tolerance to the participant's [185, 192]. On the other hand, in interactive soundscapes, the machine responds to the participant's actions by controlling the sound environment such as offices [261], machinery [178], or natural environments [102, 243, 196, 175] in a predefined and impersonal way.

Semi-Auto Supervision: On this occasion, the adaptive process is added and provides an evaluation based on observing the subject's reactions and input/output modalities (e.g., biosensor data). The data are used to customize the content, the steps needed, or sometimes even the task itself according to the participant's capabilities, thus providing a more personalized experience. This customization may happen in real time or after practice. Here the variation occurs between a human and a computational process implementing the adaptation. The observer is always human and in the first case (cf. Fig.4.9 variation A) the role of the observer and the adaptive system merge [250, 167, 241, 183, 237, 171, 255, 156, 256, 187, 235, 189, 249, 228, 233]. In the second case (cf. Fig.4.9 variation B), the evaluation/customization is implemented by the computational process, and the observer provides assistance to the subject or supervises the decisions that the machine/algorithm takes [248, 240, 170, 183, 221]. The therapist, in case B, does not modify the content.

In Semi-Auto Supervision, two studies used interactivity in the soundscape. Chen et al. [171] applied an integrated environment of both physical elements and interactive audio and visual feedback to train reach and grasp activities. The adaptation included feedback level, sensitivity, and media selection. This semi-supervised adaptation system automatically customized the exercise based on the participant's progress, allowed a therapist to review the progress, and adjusted the training strategy weekly. Johnston et al. [167] invited children with ASD to improve attention, social interaction, and cognitive development using specialised sound sources in building natural soundscapes. The level of progression was controlled by the support worker observing the levels of distress. Burdea et al. [248] (1st and 2nd experiment) and Shu and Ma [91] used passive soundscapes without the interactive process affecting the reproducing natural environments.

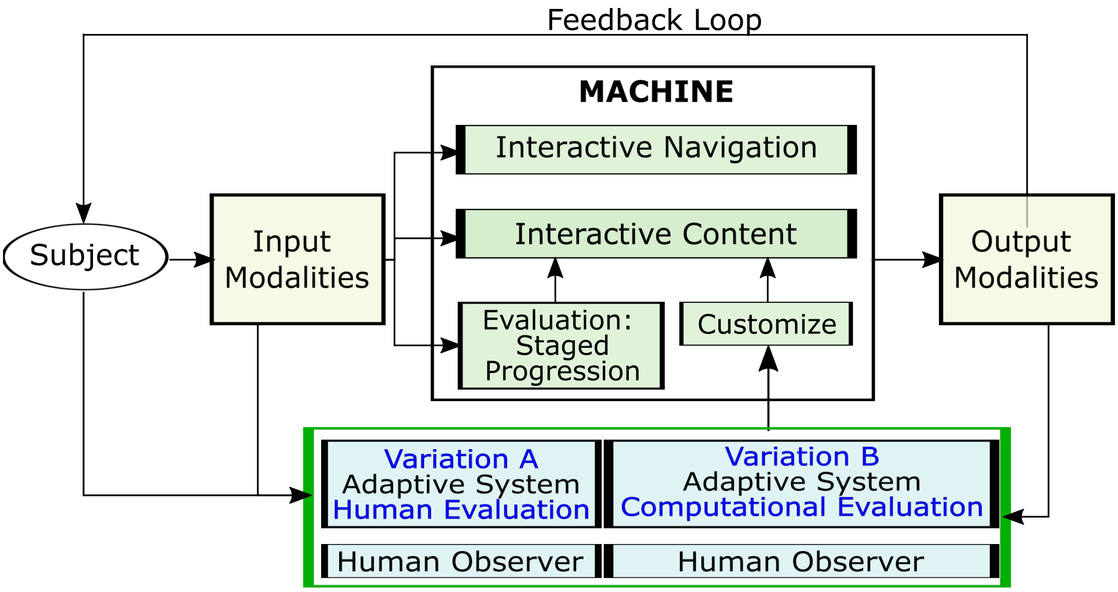


Figure 4.9: Diagram presenting the Semi-Auto System configuration where the Adaptive System, either by human evaluation A or computational process B, evaluates and customizes the content/process

Auto Supervision: In this automatic-standalone system, the adaptive process is driven entirely by computational evaluation, and the role of the observer is excluded, as seen in Fig. 4.10, [262] (2nd exp) [176, 194, 193, 97, 188, 240]. This was done by collecting data on the user's physiological responses, such as heart rate and skin conductance [194, 193, 97, 262], as well as their behavioural responses, such as their movement, voice recognition and vocalizations [176, 97, 240], and using this data to make real-time adjustments to the interactive structure. In their study, Lc et al. [188] applied machine learning methods to assist individuals with stuttering in managing their imminent episodes. Their algorithm utilised stress levels from galvanic skin resistance (GSR) sensor data and voice commands as input layers to customise the level of distraction, such as audience size, noise level, and distracting movements, thereby determining the optimal difficulty level for speech training in real time.

Three studies used interactive soundscapes. Zhao et al. [97] used physiological data from motion and facial expression to automatically create atmospheric effects such as light, sound, and video influencing occupants' ability to focus and restore from a stressful situation [97]. Four natural soundscapes plus silence varied according to focus or therapeutic activities. Lc et al. [188] used galvanic skin resistance measurements and machine-learning techniques in evaluating the stress level of stutters. The algorithm controlled the level of exposure (VRET) to distractive sound elements in the soundscape. Pares et al. [240] created an interactive installation where individuals with severe autism gain a sense of agency by "being able to exert control over their surrounding environment and obtaining a coherent response." The 'brain,' as the authors referred to their system, implemented the evaluation of participants' reactions and the 'signature analysis,' which provided the personalisation characteristics for the decision-making system to synthesise and modify the soundscape.

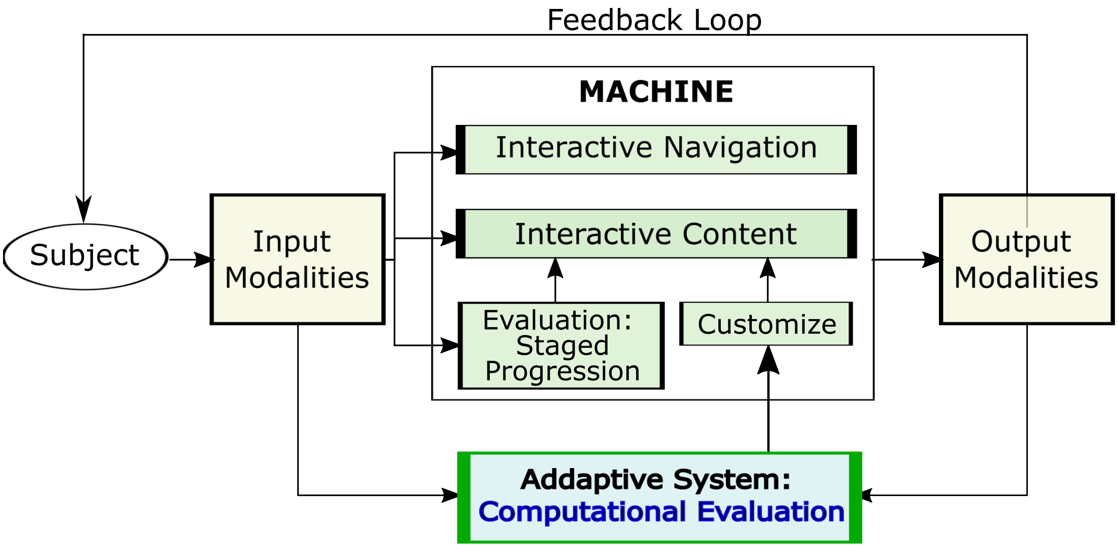


Figure 4.10: Diagram presenting the Auto System configuration where the Adaptive process is implemented by Computational Evaluation and there is no observer

Discussion: Interactive Structures

A personalised experience is significant for the effectiveness of the therapeutic practice. On the one hand, customising available treatment to the subject's personal needs increases the practice's accuracy. It provides a feeling of *trust in the process* to the subject, essential for a successful treatment. Furthermore, interacting with a personalised system enhances engagement and thus immersion, another critical element for an effective TIE. Fig. 4.11 maps the emerging configurations of interactivity to variations of agency roles.

According to the studies examined, a highly personalised experience was achieved based on the active role of the observer and the adaptive process. In the Manual and Semi-Auto Supervision systems, the observer supervises and provides support to the subject and, at the same time, evaluates the process to customise the content. The Auto Supervision system does not include the observer, and thus, the lack of communication and support to the subject only provides a low personalised experience. Finally, Responsive Systems hold the least impersonal experience with the passive observer and no adaptation.

Agents		Interactive Configurations					
		Manual Supervision	Responsive System		Semi-Auto Supervision		Auto Supervision
				Var.	Var. A	Var. B	
Subject	Navigation	X	X	X	X	X	X
Subject	Interact	-	X	X	X	X	X
Observer	Human	X	-	X	X	X	-
Adapting	Human	X	-	-	X	-	-
Adapting	Machine	-	-	-	-	X	X
Personalised Experience		**High**	**None**	**None**	**High**	**High**	**Low**

Figure 4.11: Categories of Interactive Configurations: Levels of Personalized Experience Based on Agency Roles. In the left column labelled 'Agency,' situations in which subjects either solely navigate in a VE or have the opportunity to engage in interactive experiences are described. The observer is consistently a human, while adaptive processes can be carried out by either a human or a machine, typically in the form of a computational process.

The adaptive process is critically vital for personalized treatment. It includes the evaluation, based on which the customization of the interactive content takes place. A human implements the evaluation in the cases of Manual and Semi-Auto whereas computational processes in the cases of Semi-Auto and Auto. The main difference is that the human implementation also incorporates the role of the observer. The observer enhances the adaptive process by supervising safety and anomaly detection and gaining a holistic understanding of the real time development of the therapeutic process, thus providing enriched support to the evaluation. Indeed, in the case of the computational processes, the evaluation is based on incorporating and analyzing physiological data for further execution of multi-tier conditions or, in more recent studies, the application of machine-learning techniques. This computational process aims to draw conclusions and attempts an approximation of the real time understanding of the therapeutic process. Even though the computational support in the adaptive process looks promising, a gap appears to extend the implementation to cover the role of the observer as well.

It was observed that in most cases of VRET [190, 184, 207] and in the cases of ADHD [235, 233, 177] and self-awareness [202, 193, 203, 228, 262], the subjects did not interact directly with the content of the VE and retained the minimum level of interactivity by navigating within it. In those cases, the observer completed the feedback loop (manual supervision) by supervising and evaluating the subject's reactions and the extracted data from the input modalities and then customizing the outcome stimulus. According to Miller [155], this is for the protection of the subject, who lacks adapting capabilities and needs guidance and training.

The system's interactive structure variations and the role of the observer did not reflect the implementation of interactive and passive soundscapes as a single selection between the two. Even though a combination of sound components like music and sound stimuli or speech was used to implement sound interactivity, they didn't always include soundscape content. This fragmented approach reveals the need for a unified form of therapeutic soundscape supporting the VE, where the individual sound components co-exist in a technical, compositional, and therapeutic manner. However, a similarity exists in the customization of the soundscape content. It was implemented by the same agent that evaluates the process in each structure. For example, the customization of the soundscape content is implemented in the case of Manual Supervision by the observer, in the Responsive System by the machine in a predefined way, in the case of Semi-Supervision by the machine over the observer's supervision and finally in the Auto-Supervision controlled by the adaptive computational mechanism.

4.5 Limitations

Immersive technologies develop further every year, improving the interfaces, the quality of visuals, and player interaction. The primary research limitation of the immersive practices examined is the difficulty of establishing standardized methods relative to technologies, input and output modalities, and the content used. Variations exist in technologies such as motion sensors and cameras for enhanced tracking and interactivity, image resolution, colour accuracy, and dynamic range for a visually immersive experience such as HMD and surround-screen display system. Likewise, the selection of interfaces such as controllers, keyboards, or non-invasive methods affects the type of interaction. Differences in the sound reproduction methods, such as the number and arrangement of speakers or the type of Ambisonic encoding, affect auditory and spatial perception. Similarly, the combination of physiological and biosensors selected in each case results in variations in sensitivity, accuracy, resolution, response time, interference, range, and signal-to-noise ratio.

The limitation of non-standardised methods involves difficulty defining and reproducing sound content, especially for abstract sounds and soundscapes. From the studies examined, the sound content used for stimulation consists of various sources and recordings, making it difficult to reproduce the experiments and compare the results. Soundscape compositions, sound synthesis, and real time audio processes are challenging to describe and reproduce. The only exceptions are the studies that used the International Affective Digitized Sounds (IADS) database

[221], aiming to produce a solid methodology.

4.6 Conclusions

This scoping review explored the application of soundscapes within TIEs. The investigation primarily focused on the therapeutic qualities of three principal characteristics of soundscapes: the reproduction methods (including both immersive and non-immersive technologies), the content featured as part of the sound components, and the level of interactivity.

Despite the increasingly dominant use of immersive environments across a range of psychophysiological healthcare services and well-being practices, there has been a limited emphasis on the incorporation of sound. The findings indicate that only 58% of the studies made a reference to sound, and within these, many merely mentioned the existence of sound or audio feedback briefly. This underscores a conceptual gap in integrating sound into the therapeutic process. Approximately a third of these sound-inclusive cases introduced some form of soundscapes, often without explicitly using the term. Instead, they often depicted a calm, natural sound environment, which the authors classified as a soundscape based on its content.

In the TIEs under study, it was observed that significant effort had been applied in the construction of 3D visual environments to immerse and engage the participants. However, the audio construction of a corresponding 3D sonic environment seemed to have been underdeveloped. Immersive technologies have been introduced to soundscape reproduction to a minimal extent. Only five studies (qv. Table 4.3) employed spatial audio reproduction techniques over binaural audio or speaker arrangements. These studies demonstrated the capabilities and impact of sound immersion as an integral part of the therapeutic process by enhancing concentration, promoting well-being, and facilitating social interaction for children with Autism Spectrum Disorder (ASD). Furthermore, immersive soundscapes were found to assist Visually Impaired People (VIP) in self-navigation and the construction of coherent spatial mental models. The primary therapeutic contribution of soundscapes was seen to derive from the utilization of realistic sound environments to evoke emotional changes for the purposes of relaxation, mood enhancement, and anxiety management. In the case of VERT and the bolstering of self-confidence in drug-related cases, soundscapes were used to introduce distractors to augment tolerance or regulate anxiety. Cases focusing on self-awareness used soundscapes to promote biofeedback, achieved by manipulating natural sounds that directly reflected physiological measurements.

Diving further into the role of sound in therapeutic practices, this review identified and mapped the association of sound contributions relative to the therapeutic tasks and the sound components as presented individually in Tables A.1-A.10 and summarised in Appendix Table A.11. Consideration was given to examples from therapeutic psychological tasks, Anxiety/Stress required Emotional shift and controlled Exposure, which were implemented using Sound Stimuli, Soundscapes and Speech. Memory/Cognitive Rehabilitation uses Interactivity and processes or stimuli that support Focus and Memory, like Sound Stimuli, Soundscapes, Speech and Auditory Display. Concentration/Attention seeks Encouragement and Interactivity, which are fulfilled with Sound and Music Stimuli and Auditory display. Physiological health tasks were found to require a broader combination of Sound Contributions and Sound Components, as seen in cases of Physical Rehabilitation and Pain Reduction. Interactivity and Social Skills were determined to support

ASD cases by combining all Sound Components. Well-being practices like Mindfulness were found to require Focus, Body and Mind, and Emotional shifts, implemented using Music and Sound Stimuli, Soundscapes, Speech, and Auditory Displays. Mood Repair and Anxiety were reliant on Immersion and Emotional change, applied via Spatial Audio, Music and Sound Stimuli, and Soundscapes. The aforementioned examples illustrate the Sound Contribution applied to Health and well-being practices, which can be bidirectionally interpreted. Starting from the Sound Components, one can observe which Sound Contributions are served (supplementary Table S6), or from the Sound Contributions, one can examine which therapeutic tasks are fulfilled and which Sound Components are required (supplementary Table S5 and Graphs S1-S2). These mapped associations can be interpreted according to the required interests and can guide future designs.

An analysis was conducted in the review of the relationship between input-output modalities and the roles assumed by agents in interactive systems. Differences in roles within these structures were mapped out, with the impact of new technologies on the adaptation process taken into account. The roles were found to vary across a spectrum of systems, from manual and responsive to semi- and fully automated, depending on the system's adaptation capabilities and the presence of the observer. This analysis allowed the identification of an emerging quality of personalized experience. Interactive structures were categorized according to their level of personalization, with impersonal experiences provided by Responsive Systems, some degree of customization incorporated by Automatic Supervision, and highly personalized experiences resulting from Semi-Auto and Manual Supervision, thereby emphasizing the observer's role.

No correlation was identified between the passive-active implementation of soundscapes and the variations in interactive structures, thereby suggesting that the selection of the interactive strategy is primarily guided by the therapeutic task. However, when interactive soundscapes were employed, customization was consistently executed by the agent specified in the interactive structure, indicating a consistent relationship between the interactive structures and their implementations in both visual and auditory modalities.

Future implementations could be informed by these observations to select an appropriate interactive structure tailored to the therapeutic objective. For practices that adopt a predetermined structure for each therapeutic session and reevaluate it afterwards to prepare for the subsequent session, such as in cases of physical rehabilitation or self-awareness, structures involving responsive and semi-automatic supervision might be fitting. In contrast, for psychologically sensitive cases such as phobias or trauma, where the evaluation and selection of exposure stimuli differ among participants, manual and automatic supervision structures should be contemplated, taking into account the observer's involvement. The potential for future research is suggested by the introduction of machine learning techniques in the observer's role, overseeing the adaptive process and ensuring the psychophysiological safety of the subject. This suggestion is not intended to replace the therapist but to facilitate the development of an assistive tool that promotes the agents into new roles within more flexible structures.

The term TIS was proposed as a unified soundscape form that encapsulates the therapeutic qualities of the three main soundscape components. The analysis highlighted the therapeutic contributions of the individual components, starting with the impact of spatial audio on immersiveness, followed by the role of interactivity in enhancing engagement and personalizing the experience. Certainly, considerations need to be made when applying accurate virtual acoustics, including the representation of all sound sources within a unified space. The soundscape should interact not only with the participant's actions but also with changes in the environment, such as distance and surroundings in the virtual environment, through real-time processes. Finally, the topology, including the sound contribution and sound components generated from this review, could be utilized in the synthesis of soundscapes to construct the required therapeutic content.

4.7 Summary

This scoping review provided a comprehensive investigation of soundscapes within TIEs, revealing several critical insights that significantly influenced the next stages of my research. The systematic approach adopted in this review was invaluable in identifying gaps and opportunities within the current landscape, which in turn shaped the development of my experimental approach.

The limited utilization of soundscapes in therapeutic processes underscores the necessity for more comprehensive evidence regarding their therapeutic applications. This observation highlights the pressing need for further empirical research on the efficacy of incorporating soundscapes within therapeutic interventions.

The investigation into the sound components and stimuli provided a critical understanding of their contribution to therapeutic processes. This led to the main contribution of this review: identifying the sound contributions and components supporting therapeutic purposes. This process helped pinpoint the role of soundscape content as part of a broader array of sound stimuli and audio processes, thereby aiding in the formation of the structure for TIS. This understanding was instrumental in forming my research questions, focusing on exploring the content creation and spatialization of soundscapes and the integration of dynamic elements for exploring soundscapes in ADHD therapy.

The review confirmed the versatility of soundscapes in achieving a broad range of emotional and psychological impacts. However, the content was often not developed or composed innovatively, mainly focusing on natural or realistic sound environments. This observation prompted the need to explore novel methods of constructing alternative sonic materials and compositional methods without compromising the therapeutic qualities of existing soundscapes.

Few studies utilized spatial audio techniques, yet these highlighted the potential of sound immersion to enhance therapeutic outcomes. This observation led to a research direction to evaluate the specific impact of spatial audio in ADHD therapy and to quantify therapeutic metrics associated with spatial sound.

The review indicated that soundscapes had been under-examined in ADHD studies. My research aimed to provide empirical evidence in this area, focusing on how soundscapes can play a more central role in ADHD therapy.

The review's analysis of interactive structures underscored the importance of personalized interventions. This influenced the direction of my research to introduce innovative methods for personalized soundscape content in ADHD therapy. Furthermore, it suggested the integration of dynamic elements into the soundscape design, examining its effect as stimulation or distraction.

The review's limitation pointed to the need for standardized content creation methods. This led to the development of an auto-mixing method for personalized soundscape content based on the spectral characteristics of pink noise and a sound level calibration method to ensure accuracy at the listener's ears.

The review covered an extensive range of studies and therapeutic practices, providing a crucial overview of soundscapes and their contribution to the therapeutic process. While it offered significant insights, extended details specific to ADHD were not deeply explored. If I were to approach this review again, I would consider focusing further on the impact of soundscapes across a wider range of neurodevelopmental disorders. This adjustment would likely yield deeper insights into the specific applications and effectiveness of soundscapes in these contexts.

Overall, this scoping review was a foundational step in my research journey, informing my understanding of soundscapes in TIEs and guiding the development of my experimental approach in ADHD therapy. It has broadened my perspective on the potential of soundscapes in therapeutic settings and underscored the importance of continued exploration in this field.

5 Methods: Main Structure

5.1 Introduction

In line with the discussions from Chapters 2 and 3, the theoretical framework has been established that encompasses the primary fields relevant to this research. This includes understanding the aetiology and symptoms of ADHD, which are inherently connected to environmental stimulation and applied by Noise Therapy. Moreover, the theory and properties of soundscapes have been laid out, including their structure, compositional approaches, therapeutic attributes, and immersive qualities.

The objective of this research is to utilise personalised soundscapes designed to perform environmental stimulation in order to improve ADHD symptoms. The soundscape material proposed in this study stems from 'noisy natural environments' like wind, rain, and waves.

Personalised material is formed by the participants through the selection and combination of three sounds. The Conner's Continuous Performance Task (CPT) is used in its gamified version to measure cognitive performance during the soundscape experience, and hand and head tracking are utilized to evaluate the behavioural attributes of the participants.

The research examines the performance of participants across five sound conditions: The 'Silence' condition allows for an assessment of participants' cognitive and behavioural responses in the absence of auditory stimulation. This provides a fundamental point of comparison for evaluating the effects of the other sound conditions. 'Pink Noise' is incorporated as a standardized auditory stimulus, representing standard noise therapy. Its inclusion is motivated by prior research indicating potential benefits for individuals with ADHD. The purpose is to compare its effects and provide additional insights to the existing literature. This condition aims to explore whether a consistent auditory stimulus can elicit improvements in attention and behaviour. The 'Personalized Soundscape' delivered via dual mono and through binaural 3^{rd} order Ambisonics represents an innovative approach to environmental stimulation. The choice of these conditions stems from the hypothesis that personalized auditory environments, tailored to individual preferences, may offer more significant therapeutic benefits than generic stimuli. The dual mono condition allows us to examine the effectiveness of personalized soundscapes without spatial cues, while the binaural 3^{rd} order Ambisonics condition introduces a spatial dimension hypothesized to enhance the immersive experience and potentially augment the therapeutic benefits. Finally, the 'Binaural Personalized Soundscape with Interactive Audio Indicators' condition is designed to assess the impact of adding dynamic, interactive elements to the soundscape. This condition is rooted in the concept that interactive auditory cues might further engage participants, potentially leading to greater improvements in cognitive and behavioural metrics.

This chapter on Methods is divided into sections: the first details the methods associated with measuring the dependent variables, and the second provides information concerning the sound conditions constituting the independent variables.

More explicitly, the chapter begins by outlining the methodologies employed to lay the foundation for testing cognitive and behavioural characteristics and their associated metrics. These metrics, drawn from the gathered measurements, contribute to the process of calculating further metrics, collectively shaping the dependent variables of the research. The deployment of these methodologies led to a series of games, thereby transforming data collection into a more engaging, gamified process for participants. The games implemented in this study consist of a gamified version of Conner's CPT, named 'Save the Mushroom' and a 'spatial audio evaluation game' developed for this project. The latter is designed to familiarize participants with spatial audio and examine their comprehension and perception of spatial acoustics. For clarity regarding *measurement metrics* and *sound conditions*, a summary of both dependent and independent variables is provided.

The latter half of this chapter focuses on the sound conditions of the experiment, which constitute the independent variables, and offers an overview of the methods employed to construct them. The sound content selection and post-production are presented. Following this, methods related to the Auto-Mix algorithm and the generation of personalised soundscapes are explained. Further insights are offered on the 'Audio Indicators' sound condition, followed by a discussion that differentiates between 'stimulant' and 'distractor'. Lastly, ensuring precise playback audio levels is a crucial aspect of the experimental process. To address this, detailed calibration procedures are documented.

5.2 Measuring Cognitive and Behavioural Characteristics Framework

5.2.1 Conner's Contentious Performance Task

The Conner's Continuous Performance Test (CPT) is a quantitative diagnostic tool used to assess attentional processes and related executive functions in individuals with ADHD and other neuropsychiatric disorders [291, 1]. Developed by Conner in 1995, the test is designed to evaluate a variety of attention-related processes, including selective attention, sustained attention, response inhibition, and vigilance. The task is typically 14 minutes long and consists of 360 stimuli presented at varying intervals. The test is based on Go-NoGo decision-making and consists of a series of stimuli such as letters, numbers, or shapes presented on a computer screen. The participant is instructed to press the mouse button when a specific target letter appears while ignoring all other non-target letters. The test measures various aspects of attention and impulse control, including reaction time, accuracy, and the ability to sustain attention over a period of time.

Studies have shown that CPT is a reliable and valid measure of attention and executive functioning in both children and adults. For example, a study conducted by [292] found that the CPT was able to differentiate between children with ADHD and normal controls on measures of accuracy, reaction time, and variability in response times. Similarly, [293] differentiated ADHD cases and other psychiatric diagnoses within college students, and [294] identifies ADHD cases and non-clinical adults. Research studies have consistently reported that individuals with ADHD show impaired performance on the CPT, characterized by increased omission errors, commission errors, and reaction time variability [295]. In addition, the CPT has been shown to have good test-retest reliability and internal consistency, making it a reliable measure of attention and impulsivity [296, 297]. Several studies have also explored the efficacy of interventions aimed at improving the performance on CPT in individuals with ADHD. For example, a randomized controlled trial conducted by Bedard et al. [298] found that a 12-week cognitive training program improved performance on the CPT in children with ADHD, as well as reduced symptoms of inattention and hyperactivity. Similarly, a study by Bioula et al. [299] showed that VR classroom remediation programs reduced distractibility on the CPT scores in children with ADHD.

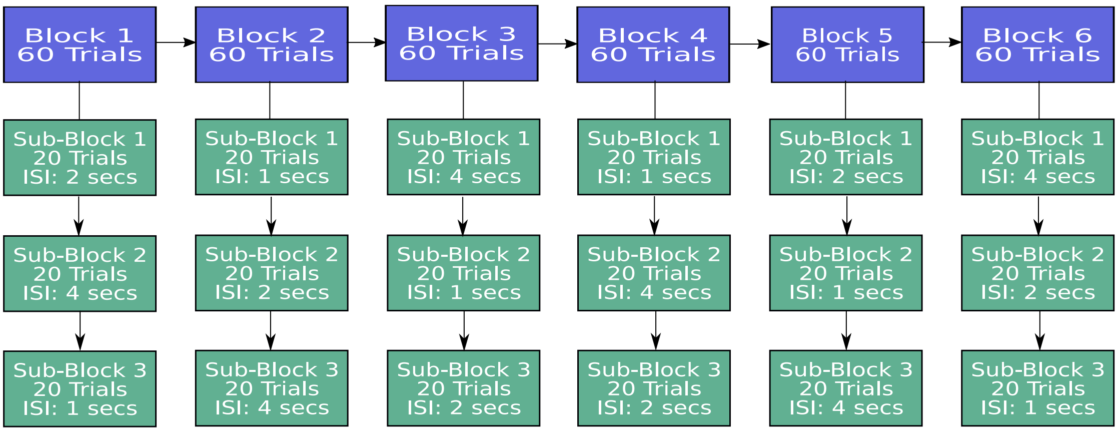


Figure 5.1: Conner's CPT Test Structure. Consists of 6 blocks of 60 trials. Each block has 3 sub-groups of 20 trials. The inter-stimulus intervals (1,2 and 4 secs) vary randomly within each block.

Despite its strengths, the CPT has some limitations that need to be considered. CPT may not be sensitive enough to detect subtle changes in attention and impulsivity, particularly in individuals who are high-functioning and able to compensate for their ADHD symptoms [295]. This means that the CPT may not be a suitable tool for assessing the severity of ADHD symptoms in all individuals. Furthermore, the CPT may be affected by factors such as motivation, fatigue, and anxiety, which can influence an individual's performance on the task [300]. This means that the results of the CPT may not be entirely representative of an individual's sustained attention and impulsivity but rather reflect the influence of extraneous factors. Overall, the Conner's CPT is a widely used and reliable measure of attention and impulsivity in individuals with ADHD, and research continues to explore effective interventions for improving performance on this task.

The structure of Conner's CPT consists of six blocks of 60 trials each, and each trial lasts for 250ms [301]. Within each block, there are three sub-blocks of 20 trials each, and each sub-block has a different Inter-Stimulus Interval (ISI) or gap between the stimuli. The ISIs for the three sub-blocks are 1, 2 and 4 seconds, which randomly vary within each block, as shown in Fig. 5.1. During each trial, a single letter appears on the centre of the screen presented in a black background. Letters are used for stimuli, where the non-target is the letter 'X' and the target letters are all the rest, Fig. 5.2. The participant is required to press the mouse button as quickly as possible when a target letter appears and do nothing when the non-target letter appears. The letters are presented randomly, with a probability of 15% for each target letter.

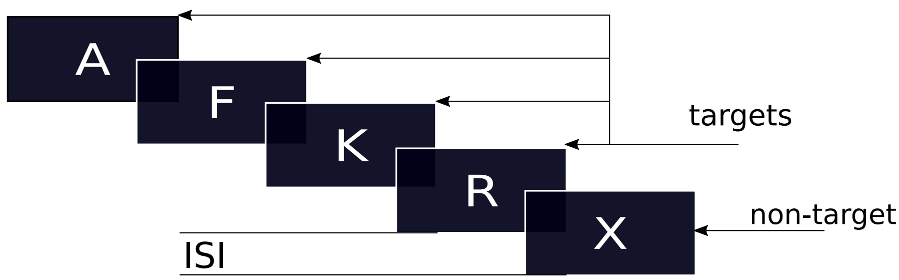


Figure 5.2: Conner's CPT Test Structure. Letters are used for stimuli. Targets are all letters except the letter 'X', which is the non-target. The stimuli are presented for 250ms, and the time between trials is defined by the inter-stimulus interval (ISI), which varies between 1, 2 or 4 secs.

The participant's response time and accuracy are measured for each trial, and the results are used to calculate various measures of attention and impulse control, such as the hit rate, the false alarm rate, and the variability of response times. The use of different ISI duration and target letters in the sub-blocks helps to assess the participant's ability to sustain attention over time and to inhibit impulsive responses to non-target stimuli. The six blocks of trials allow for the examination of the participant's performance across different levels of task demand and fatigue, which can provide valuable information for diagnosing attentional disorders.

5.2.2 "Save the Mushroom": Gamified CPT

For the purpose of this research, a modified version of Conner's CPT is utilized that incorporates gamification as a significant factor in motivating children to participate by making the task more enjoyable and less tedious. Previous research has utilized gamified versions of CPT in both virtual settings [302, 43, 303, 304] and non-virtual settings that featured variations in shapes, colours, or images [305, 306].

The gamified version of Conner's CPT was developed using the Unity game engine [307] for the game's visual aspects. The Supercollider real-time audio synthesis engine [308] was employed for the game logic, stimuli sequence, audio reproduction, and data storage process. The communication between the two software platforms was facilitated via Open Sound Control (OSC).

For this research, several modifications are made to the CPT. Firstly, the background is transformed from a solid black colour to a 3D representation of open countryside, as shown in Figure 5.3. This change aims to create a more engaging and immersive visual environment. Moreover, instead of using letters as stimuli,

Figure 5.3: "Save the Mushroom" is a gamified version of CPT built in a 3D environment. Left: 3x3 grid with the possible positions for the targets and non-targets. The icons of targets represent the 'target,' i.e. 'go' state and the 'mushroom' the 'non-target,' i.e. 'no-go' state. The green bar is a time bar representing the remaining time.

the task featured icons of targets to represent the 'go' state, while a cartoon image of a mushroom was used to represent the 'no-go' state. The game is named 'Save the Mushroom' based on the instruction given to the participants to hit the targets and avoid hitting the mushroom (non-target). Additionally, the positioning of the stimuli on the screen is modified. Instead of being solely centred, both the targets and non-targets are arranged in a 3x3 grid, equidistant from the centre, as illustrated in Figure 5.3. This layout can provide information about the visual-spatial attention of the participants, which is useful for understanding their learning style. To ensure an equal number of presented stimuli per column, the number of trials per subgroup is increased from 20 to 21, resulting in a total of seven icons displayed in each column for every subgroup.

The final modifications made based on feedback from the pilot test include incorporating a time bar to show the remaining time for completing the task and providing visual feedback, such as fireworks, when the participant successfully hits a target. This feedback is designed to occur only once and exclusively for targets, with the intention of discouraging continuous use.

Figure 5.4: Additional features in the gamified version of CPT include the time bar (green bar) indicating the remaining time for completion and the visual feedback after the target is hit to verify the response.

Symptoms	**Scores**	**Description**
Inatte-ntiveness	Detectability d’	Ability to discriminate between targets and non-targets
	Omissions	Missed targets
	Commissions	Incorrect responses to non-targets
	Hit Reaction Time (HRT)	Response speed
	HRT Standard Deviation	Response speed consistency
	Coef. of Variability (CV)	Variability of response speed consistency
Impulsivity	HRT	Response speed
	Commissions	Incorrect responses to non-targets
	Preservations	Random or anticipatory responses (i.e., HRT <100ms)

Table 5.1: Conner’s CPT scores: ADHD symptoms associated with CPT scores and their descriptions. [291].

Considering these modifications, the CPT metrics utilised in this research must be described and adjusted appropriately. As outlined in the structure presented in the prior section (Figure 5.1), there are six primary groups, each subdivided into three sub-groups with distinct ISIs. For this CPT implementation, each subgroup undergoes 21 trials, resulting in a total of 378 trials. Adapting to these specifications, Table 5.1 illustrates the measured and computed CPT metrics provided for this research, which are subsequently explained. The measured metrics encompass:

- Hit Reaction Time (HRT): This metric, indicative of either inattention or impulsivity, encapsulates the speed of correct responses throughout the entire administration. An atypically slow HRT (higher scores) could be symptomatic of inattention, whereas an unusually fast HRT (lower scores) may hint at impulsivity;

- Omission Errors: This index, signifying inattention, measures the instances of failed responses to targets;

- Commission Errors: An indicator of impulsivity represents the amount of response to non-targets;

The metrics derived from these measurements include the following:

- Hit Reaction Time Standard Deviation (HRT SD): This is a measure of consistency in response speed throughout the entire administration, serving as an indicator of inattention. A higher HRT SD value signifies a more inconsistent response speed;

- Preservation: An indicator of impulsivity represents those that are made in less than 100 milliseconds following the presentation of a stimulus;

- Coefficient of Variability (CV), like HRT SD measures the response speed consistency; however, CV measures the amount of variance the respondent showed in 18 separate sub-blocks of the administration in relation to his overall HRT SD score. Higher values are indicative of greater inconsistency in response times, which might reflect difficulties with sustained attention, impulse control, or both. CV is calculated by:

$$CV = \sigma/\mu \tag{5.1}$$

where σ = standard deviation of HRT throughout the administration in seconds and μ = median HRT throughout the administration in seconds

- Detectability *d'*: This refers to a metric indicating inattention, signifying the capacity to distinguish non-targets from targets. The calculation is carried out by

$$d' = z(FA) - z(H) \tag{5.2}$$

where *FA* is the False Alarm rate and *H* is Hit rate.

In this case, the term 'False Alarms' denotes instances where targets are absent, yet participant responses occur. This is demonstrated by participant reactions to non-targets, depicted as 'mushrooms'. Such instances are identified as Commission errors. Similarly, the Hit Rates refer to occasions where the participant responded to a target. Therefore, the preceding Equation 5.2 can be interpreted as follows:

d' = Commission Errors - Total number of Targets - Omission Errors

Total number of targets = 306 (max Omission errors).
Total number of non-targets = 72 (max Commission errors).
Total number of trials in each administration = 378.
Applying the numbers related to this experiment to the formula mentioned above,

the output range is determined to be: a best detectability of -306 (calculated from the minimum commission errors of 306 minus the minimum omission errors) and a worst detectability of 72 (computed from the maximum commission errors of 306 minus the maximum omission errors). In some instances, the literature presents the terms *FA* and *H* in Equation 5.2 in an inverted order, leading to a reversal of the results. Under such circumstances, the best *d'* value would be 306, while the worst would be -72. As outlined in Conner's CPT manual [1], *d'* is represented with higher raw score values signifying poorer performance (or worse discrimination), which aligns with the outcome derived from the preceding formula.

5.2.3 Behavioural Characteristics: Hand and Head Movement

Hyperactivity is described in the DSM-V manual [309], which involves excessive over-activity, fidgeting, and inability to remain seated, surpassing what is typical for the individual's age or developmental level. Studies have demonstrated that children with ADHD exhibit differences in the quantity and severity of their movements compared to those without ADHD [310]. Wood et al. [311] found that the number of movements made can effectively differentiate between ADHD and comparison groups, while Teicher et al. [312] observed extended duration and heightened intensity of movements in individuals with ADHD.

These differences have been assessed using various methods of movement measurement, including infrared motion analysis with motion tracking systems [312], parent and teacher rating scales [312], and accelerometers [313, 314, 315]. However, there is currently no universally accepted method for measuring activity levels across different age groups and for various assessment purposes.

Two methods are implemented in the context of this research to measure movement and capture behavioural characteristics associated with hyperactivity. The first method involves analyzing hand movement data collected from mouse interactions of the dominant hand. The second method utilizes a wireless head tracker to monitor head movement. These adaptations enable the extraction of relevant behavioural information for the investigation of hyperactivity.

Hand Movement

The hand movement is captured in Supercollider by tracking the mouse movement. The X and Y coordinates of the mouse position along with the relative *time stamp* are recorded at a 1ms sampling rate. To calculate the total hand movement (TM_{HAND}), the displacement between consecutive points is measured, representing the change in position over time. This calculation is performed using the following Equation 5.3. The X and Y coordinates are normalized to values between 0 and 1, representing the relative position of the hand. Therefore, the TM_{HAND} is represented in terms of the magnitude of displacement.

$$TM_{HAND} = \sum_{i=0}^{n} \sqrt{\Delta x^2 + \Delta y^2} \tag{5.3}$$

Head Movement

The wireless Bluetooth NX Head Tracker device from Waves [316] is utilised to capture the head movement. This device tracks the position of the head in terms of *Pitch, Roll*, and *Yaw* at a refresh rate of 50 frames per second [317]. The head tracker device is positioned on the top centre of the headphone band as shown in Figure 5.5. During data recording, the device captures the angles of the head as it shifts from its origin. To establish the origin of the measuring system, the system is calibrated while the participant looks at the centre of the screen. Any deviation from this origin produces changes in the relative angles, specifically *pitch*, *roll*, and *yaw*, corresponding to rotation around the x, y, and z axes, respectively. To quantify the extent of head movement, the Total Head Movement (TM_{HEAD}) for each participant and for each sound condition is calculated using the formula described in Equation 5.4 [43]. This metric allows us to assess and compare the overall movement patterns across different participants and sound conditions.

$$TM_{HEAD} = \sum_{i=0}^{n} \sqrt{\Delta pitch^2 + \Delta roll^2 + \Delta yaw^2} \tag{5.4}$$

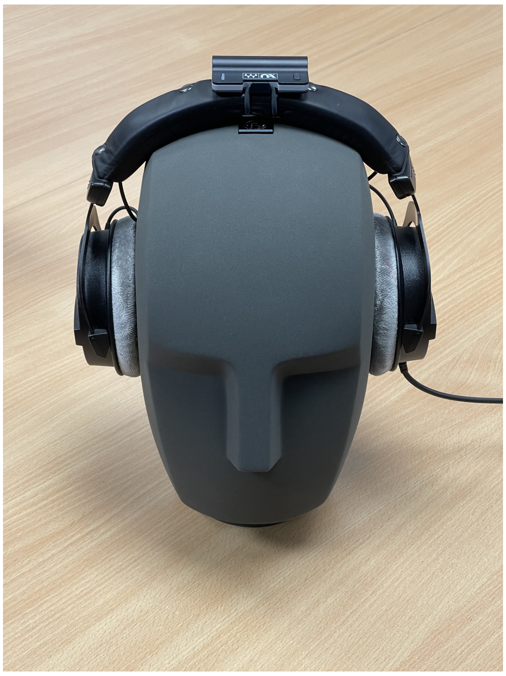


Figure 5.5: Head tracking device placed on the top-centre of the headphone band.

5.2.4 Spatial Audio Evaluation Game

The Scoping Review in Chapter 4 highlights the positive effects of immersion in therapeutic practices utilizing XR techniques. The literature suggests the potential of specialised sound to enhance the sense of presence [318] and immersion [319, 109], though this is not universally observed across all studies. This thesis explores whether specialised sound, compared to dual mono sound, potentially acts as beneficial stimulation or as a distraction based on participants' responses.

To accomplish this, an application has been developed to introduce participants to spatial audio in an engaging and enjoyable manner. The objective of this application is to gather valuable insights into participants' perception of spatial audio while evaluating their ability to distinguish directional sound sources in space. The findings from this application directly contribute to the selection of suitable HRTFs for the binaural decoder.

As explained in Section 3.6.6, HRTFs are highly individualized characteristics influenced by anthropometric factors such as the shape and size of a person's pinnae and head. Obtaining personalized HRTFs presents challenges due to the experimental procedures involved, which include participants having to visit an anechoic chamber and the time-consuming nature of the process. To address these challenges, generalized HRTFs are commonly employed. Two widely used dummy heads for producing HRTFs are KEMAR [146] and Neumann KU100 [147]. HRTF datasets can be found in SADIE II [148]. These dummy heads are designed based on the average characteristics of an adult head in terms of shape and size. Braren and Fels conducted a unique study focusing on children's HRTFs [153], making them the most appropriate for this research experiment. In their research, they measured HRTFs of children aged 5-10 years old in a hemi-anechoic chamber with

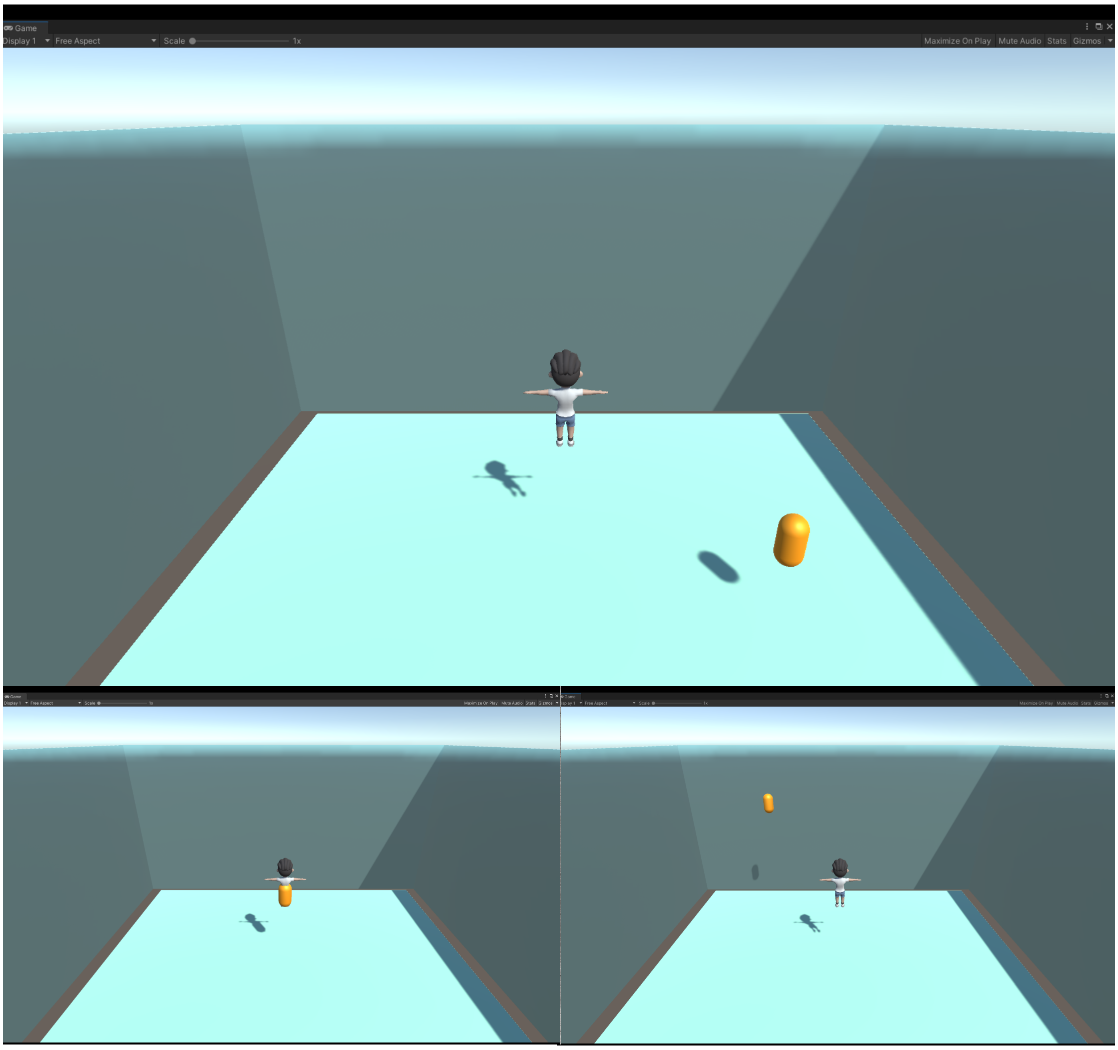


Figure 5.6: Spatial Audio Game at Unity: The avatar represents the participant in the centre of the screen. The yellow capsule represents the sound source. The participant moves the sound sources with the use of the keyboard and listens to the sonic representation of the spatial position of the source. Top: source positioned at left-rear-down, Bottom Left: source positioned at the origin, Bottom Right: source positioned at left-front-up.

a 5-degree resolution.

To explore the practical implications of this choice, an informal assessment was conducted during the pilot test. Two child participants were exposed to soundscapes decoded using both the KU100 and Braren's HRTFs. This exploratory test showed that the children demonstrated better spatial perception and performance with Braren's HRTFs. This observation aligns with the literature suggesting that children's auditory spatial perception can differ from adults and may be better represented by HRTFs measured from children.

The application utilizes Unity for visual implementation and Supercollider for real-time audio rendering. Figure 5.6 displays the visual environment of the game. In this environment, an avatar representing the participant is positioned at the centre, surrounded by walls located at a distance of 10m, with the floor at 2.5m. The yellow capsule represents the sound source. Participants can control the position of the source using the keyboard: arrow keys for front, back, left, and right movements, and the letters 'Q' and 'Z' for upward and downward movements, respectively. Pressing the space bar resets the source to its origin, which is the centre of the avatar (Figure 5.6, bottom left). The coordinates (x, y, z) of the sound source are transferred to Supercollider through OSC. They are then converted to spherical coordinates using the Equations 5.5, 5.6, 5.7 [103].

$$\mathbf{r} = \sqrt{x^2 + y^2 + z^2} \tag{5.5}$$

$$\phi = \arctan\left(\frac{y}{x}\right) \tag{5.6}$$

$$\theta = \arctan\left(\frac{\sqrt{x^2+y^2}}{z}\right) \tag{5.7}$$

where r = radius, ϕ = azimuth angle, and θ = elevation angle.

The amplitude of the sound decreases in relation to the distance from the source, following the inverse square law (Equation 5.8).

$$\mathbf{L_P} = L_R - 20 \cdot \log_{10}\left(\frac{r_2}{r_1}\right) \tag{5.8}$$

where:

L_P = the sound pressure level at a certain distance in dB.

L_R = the reference sound pressure level in dB.

r_1 and r_2 are the initial and final distances from the sound source in meters, respectively.

Flowchart 5.7 shows the data and audio communication paths from Unity to the Ambisonic encoder and decoder.

5.2.5 Dependent and Independent Variables

This section provides an overview of the dependent variables utilized in this thesis, which encompass a range of metrics employed to gain insights into the hypotheses formulated in Studies I and II. These metrics are derived from both the cognitive performance data obtained through Conner's CPT, as described in Section 5.2.1, and the behavioural responses obtained from the measurements of hand and head movement, as outlined in Sections 5.2.3 and 5.3.4. The within-group dependent variables for the experiments are encapsulated by these matrices, as outlined in Table 5.3.

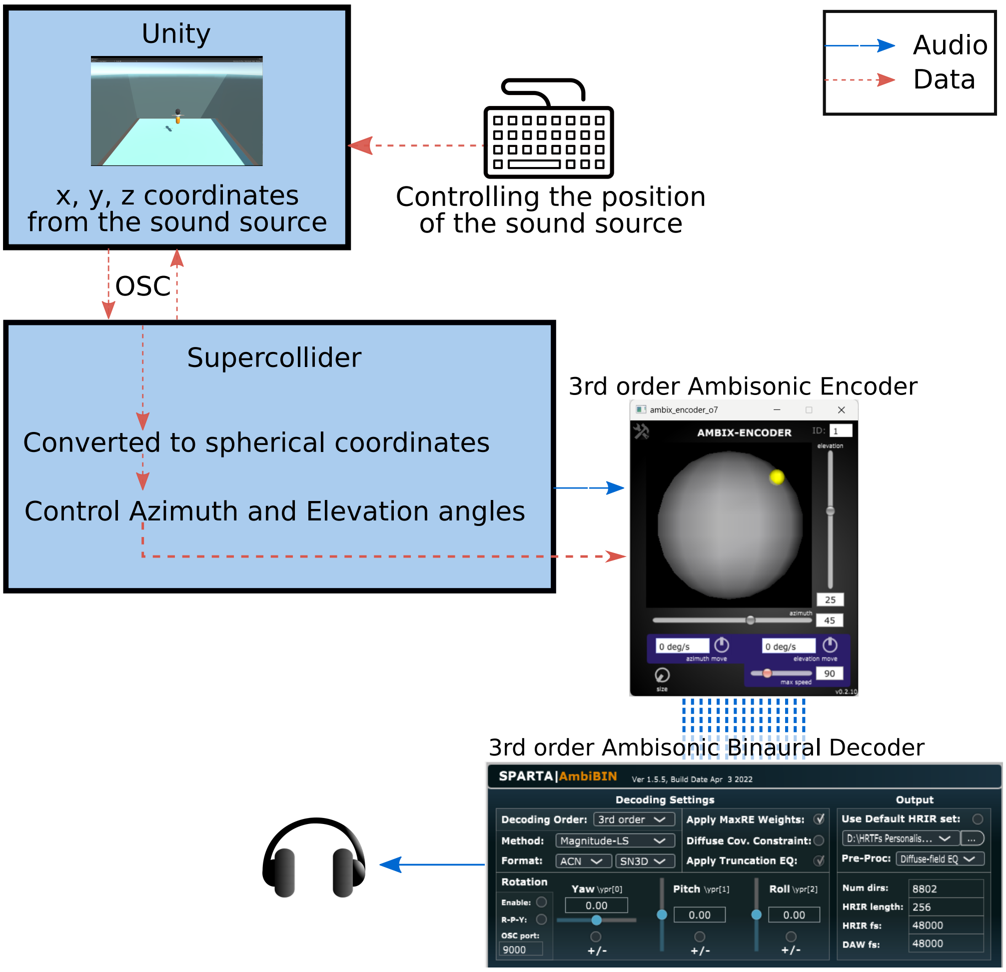


Figure 5.7: Flowchart: Spatial Audio Application. Coordinates from the position of the sound source in Unity are transferred to Supercollider to control the Ambisonic encoder.

There are two independent variables, the *sound conditions* and the *groups*. Studies I and II manipulated five *sound conditions* to evaluate their effect on the dependent variables. The conditions comprised the baseline situation of ‘Silence’ followed by ‘Pink Noise,’ a ‘Personalized Soundscape’ delivered via dual mono, a ‘Personalized Soundscape’ reproduced through binaural 3^{rd} order Ambisonics, and finally, a ‘Personalized Soundscape’ presented over binaural 3^{rd} order Ambisonics with integrated 'Interactive Audio Indicators.' These conditions are tabulated in Table 5.2. Additionally, the independent variable *groups* includes two categories of participants: the control group and the focus group. The interactions between these groups are explored in this study through the between-group statistical analysis.

Independent Variables - Sound Conditions

Sound Condition	Audio Reproduction Method	Audio Reproduction Level	Study
Silence (SLN) - Baseline	–	–	I
Pink Noise (PN)	Dual Mono	80 dBA	I
Personalised Soundscape (SS-MN)	Dual Mono	78 dBA	I
Personalised Soundscape (SS-BN)	Binaural 3^{rd} ord Amb.	78 dBA	II
Personalised Soundscape with Audio Indicators (SS-AI)	Binaural 3^{rd} ord Amb.	Sound Content: 72dBA Audio Indicat.: +6dB	II

Independent Variables - Groups

Focus Group
Control Group

Table 5.2: The table displays the independent variables used in the experiment. It outlines the Sound Conditions associated with the respective Studies, which are categorized into Study I and II based on the study hypothesis. During the CPT, participants are exposed to varying sound conditions. Additionally, the table provides details about the corresponding audio reproduction method and level. The participant Groups are considered the secondary independent variable.

Within-Subject Dependent Variables	
Cognitive Response	
Measured Matrices	*Calculated Matrices*
Hit Response Time (HRT) Omission (OM) Errors Commission (COM)Errors	Standard Deviation (HRT SD) Preservation (Pres.) Errors Coefficient of Variability (CV) Detectability d'
Behavioural Responses	**Hand Movement**
Measured Matrices	*Calculated Matrices*
x displacement y displacement	Total Hand Movement
Behavioural Responses	**Head Movement**
Measured Matrices	*Calculated Matrices*
Pitch Roll Yaw	Total Head Movement Total Azimuth Displacement Duration of Head-Movement Beyond Limits

Table 5.3: Within-Subject Dependent Variables: The table displays matrices representing cognitive and behavioural responses. In addition to the measured responses, a set of derived matrices is also calculated (shown in the right column).

5.3 Sound Conditions Framework

Table 5.2 presents the five *sound conditions*, serving as the independent variables of this thesis. Each sound condition is characterized by three components: the sound content, the level of sound reproduction, and the method of audio reproduction. These components are examined in the subsequent sections.

The five sound conditions are examined within the framework of the respective Study hypotheses. In Study I, the influence of content is examined by exposing participants to three distinct sound conditions: 'Silence' (serving as the baseline), 'Pink Noise,' and a 'Personalized Soundscape'. The latter two conditions are delivered via dual mono. The outcomes of the dual mono are then compared with the results from the 'Personalized Soundscape' reproduced through binaural 3^{rd} order Ambisonics, as examined in Study II. In this context, the impact of spatial audio is investigated. Also, within Study II, the 'Interactive Audio Indicators' sound condition is explored, aiming to clarify dynamic external sound as either a distraction or a source of stimulation. This condition also presented via binaural 3^{rd} order Ambisonic rendering, integrates interactive auditory cues corresponding to head movements within the personalized soundscape.

5.3.1 Soundscape Content

As elaborated in Section 3.2.2 from a theoretical standpoint, Schafer distinguishes between *sound*, which refers to any auditory phenomenon, and *noise*, which is an unwanted sound. This separation is based on the communicated *auditory information* rather than characteristics such as loudness.

In this context, the present research draws parallels between the notion of 'noise' and 'natural sound environments', focusing on the correlations between *sound content, spectral characteristics,* and *personal meaning.* To clarify, Noise Therapy postulates that noise can be beneficial for individuals with ADHD. However, in this study, the sound content used to construct the soundscapes might technically have noisy attributes, like a broadband spectrum, but the communicated information is linked to pre-existing experiences of sounds from the natural environments. With the process of personalized selection, outlined below in Section 5.3.3, participants can infuse these sounds with personal meanings and associated emotional significance. Thus, while Noise Therapy proves beneficial in

ADHD cases, this research proposes an alternative sonic material, as a soundscape composition that is regarded not as *noise*, but rather as *meaningful sounds*.

From a technical perspective, the correlations between sound content and spectral characteristics are drawn from the beneficial impact of noise on individuals with ADHD, as discussed in Section 2.3. Discussion about reproduction levels is presented in a separate Section 5.3.6. The majority of Noise Therapy studies applied in ADHD practises concentrate on white noise, occasionally using pink noise or environmental sounds such as rain, traffic, classroom noise, or conversational voices, with varying outcomes. This research selected to utilise pink noise instead of white noise as the *principal source* [1].

This decision primarily rests on the attributes of pink noise, which carries more energy at lower frequencies, generating a warm and smooth sound. It is perceived that pink noise appears more spectrally flat, while white noise, although technically spectrally flat, is perceived as possessing a notably elevated High-Frequency (HF) component. Additionally, pink noise is considered perceptually closer to natural noise sound sources like wind and water [320], making it appropriate for the correlations of this experiment.

Building on this, the research further explores the potential of Noise Therapy by examining a comparative effect between pink noise and composed personalised soundscape. The aim is to supplement the existing evidence base and clarify the contradictory findings in the current literature regarding the influence of pink noise on individuals with ADHD and enhance it with a proposed soundscape compositional method.

[1] Pink noise is referred to as the 'principal source' due to its consistent and easily comparable characteristics to white noise, facilitating the comparison of results as well. The spectrum of pink noise is employed to match the soundscape composition spectrally, as presented in the subsequent section 5.3.2

To enhance the above-mentioned correlations between 'noise' and 'natural sound environments' and align with the principles of Noise Therapy, a two-step method for soundscape creation is proposed: First, personalised sound content, obtained through individual selection, should be integrated into the soundscape composition, as detailed further in Section 5.3.3. Second, an algorithm is developed to match the spectral characteristics of the sounds selected by the participant with those of pink noise, as outlined in Section 5.3.2.

The sound content selected for the experiment shared similar characteristics with that of the pink noise. The aim is to collect recordings of natural soundscapes that carry broadband noise characteristics with random spectral textures and avoid distinct tonal or rhythmical characteristics. Recordings also include narrower-band noise mainly centred around a centre frequency without covering the whole spectrum. The samples selected are categorized into three categories according to their central frequency of narrow-band characteristics:

1. Low-frequency band samples: 20Hz - 800Hz
2. Mid-frequency band samples: 800Hz - 2kHz
3. High-frequency band samples: 2kHz - 20kHz

The categories consist of six, seven and seven samples relative to the high, mid and low frequency bands, respectively, as can be seen in Table 5.4. From these categories, each participant selects three sounds, one from each frequency band, to build his/hers personalised soundscape content. Recordings of *rain, wind, river/stream, sea waves* and *fire* are selected from a number of sound libraries [321, 322, 323, 324, 325]. The soundscapes are presented to the participants in binaural 3^{rd} order Ambisonic audio format or dual mono, according to the sound condition defined by the current study's design. Recordings of 3^{rd} order Ambisonic are preferred to retain the high spatial detail, reflecting on the immersion level. The selected sounds are mostly recorded as 3^{rd} order Ambisonic apart from some that were 1st order (Table 5.4).

High Frequency Band	
Sounds	Amb Ord
Rain, Heavy, Trees	3rd
Wind, Moderate, Leafy Trees	3rd
Fire, Mid Density, Close Cracks	1st
Fire, High Density, Close Cracks	1st
Rain, Light, Tin Roof	3rd
Fireplace	1st
Mid Frequency Band	
Sounds	Amb Ord
River, Moderate, Rocks	3rd
Rain, Tin Shed	1st
Stream, Gentle Flow	3st
Waves, Ocean, Gentle, Rocks	3st
Waves, Ocean, Intense, Rocks	3rd
Wind, Trees	3rd
Summer Rain Medium	3rd
Low Frequency Band	
Sounds	Amb Ord
Fire, Low-Density Flames	1st
Fire, High-Density Flames	1st
Rain, Moderate, Large Drops	3rd
Light, Rain, Heavy Drop	3rd
Waves, Beach	3rd
Wind, Forest, Autumn	3rd
Fire, Low-Density Cracks	1st

Table 5.4: Soundscape Content: Natural sound recordings presented according to the frequency band and order of c recording.

The samples are imported to Reaper for post-processing. Minimum editing is implemented on the samples. The aim is to retain the continuity of the sonic events without unexpected tonal or rhythmic sonic incidents like bird songs, bells, knocking on wood or the sound of a metal cottage gate. Trying to keep low variation in the level of the samples within ±2 dB, some of the samples were compressed to a maximum of ±2 dB(A), mainly those containing sounds of fire crackling. The length of the samples varied between 1.5 - 4 minutes. The samples are edited to seamless loops to avoid clicking and sudden changes while looping in the playback. All sounds are rendered according to broadcast standards [326, 327, 328] at −24 dB LUFS to ensure consistency of audio level loudness and provide enough headroom.

The recordings at 3^{rd} order Ambisonic accuracy provide the necessary sixteen audio tracks to reproduce spatial information. In contrast, 1^{st} order recordings use the Ambix encoder [329] to expand the four audio channels to sixteen, equally distributing sources as illustrated in Fig. 5.8. The Ambix encoder calculates the new channel values based on the existing 1^{st} order channels, taking into account the principles of Ambisonics, which involve spherical harmonics and mathematical operations to describe sound fields in spherical coordinates. Transitioning from 1^{st} to 3^{rd} order Ambisonics aims to enhance spatial resolution and sound field accuracy. While 1^{st} order Ambisonics relies on four cardinal channels (front, back, left, and right), 3^{rd} order expands to sixteen channels, enabling a more detailed capture and reproduction of sound, especially from intermediate directionsthe diagonals between cardinal points. This increase in spatial resolution isn't just a technical enhancement; it's purposely intended in the context of this research. Children with ADHD, often experiencing differences in sensory processing, may benefit from an enriched auditory environment. The heightened spatial resolution of 3^{rd} order Ambisonics allows precise placement and description of sound sources, potentially leading to increased immersion and spatial awareness a potential therapeutic benefit. Moreover, the finer gradation of directional cues in 3^{rd} order Ambisonics allows for a more realistic replication of natural sound environments. This realism is crucial in this therapy-focused application, where the plausibility and familiarity with the sound environment may have the potential to positively influence participant engagement and response to treatment, leading to cognitive and behavioural improvements.

After preparing the samples, the Sparta binaural decoder [330] is utilized to decode the samples into their final version. The Sparta plugin converts the 3^{rd} order Ambisonic audio to 2-channel binaural audio (Fig. 5.9), employing the children's HRTF library [154] by Braren et al. [153], as detailed in Section 3.6.6. Specifically, a SOFA file from a 10-year-old child is selected based on its closest match to the participants' anthropomorphic characteristics (age and height) for the experiment. The resulting 2-channel binaural audio samples are then organized

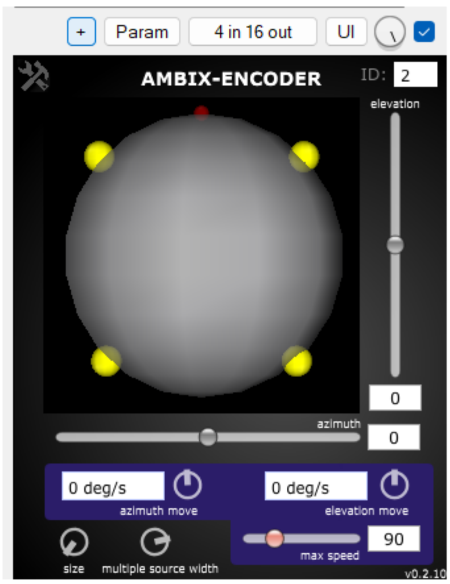


Figure 5.8: Ambix Ambisonic Encoder from 1st to 3rd order, with equally spaced sources and without any change in the orientation.

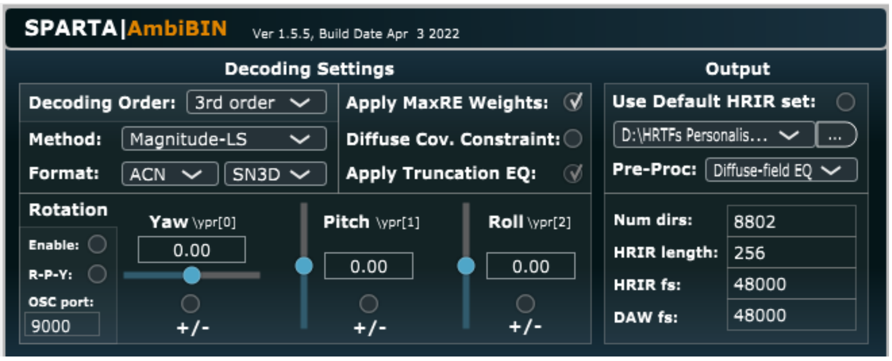


Figure 5.9: SPARTA Ambisonics Decoder converting 3rd order to 2 channel binaural audio, using the SADIE KU100, HRIR SOFA files.

into three separate folders based on their frequency bands, ready for playback. Additionally, a mono file is necessary for analysis by the Auto-Mix algorithm in Matlab, which generates a list of relevant gains. In this case, the mono file is derived from the 1^{st} channel (W Channel) of the 16 channels produced by the encoder, as it contains the omnidirectional component that encapsulates all the audio information. These mono files are also used in the presentation of dual mono cases.

The initial level for sound reproduction for the complete soundscape was established at 80 dB(A), as discussed in Section 5.3.6. This level was employed during the Pilot Test. Subsequent feedback from participants and additional considerations, clarified in Section 6.4, led to the determination of the final sound reproduction level for the main experiment. A level of 78 dB(A) was set for all sound conditions, including dual mono, binaural 3^{rd} order, and binaural 3^{rd} order with added auditory cues.

5.3.2 Soundscape Content Integrating Method: Auto-Mix Algorithm

A primary objective of this research is to propose a method of constructing soundscapes using natural sound content as an alternative environmental stimulation retaining the beneficial practice of Noise Therapy. As explained previously, the participants are invited to select one natural sound recording from each frequency band (low, mid, high) to create a personalised soundscape consisting of three sounds in total.

A Matlab algorithm was developed to identify the optimal spectral proportion between the three recordings aiming to output the flattest spectral response when combined. It is based on 'lsqnonlin' function, which is used for solving nonlinear least-squares problems of the form [331]:

$$\underbrace{\min}_{x} [[f(\mathbf{x})]]_2^2 = \underbrace{\min}_{x} (f_1(x)^2 + f_2(x)^2 + f_3(x)^2) \tag{5.9}$$

In the optimization process using the 'lsqnonlin' function, the variables are defined as follows: The unknown variables, represented by x, are the individual gains for each sound sample in the low, mid, and high frequency bands, denoted as G_{low}, G_{mid} and G_{high}, respectively. The functions $f_1(x), f_2(x)$ and $f_3(x)$ calculate the squared residuals for each frequency band. These residuals measure the difference between the actual frequency response of each sound sample when applied with the respective gain and our target response, aiming for an optimal flat response. The objective of the 'lsqnonlin' algorithm is to minimize the sum of these squared residuals, thus optimizing the overall frequency response of the combined sounds. In our case, the input objective function is the 'lossFunction', a user-defined func-

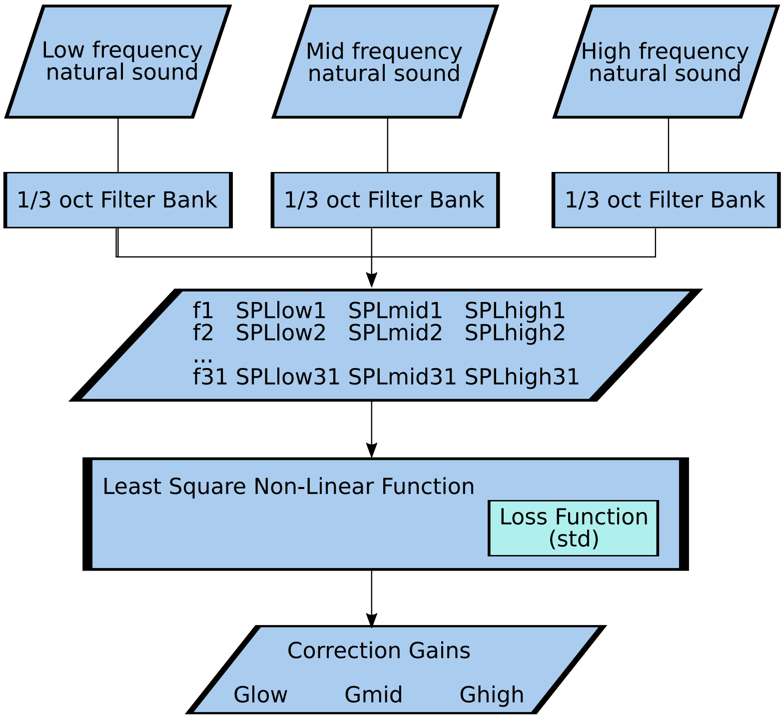


Figure 5.10: Flowchart of Least Square Function: Natural sounds from each frequency band are analysed through 1/3 oct band filter to produce relevant SPLs to centre frequencies. The 'loss function' calculates the standard deviation (std) of the SPL sum for each frequency. The 'least square function' optimises the std by finding output gains (one for each sound) that minimise the std.

tion that uses the proposed gains for the unknown variables to optimise the overall frequency response of the combined low, mid and high natural sounds. The aim is to find the three individual gains, G_{low}, G_{mid} and G_{high}, one for each sample of the low, mid and high frequency-band-triad that produces the best-fit relative to an optimal flat response 5.10.

$$\mathbf{Opt.Resp.} = \mathrm{G_{low}(LFrSamp) + G_{mid}(MFrSamp) + G_{high}(HFrSamp)} \tag{5.10}$$

where:

HFrSamp = sample from the high-frequency sound bank

MFrSamp = sample from the middle-frequency sound bank

LFrSamp = sample from the low-frequency sound bank

The flowchart in Fig 5.10 describes the steps for the analysis. The samples from each frequency band are loaded and lengths and sampling rates are obtained. An octaveFilterBank function analyzes the energy of each audio sample in one-third octave frequency bands. This produces a matrix that holds the 31 central band frequencies and the relative SPLs from each of the three samples, presented as matrix 5.11.

$$\mathbf{A} = \begin{pmatrix} LowSPL_1 & MidSPL_1 & HighSPL_1 \\ LowSPL_2 & MidSPL_2 & HighSPL_2 \\ \vdots & \vdots & \vdots \\ LowSPL_{31} & MidSPL_{31} & HighSPL_{31} \end{pmatrix}. \tag{5.11}$$

The 'lossFunction' first calculates the total SPL for every frequency $fr_{1\rightarrow 31}$ by adding the SPLs with the relevant gains. Here is an example for the first frequency 5.12:

$$SPLtot_{fr1} = LowSPL_1 + G_{low} + MidSPL_1 + G_{mid} + HighSPL_1 + G_{high} \tag{5.12}$$

Finally, it calculates the standard deviation of all $SPLtot_{1\rightarrow 31}$, 5.13.

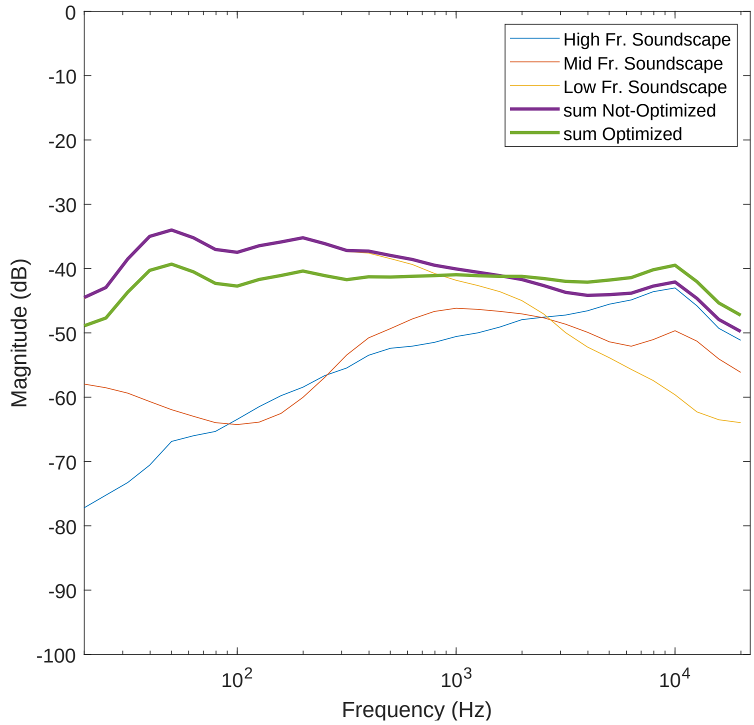


Figure 5.11: Auto-Mix example A: The frequency response of the low, mid, and high-frequency sounds is presented along with the overall soundscape response before and after optimisation. The optimised version is designed to attain the most flat response.

$$\mathbf{Std} = \begin{pmatrix} SPLtot_{fr1} \\ SPLtot_{fr2} \\ \vdots \\ SPLtot_{fr31} \end{pmatrix}. \tag{5.13}$$

Examples of the auto-mix algorithm's results can be seen in Figures 5.12 and 5.11 depict the individual responses of the low, mid, and high frequency sounds, as well as the combined response before and after the optimization process.

In summary, the optimization process using the 'lsqnonlin' function iteratively runs the 'loss Function' to optimize the gains G_{low}, G_{mid}, and G_{high} in order to minimize the standard deviation. The optimized gains G_{low}, G_{mid}, and G_{high} for each combination of sounds from the low, mid, and high frequency band folders, a total of 294 combinations ($6 \times 7 \times 7$) are saved in a lookup table. These gains are then utilized in Supercollider during the real-time execution of the Personalised Soundscape application. In addition, throughout the playback procedure, the gains are weighted to correspond to the diminished high-frequency components inherent in pink noise, in contrast to white noise which possesses equal energy across all frequencies. Consequently, the G_{low} is amplified by +6 dB, while the G_{high} is reduced by -6 dB to simulate the response of pink noise.

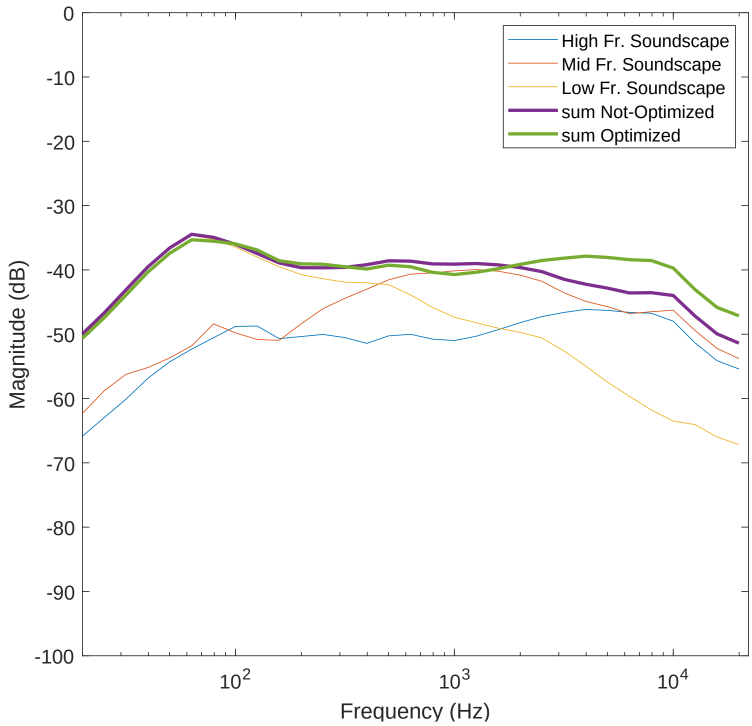


Figure 5.12: Auto-Mix example B: The frequency response of the low, mid, and high-frequency sounds is presented along with the overall soundscape response before and after optimisation. The optimised version is designed to attain the most flat response.

5.3.3 Personalised Soundscape Design Game

As analysed in the Scoping Review, Section 4.4.3 personalization of the therapeutic intervention is critical for its effectiveness. An application is developed that enabled participants to personalize their soundscape. The objective of this application is to promote individualism in personal preferences and enhance participant engagement in the process. By personalizing the selection of sounds, potential cultural differences between the sample populations from the United Kingdom and Greece can be mitigated, and the effectiveness of the intervention can be increased.

An application is designed in Supercollider. The algorithm's flowchart is illustrated in Figure 5.13. Focus is drawn on presenting the soundscape stimulus in its final form, i.e. as the participants would experience it during the experiment. The sounds are presented encoded in binaural 3^{rd} order Ambisonic reproduction. The gains change according to the participant's selection, based on the lookup table produced in Matlab, see Section 5.3.2. Figure 5.14 shows the GUI of the application where each row of sounds is associated with each frequency sound bank, starting from the top with the high frequency band (6 sounds) followed by the mid (7 sounds) and low (7 sounds) frequencies. While initiating the application, the subject ID is entered, so when the final sound selection is made, the name of the selected sounds and the subject's ID are stored in a file.

5.3.4 Audio Indicators - Interactive Soundscapes

The second part of Study II explained in detail in Section 7.5, is centred on the integration of dynamic auditory cues, serving as auditory indicators, into the soundscape design. As mentioned earlier, the system is initially calibrated with the *yaw, pitch* and *roll* angles of 0° while the participants fixate their gaze towards the

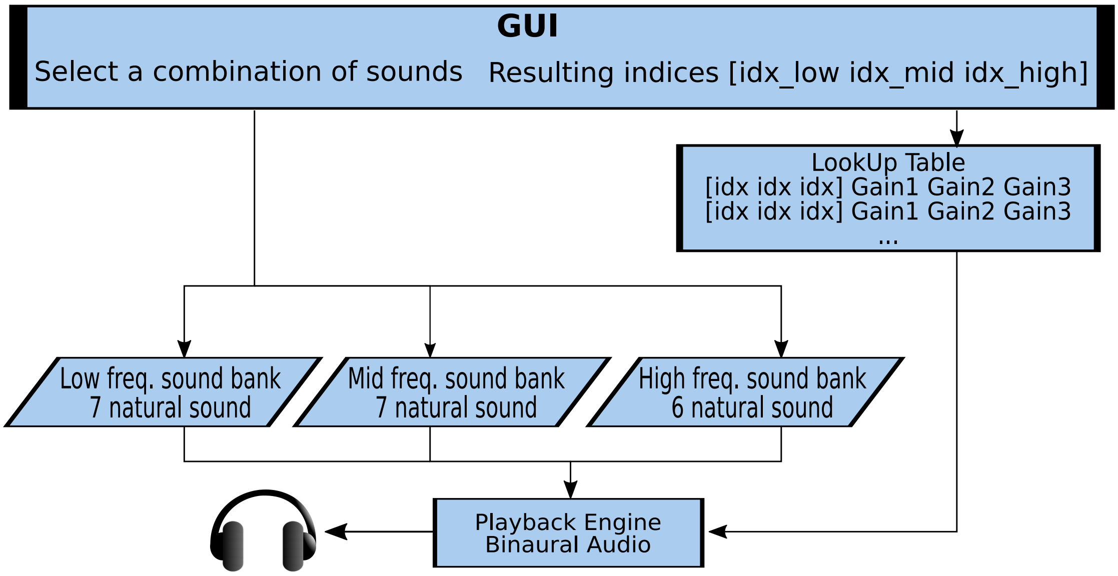


Figure 5.13: Flowchart of the Personalised Soundscape App. GUI receives data on sound selections, and the relative gains are retrieved from the lookup table. The sounds are reproduced with the relevant gains binaurally from the sound engine in Supercollider.

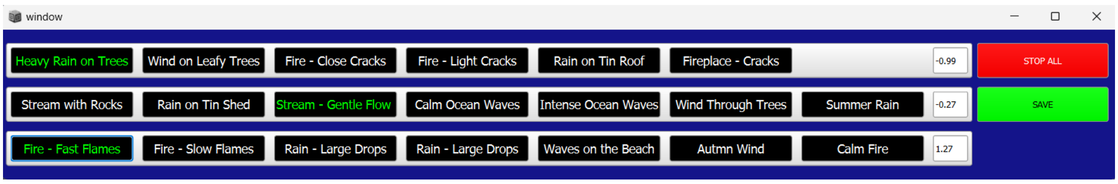


Figure 5.14: GUI of the Personalised Soundscape App. Each row consists of natural sounds from different frequency bands. Top row - high frequencies, mid row - mid frequencies, low row - low frequencies.

centre of the screen. With regards to the interactive audio indicators, emphasis is placed on the azimuth, particularly the *yaw* angle relative to the head movement. These dynamic cues are triggered when participants turn their heads left or right beyond $\pm 25°$ in either direction, as illustrated in Figure 5.15. These audio indicators function as auditory cues, presented in the ear contralateral to the head

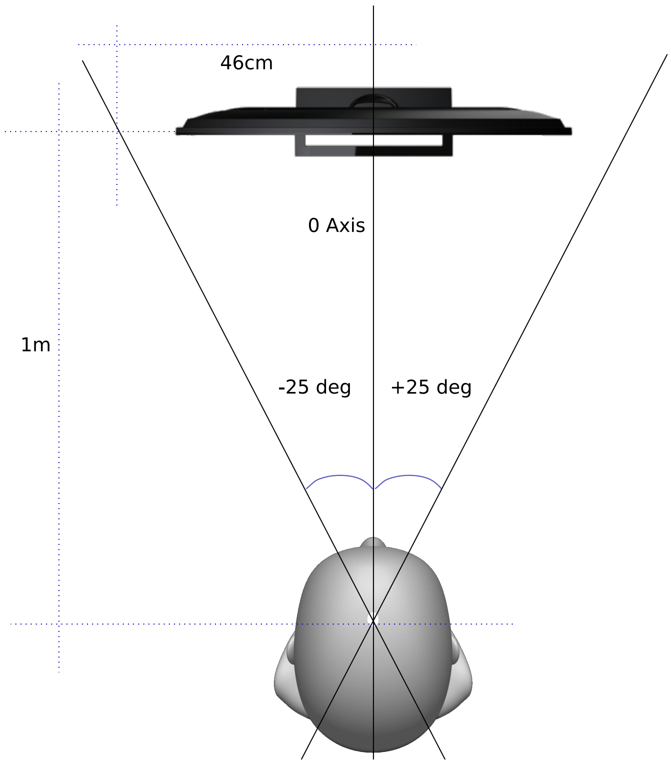


Figure 5.15: The diagram illustrates the position of the participant positioned 1m from the screen. The Auditory Indicators are triggered at an angle of $\pm 25°$ off-axis, $\approx 46cm$.

movement. For instance, a participant turning their head left would hear a sound indicator in the right ear, guiding them to pivot towards the task located in the right direction (on the screen). The sound content chosen for the audio indicators is characterized by an almost continuous sound of cicadas. A delta-shaped envelope featuring extended attack (2 seconds) and release stages (3 seconds) is utilized to prevent sudden changes in sound throughout the listening period.

The selected threshold of $\pm 25°$ on the horizontal plane translates to approximately ≈46cm lateral displacement from the screen's centre, given that the participant is positioned 1m away. This range accommodates the primary visual field (the screen) while also permitting some additional head movement space.

The measurement of head movement, specifically the *yaw* angle, was employed to gain insights into the impact of interactive audio indicators on participants' behavioural responses. Two aspects were assessed: Firstly, the total Azimuth displacement made beyond the left or right limits was measured, indicating head movements away from the screen. Secondly, the duration of time participants spent exceeding these limits was calculated, reflecting periods of diverted attention from the screen throughout the administration.

The sound reproduction level of personalised soundscape is established at a decreased level of 72 dB(A). The audio indicators are consistently reproduced at an SNR of +6 dB. This is realised through the incorporation of an *amplitude follower* at the soundscape output channel in Supercollider, which dynamically controls the indicator's signal by +6 dB.

5.3.5 Control Conditions

The arrangement of the experimental environment relates to various parameters, which incorporate the participant, researcher, equipment, reproduction conditions, and visual content, in addition to sound content, sound reproduction method, and sound level. A significant level of consistency is necessitated in these parameters throughout the experiment. This includes maintaining uniformity in equipment, reproduction conditions (including seating and viewing conditions, room setup, furniture, and environmental factors), and experimental procedures such as the application of the CPT test battery and visual stimuli. The role of the researcher is to act as an observer and facilitator, following a predefined protocol and maintaining a neutral presence. The researcher is responsible for providing information and assistance to participants, addressing their questions and concerns, and adhering to the experimental protocol. Participants are positioned as the key sources of information, and their sense of safety and feeling informed is critical in facilitating free and independent responses to the test battery, following a uniform and consistent setup for all individuals involved.

The level of sound reproduction is a significant parameter, which according to comparative studies, varies depending upon the theoretical framework, the specific cognitive and/or behavioural test battery employed, and the character of the sound content. The following section discusses this issue and provides a conclusive approach to the selected sound levels.

5.3.6 Sound levels

According to the concept of Moderate Brain Arousal (MBA) discussed in Section 2.3.1, individuals with ADHD may require higher levels of noise to improve their performance compared to typically developed individuals. Therefore, the level of sound reproduction plays a significant role in the effectiveness of therapeutic methods. However, the literature shows varying results regarding the optimal sound level for therapeutic interventions, considering the relationship between sound content and the desired therapeutic outcomes. This thesis examines the impact of the five *sound conditions*, including pink noise and personalised soundscapes on participants' cognition during the CPT.

In the process of identifying the appropriate sound level for the experiment, this section evaluates the current literature and concludes to the most suitable one, with relevant studies presented in Table 5.5. Research conducted by Sikstrom et al. [48] suggests a beneficial effective range within noise levels of 70 to 80 dB(A) (as also mentioned in [332]). In a study by Usher at al. [332], the cognition ability of typically developed individuals was examined by measuring response speed in a memory retrieval task. Acoustic noise (random frequency tones) was evaluated at six different level steps ranging from 51 to 90 dB(A) using headphones. The study revealed that the fastest reaction times were observed at a sound pressure level of 77 dB(A). However, it is important to note that according to the concept of MBA, this noise level may not be sufficient for individuals with sub-attentive conditions such as ADHD. In a study conducted by Helps et al.[50], Go-NoGo test responses were investigated as part of Executive Function tasks. The participants were tested under three different sound pressure levels (SPL) delivered through headphones: 65 dB(A), 75 dB(A), and 85 dB(A). The study found that for Executive Function tasks, moderate levels of white noise (75 dB(A)) had a facilitative effect on sub-attentive children, while the performance of 'super-attentive' children deteriorated. However, it is important to note that the level steps used in the study had a large interval of 10 dB per step, which was insufficient to differentiate finer distinctions within the effective level range of 70-80 dB(A). In a research conducted by Bath et al. [58], the impact of different types of background noise on performance in reading and writing tasks was examined. Participants were exposed to two conditions: classroom babble and white noise, both played at a sound pressure level of 70 dB(A) from a speaker positioned behind them. The study revealed that individuals with ADHD performed better in the presence of white noise, demonstrating faster reading times and higher word counts in their essays compared to the classroom noise condition and silence. However, the white noise did not lead to improved accuracy in academic tasks. Contrary to the previous findings, Soderlund et al. [51] investigated the effect of different noise conditions, including silence, white noise, and classroom noise (students discussing in a classroom), on visuospatial working memory (vsWM) tests. The sound pressure level used in this study was 78 dB(A). The inattentive group benefited from noise, and interestingly, the classroom noise condition improved their performance as well, while the attentive group did not experience the same benefit.

Several studies conducted by Soderlund emphasize the positive effect of white noise played at 78-80 dB(A). In his study [56], he reports that the reproduction of white noise at 80 dB(A) positively influenced cognitive performance, particularly in tasks associated with low and high memory. This effect was observed within the ADHD group, while a decline in performance was noted in the control group. This suggests that individuals with ADHD may need a higher level of noise for optimal cognitive functioning compared to their peers. In another study by Soderlund et al. [60] the effects of exposure to 80 dB(A) of white noise were explored in both medicated and non-medicated children with ADHD. Significant improvements were reported in tasks related to Visuo-Spatial Working Memory and Verbal Episodic Memory. Moreover, a study by Soderlund [333] that investigated the effects of exposure to both visual and auditory white noise presented binaurally at 80 dB(A) revealed improvements in reading and memory capabilities among children experiencing reading disabilities and phonological decoding difficulties.

Regarding the specific use of white noise in children with ADHD using the Go-NoGo method, Baijot et al. (2016) conducted a study where binaural white noise at 77 dB SPL was delivered. They reported a positive but limited effect, mainly in reducing omission errors. Noise exposure resulted in a reduction in omission rates in children with ADHD, bringing their performance closer to that of typically developing children. The limited impact of white noise on positive outcomes in this study raises the question of whether the reproduction level was sub-optimal, considering the positive effect observed at 80 dB in the aforementioned studies by Soderland et al. Overall, these studies collectively highlight the significance of white noise at appropriate levels in improving cognitive performance and specific tasks in individuals with ADHD and other related difficulties.

The two studies that utilized pink noise as a stimulus did not yield significant effects. Deceunick et al.[334] investigated the influence of arousal-inducing factors, including pink noise, on the performance of adults with ADHD using a Go/No-Go test. The pink noise was played over headphones at a level of 75 dB(A). However, the study did not find any significant impact of pink noise on response speed or omission/commission errors. This result may be attributed to the method of selecting the experimental population or the sound level itself. The participants were evaluated for ADHD symptoms using the Adult ADHD Self-Report Scale Symptom Checklist [335], but at the same time individuals with a formal diagnosis of ADHD or other developmental disorders were excluded. Similarly, in a study by Metin et al. [336], the effect of pink noise at 80 dB(A) on impulsive choices in children with ADHD was examined. However, no significant restraint in impulsive choices, such as waiting longer for a larger reward, was observed compared to the control group. This raises questions about the effect of pink noise or the sound level itself on impulsive behaviour.

With the objective of achieving the appropriate SPL for eliciting optimal stimulation and considering pink noise alongside soundscapes as the stimuli of the experiment, the following conclusions can be drawn from the analysis:

- Results from studies employing pink noise have been inconclusive
- For typically developed individuals, cognitive performance appears to be enhanced at a level of 77 dB, which implies a higher level may be required

for the ADHD population according to MBA

- Soderlund et al.'s studies provided consistently beneficial results, utilising white noise reproduced at 80 dBA, leading to the decision of an 80 dBA sound reproduction level for the stimuli in the experiment of this research.

Even though Soderlund et al. utilized white noise as the stimulus, which is different from the stimuli used in this research, the choice of the 80 dB(A) level as the optimal stimulation level is justified by the consistently positive outcomes reported from their experiments involving the majority of participants being children with ADHD.

Citation	Population	Content	Level	Task	Suc/ful
[336]	Child. ADHD	Pink Noise	80 dB	Impulsivity	No
[334]	Ad. ADHD	Pink Noise	75 dB	Influence on performance (Go-NoGo)	No
[50]	Sub-attentive	White Noise	75 dB	Executive Func. (Go-NoGo)	Yes
[332]	TD individuals	Acoustic Noise	77 dB	Memory retrieval	Yes
[58]	Youth ADHD	White Noise	70 dB	Reading-writing	Yes
[58]	Youth ADHD	Classroom babble	70 dB	Reading-writing	Yes
[56]	Child. ADHD	White Noise	80 dB	High-Low memory	Yes
[51]	Inattentive child	White Noise	78 dB	Visuospatial working memory	Yes
[51]	Inattentive child	Classroom noise-speech	78 dB	Visuospatial working memory	Yes
[60]	Child. ADHD med. & non-med	White Noise	80 dB	Visuospatial working-episodic memory	Yes
[333]	Child. with reading disabilities & phonological diffic.	White Noise	80 dB	Reading & memory	Yes
[15]	Child. ADHD	White Noise	77 dB	Go-NoGo	Yes

Table 5.5: The table shows the relationship between studies, their population type and the task under research.

5.3.7 Sound Calibration

Despite the importance of audio reproduction levels, the calibration methods described in many studies are generally inadequate. In a majority of the studies, there is minimal or even absent description of the calibration method for the audio reproduction system, despite references to the exact audio level of noise or the signal-to-noise ratio (SNR) in the case of threshold SR. Some studies mention the use of a sound level meter to ensure accurate reproduction of noise through speakers, as seen in [57] and [337]. However, the use of speakers introduces a challenge in maintaining consistent sound levels across multiple subjects in the room due to variations based on their distance from the speakers. While this approach of calibration may be adequate for loudspeaker reproduction, it is insufficient when headphones are used. Certain studies focus on the accuracy of the sound source without considering the level as perceived by the listener. For instance, [334] delivered binaural sounds at 77 dB SPL using Etymotic earphones, and [53] calibrated the intensity range of the noise generator to provide white noise with a standard deviation of 65 to 75 dB SPL. In both cases, the emphasis was primarily on the accuracy of the source rather than its perceived level by the listener. A few studies briefly mention calibration without providing explicit descriptions, as seen in [338], [53], [45], and [339]. A more accurate example of headphone calibration is presented by Metin et al. [336], that examined impulsive choice in ADHD while participants were exposed to pink noise. They utilized a sound level meter to measure the signal from an artificial head, which is beneficial as it calibrates the sound from the listeners' perspective and takes into consideration the morphology of the ear.

Due to the specific nature of this research, two different reproduction methods were employed during the experiment: dual mono and binaural 3^{rd} order Ambisonics. To address the calibration challenge associated with these methods, a calibration system was designed with two main objectives. Firstly, to ensure that the SPL at the listener's perspective remains consistent when reproducing dual mono audio and 3^{rd} order Ambisonic rendered audio (monitoring phase), as illustrated in Figure 5.16. Secondly, to maintain the desired SPL at the listener's perspective during binaural reproduction of both dual mono audio and 3^{rd} order Ambisonic rendered audio (calibration phase), as illustrated in Figure 5.17. To achieve this, a 50-speaker loudspeaker rig was utilized, located at the AudioLab, University of York, as depicted in Figure 5.18. The loudspeakers were arranged in a 50-point Lebedev grid configuration and had the capability to render up to 5^{th}-order Ambisonics, able to simulate immersive soundscapes with the high spatial accuracy required [145]. A KU100 dummy head, incorporating artificial ear acoustics, was employed to simulate the listener. The experimental test sound utilized in the calibration process was pink noise. It was reproduced identically in two channels for the dual mono setting and spatially rendered using the Ambix 3^{rd} order Ambisonic encoder, expanding across 26 channels.

The general approach involves reproducing a realistic acoustic environment that encompasses both the listener and the sound sources. The aim is to calibrate the output gain of the audio interface to ensure consistency between the ear-microphone signals (located at the artificial ears of the KU100) when reproducing test sounds through both loudspeakers and headphones.

Monitoring phase:

For the dual mono setup, the test sound is played through two speakers directly facing the left and right ears of the KU100. In the case of 3^{rd} order Ambisonic noise,

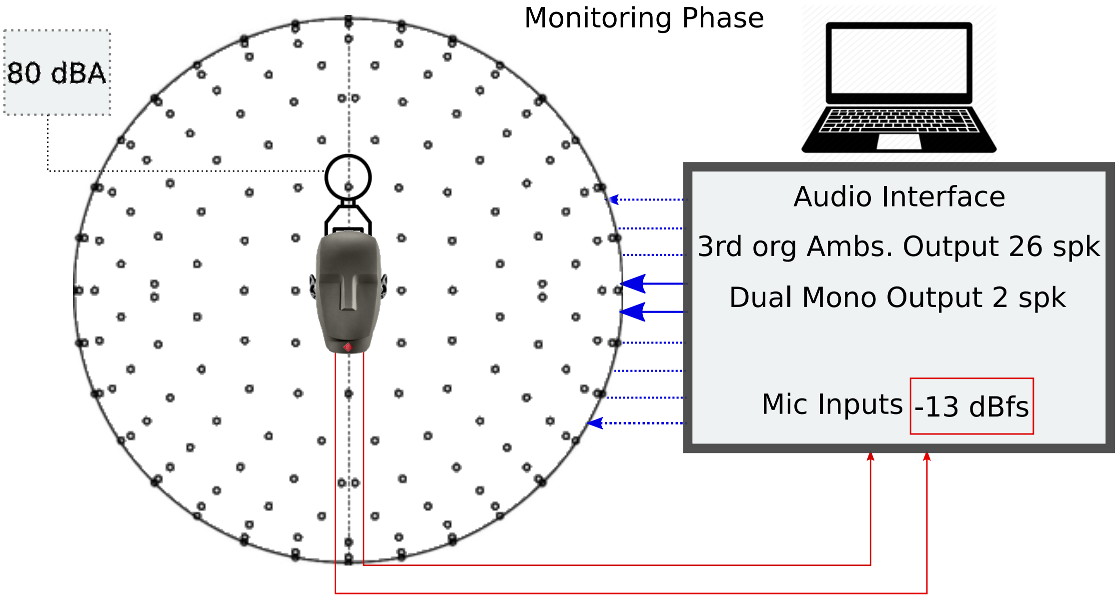


Figure 5.16: Calibration System: Monitoring Phase. 50-speaker loudspeaker rig, reproducing dual mono (only 2 spk, left and right) or 3^{rd} order Ambisonics audio over 26 spks. Sound level meter monitoring at 80dB(A). KU100 at the listener's position, while the output of its ear-microphones is marked (-13dBFS) reference level for the calibration phase.

it is reproduced using the 26 loudspeakers in the rig. To achieve the 80 dB(A) sound pressure level (SPL) at the listener's position, the 3^{rd} order Ambisonic setup requires 2 dB less gain compared to the dual mono configuration. It is crucial to highlight that when producing 80 dB(A) SPL with both dual mono and 3^{rd} order Ambisonic setups, the level generated by the ear-microphone remains consistent, ranging between -13 and -14 dBFS. This establishes the reference level for the binaural reproduction process in the calibration phase.

Calibration Phase:

During the calibration phase, dual mono audio is played over the headphones at an output level of -15 to -16 dBFS, as required by the audio interface, in order to achieve an input microphone level of -13 to -14 dBFS. Similarly, for binaural

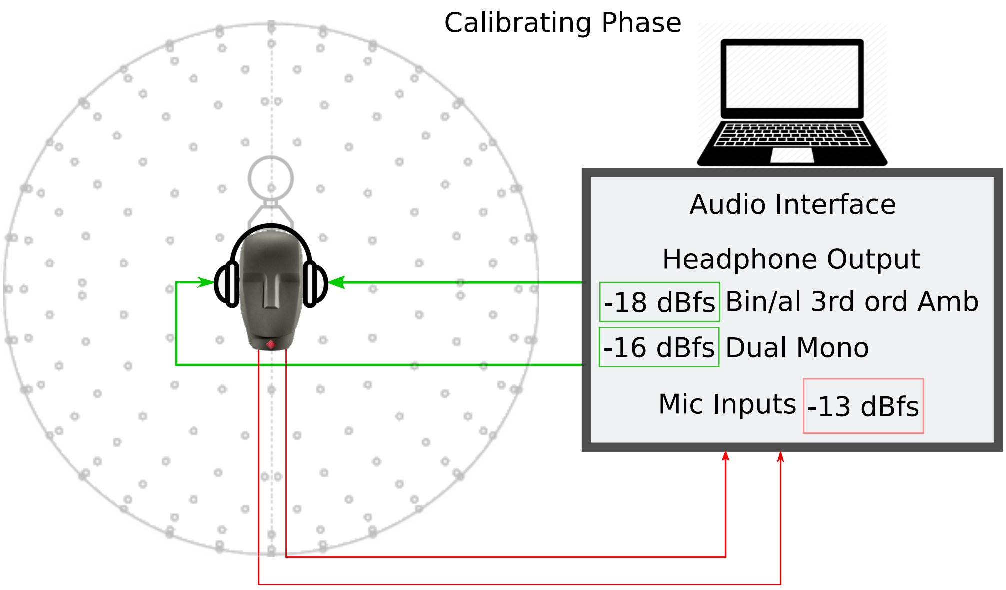


Figure 5.17: Calibration System: Calibration Phase - Headphones worn at KU100 are used to reproduce dual mono or binaural 3rd order Ambisonics rendered audio. The output of the audio interface is set to the appropriate output gain (-16 dBFS dual mono & -18dBFS binaural 3^{rd} order) to produce the reference level at mic output (-13dBFS).

encoded 3^{rd} order Ambisonic audio played over headphones, an output level of -17 to -18 dBFS is required to attain the same input microphone level. These calibration settings establish a correlation between the output level of the audio device and the SPL received by the listener, with the playback gain being a crucial factor in controlling the listener's SPL according to soundscape level variations.

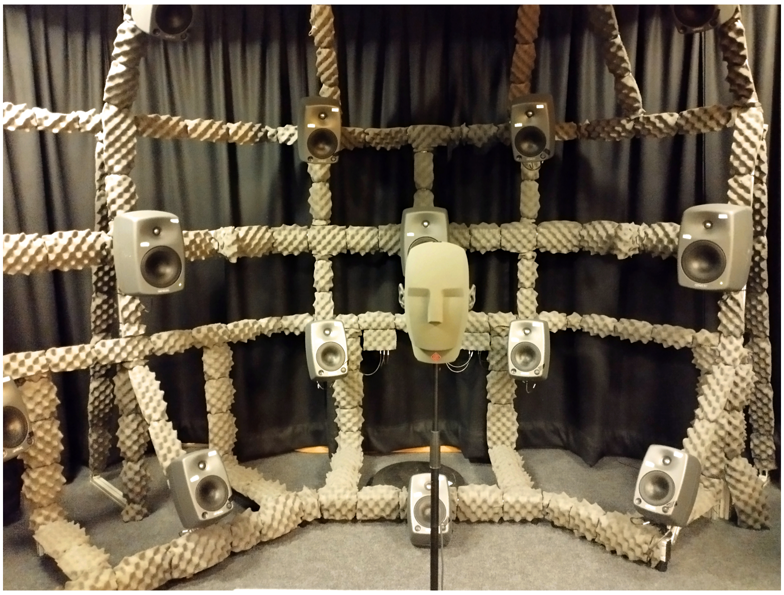


Figure 5.18: 50 speaker loudspeaker array located at the AudioLab, University of York.

Figure 5.19: KU100 dummy-head on front view, with Sound Level Meter on top.

Figure 5.20: KU100 dummy-head side view, with Sound Level Meter on top.

5.3.8 Distractors

In the context of ADHD, a *stimulant* typically refers to a medication type or, more relevantly in this research, any form of sensory input or environmental factor that excites or activates the nervous system. Conversely, a *distractor* is generally an environmental factor or a form of sensory input that redirects attention from a main task or goal. External distractors, such as the sound of books falling or an experimenter shuffling papers or moving around the testing room, tend to impact word recall tasks for children with ADHD more negatively compared to those without the condition [340]. Cassuto et al. [306] employed both auditory and visual distractions in the form of various sounds and cartoon images depicting a gong, a bowling ball, birds singing, and an airplane during a CPT. Similarly, Berger et al. [305] utilized distractions such as cartoon-like dogs and the sounds of barking dogs while conducting a CPT. As Zentall [41] posits, an organism seeks stimulation when under-stimulated and avoids stimulation when over-stimulated. In the neurological context, many individuals with ADHD are especially sensitive to distractions due to their lower levels of neural DA. This lower level makes them hyper-responsive to all forms of external stimulation. Sikstrom et al. [22] classify sharp changes in environmental stimuli, unrelated to the cognitive task at hand, as 'attention-removing stimuli.' Such stimuli can divert attention from the main cognitive task, consequently undermining individuals' performance. A study by the same author [48] elaborates on distraction's effect, linking it to an ongoing competition for attentional resources between the target stimuli and the distractor, essentially causing the latter to shift attention away from the task at hand.

This study, therefore, proposes a question concerning the optimal combination of natural sounds that continue to serve as stimulants and contribute positively. As previously discussed in Section 5.3.1, a variety of auditory content, including classroom noise, conversations, rain, and traffic sounds, have been used to enhance stimulation in cases of ADHD. Nevertheless, the results of these methods have varied. For instance, the study by Allan et al. [57], which introduced classroom noise through speakers, had partial success. According to Soderlund [56], to induce the SR effect, the noise should be continuous (to avoid becoming a distraction) and sustain a high energy level across all frequencies, much like white or pink noise.

When designing the soundscape content, these guidelines are kept in mind, as described in Section 5.3.1. Special care was taken to exclude unexpected sounds from the main body of the soundscapes, like bells or animal sounds; variations in level or content within the sound material were introduced using a long attack and release. This involved sounds like waves in the main soundscape body or, as a creative technique, the introduction of the sound of 'cicadas' in the interactive soundscape.

Additionally, this study raises a question about the potential for distraction associated with the method of sound reproduction. While the sound content is reproduced identically in both ears (dual mono), it is worth examining whether the introduction of the spatial representation of the sound environment might heighten distractibility. Likewise, the dynamic integration of the audio indicators may be perceived as a distractor, thereby raising another point for consideration.

Lastly, it's important to remember that what may serve as a stimulant for one individual could be a distractor for another. In the case of ADHD, some individuals may find that specific types of sensory input, such as white noise, can improve their focus on a task, while others may find these same inputs distracting.

This reflects the inherent variability within the ADHD population.

5.4 Summary

In this chapter, the methodologies employed to measure the dependent variables are detailed, alongside the necessary decisions made based on preceding studies. 'Save the Mushroom' is presented as a gamified version of Conner's CPT, which offers insights into participants' cognitive responses. Behavioural characteristics are recorded during administration through the use of head and hand tracking. A spatial audio game is designed to familiarize participants to sound spatialization, and it also serves as an indicator of their spatial perception.

The second part of the chapter is dedicated to explaining the sound conditions, which comprise the independent variables. It offers a detailed understanding of the selection of sound content, its post-production, and categorisation into three folders based on spectral characteristics. Utilising these samples, the Auto-Mix algorithm in Matlab generates a look-up gain table for every low-mid-high triad combination. Subsequently, during real-time reproduction, the gains are adjusted to simulate the spectral response of pink noise. A GUI is constructed, enabling participants to select a combination of three sounds of their choice while audibly experiencing the outcome in 3rd order Ambisonic binaural sound. Additionally, the setup for the audio indicators is presented, providing insights into their structure and functionality. A discussion is conducted concerning *stimulants* and *distractors*, bringing to light questions regarding the potential distractibility of spatial audio and interactive audio indicators, insights that will be revealed by the findings of this study. The concluding segment of this section discusses the optimal playback audio levels, determining a reproduction level of 80 dB(A). To ensure a precise level of accuracy at the participant's ear, comprehensive calibration procedures for both dual mono and 3rd order Ambisonic formats are described in detail.

6 Pilot Test

6.1 Introduction

Chapter 5 described all the individual methods required for the implementation of the experiment. It covered both the methods of measuring the participants' responses and the sound conditions under investigation. Now the individual sections of the experiment are described, a small-scale pilot test took place to examine the technical consistency of the methods in real-life circumstances. The aim of the pilot tests is to collect feedback from participants on the technical and practical issues, usability, and fluidity of the processes.

6.2 Participants

For the pilot test of this study, the participant selection was carefully considered, keeping in mind the constraints and objectives of the research. The main challenge was recruiting participants who could provide relevant and insightful feedback without depleting the pool of children with ADHD required for the main experiment. Given the difficulty in finding additional children with ADHD for the pilot test, a decision was made to involve a smaller, diverse group of participants who could offer varied perspectives relevant to the study's aims.

The pilot test was thus conducted with a small, yet diverse group of four individuals. This included two adults and two typically developed children (TDC). The adult participants included a 25-year-old male and a 39-year-old female, both colleagues from the University of York, who offered a mature perspective on the experimental process. The female participant, being a children's clinical psychologist with prior experience working with children with ADHD, provided valuable insights from a clinical standpoint. This perspective was crucial in understanding the potential reactions and needs of children with ADHD in the main experiment. The children participants, a 9-year-old male and a 10-year-old female, were recruited through their parents, who were acquaintances of the author. Their feedback was instrumental in addressing procedural and functional aspects of the experiment, ensuring that the setup and processes were engaging and comprehensible for younger participants. This adjustment aimed to better align the study with the characteristics of the main experiment population.

The demographics of the pilot group - encompassing different ages and professional backgrounds were chosen to mirror a range of viewpoints that could critically assess the experimental setup from various angles. While this limited number of participants was a practical decision influenced by the availability and accessibility of the target group, it provided a balanced mix of insights that were instrumental in refining the experiment for the main study.

6.3 Design & Procedures

The pilot test took place for the adults in the AudioLab premises, University of York, while the children completed it at their house with the agreement and presence of their parents.

The pilot study aimed to gain an understanding from the participant's perspective on the functionality of the games, the experimental procedure, and feedback on the sound conditions rather than examine the effect of the sound conditions.

The pilot test was organised in a single session and some modifications were required compared to the main experiment. A variation in the 'Save the Mushroom' game was introduced for the pilot test. The CPT, typically running 378 trials (six repetitions of 63 trials) for an approximate duration of 15 minutes, was modified. A shorter version was designed specifically for the test, comprising a group of 126 trials lasting 5 minutes. This modification allowed participants to experience all conditions and games within a single session of approximately an hour.

A further variation was necessitated by the requirement to examine the effectiveness of the HRTF library used in binaural decoding. To facilitate this, the 'Spatial Audio Game' was administered twice. The initial administration was intended to test the implementation of the SADIE II library on a KU100 dummy head [148], while the subsequent run was purposed for testing Braren's library, which was measured on children [154]. This extra section was implemented only for the two children.

Considering the above requirements and variations, the structure of the pilot test was formulated as follows:

1. 'Personalised Soundscape game'.
2. 'Save the Mushroom' - Silence.
3. 'Save the Mushroom' - Pink Noise reproduced over dual mono.
4. 'Save the Mushroom' - Personalised Soundscape over dual mono.
5. 'Spatial Audio game' - KU100 HRTFs library.

6. 'Save the Mushroom' - Personalised Soundscape reproduced over binaural 3^{rd} Ambisonics audio.

7. 'Spatial Audio game' - Braren's HRTF library, only children participated.

8. 'Save the Mushroom' - Personalised Soundscape with integrated Audio Indicators reproduced over binaural 3^{rd} Ambisonics audio.

9. Discussion

The process was initiated by informing the participants of the experiment's purpose and the series of games to follow, and resolving any inquiries that surfaced. For the 'Save the Mushroom' game, participants were guided by instructions to react as quickly as possible upon spotting a 'target' and withhold when they identified a 'mushroom'. A practice round was included to familiarise participants with the game. In the 'personalised soundscape' game, participants were encouraged to listen to the sounds individually, selecting one sound from each row. This activity was designed to construct a soundscape that the participants found appealing and comforting. Finally, for the 'Spatial Audio Game,' participants were briefed on how to use the keyboard to move a sound source around them virtually. This task facilitated their familiarity with specialised sound and also helped establish the correlation between the auditory and its visual representation. Once the participants were comfortable with the spatialization, they informed the researcher. Subsequently, the visual representation of the sound source was removed by the researcher, who then played a sequence of stimuli positioned at different spatial locations.as detailed in Table 6.1 and visually presented in Figure 6.1. Participants were then requested to indicate the direction they believed the sound was originating from.

Target Number	Position	Target Number	Position
1	Left-Mid-Mid	7	Right-Rear-Down
2	Right-Mid-Mid	8	Left-Front-Down
3	Left-Front-Up	9	Left-Rear-Mid
4	Right-Rear-Mid	10	Right-Front-Up
5	Right-Front-Mid	11	Left-Front-Mid
6	Left-Rear-Down	12	Right-Rear-Up

Table 6.1: Spatial Audio Game: The 12 sound source positions the participants were asked to point during the game. The positions are formed with the following components Left/Right - Front/Mid/Rear - Up/Mid/Down.

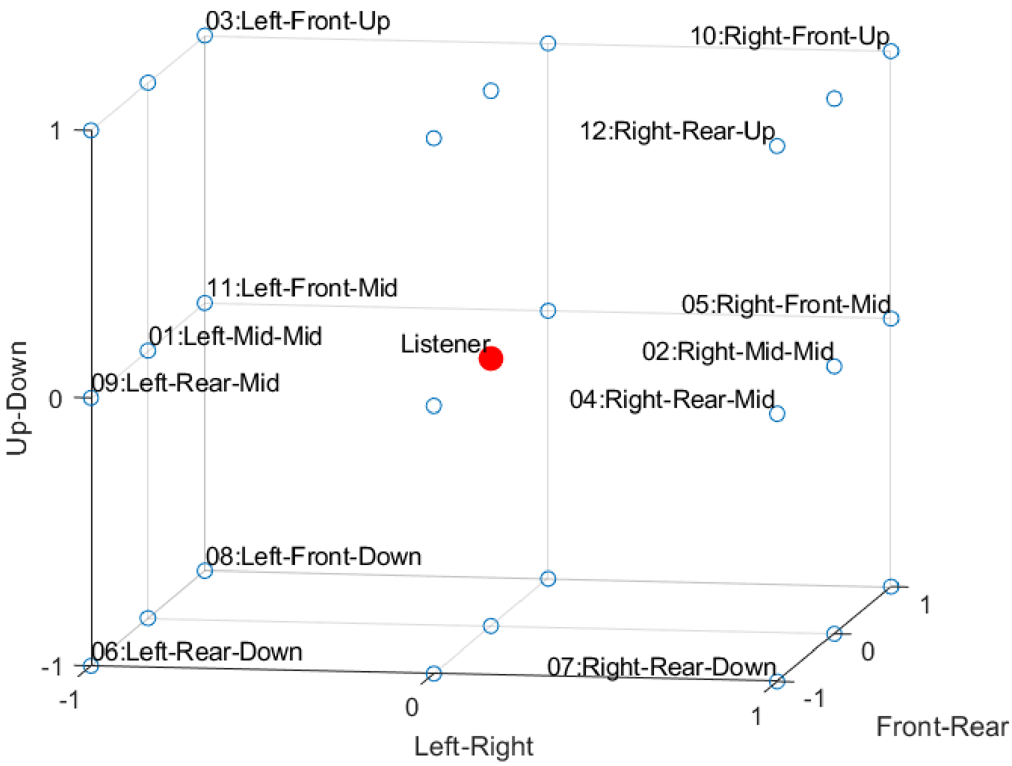


Figure 6.1: Visual representation of the 12 sound source spatial positions according to Table 6.1.

6.4 Results - Feedback

The outcome of the pilot test consists of feedback comments provided by the participants on the procedures of the experiment and the functionality of the games. This valuable information directed changes and improvements for the main experiment.

In terms of general observations, the children's clinical psychologist highlighted the difficulty children with ADHD will face completing a monotonous task such as CPT. At that time, there were discussions on running CPT twice in each session, aiming to reduce the overall sessions required, a suggestion that the psychologist raised serious concerns about. Additionally, children with more prominent symptoms might show excessive use of equipment accompanied by dynamic behaviour, suggesting that the system software and hardware should be robust, avoiding any unnecessary parts.

One of the participants was left-handed, and up to that point, there were no arrangements for left-handed participants.

On the 'personalised soundscape' game, the comments related to the presentation of the application, such as to improve the description and increase the font of the letters, where the children suggested the size of the GUI to get bigger.

Regarding the 'Save the Mushroom' game, the clinical psychologists highlighted the importance of a *time bar* continuously updating participants about the remaining time. The children expressed a similar opinion since they found the game monotonous or "boring," as they said and were asking "how long they have left". Furthermore, it was recommended to incorporate visual feedback, such as fireworks, to reward participants visually when they successfully hit a target.

As discussed earlier, the selection of the most suitable HRTF library for this study was primarily informed by a thorough review of the literature. The unique research by Braren et al. [153], which focused on measuring HRTFs of children aged 5-10 years old, stands out as particularly relevant for this study. This choice is underpinned by the literature's emphasis on the distinct auditory spatial characteristics of children compared to adults.

To supplement this literature-based decision with empirical observation, a pilot test was conducted using the 'spatial audio' game. This informal assessment aimed to explore whether the trends identified in the literature would manifest in a practical setting. The pilot involved testing two HRTF libraries the KU100 and Braren's children HRTFs with a small sample of child participants. This test was not meant to provide definitive evidence but rather to observe if the theoretical assumptions held true in a controlled setting.

The results from this pilot test, as summarized in Table 6.2, indicated a more precise distinction in directional sound identification with Braren's HRTFs. While the Left-Right differentiation was as expected, there was a notable improvement in Front-Back and Up-Down distinctions with Braren's HRTFs, which aligns with the literature suggesting more accurate spatial representation for child listeners. Additionally, the analysis of the Front-Rear confusion, a common issue in spatial audio known as the '*cone of confusion*', also supported the choice of Braren's HRTFs (Table 6.3). Though some misplacements due to the cone of confusion were observed, the overall identification of front-back direction was more accurate with Braren's HRTFs.

Upon reviewing the feedback on *Sound Conditions*, it was observed that the adults raised concerns about variations between the mixing level of the sound content they heard while playing the 'Save the Mushroom' and the one they ex-

Positions	Total Number	KU100 Child1	KU100 Child2	KU100 %	Braren Child1	Braren Child2	Braren %
Left	6	6	6	100%	6	6	100%
Right	6	6	6	100%	6	6	100%
Up	3	0	1	16%	1	1	33%
Down	3	0	0	0%	1	1	33%
Front	5	1	1	20%	2	2	40%
Rear	5	2	1	30%	2	2	40%

Table 6.2: The results from the Spatial Audio Game Pilot-Test are depicted in the table, illustrating each individual direction included in the spatial sound positions. For instance, the 'Up' direction was incorporated in a total of three positions, specifically, positions 3, 10, and 12, as per Table 6.1. Additionally, the responses from both children are presented, encompassing the KU 100 and Braren's measured HTRFs.

		KU100				Braren			
	Total	Child1		Child2		Child1		Child2	
Positions	Number	Id.	Mispl.	Id.	Mispl.	Id.	Mispl.	Id.	Mispl.
Front	5	1	2	1	2	2	1	2	2
Rear	5	2	0	1	2	2	1	2	2

Table 6.3: The table presents the Front-Back responses of the children. Their correctly identified directions are denoted as 'Id.', while their misplaced responses are indicated as 'Mispl.' These labels represent the disorientation between the front and back or vice versa. For instance, in the case of child 1 using KU100 HRTFs, one response was correctly identified as Front, whereas two responses were misplaced, erroneously characterizing the Front as Rear.

perienced while selecting and combining the sound content during the soundscape personalisation game. The issue was attributed to the fact that the mixing levels of the samples were not updated from the *gain lookup table* exported from Matlab during the soundscape creation process (for more details, see Sections 5.3.2 and 5.3.3). Instead, the sound files were presented at a level of -24 dBLUFS, as rendered during post-production (refer to Section 5.3.1). This feedback implied that the weighted gains ought to be incorporated at an early stage of the soundscape personalisation process, enabling participants to listen to the final outcome.

Furthermore, comments were made by the children regarding the high volume of both the pink noise and the soundscape. When they were asked about pink noise, they indicated they adjusted to it during administration and showed a preference for it over silence. For the dual mono reproduction of the soundscape, the high level became more noticeable due to variations in the content. It was further commented that a reduction in its level would be preferable.

The reproduction level of pink noise was established at 80 dB(A). This decision was informed by its consistently observed beneficial impact on the ADHD population, as outlined in Section 5.3.6.

In the pilot test, the level of soundscape reproduction was established at 80 dB(A), similar to the pink noise. Participant feedback formed concerns regarding exceeding 80 dB(A) due to the soundscape's dynamic range being set at ± 2 dB, peaking at 82 dB(A). Recognising the potential disturbance that high-level sounds may introduce, as well as the 80 dB(A) limit defined in the WHO's 'Recommended Exposure Limit for Children Exposure to Recreational Noise Establishing' report [341], the decision was made to lower the soundscape reproduction level to 78 dB(A) ± 2 dB in both dual mono and binaural formats. This way the peak would not exceed the limit of 80 dB(A). Similarly, the 'audio indicators' reproduction level was adjusted accordingly. The soundscape was reduced to 72 dB(A) from the initial 74 dB(A), and the indicator was set to play at +6 dB SNR, thereby maintaining an overall level at ≈ 78 dB(A).

6.5 Summary

The pilot test provided critical insights regarding the experimental procedures and the functionality of the games, directing changes and improvements in the main experiment. These insights included:

It was pointed out that children with ADHD could find monotonous tasks like CPT challenging. Given this, there was concern over conducting two CPT administrations in one session to reduce the total sessions required.

The observation of a higher likelihood for children with more noticeable ADHD symptoms to potentially misuse or excessively use the equipment was made. This emphasized the requirement for a robust and reliable system comprising both software and hardware, avoiding any unnecessary components.

The need to accommodate left-handed participants was observed, as there was no arrangement for such individuals previously.

Feedback on the personalised soundscape game led to suggestions for improving the user interface, such as simplifying the description and enlarging the font size.

The inclusion of a time bar in the 'Save the Mushroom' game was suggested by both the psychologist and the children to keep players informed of the remaining time.

The decision to employ Braren's children HRTFs for the main experiment was primarily guided by their alignment with the literature on children's auditory spatial perception. The pilot test served as an additional, informal validation of this decision, demonstrating a practical manifestation of the trends highlighted in academic research. This approach ensures that the auditory experience in the experiment resonates closely with the natural auditory perception of the child participants, enhancing the ecological validity and relevance of the study's findings.

Feedback on sound conditions revealed differences between the mixing level experienced during the 'Save the Mushroom' game and that experienced during the soundscape personalisation game. This prompted changes to ensure weighted gains were incorporated earlier in the soundscape personalisation process.

Both adults and children expressed concerns about volume levels. Children found the volume of the pink noise and soundscape too loud. However, they reported getting used to the pink noise over time. After considering feedback and health guidelines, the soundscape reproduction level was lowered to 78 dB(A) ±2 dB, ensuring the peak would not exceed the 80 dB(A) limit recommended by the WHO. The level of the 'audio indicators' was adjusted accordingly, and the soundscape was reduced to 72 dB(A) while maintaining an SNR of +6 dB.

7 Main Experiment: Evaluating the Effect of Different Sound Conditions in the Cognitive and Behavioural Response in Children with ADHD

7.1 Introduction

The primary experiment of this research is a repeated-measures experiment consisting of five sequential sessions. Each of these sessions refers to different *sound conditions*, which serve as the independent variables of the experiment, as elaborated in Chapter 5. This experiment took place across two countries, over the period of four months, with 31 participants contributing to a total of 155 sessions.

The experimental framework is divided into two distinct studies, each addressing specific hypotheses. Study I delves into the influence of personalised content over three sessions, whereas Study II examines the effect of spatial audio and dynamic auditory cues as potential factors of stimulation or distraction across two sessions. Table 5.2 presents the sound conditions, the corresponding audio reproduction methods, and applicable levels for each study.

The pilot test, outlined in Section 6, played a key role in refining the main experiment. It facilitated the implementation of numerous modifications concerning game mechanics, GUI, audio rendering, and experimental procedures, all based on feedback garnered during the pilot phase.

This chapter proceeds by discussing the common aspects across the studies, including participant demographics, the experimental procedures developed across two countries, and soundscape content leading to the individual study designs and procedures. Following this, a comprehensive description and analysis of Study I and Study II are presented, ultimately leading to the findings.

7.2 Participants

As outlined in Chapter 2 regarding ADHD symptoms, Section 3.3 on therapeutic soundscapes, and Section 5.3.6 concerning sound level results, inconsistencies in outcomes of ADHD studies are noted. In children, symptoms of ADHD are typically more pronounced than in adults, who may have developed partial compensatory strategies, particularly if therapeutic treatments have been undertaken [342]. This reinforces the decision taken in this study to focus on the population of children. While the recruitment of such participants may present challenges, children's responses are often perceived to possess a higher degree of authenticity [334].

The sample size was determined based on the type of experiment and the initially chosen statistical methods for analysis. For this purpose, the software G-Power [343] was used. The experiment examined the response of each participant to five distinct sound conditions, i.e. the *number of measurements* = 5 as illustrated in Figure 7.1. Participants' characteristics were used to form two groups: the control group consisting of typically developing children (TDC) and the focus group consisting of children with ADHD (*number of groups* = 2). This arrangement calls for the utilization of a Two-Way repeated measures ANOVA, a within

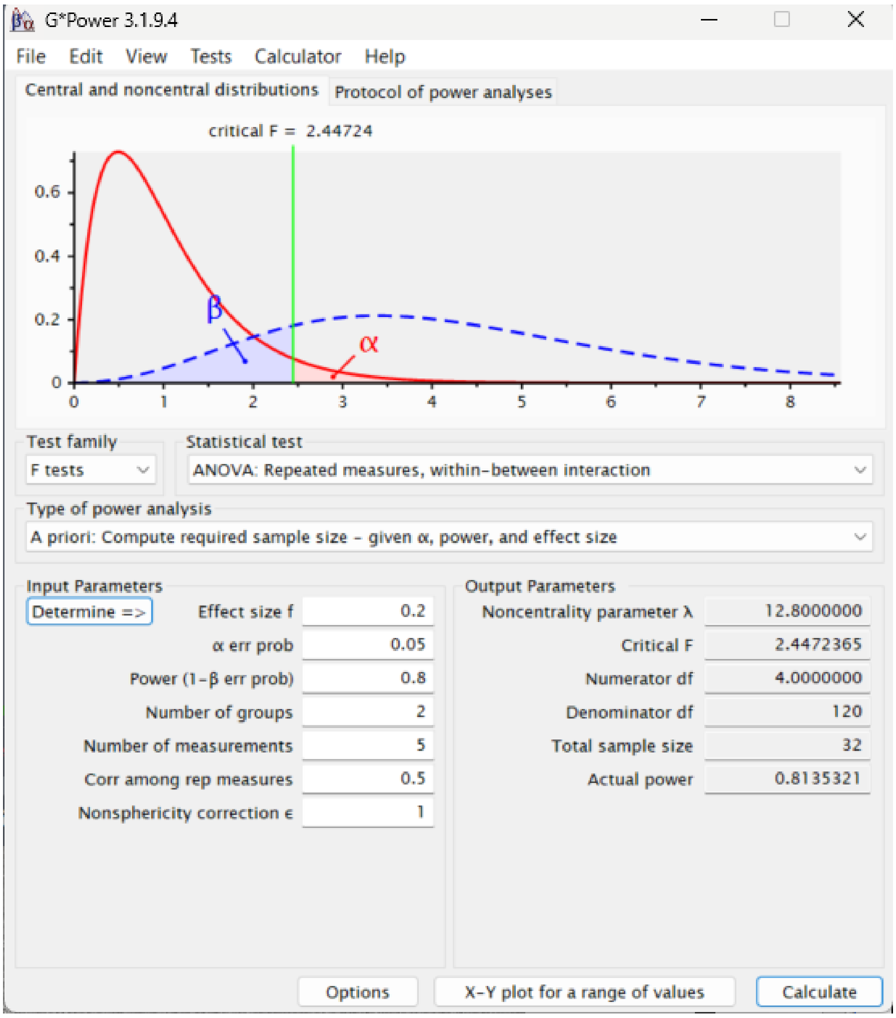


Figure 7.1: Statistical Power: G-Power

and between-subject analysis.

A *standard statistical significance level* (α) of 0.05 and a *power* of 0.8 were utilized, following the guidelines presented by Coolican [344]. The *effect size* ‘f’ is a standardized measure of the magnitude of the observed effect and the difference between group means or the strength of a correlation. In terms of effect size, the relevant literature refers to Cohen’s criteria, which suggests a 0.8 value indicating large effects [344]. Metin et al. [336] found that pink noise did not affect environmental stimulation in children with ADHD, and the children still showed a preference for smaller sooner rewards over larger later rewards, with an effect size of 0.79. Soderland et al. [333] demonstrated that sensory white noise improves reading skills and memory recall in children with reading disabilities, with effect sizes for the noise benefits ranging from 0.52 to 0.97. In word memory recall tasks, effect sizes were found to be medium, ranging from 0.41 to 0.46 [63, 56]. However, in visuospatial working memory tasks and executive functioning tasks, the effect sizes were large, with Cohen's d exceeding 0.80 [15, 50, 60]. These findings encompass an effect size ranging from 0.4 to 0.9. An effect size of 0.8, representing a high degree of variance in the outcome, was examined by the author, resulting in a limited sample size of only four participants. Subsequently, a more conservative estimate of 0.2 was selected, necessitating a total of 32 participants divided between the two groups.

Recruiting the participants was a difficult and time-consuming process. It started in June 2022 and was completed in December 2022. Initial communication with the head of the mental health office of the William Henry Special School led to the collaboration with the Trinity Academy School in Halifax. The Vice-Principal of the Trinity Academy arranged for 17 TDC to constitute the control group and 6 students with ADHD to form part of the focus group. Despite extended outreach of the research to schools, charities and ADHD support centres in the wider Yorkshire area, no more participants for the focus group were obtained in the UK. The research was then extended to Athens, Greece, the author's country of birth. A collaboration with Angela Moojer, a children's clinical psychologist, at the 'Child & Family' educational support centre provided 10 children with ADHD within the same age range to complete the focus group. A group of 6 TDC was also gathered in Athens to form additional members for the control group.

For the UK participants, consent was obtained through contact with the parents by the school's Vice-Principal. In contrast, in Greece, written consent was provided directly by the parents who convened in person. All participating children gave verbal consent. The consent form, parent information sheet, and participant information sheets in both English and Greek are included in Appexendix C.

However, the recruitment method presented certain limitations. The inclusion of only individual schools from the UK and Greece resulted in a restricted pool of participants, potentially impacting the study's broad applicability. Relying solely on teachers and school staff to screen and identify suitable children, without a standardized behaviour and academic performance questionnaire, limited me from directly confirming the diagnoses and selection criteria. This approach may have introduced selection biases or inconsistencies. The absence of standardized categorization by teachers for the academic and behavioural performance of TDCs might have resulted in a diverse control group.

While ADHD is a heterogeneous disorder that presents in various forms and intensities, the study specifically focused on children with Combined presentation ADHD (ADHD-C), a subset characterized by both inattentiveness and hyperactivity-impulsivity. All sixteen children participating in the ADHD group had been diagnosed with ADHD-C by certified clinical psychologists, strictly adhering to the DSM-V criteria [2]. This ensures a standardized and reliable identification of the disorder as per established psychiatric guidelines. The teachers of these children corroborated the diagnosis, reporting consistent academic and behavioural difficulties aligned with ADHD-C manifestations. Targeting ADHD-C allowed a more focused investigation into the effects of the intervention specific to this presentation, contributing to understanding the nuances of managing different ADHD subtypes. The TDCs were reported by their teachers to have no behavioural, academic, or social difficulties, denying the need for additional physical or neurological examinations.

Exclusion criteria for all participants included impaired cognitive function, other long-term health conditions, consistent use of medications, or a primary psychiatric diagnosis such as depression, anxiety, or psychosis. Participants were also required to have no hearing impairments, leading to the exclusion of one TDC from the UK with a hearing issue in the left ear. In the ADHD group, no dropouts were recorded. In the TDC group, two female participants - one from the UK and one from Greece - were not continued after the initial session. Both found the experiment overly exhaustive and monotonous, expressing a desire to cease participation.

This led to the final 36 participants aged 8-14 who completed all five experiment sessions. The clinical (focus) group consisted of ten male and six female participants, whereas the control group included nine male and eleven female participants. The focus group was composed of 16 participants (mean age = 10.94, S.D. = 1.57) and the control group of 20 (mean age = 10.55, S.D. = 2.33). Table 7.1 shows the age groups relative to their age analytically.

The study specifically targeted children with ADHD-C who had no comorbid conditions and were not on ADHD medication. The primary aim of this criterion was to isolate the effects of ADHD itself, thereby avoiding the confounding factors that could arise from comorbidities or medication. However, this stringent inclusion criterion presented several limitations: Challenges in finding children with ADHD who were not on medication and without comorbidities led to recruitment difficulties and a limited number of subjects who met the study's requirements, potentially affecting its generalizability. Additionally, variations in initiating the process of ADHD diagnosis between countries may have resulted in differing symptom severities among participants. For instance, in Greece, initiating the ADHD diagnostic process might be more straightforward compared to the UK, possibly contributing to fewer UK participants. Lastly, there are significant differences in ADHD medication consumption between the UK and Greece, as highlighted by Chan et al. longitudinal study [345]. National guidelines and practices may differ substantially in their recommendations on the roles and balance between pharmacological and non-pharmacological treatment, which could affect the characteristics of the participant pool.

Group	Gender	Country	n	Age (Count)	SD	Age (Gen)	SD
Focus Group	Male	Uk	5	11.8	1.3	11	1.88
		Gr	5	10.2	2.17		
	Female	Uk	1	12	-	10.83	1.88
		Gr	5	10.6	0.89		
Control Group	Male	Uk	7	10.57	2.44	10	2.39
		Gr	2	8	0		
	Female	Uk	8	10.87	2.47	11	2.28
		Gr	3	11.33	2.08		

Table 7.1: Demographics of the participants: This presents the number of participants, their mean age, and the standard deviation. The data is segmented first by focus and control, then by country (Age Count), and finally by gender (Age Gen).

7.3 Experimental Procedures Developed Across Two Countries

When combining populations from different countries to participate in an experiment, there are several main scientific issues and difficulties that can arise [346]:

Cultural and Language Differences: Participants from different countries may have diverse cultural backgrounds and speak different languages. To address these issues, the author, whose native language is Greek, facilitates precise communication of the instructions and ensures participants' accurate interpretation and understanding of the experimental context. This enables effective communication between researchers and participants, overcoming language barriers. Cultural differences can influence participants' responses to stimuli. For instance, the sound of rain or sea may evoke different reactions among participants from the UK compared to Greece. The essence of personalized soundscapes lies in the participant's ability to select sound content that aligns with their personality, mindset, and experiences. In addition to choosing individual sounds, participants are given the opportunity to construct a sonic environment that feels comfortable, familiar, and fosters a sense of belonging. This flexibility shifts the focus from cultural perceptions of sound as a socio-cultural construct to personal emotions. This approach builds a sonic environment supporting comfort and familiarity based on participants' individual emotional experiences.

Socioeconomic and Demographic Variations: Countries vary in terms of socioeconomic status, education levels, and demographic characteristics. Russell's systematic review [347] indicates increasing evidence for an association between socioeconomic disadvantage and ADHD, suggesting socio-economic disadvantage may affect ADHD manifestation but the strength of this association varies substantially between studies. To account for these factors and analyze the demographics, Table 7.1 illustrates the male-female ratio in the control group, with 45% males and 55% females. In the focus group, males comprise the majority at 62.5%, while females account for 37.5%. This distribution aligns with expectations, as ADHD tends to be more prevalent among males in this age group [348]. It is worth noting that all participants attend state schools.

Data Collection and Standardization: To ensure the reliability of the results, various aspects of the experiment were standardized across countries. This included maintaining consistency in experiment procedures, control variables, equipment, data collection methods, and measurement scales. The researcher diligently adhered to the same design protocols to establish uniformity and comparability in data collection.

Bias and Sampling Issues: Combining populations from different countries can introduce biases and sampling issues. The sampling method aimed to retain the homogeneity of the participants and practices. The participating countries belong to the modern Western World with commonalities in certain values, beliefs, and cultural norms while retaining the diversity of perspectives and cultural variations. The participant recruitment strategies aimed to keep similar features:

- The requirement would be implemented by educational organizations.
- The experiment procedure would take place on their premises, especially for the focus group.

However, there were some differences in the experimental conditions between the two countries. At Trinity Academy in the UK, the experiments were conducted between 09:00 am and 02:00 pm. In contrast, at the ‘Child and Family’ educational support centre in Greece, the experiments took place between 01:00 pm and 05:00 pm. The regulations of the institutes indicated the implementation of the experiment schedule. Furthermore, the five participants from Greece who were assigned to the control group completed the experiment in the comfort of their homes. The researcher visited their houses and set up the experiment equipment on the dining table in the living room or kitchen, complying with the direction described in Section 7.4.3. The experiments were scheduled for weekend mornings, specifically between 09:00 am and 01:00 pm.

Despite the initial requirement for a two-country collaboration to recruit participants exclusively for the focus group, additional participants from Greece were also recruited for the control group. This decision was made with the aim of further reducing bias and ensuring the validity of the findings. Specifically, a quarter of the control group participants were invited from Greece, comprising 5 participants from Greece and 15 participants from the UK. By including participants from both countries in both groups, a similarity in the structure of the two groups was achieved and contributed to the overall study design.

The aforementioned scientific issues were effectively addressed through the implementation of standardized experiment protocols and equipment, careful planning, clear communication, and fruitful collaboration with institute staff and parents.

7.4 Study I: Soundscape Content

Study I focuses on investigating the influence of personalised sound content on participants' responses. Section 4.4.3 underscores the significance of personalising the therapeutic process, which is crucial for a successful practice.

The emphasis in this study is placed on exploring the impact of *personalised soundscapes* in contrast to a baseline sound condition of *silence* and the *pink noise*, a standardised type of noise with references in the literature. While earlier literature has examined various sound content within potential environmental stimulation for ADHD symptoms [50, 58, 56, 332, 51], these studies have not incorporated any references to participants' personal preferences. Moreover, the positive effects of pink noise have not been definitively confirmed in prior studies [336, 334]. As such, this study aims to perform a dual comparison. Firstly, it will aim to provide further insights into whether pink noise provides benefits. Secondly, it will investigate the effects of personalised soundscapes in comparison with both pink noise and silence conditions.

This consideration serves as a central, novel motivation for this study. It enhances previous achievements related to predefined therapeutic sound content and soundscapes by examining the influence of personal preference within the therapeutic soundscape process.

To maintain an unbiased comparison regarding the method of sound reproduction, both the pink noise and soundscape will adopt a dual mono approach.

7.4.1 Hypothesis

The investigation presented in this study aims to answer the following research question:

RQ : *Can cognitive and behavioural responses improve in children with ADHD by introducing auditory stimulation of personalised natural content soundscapes presented over dual mono?*

The outcome will be evident through improved responses in response time and error handling and reduced physical activity on hand and head movement. Based on this research question the following hypotheses are put forward:

H_1: Children with ADHD, while exposed to *Pink noise* will display improved cognitive performance and reduced behavioural activity.

H_2: Children with ADHD, while exposed to *Personalised Soundscape* will display improved cognitive performance and reduced behavioural activity.

It is predicted that pink noise should follow the positive influence that white noise has been found to exert on certain metrics, as documented in the literature. Similarly, the soundscape, adapting similar sonic characteristics to pink noise, is also anticipated to yield a positive impact.

7.4.2 Experiment Design

Study I employs a mixed-model design utilising within-subject and between-subject strategies. Both the focus and control group participants are randomly exposed to identical experimental sound conditions, which are allocated between sessions. Data collection involved measuring cognitive response through various metrics, including response time, omission and commission errors, as well as behavioural response measured through hand and head movements. Detailed descriptions of the dependent variables can be found in Table 5.1.

Study I comprised three sessions corresponding to three sound conditions, as presented in Table 5.2. A total of 21 participants from the UK completed 63 experimental sessions over a three-week period. Similarly, 15 participants from Greece underwent the same three experimental sessions, resulting in a total of 45 completed sessions spanning three weeks. The initial session performed in Silence condition served as the baseline, during which all participants were assessed before any interventions were introduced. Aiming to minimize biases, the second and third sessions randomly assigned participants to experience pink noise and personalized soundscapes. Furthermore, an additional process to CPT was implemented during the first and second sessions. In the first session, the Personalized Soundscape Design process was carried out, while the Spatial Audio Game was conducted in the second session, as depicted in Figure 7.2.

7.4.3 Stimuli and Procedures

Control Conditions

The experiments took place within the participants' recruitment school or educational centre, apart from the cases of five control group children in Greece

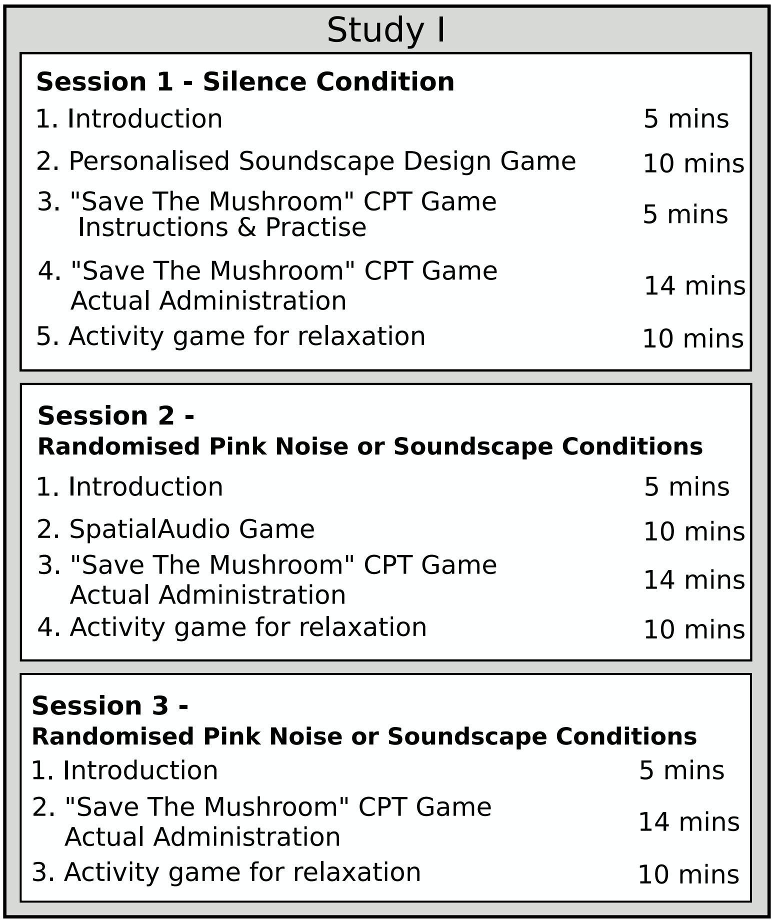


Figure 7.2: Experiment Structure - Study I: Sessions one and two involve an additional step to the CPT. During the first session, participants begin by selecting material for their personalized soundscape.

that took place at their homes. In order to minimize the influence of extraneous variables and establish a stronger link between the observed effects and the independent variables, several actions were taken to control and maintain consistency throughout the experiment. The experiment was conducted in quiet rooms located within the school or educational centre premises, with a deliberate effort made to minimize external noise. While some occasional disturbances, such as the sound of a bell, students passing by in the corridor, or nearby doors closing were unavoidable, attempts were made to keep these interferences to a minimum. The background noise level was measured throughout the CPT experiment using a sound level meter ranging from 42.4 to 48.9 dB(A). Attention was paid to the surrounding environment to eliminate potential distractions for the participants. This involved avoiding windows located behind the screen or closing the curtains and removing any elements, such as posters, books, or equipment, that could divert the participants' attention. Furthermore, the monitor was positioned at eye level, approximately one meter away from the viewing position. Examples of different rooms can be seen in Fig. 7.3. By implementing these actions, the study aimed to ensure a controlled experimental setting, reducing the impact of external factors and allowing for greater confidence in attributing observed effects to the independent variables.

Personalised Soundscape Game

Prior to each session, the participant received a briefing about the purpose and procedures of the experiment, and any questions they had were answered.

As illustrated in Figure 7.2, the initial two sessions of Study I involved an additional process. In session one, the participants engaged in the Personalised Soundscape Design game, which is described in detail in Section 5.3.3. During this game, participants were prompted to listen to various audio samples of natural sounds individually, accessible through the game's graphical user interface displayed on the screen. The sounds were categorized into three rows based on their frequency ranges: low, mid, and high. Participants were then asked to:

"Create a combination of three sounds, selecting one sound from each row which you find pleasant, familiar, or satisfying'.

Figure 7.3: Experiment Room: Different rooms where the experiments took place.

Their selections were saved in their personal data folder, and a brief discussion followed. Participants were encouraged to share whether they recognized the sounds and provided reasons for their specific choices.

Spatial Audio Game

In session two, the participants began by engaging in the Spatial Audio Game. Using the keyboard, they familiarized themselves with the concept of spatial audio by manipulating a sound source within a virtual environment. They were able to observe the position of the sound source in relation to their virtual position on the screen. The game's detailed description can be found in Section 5.2.4. After spending 5-10 minutes becoming familiar with the concept of virtually moving a sound source around them, the participants were invited to participate in a game. In this game, a set of 12 sounds were played one after the other without a visual representation of the sound source on the screen (the screen was turned off). The following directions were given to the participant:

"You will listen to a sequence of sounds, one after the other, without any images on the screen. At the end of each sound, point with your hand where you think the sound comes from. Use a combination of the following words "left, right, up, down, front, back" to describe the position verbally."

After each sound, the administrator asked the participants to indicate the direction by pointing with their hands and verifying it verbally. The direction was then noted by the administrator. The 12 sound source positions are shown in Table 6.1. This exercise aimed to assess the spatial perception of the participants.

CPT: Save the Mushroom Game

After the introductory game, the sessions proceed with the CPT experiment. All procedures followed are according to Conner's CPT protocol [291]. The participant was instructed to refrain from consuming any confectionery gum or candy before the administration, as it may affect attention and vigilance. The participants were assured about the confidentiality of their results and informed that they had the option to stop the process at any time without having to provide an explanation. The administrator provided instructions for the Save the Mushroom CPT game, as seen below, and allowed the participant to practice to become familiar with the visuals and the game.

"I'm going to press the okay to start button on the computer program, then the sequence of 'targets' and 'mushrooms' will flash very quickly on the screen, one at a time. You have to click the mouse each time you see a 'target', except when you see a 'mushroom'. When do you see the 'mushroom', don't press anything; just wait for the next 'target' to appear. If you make a mistake, it's okay, don't worry about it and just keep going. Respond as fast and as accurately as you can. Let's practice these rules. Place your finger on the mouse button and get ready."

The administrator initiates the practice test, which lasts approximately one minute. Throughout the practice session, the administrator diligently observes the respondent to ensure their understanding of the instructions and readiness for the actual administration. If the respondent raises any questions, such as asking why the test is boring, the administrator promptly addresses the queries, as such distractions can potentially impact the respondent's performance. The recommended response to most questions should be, *"I will answer that question after you have completed the test. Please continue."* In cases where the respondent becomes disengaged from the task, a warning approach is employed. Disengagement can manifest in various ways, such as the respondent diverting their attention, looking around the room, or even leaving their seat. In such instances, the administrator should make one attempt to re-orient the respondent by providing a verbal prompt like, *"Remember, you need to maintain focus throughout the entire duration of the test."* If the respondent continues to disengage from the task, no further prompts should be given.

At the end of each session, the participant had the opportunity to unwind by engaging in a VR activity game using a VR headset for a duration of ten minutes.

7.5 Study II: Immersive and Interactive Soundscapes

7.5.1 Introduction

Study II investigates the utilization of binaural-based 3^{rd} order Ambisonics as an audio-rendering technique intended for auditory stimulation experienced by children with ADHD. Supplementing the spatial audio rendering, the study extends its scope by examining the effect of introducing dynamic auditory cues. These cues function as audio indicators, triggered in correspondence with head movement and aiming to sustain focus on the visual target on the screen. Spatial audio and dynamic auditory cues are treated as variations of the stimulation effect. Drawing reference from Hyunkook Lee's model of immersive experience [122], realistically immersive soundscapes are implemented to partially immerse the participants through establishing a sense of 'physical presence'. This allows their focus and engagement in the visual CPT task. To achieve this, 'interestingness' and 'plausibility' are targeted through the processes of personal content selection (Study I) and spatial audio (Study II), respectively. Spatial audio has been recognized for its positive impact on the sense of presence [318, 109], and natural soundscapes have been observed to support psychological mechanisms. These include reducing symptoms of pain and anxiety [83, 90] and improving cognitive performance aspects such as reaction time and short-term memory [87, 91]. Therefore, the primary aim of this study is to examine the impact of stimulant exposure towards Ambisonic rendered and interactive soundscapes upon individuals with ADHD.

These considerations form the central, novel motivation for this Study and thesis, building upon previous accomplishments utilizing non-spatialised audio rendering and non-interactive techniques for ADHD symptoms [87, 86, 93, 242].

7.5.2 Hypothesis

The investigation presented in this Study aims to address the following research questions:

*RQ*1 : *Does the application of* 3^{rd} *order Ambisonic rendering serve as a beneficial factor that enhances the desired stimulation for participants with ADHD, or does it act detrimentally, categorizing it as a distractor?*

*RQ*2 :*Does the integration of interactive audio indicators delivered through a personalised soundscape produced over* 3^{rd} *order Ambisonic rendering enhance focus towards the visual task, or rather perceived as a source of distraction?*

Informed by these research questions, the following hypotheses have been proposed:

H_1: Incorporating a binaural 3^{rd} order Ambisonic personalised soundscape, as opposed to a baseline of *silence*, will enhance the cognitive performance and behavioural traits of participants with ADHD.

H_2: Incorporating a personalised soundscape reproduced over binaural 3^{rd} order Ambisonics as opposed to dual mono reproduction will have a favourable impact on participants' cognitive performance and behavioural attributes.

H_3: Integrating auditory cues into the personalised immersive soundscape, in comparison to the baseline of *Silence*, will enhance the participants' cognitive performance and behavioural traits positively.

7.5.3 Experiment Design

Study II adopted a mixed-model design, incorporating both within-subject and between-subject approaches. Participants in both the focus and control groups were randomly subjected to the same experimental sound conditions, with the allocation varying across different sessions.

Similar to Study I, the data collection in Study II involved the same metrics, as detailed in Table 5.1. Study II is composed of two sessions, corresponding to two distinct sound conditions outlined in Table 5.2. A group of 21 UK-based participants completed 42 experimental sessions over a period of three weeks. Likewise, 15 Greek participants completed the pair of experimental sessions, yielding a total of 30 sessions over the same duration. No supplementary processes to the CPT were introduced, as depicted in Figure 7.4. The procedure for participants in Study II consisted of fewer steps than in Study I. It initiated with a brief introduction, succeeded by directions for the 'Save the Mushroom' game. A brief discussion followed, leading to the VR game and concluding the session.

7.5.4 Stimuli and Procedures

The control conditions for Study I and Study II were maintained consistently. Both experiments were conducted in identical locations, under the same environmental conditions, using the same equipment and setup. The only variable manipulated between the two studies concerns the two sound conditions, which form the primary focus of the investigation. As mentioned above, Study II consists of two sessions. The sound conditions comprised of the *binaural* 3^{rd} *order Ambisonic Personalised Soundscape* sound condition, which is reproduced at 78 dB(A) for the one session and the same soundscape represented at 72 dB(A) integrated with auditory indi-

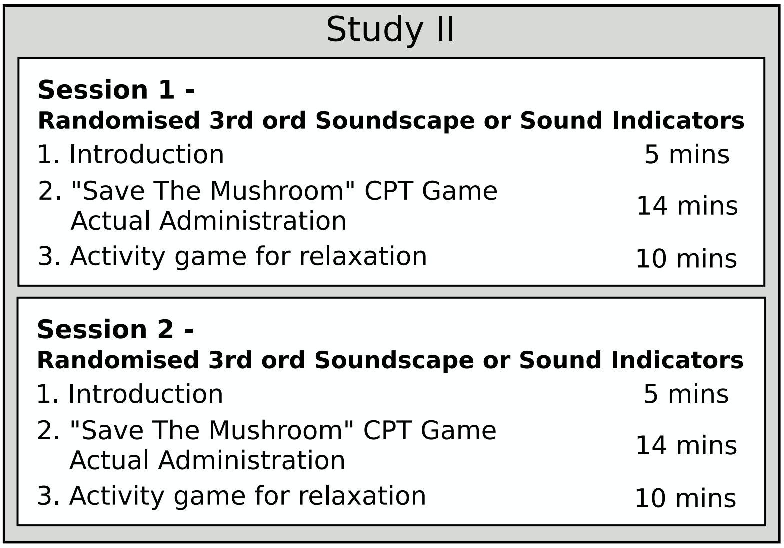


Figure 7.4: Experiment Structure - Study II: Sessions constitute the CPT and the relaxation activity.

cators reproduced at +6 dB at the other. The indicators use the sound of cicadas, introduced to the ear contralateral to the direction of head movement. They are triggered when the head movement deviates by more than $\pm 25°$ off-axis in the azimuth plane. The sound follows a long attack and release to avoid sudden changes during listening as described in Section 5.3.4.

Participants were randomly assigned to these sound conditions across different sessions.

7.6 Results

The results are presented based on the type of responses, beginning with the cognitive and then proceeding to the behavioural. In order to facilitate comparison and gain a comprehensive understanding of the responses for each metric, the graphs contain the data for all five sound conditions from Studies I and II. Subsequent discussions are formulated to address Study I and II individually.

7.6.1 Results: Cognitive Responses

Cognitive performance is measured for each of the sound conditions using three different independent variables: hit response time (HRT), omission (OM) errors, and commission (COM) errors. All data from the participants were collected in a single comprehensive table in Matlab, where the remaining calculated independent variables (Table 5.3) are obtained.

During data analysis, it is observed that a few outliers are present, mainly in the focus group but also a couple in the control group. For the focus group, this result is somewhat expected, given the potential for widely varying responses. Conversely, within the control group, certain instances might reflect a tendency towards inattention, despite the absence of a formal diagnosis. As a result, the data distribution became unequal. To assess the equality of the data distribution, four methods are employed in Matlab: the One-sample Kolmogorov-Smirnov test, Jarque-Bera test, Lilliefors test, and Anderson-Darling test. The results of these tests, along with an indication of '1' denoting unequal distribution, are presented in Table 7.2. The Shapiro-Wilk test is also performed in SPSS to validate these results. Consequently, the statistical analysis method has to be changed from Two-Way repeated measures ANOVA to the Friedman test in order to compare the effects of sound conditions within subjects for each metric. In instances where a significant difference is detected, the significance between pairs of sound conditions is determined using Wilcoxon's signed-rank test. Additionally, the Mann-Whitney test is used to compare differences between the focus and control groups.

Both the Friedman test and the Mann-Whitney test are non-parametric statistical methods. These non-parametric tests are based on rankings meaning that the analysis is focused on median values rather than mean values. This approach is a significant distinction in the analytical procedure. However, in instances where a comparison with other studies is required, and these studies specifically reference mean values (such as mean HRTs), the mean is calculated.

Given the division of the statistical analysis method from the initially designed Two-Way repeated measures ANOVA, a question is raised concerning the statistical power of the experiment and the significance of the retained sample size. To respond to this matter, *Cohen's effect size* is utilized. Whenever a significant difference is detected in conjunction with the Wilcoxon signed rank test, the Cohen effect size is calculated and showcased as an indicator of effectiveness.

Within Subject Statistical Comparison

Within the context of this research, the term 'within-subject statistical comparison' is employed to denote the examination of the impact each sound condition exerts on the individual CPT metrics (dependent variables), conducted separately within each group.

The evaluation begins with an assessment of hit reaction times (HRT), which are obtained from responses exceeding 100 msec [1]. Responses faster than 100 msec are classified as *preservation errors*. The median of the total RT responses

		Control Group				Focus Group			
Met/ rics	Sound Cond.	ks test	jb test	lillie test	ad test	ks test	jb test	lillie test	ad test
HRT	SLN	1	0	0	0	1	1	0	0
	Pn	1	0	0	0	1	0	0	0
	SS-MN	1	0	0	0	1	0	0	0
	SS-BN	1	1	1	1	1	0	0	0
	SS-AI	1	0	0	0	1	0	0	0
HRT SD	SLN	1	1	1	1	1	0	0	0
	PN	1	0	1	1	1	0	0	0
	SS-MN	1	0	1	0	1	1	1	1
	SS-BN	1	0	1	0	1	0	0	0
	SS-AI	1	0	0	0	1	1	0	0
Om Errs	SLN	1	1	0	1	1	0	0	0
	PN	1	1	1	1	1	1	1	1
	SS-MN	1	0	0	0	1	1	1	1
	SS-BN	1	0	1	1	1	1	1	1
	SS-AI	1	0	0	0	1	1	1	1
Com Errs	SLN	1	0	0	0	1	0	0	1
	PN	1	0	0	1	1	0	0	0
	SS-MN	1	0	1	1	1	0	0	0
	SS-BN	1	0	0	0	1	0	0	0
	SS-AI	1	0	0	0	1	0	0	0
Pres Errs	SLN	1	0	1	1	1	0	0	1
	PN	1	0	1	1	1	0	1	1
	SS-MN	1	1	1	1	1	1	1	1
	SS-BN	1	1	1	1	1	1	1	1
	SS-AI	1	1	1	1	1	1	0	1
Det.	SLN	1	0	0	0	1	0	0	0
	PN	1	0	1	0	1	1	1	1
	SS-MN	1	0	1	1	1	1	0	0
	SS-BN	1	0	0	0	1	0	0	0
	SS-AI	1	0	0	0	1	1	0	0

Table 7.2: Data Distribution Table: Presents the data distribution test results for all metrics. An indication of '1' mean non-equal distribution. Abbreviations: ks= Kolmogorov-Smirnov test, jb=Jarque-Bera test, lilie=Lilliefors test, ad=Anderson-Darling test, HRT= Hit Response Time, SD=Standard Deviation, Om Err=Omission Errors, Com Errs= Commission Errors, Pres= Preservation Errors, Det.= Detectability, SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators.

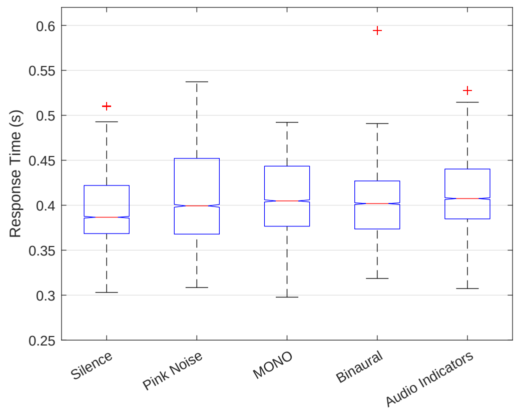


Figure 7.5: Results:
Hit Response Time, Control Group.

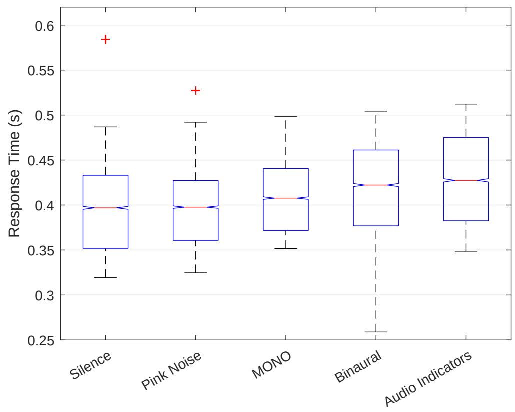


Figure 7.6: Results:
Hit Response Time, Focus Group.

was used to calculate the resulting RT for each participant. The HRT of both the control and focus groups, as depicted in Figures 7.5 and 7.6. To compare the participants' response time across all sound conditions, Friedman's test is employed. The results indicated a non-statistically significant difference (p) for both the control group (chi-squared values (χ^2) = 8.48, degrees of freedom (df) = 4, p = 0.0755) and the focus group (χ^2 = 6.8, df = 4, p = 0.1468). The absence of a pink noise effect on the focus group corresponds with the findings from Deceuninck's study, which was conducted on adults with ADHD [334].

The standard deviation (SD) between the HRTs for each participant is measured to assess the consistency of responses during the entire administration. Figures 7.7 and 7.8 illustrate the resulting SD values for both the control and focus groups. To compare the consistencies across all sound conditions, Friedman's test is used, revealing a non-statistically significant difference for both the control group (χ^2 = 5.475, df = 4, p = 0.0674) and the focus group (χ^2 = 2.84, df = 4, p = 0.563).

The Coefficient of Variability (CV) is calculated by the ratio of the SD to the

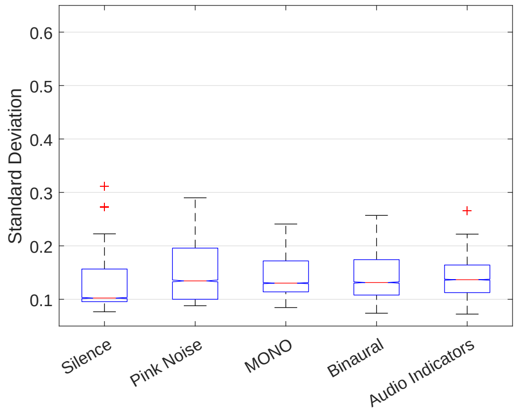


Figure 7.7: Results:
Hit Response Time Standard Deviation, Control Group

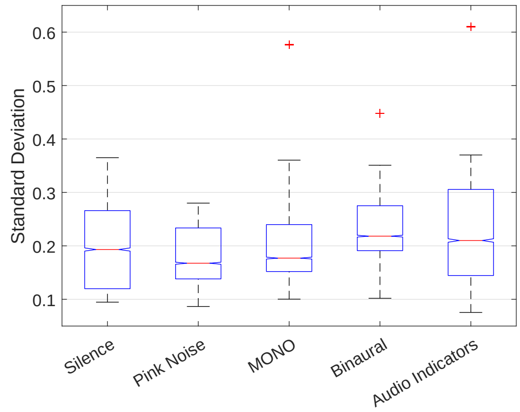


Figure 7.8: Results:
Hit Response Time Standard Deviation, Focus Group

median HRT. It offers an assessment not solely dependent on the consistency of responses, thus providing a relative measure of the average response time. Figures 7.9 and 7.10 describe the CV for both groups across all five sound conditions. Friedman's test failed to uncover any significant difference within either group, with the control group delivering a result of $\chi^2 = 5.8$, df $= 4$, $p = 0.214$, and the focus group generating a value of $\chi^2 = 6.85$, df $= 4$, $p = 0.144$.

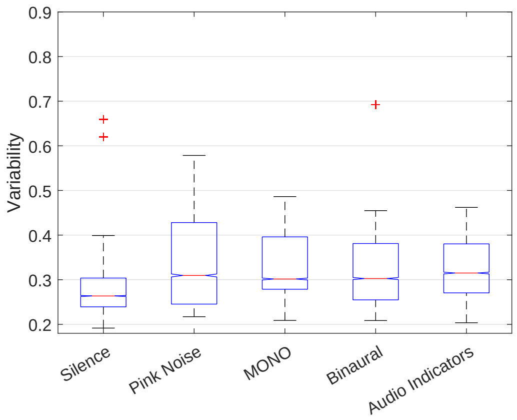


Figure 7.9: Results:
Coefficient of Variability, Control Group

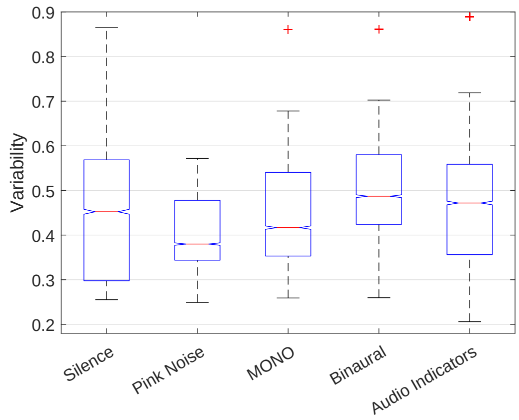


Figure 7.10: Results:
Coefficient of Variability, Focus Group

Omission (OM) errors occur when targets are missed. Total OM errors represent the combined number of missed responses to targets throughout the entire administration. Figures 7.11 and 7.12 illustrate the Omission (OM) errors across all sound conditions for both groups. The control group displayed a statistically significant difference in Friedman's test with $\chi^2 = 9.78$, df = 4, $p = 0.0442$, while the focus group showed a non-statistically significant difference with $\chi^2 = 7.23$, df = 4, $p = 0.124$. Since there is a significant difference in the control group, all potential combinations of sound conditions are examined to identify the source of the difference. The Wilcoxon signed-rank test is applied to each paired comparison, and the results are displayed in Table 7.3. The significance identified is confirmed by the effect size, with values exceeding 0.6, aside from the pair consisting of silence and pink noise where an average effect is observed.

Commission (COM) errors refer to incorrect responses by the participants when they mistakenly hit non-targets, specifically the mushrooms. The measurement of COM errors is determined by adding up all the COM errors made by each participant during the entire administration. Figures 7.13 and 7.14 illustrate the

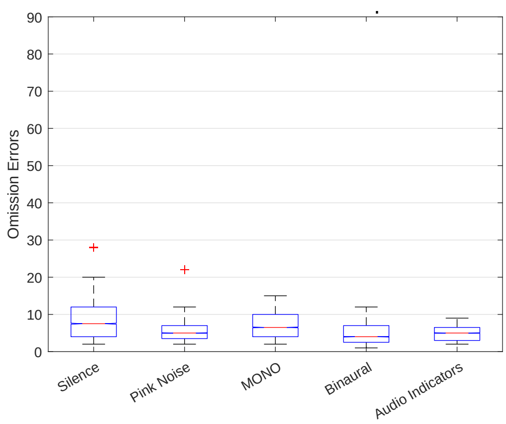


Figure 7.11: Results:
Present the number of Omission Errors for the control group, ranging from 0 to 306.

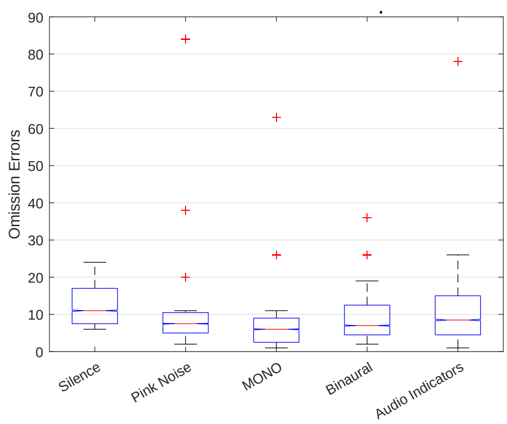


Figure 7.12: Results:
Present the number of Omission Errors for the focus group, ranging from 0 to 306.

Omission Errors - Control Group		
Sound Condition Pairs	**Wilcoxon's Paired Result**	**Cohen's Effect Size**
SLN - PN	0.045	0.386
SLN - SS-MN	0.315	0.34
SLN - SS-BN	0.01	0.809
SLN - SS-AI	0.014	0.9
PN - SS-MN	0.101	0.304
PN - SS-BN	0.39	0.217
PN - SS-AI	0.223	0.468
SS-MN - SS-BN	0.049	0.62
SS-MN - SS-AI	0.031	0.76
SS-BN - SS-AI	0.684	0.0721

Table 7.3: Results, Omission Errors: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Control Group. The effect size is presented as well. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators

COM errors. Running Friedman's test revealed a statistically significant difference in both the control group with $\chi^2 = 18.62$, df = 4, $p = 0.0009$ and the focus group with $\chi^2 = 11.06$, df = 4, $p = 0.0259$. The results of the Wilcoxon test and the effect size are presented in Tables 7.4 and 7.5, highlighting the significant differences between the pairs of sound conditions. The effect size indicated values above 0.6, typically a mid-to-high level of practical significance. It suggests that the impact of these conditions on commission errors is substantial. However, for the silence-pink noise pair, the effect size was found to be 0.394, which is lower than 0.6. This indicates that while there may be a statistically significant difference, the practical impact of this difference is relatively smaller or 'average' compared to other pairs. In other words, while the silence and pink noise conditions differ statistically in their effect on commission errors, the magnitude of this difference is not as pronounced or impactful as those conditions with higher effect sizes.

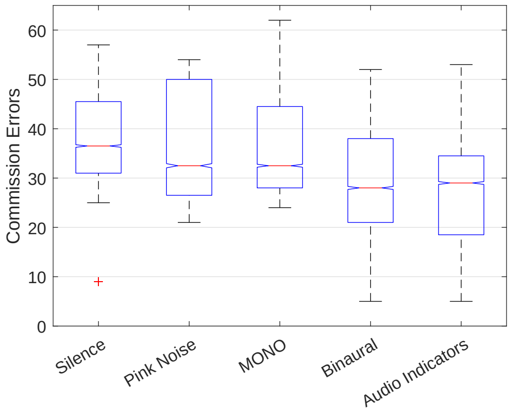


Figure 7.13: Results: Present the number of Commission Errors for the control group, ranging from 0 to 72.

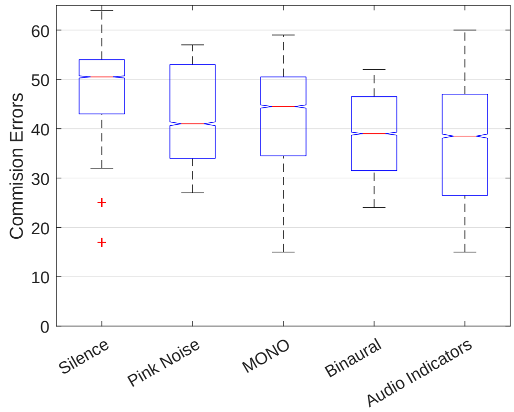


Figure 7.14: Results: Present the number of Commission Errors for the focus group, ranging from 0 to 72.

The detectability score, denoted as *d'*, represents a participant's ability to differentiate between targets and non-targets. Higher scores indicate poorer performance, meaning a reduced ability to discriminate between targets and non-targets. Figures 7.15 and 7.16 illustrate the participant's *d'* across all sound conditions. Both groups displayed a statistically significant difference in Friedman's test, $\chi^2 = 20.25$, df = 4, $p = 0.0004$ for the control group and $\chi^2 = 9.77$, df = 4, $p = 0.0444$ for the focus group. Since there is a significant difference, the Wilcoxon signed-rank test and effect size are applied to each paired comparison, and the results are displayed in Tables 7.6 and 7.7.

Preservation errors refer to responses that occur within 100 milliseconds of stimulus presentation and are considered either random or anticipatory. The Preservation errors for both groups and across all five sound conditions are illustrated in Figures 7.17 and 7.18. Friedman's test revealed no significant difference in either of the groups, with the control group yielding $\chi^2 = 2.95$, df = 4, $p = 0.5654$, and the focus group yielding $\chi^2 = 8.44$, df = 4, $p = 0.0768$.

A comprehensive summary of all the metrics produced in response to the sound

Commission Errors - Control Group		
Sound Condition Pairs	Wilcoxon's Paired Result	Cohen's Effect Size
SLN - PN	0.489	0.038
SLN - SS-MN	0.856	0.021
SLN - SS-BN	0.013	0.644
SLN - SS-AI	0.008	0.82
PN - SS-MN	0.81	0.016
PN - SS-BN	0.006	0.593
PN - SS-AI	0.009	0.772
SS-MN - SS-BN	0.017	0.611
SS-MN - SS-AI	0.019	0.791
SS-BN - SS-AI	0.198	0.171

Table 7.4: Results, Commission Errors: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Control Group. The effect size is presented as well. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators.

Commission Errors - Focus Group		
Sound Condition Pairs	Wilcoxon's Paired Result	Cohen's Effect Size
SLN - PN	0.038	0.394
SLN - SS-MN	0.244	0.362
SLN - SS-BN	0.009	0.704
SLN - SS-AI	0.015	0.727
PN - SS-MN	0.836	0.011
PN - SS-BN	0.245	0.333
PN - SS-AI	0.162	0.41
SS-MN - SS-BN	0.213	0.321
SS-MN - SS-AI	0.139	0.399
SS-BN - SS-AI	0.609	0.14

Table 7.5: Results, Commission Errors: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Focus Group. The effect size is presented as well. These significant differences are indicated in blue.Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators.

conditions is displayed in Table 7.8. Details such as the minimum and maximum values are provided to facilitate improved comprehension.

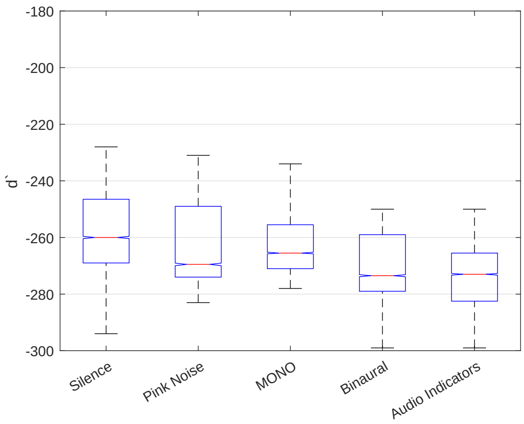


Figure 7.15: Results: Detectability d', Control Group. In a range of -306 to 72, higher scores indicate poorer performance, meaning a reduced ability to discriminate between targets and non-targets.

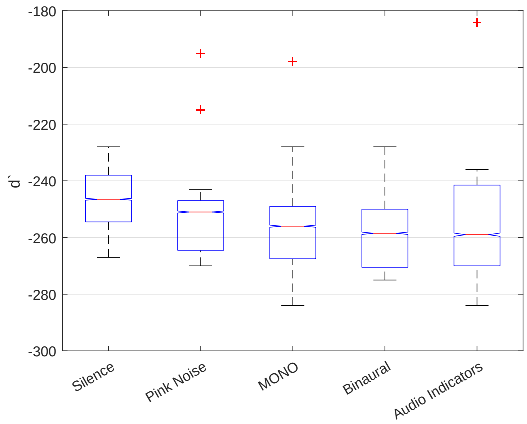


Figure 7.16: Results: Detectability d', Focus Group: In a range of -306 to 72, higher scores indicate poorer performance, meaning a reduced ability to discriminate between targets and non-targets.

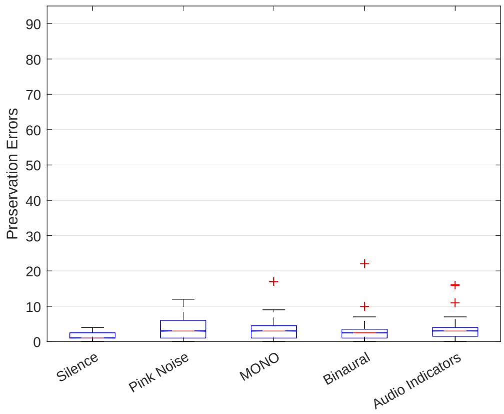


Figure 7.17: Results: Present the number of Preservation Errors (HRT $\leq$ 100ms) for the control group, ranging from 0 to 306.

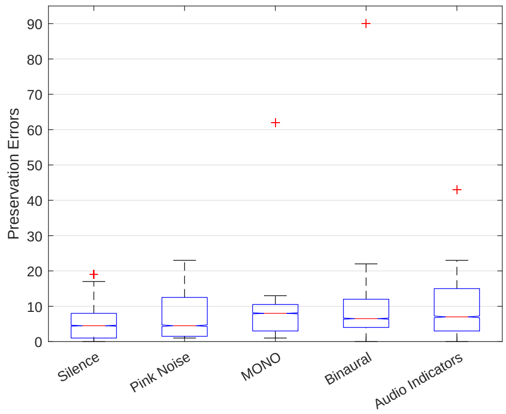


Figure 7.18: Results: Present the number of Preservation Errors (HRT $\leq$ 100ms) for the focus group, ranging from 0 to 306.

Detectability *d'* - Control Group		
Sound Condition Pairs	**Wilcoxon's Paired Result**	**Cohen's Effect Size**
SLN - PN	0.331	0.182
SLN - SS-MN	0.489	0.147
SLN - SS-BN	0.004	0.836
SLN - SS-AI	0.005	1.007
PN - SS-MN	0.825	0.047
PN - SS-BN	0.007	0.622
PN - SS-AI	0.008	0.787
SS-MN - SS-BN	0.009	0.728
SS-MN - SS-AI	0.005	0.909
SS-BN - SS-AI	0.191	0.177

Table 7.6: Results, Detectability: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Control Group. The effect size is presented as well. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators

Detectability d' - Focus Group		
Sound Condition Pairs	**Wilcoxon 's Paired Result**	**Cohen's Effect Size**
SLN - PN	0.074	0.196
SLN - SS-MN	0.053	0.437
SLN - SS-BN	0.011	0.799
SLN - SS-AI	0.179	0.401
PN - SS-MN	0.301	0.195
PN - SS-BN	0.074	0.408
PN - SS-AI	0.301	0.203
SS-MN - SS-BN	0.367	0.182
SS-MN - SS-AI	0.979	0.03
SS-BN - SS-AI	0.796	0.123

Table 7.7: Results, Detectability: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Focus Group. The effect size is presented as well. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators

Metrics	SLN	PN	SS-MN	SS-BN	SS-AI	Info
HRT Cg	0.387	0.399	0.405	0.402	0.407	seconds
HRT Fg	0.397	0.398	0.408	0.422	0.427	seconds
SD Cg	0.102	0.134	0.13	0.131	0.137	seconds
SD Fg	0.193	0.168	0.177	0.218	0.210	seconds
CV Cg	0.279	0.333	0.321	0.323	0.336	
CV Fg	0.492	0.416	0.4521	0.545	0.531	
Om Cg	7.5	5	6.5	4	5	max Om = 306
Om Fg	11	7.5	6	7	8	min Om = 306
Com Cg	36.5	32.5	32.5	28	29	max Com = 72
Com Fg	50.5	41	44.5	39	38.5	min Com = 72
d' Cg	-260	-269.5	-265.5	-273.5	-273	max(worst)= 72 min(best)= -306
d' Fg	-246.5	-251	-256	-258.5	-259	max(worst) = 72 min(best) = -306
Pres Cg	1	3	3	2.5	3	max Pres = 306
Pres Fg	4.5	4.5	8	6.5	7	max Pres = 306

Table 7.8: The table provides a summary of all measured and calculated metrics derived from the CPTs, as obtained through the conducted experiments. Abbreviations: Cg; control group, Fg: focus group HRTs: Hit response times, SD: standard deviation, Om.: omission errors, Com.: commission errors, Pres.: preservation errors, Detect.: detectability, CV: variability, SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

Between Groups Statistical Comparison

The analysis conducted thus far has focused on within-subject comparisons, with the aim of uncovering the impact of different sonic auditory stimuli within ADHD and TDC groups. This analysis is now being extended to examine potential interactions that may arise between the focus and control groups.

In a more specific sense, the analysis is designed to evaluate the *effect* (determined by the metrics, the dependent variables) that a particular sound condition (independent variable A) exerts on the two groups (independent variable B), with this being related to the *silence* baseline condition. This involves the execution of the Mann-Whitney test between groups across all five sound conditions, with results illustrated in Table 7.9. Subsequently, the calculation of Cohen's effect size is undertaken to evaluate the scope of the influence, as shown in Table 7.10.

Sound Conditions	**HRT**	**HRTs SD**	**Om. Errs**	**Com. Errs**	**Pres. Errs**	**Detect. d'**	**CV**
SLN	0.886	0.01	0.05	0.018	0.034	0.007	0.002
PN	0.599	0.186	0.201	0.103	0.122	0.034	0.063
SS-MN	0.987	0.01	0.443	0.139	0.009	0.161	0.006
SS-BN	0.435	0.001	0.062	0.022	0.006	0.007	0.001
SS-AI	0.644	0.008	0.02	0.037	0.013	0.011	0.004

Table 7.9: Significant Difference (p) of Comparison between Control and Focus Groups.
‘

Sound Conditions	HRTs	HRTs SD	Om. Errs	Com. Errs	Pres. Errs	Detect. d'	CV
SLN	0.112	0.88	0.568	0.784	1	0.969	0.971
PN	0.134	0.384	0.504	0.472	0.573	0.705	0.582
SS-MN	0.128	0.889	0.25	0.444	0.678	0.465	1.032
SS-BN	0.091	1.38	0.743	0.833	0.617	1.021	1.387
SS-AI	0.214	1.004	0.753	0.78	0.874	0.991	1.146

Table 7.10: Cohen's (d) standardized effect size from the comparison between focus and control groups. These significant differences obtained in Table 7.9 are indicated in blue. Abbreviations: HRTs: Hit Response Times, SD: Standard Deviation, Om.: Omission Errors, Com.: Commission Errors, Pres.: Preservation Errors, Detect.: Detectability, CV: Coefficient of Variability, SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

7.6.2 Results: Behavioural Responses

The assessment of the behavioural characteristics of the participants was conducted through the analysis of hand and head movements, as outlined in Section 5.2.3. A total of three metrics were examined, encompassing the total hand movement (TM_{HAND}), the total head movement (TM_{HEAD}), and the duration in which the head movement exceeded the $\pm 25°$ limit off-axis in the horizontal plane (Azimuth).

Behavioural Responses: Within-Groups Analysis

Hand Movement

Starting with the within-group statistical analysis of the hand movement responses, Figures 7.19 and 7.20 display only the Silence condition of the mouse displacement, which is represented as distance between consecutive points (vector of x and y co-ordinates) as they evolve over time. The responses from all sound conditions are presented analytically in Appendix B. In Figures 7.21 and 7.22, the total hand movements (TM_{HAND}) are represented, calculated as the sum of distances between consecutive points, across all sound conditions. An inverse behavioural response between groups is noticeable, with the control group exhibiting increased activity in response to spacious and interactive stimuli while the focus group demonstrated restrained activity. Analysis of the data distribution, as presented in Table 7.11, revealed unequal distribution. To examine for statistically significant differences between the participants' TM_{HAND} responses across all sound conditions, Friedman's test was performed. The results indicated a non-statistically significant difference (p) for both the control group, $\chi^2 = 6.4$, df = 4, $p = 0.1712$ and the focus group, $\chi^2 = 6.15$, df = 4, $p = 0.1882$.

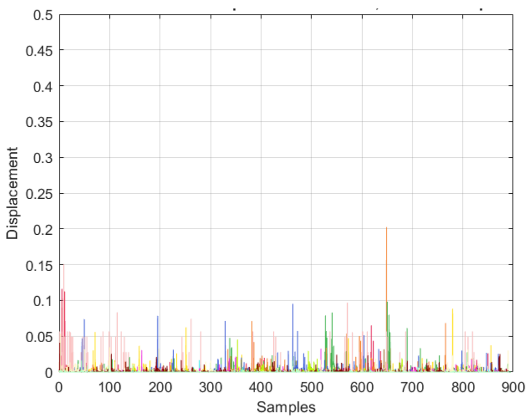


Figure 7.19: Hand movement displacement of the control group responses in Silence condition.

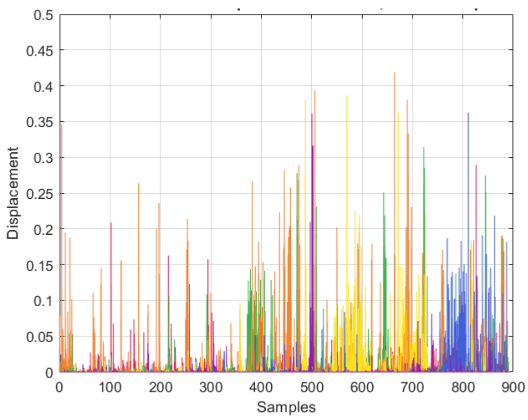


Figure 7.20: Hand movement displacement of the focus group responses in Silence condition.

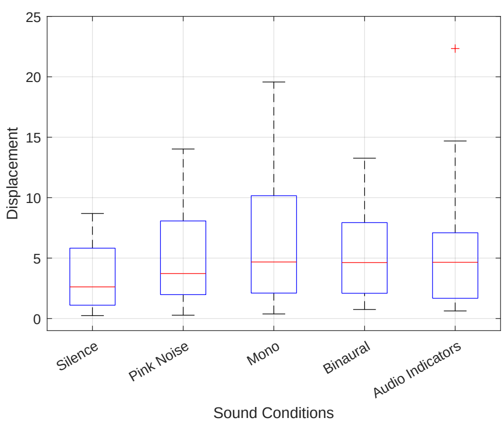


Figure 7.21: Total Hand movement comparison data in the control group across all sound conditions. Note: $y-Axis$ range is smaller than in the focus group for clarity.

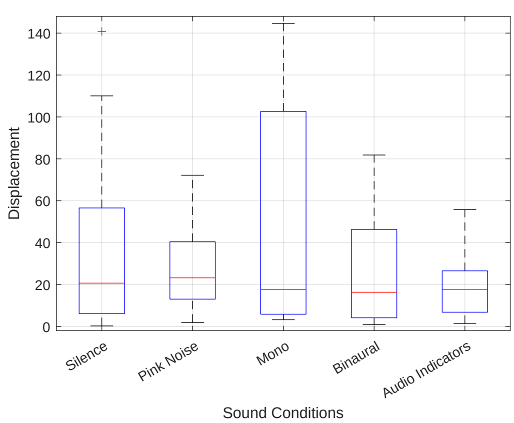


Figure 7.22: Total Hand movement comparison data in the focus group across all sound conditions.

	Control Group				Focus Group			
Sound Cond.	**ks Test**	**jb test**	**lillie test**	**ad test**	**ks Test**	**jb test**	**lillie test**	**ad test**
SLN	1	0	0	1	1	1	1	1
PN	1	0	0	1	1	0	0	1
SS-MN	1	0	1	1	1	0	1	1
SS-BN	1	0	0	0	1	0	1	1
SS-AI	1	1	1	1	1	0	0	0

Table 7.11: TM_{HAND} Data Distribution Table: This table displays the results of the data distribution test conducted on the THandM data. An indication of '1' mean non-equal distribution. Abbreviations: ks= Kolmogorov-Smirnov test, jb=Jarque-Bera test, lilie=Lilliefors test, ad=Anderson-Darling test, SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

Head Movement

Head movement was measured using a wireless head-tracking device, as described in Section 5.2.3. The recorded data represent the movement of the head in three axes (x, y, z), which correspond to *pitch, yaw,* and *roll*, respectively. A related time stamp is attributed to each response. The angles derived from this data indicate the deviation of participants' heads from the origin, which is calibrated to the centre of the screen. From the head movement, two metrics were derived: the total head movement (TM_{HEAD}) displacement and the duration for which participants' head movements exceeded the boundary of $\pm 25°$ in the horizontal plane.

The TM_{HEAD} responses combine the individual angles into a single metric, representing the continuous displacement of the head. Figures 7.23 and 7.24 illustrate the *Head Movement* responses, as the difference in degrees between consecutive angles (pitch, roll, yaw) as they evolve over time in the Silence conditions for the control and focus groups, respectively. All the rest of *pitch, roll, yaw* head movement responses are provided in Appendix B. As detailed in Section 5.2.3, the TM_{HEAD} metric acts as an indicator for hyperactivity and sustained attention. Figures 7.25 and 7.26 present the TM_{HEAD} values, calculated as the sum of the difference between consecutive angles divided by the number of samples, comparing between groups and across all sound conditions. An analysis of the data distribution, as presented in Table 7.12, reveals unequal distribution for the focus group. Friedman's test does not show any significant difference for the focus group, with $\chi^2 = 1.65$, df $= 4$, and $p = 0.7998$. Conducting a Friedman's test for the control group indicates a statistically significant difference with $\chi^2 = 9.52$, df $= 4$, and $p = 0.0493$. Subsequent to this, distinctions between sound conditions were uncovered by a Wilcoxon paired test, as detailed in Table 7.13. A significant contrast was identified between the SLN condition and the PN condition ($p = 0.027$), with an associated increase in head movement being noted. Disturbances and distractions for the participants were introduced by this increase, with values ranging from 0.85 to 1.2. In another observation, a significant difference was found between the SS-MN and SS-AI conditions ($p = 0.043$), indicating a reduction in head movement. This reduction was seen to align the movement with the SLN condition, registering a displacement value of approximately 0.8.

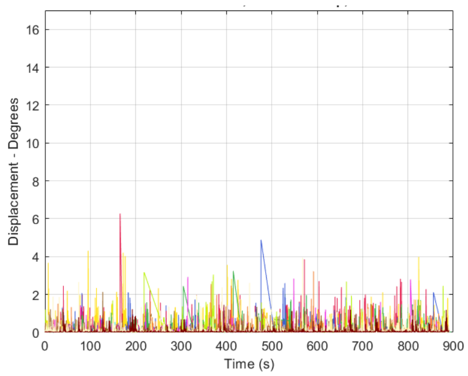


Figure 7.23: Head-Movement of the control group responses in Silence condition.

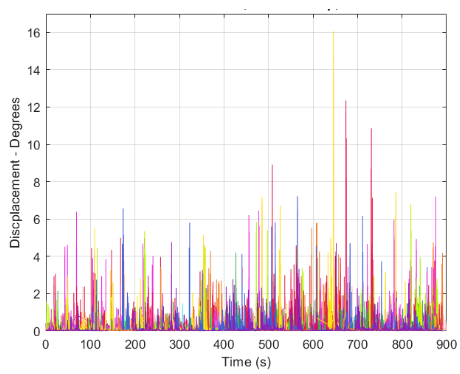


Figure 7.24: Head-Movement of the focus group responses in Silence condition.

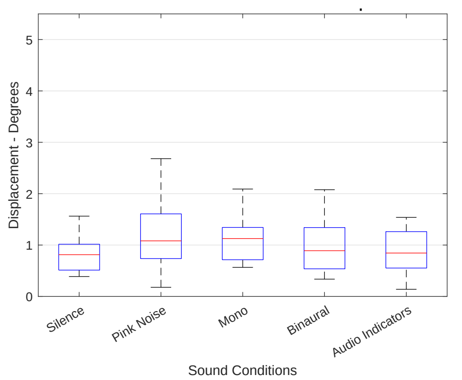


Figure 7.25: Total Head Movement comparison across all sound conditions, control group.

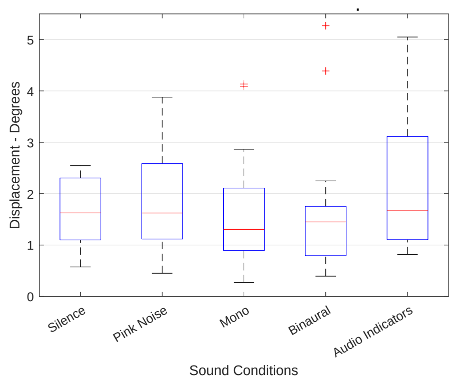


Figure 7.26: Total Head Movement comparison across all sound conditions, focus group.

	Control Group				Focus Group			
Sound Cond.	**ks Test**	**jb test**	**lillie test**	**ad test**	**ks Test**	**jb test**	**lillie test**	**ad test**
SLN	1	0	0	0	1	0	0	0
Pink	1	0	0	0	1	0	0	0
SS-MN	1	0	0	0	1	0	1	1
SS-BN	1	0	0	0	1	1	1	1
SS-AI	1	0	0	0	1	0	0	1

Table 7.12: Total-Head-Movement Data Distribution Table: This table displays the results of the data distribution test conducted on the head-movement data. An indication of '1' mean non-equal distribution. Abbreviations: ks= Kolmogorov-Smirnov test, jb=Jarque-Bera test, lilie=Lilliefors test, ad=Anderson-Darling test, SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators.

Total Head Movement - Control Group		
Sound Condition Pairs	**Wilcoxon Paired Result**	**Cohen's Effect Size**
SLN- PN	0.027	0.576
SLN - SS-MN	0.067	0.656
SLN - SS-BN	0.501	0.28
SLN - SS-AI	0.681	0.108
PN - SS-MN	0.736	0.05
PN - SS-BN	0.331	0.301
PN - SS-AI	0.052	0.479
SS-MN - SS-BN	0.0522	0.301
SS-MN - SS-AI	0.043	0.526
SS-BN - SS-BN	0.575	0.177

Table 7.13: Results, Total-Head-Movement: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Control Group. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

The examination is continued with the *duration* during which the head movement surpasses the off-axis limit of $\pm 25°$ in the horizontal plane. The head movement displacement with the marked limits for both groups is depicted in Figures

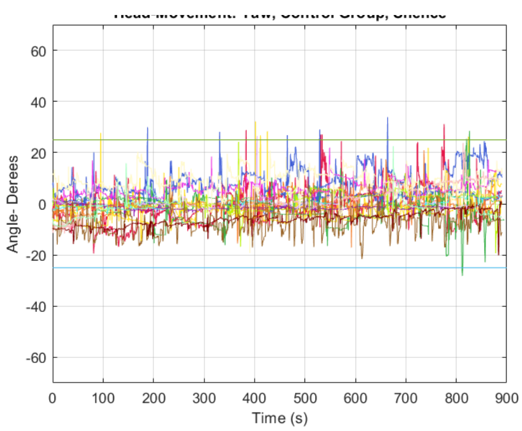


Figure 7.27: Head-Movement displacement only in the horizontal axis with the boundary of $\pm25°$ of the control group responses in Silence condition.

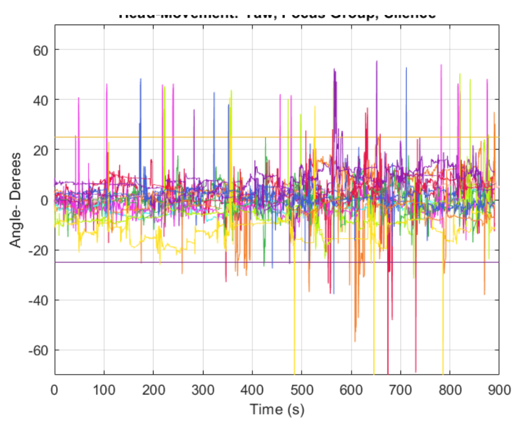


Figure 7.28: Head-Movement displacement only in the horizontal axis with the boundary of $\pm25°$ of the focus group responses in Silence condition.

7.27 and 7.28. The median of these duration responses, recorded in seconds, for both the control and the focus group are depicted in Figures 7.29 (y-axis are in smaller scale for clarity) and 7.30. Consistent with previous instances, the data distribution continues to be unequal, as displayed in Table 7.14. Friedman's test presented significant differences for both groups. The control group showed $\chi^2 = 10.85$, df $= 4$, and $p = 0.0283$ for the focus group, and $\chi^2 = 28.23$, df $= 4$, and $p \leq 0.001$ for the control group.

The results for the control group, displayed in Table 7.15, feature the within-group analysis for paired sound conditions revealing a significant difference triggered by the introduction of any form of additional auditory stimuli when compared to the silence. This pattern is echoed in the focus group, where an increase in time spent outside the horizontal limits is observed as the auditory stimuli become more spacious and interactive. These findings are laid out in Table 7.16.

In Table 7.17, an overview is provided that encompasses the results of the behavioural responses collected throughout the experiment. The total displace-

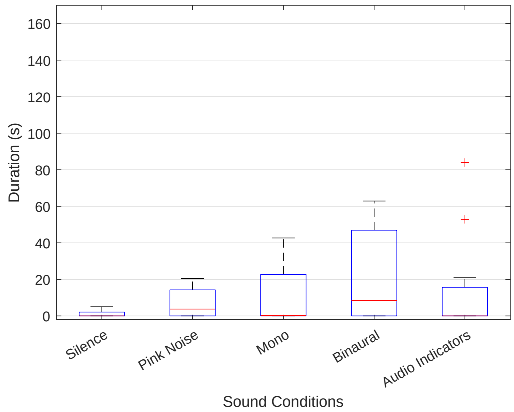


Figure 7.29: Control Group: The time duration for which the participants' heads exceeded the boundary of $\pm 25°$ in the horizontal plane.

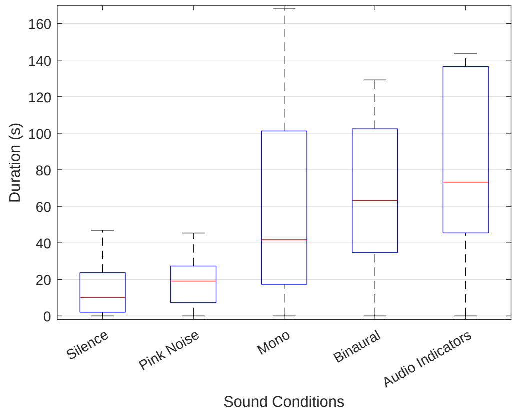


Figure 7.30: Focus Group: The time duration for which the participants' heads exceeded the boundary of $\pm 25°$ in the horizontal plane.

	Control Group				Focus Group			
Sound Cond.	**ks Test**	**jb test**	**lillie test**	**ad test**	**ks Test**	**jb test**	**lillie test**	**ad test**
Silence	1	1	1	1	1	0	0	1
Pink	1	0	1	1	1	0	0	0
Mono	1	1	1	1	1	0	1	1
Binau.	1	0	1	1	1	0	0	0
Au. Ind.	1	1	1	1	1	0	1	0

Table 7.14: This table displays the results of the data distribution test conducted on the time duration for which the participants' heads exceeded the boundary of $\pm 25°$ in the horizontal plane. An indication of '1' mean non-equal distribution. Abbreviations: ks= Kolmogorov-Smirnov test, jb=Jarque-Bera test, lilie=Lilliefors test, ad=Anderson-Darling test, SS-MN: soundscapes Mono, SS-BN: soundscapes binaural, SS-AI: soundscapes with audio indicators.

ment of both hands and head, along with the duration of the head over the limits positioning, is compared in this synopsis.

Duration of Over Lim. TM_{HEAD} - Control Group		
Sound Condition Pairs	**Wilcoxon Paired Result**	**Cohen's Effect Size**
SLN- PN	0.0023	1.1
SLN - SS-MN	0.041	0.84
SLN - SS-BN	0.002	1.15
SLN - SS-AI	0.0097	0.67
PN - SS-MN	0.389	0.3
PN - SS-BN	0.025	0.78
PN - SS-AI	0.56	0.28
SS-MN - SS-BN	0.094	0.5
SS-MN - SS-AI	0.946	0.043
SS-BN - SS-BN	0.08	0.42

Table 7.15: Results, Duration of Over-Limit head Movement: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Control Group. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

Duration of Over Lim. TM_{HEAD} - Focus Group		
Sound Condition Pairs	**Wilcoxon Paired Result**	**Cohen's Effect Size**
SLN- PN	0.193	0.32
SLN - SS-MN	0.004	1.06
SLN - SS-BN	0.006	1.52
SLN - SS-AI	0.0006	1.77
PN - SS-MN	0.029	0.95
PN - SS-BN	0.006	1.38
PN - SS-AI	0.0008	1.65
SS-MN - SS-BN	0.454	0.13
SS-MN - SS-AI	0.252	0.44
SS-BN - SS-BN	0.214	0.36

Table 7.16: Results, Duration of Over-Limit head Movement: Wilcoxon paired comparison revealed significant statistical differences ($p < 0.05$) in the sound condition pairs within the Focus Group. These significant differences are indicated in blue. Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

Metrics	**SLN**	**PN**	**SS-MN**	**SS-BN**	**SS-AI**
Hand Movement					
Disp. TM_{HAND} **Cg**	2.62	3.72	4.68	4.63	4.655
Disp. TM_{HAND} **Fg**	20.68	23.21	17.67	16.32	17.558
Head Movement					
Disp. TM_{HEAD} **Cg**	0.81	1.08	1.13	0.89	0.842
Disp. TM_{HEAD} **Fg**	1.62	1.62	1.304	1.45	1.666
Dur. HeadM Cg	0	3.76	0.23	8.44	0
Dur. HeadM Fg	10.16	19.1	41.7	63.23	73.24

Table 7.17: The table provides a summary of all metrics derived from the hand and head movement, as obtained through the conducted experiments. Abbreviations: Cg; control group, Fg: focus group, SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators.

Behavioural Responses: Between Groups Analysis

The analysis presented herein progresses to explore potential interactions that may arise between the focus and control groups. The interaction across all five sound conditions is determined by the Mann-Whitney test, with the results depicted in Table 7.18. Additionally at the same table, Cohen's effect size is computed to measure the extent of the influence. Notable interactions were identified across all sound conditions, supported by a strong effect size. The expected differentiation between the ADHD group and the TDC group is indicated by the interactions across all three metrics introduced by the SLN. Interactions in TM_{HAND} were introduced by all soundscape sound conditions, while in TM_{HEAD} were interactions introduced only by the SS-AI. Finally, the Time Duration metric influenced all sound conditions.

	Interactions Between Groups					
Sound	**THandM**		**THeadM**		**Time Dur**	
Cond.	**p**	**d**	**p**	**d**	**p**	**d**
SLN	0.0003	1.13	0.0006	1.51	0.0002	1.34
PN	3.744	1.57	0.054	0.82	0.0047	1.13
SS-MN	0.0029	1.22	0.122	0.69	0.0018	1.21
SS-BN	0.012	1.13	0.054	0.73	0.0036	1.25
SS-AI	0.0015	1.21	0.0006	1.33	0.0005	1.85

Table 7.18: Between Groups Analysis including significant differences, indicated in blue, and Cohen's Effect Size.Abbreviations: SLN: silence, PN: pink noise, SS-MN: soundscapes Mono, SS-BN: soundscapes Binaural, SS-AI: soundscapes with audio indicators

7.7 Discussion - Study I

Study I examines the influence of sound content as an external sonic stimulation on participant responses. The assessment involves three sound conditions: pink noise

(PN), which is introduced as a standardised content; personalised soundscapes in mono (SS-MN), which are a proposed element from this research; and silence (SLN), which serves as the baseline for comparison. Both PN and SS-MN are reproduced in a dual mono format, with PN presented at 80dB(A) and SS-MN at 78dB(A).

The results of the 'Save the Mushroom' CPT game are used to inform the cognitive responses. Combinations of metrics are proposed by Conner's manual as an interpretation method for inattention and impulsivity [1].

- For *inattentiveness*, it is suggested that low detectability *d'* and high scores of OM errors are indicative, combined with slow HRT and high levels of inconsistency in response speed (reflected by HRT SD and CV).

- Indications of *impulsivity* are typically characterized by a faster than average HRT and an increased rate of COM and/or Pres. errors.

Established research demonstrates that children with ADHD exhibit slower HRTs and increased HRT variability across all neuropsychological tasks. Furthermore, these children are more prone to omissions and exhibit increased impulsivity [15, 349, 350, 351]. The results gathered under the SLN baseline sound condition of this study are found to be in alignment with the characteristics of ADHD as described in the literature.

In terms of behavioural responses, measurements are taken for total hand movement, total head movement, and the duration of off-limit metrics. The latter metric is separately discussed, encompassing an overview of all sound conditions.

7.7.1 Pink Noise - Dual Mono

In the within-group comparison, PN manifested a positive response in the focus group, as evidenced by a significant decrease in COM errors relative to the SLN condition (refer to Table 7.5). This finding indicates an improvement in impulsivity, expressed by an increased capacity to withhold responses to non-targets. However, these results seem to contrast with those of Deceuninck's research, where PN did not impact COM errors in adults with ADHD [334].

In the case of the control group, a significant decrease in OM errors was observed as a result of PN (refer to Table 7.3). This decrease suggests an improvement in attention. The improvement in performance implies that participants managed to sustain their focus, resulting in fewer missed targets, indicating enhanced attention.

In the between-group comparison, PN was found to have a uniformly positive effect on both groups. A significant interaction manifested, suggestive of an augmentation in *d'*, which predominantly favoured the control group (refer to Tables 7.8 7.9.

As predicted, PN follows the positive effect of white noise on children with ADHD albeit on different CPT metrics. Whereas white noise improves performance in OM errors and detectability [15, 50], pink noise reduces COM errors.

When examining the behavioural responses in the within-group analysis, no significant effect occurred in the focus group. The control group showed a significant increase in TM_{HEAD} during PN exposure, a phenomenon that, when coupled with the positive cognitive improvement in attention metrics, might be interpreted as a sign of alertness (refer to Table 7.13). Interactions between the groups were not detected.

The initial hypothesis in Study I proposed that exposure to Pink Noise would positively impact cognitive performance and reduce behavioural activity among children with ADHD. The findings revealed a positive impact of PN on cognitive performance, notably reflected in a significant reduction in COM errors. This reduction suggests an improvement in impulsivity control, as indicated by the consistent number of Preservation errors and stable HRTs. Furthermore, the neutral behavioural responses, rather than indicating a negative impact, suggest that PN does not result in performance deterioration or act as a distraction. Hence, the hypothesis can be accepted based on the observed improvements and the absence of any adverse effects on behaviour or other performance metrics. These results provide novel insights into the literature, representing the first demonstration of PN's specific influence on cognitive processes in children diagnosed with ADHD.

7.7.2 Personalised Soundscapes - Dual Mono

In the within-group comparison, the focus group exposed to the personalised soundscapes SS-MN did not display significant differences in responses, although a favourable trend was noted across the majority of metrics. A similar response was observed in the responses of the control group to SS-MM with no significant differentiation confirmed.

Examining the between-groups comparison for the SS-MN condition, significant interactions were observed in SD, CV and Preservation errors (refer to Tables 7.8, 7.9).

The lack of a significant effect in the within-group comparison means that, individually, neither the focus nor the control groups showed a significant change in any of the above metrics after being exposed to SS-MN. However, the significant interaction in the between-group comparison indicates that the effect of the SS-MN differs between the two groups. So, while neither group showed a significant change on their own, the difference in how the two groups responded to the SS-MN was significant. Contrary to the control group, the focus group achieved considerable improvement in performance variability (CV) and consistency (SD) throughout the process. This implies that personalising soundscape content may foster enhanced attention in children diagnosed with ADHD. Moreover, the increase in Preservation errors compared to the control group points to the notable influence exerted by SS-MN, indicating a potential amplification in impulsivity.

Along the same lines, within the behavioural response metrics, the within-group analysis did not reveal any significant effect for either group. Concerning the between-group analysis, no interaction was observed for the TM_{HEAD}, but a significant reduction in TM_{HAND} movement positively influenced the focus group when subjected to SS-MN exposure indicating a tendency towards controlled hyperactivity (refer to Tables 7.17 7.18).

The second hypothesis of Study I proposed that exposure to personalized soundscapes (SS-MN) would lead to improved cognitive performance and reduced behavioural activity in children with ADHD. The within-group comparison did not show significant differences in cognitive performance metrics for both the focus and control groups. However, between-group comparisons revealed significant differences in performance consistency (SD) and variability (CV), indicating improved attention in the focus group. Concerning behavioural responses, no significant changes were observed within each group. However, the between-group interaction indicated a reduction in hand movement in the focus group during SS-MN exposure, suggesting a potential improvement in controlled hyperactivity. Based on these findings, the hypothesis is accepted, as the personalized soundscapes (SS-MN) led to improvements in certain cognitive and behavioural metrics in children with ADHD, specifically in attention and controlled hyperactivity. While the improvements were more pronounced in certain metrics and the results were mixed, the overall trend supports the hypothesis.

While SS-MN and PN each had positive effects on attention and impulsivity, they supported different metrics/dimensions. Nevertheless, this study suggests and provides empirical evidence for a methodology for soundscape content creation through personal content selection. This process adapts standardised noise characteristics and preserves the beneficial attributes of noise therapy.

7.8 Discussions: Study II

Study I conducted an analysis on the impact of a personalised soundscape in comparison to a standardised audio stimulus, with silence serving as the baseline. In this study, the soundscape was replicated identically in both ears. Study II spatially represented the identical soundscape through binaural 3^{rd} order Ambisonic rendering (SS-BN). This was undertaken with the aim to investigate the role of sonic spaciousness as either a distracting or stimulating factor and the influence of interactive sound as an external sonic stimulant on participant responses. This second condition in Study II builds upon the concept of dynamically incorporating auditory cues (SS-AI), thereby assessing the impact of interactivity as either a distraction or a stimulus.

7.8.1 Personalised Soundscape - Binaural 3^{rd} order Ambisonics

In the within-group comparison, a significant enhancement in *d'* and a reduction in COM errors were observed when the SS-BN was introduced to the focus group, as compared to the SLN condition (refer to Tables 7.7 7.5). This finding offers valuable evidence demonstrating the positive effect of spatial audio reproduction on attention and impulsiveness. Spatial audio appears to be beneficial in augmenting cognitive stimulation for the focus group.

Notably, a broader positive impact from the SS-BN compared to silence was recorded in the control group. Performance improvements related to *d'*, COM, and OM errors were evident across all other conditions (refer to Tables 7.3 7.4 7.6). The substantial decrease in COM errors highlighted an improvement in impulsiveness in contrast to SLN and PN, as well as SS-MN. Meanwhile, the reduction in *d'* and OM errors indicated a partial advancement in attention. The benefits of spatial sound were conspicuous over dual mono reproduction and SLN and PN, proposing its role as a stimulant rather than a distractor. Such observations reinforced the positive effect of spatialised sound on the TDC population by partially improving impulsive responses and attention.

The between-group comparison revealed mixed interactions concerning the influence of SS-BN on attention and impulsivity. With regard to the focus group, it was observed that there was an improvement in COM errors but a decreased performance in Preservation errors and CV, which resulted in a mixed outcome for impulsive responses - one dimension improved while the other declined. The interactions for the control group also presented mixed results, demonstrating an improvement in the *d'* metric, yet a reduction in performance with respect to SD, both of which are associated with attention (refer to Tables 7.8 7.9.

Regarding the behavioural responses to SS-BM exposure, no significant differences were observed in either TM_{HAND} or TM_{HEAD} within both the focus and control groups. In the between-group analysis, although no interaction was observed among the groups concerning head movement (TM_{HEAD}), the reduction in TM_{HAND} within the focus group reinforces the notion of improved sensory-motor control, indicating a positive effect on hyperactivity.

In relation to the initial hypothesis of Study II, the utilization of binaural 3^{rd} order Ambisonic audio is found to have a beneficial effect on certain aspects of attention and impulsivity compared to the SLN for participants with ADHD. The results confirm this hypothesis's acceptance with some nuances. The study found significant enhancements in attention and impulsivity metrics, such as improvements in the *d'* metric, indicating an enhancement in target differentiation, providing evidence for advancements in attention. The findings substantiate the acceptance of this hypothesis with nuanced insights. The study observes notable improvements in attention and impulsivity metrics. Enhanced *d'* metrics suggest improved target differentiation, indicating advancements in attention. Moreover, the reduction in COM errors signifies enhanced impulse control. Furthermore, the behavioural responses to SS-BM exposure showed improved sensory-motor control (reduced TM_{HAND}), implying a beneficial impact on hyperactivity within the ADHD group. However, the between-group comparison revealed mixed interactions, concluding on the association that improved error metrics (*d'*) alongside declined HRT-related metrics (SD, CV, Preservation err.). This complexity in results underlines the multifaceted nature of cognitive responses to auditory stimuli in ADHD and points to the need for further research to explore these nuances more deeply.

Interestingly, the binaural soundscape representation also appears to enhance certain elements of attention and impulsivity in TDC, in comparison to the SLN condition. Enhancements in the *d'* metric and reductions in OM errors provide evidence of attention improvement. The decrease in COM errors indicates a positive change in managing impulsive responses.

Addressing the second hypothesis of Study II, the comparison between soundscapes reproduced over binaural 3^{rd} order Ambisonics and dual mono shows favourable outcomes, particularly for the control group, and neutral results for the focus group. This hypothesis is accepted, as significant improvements in attention and impulsivity metrics such as *d'*, OM, and COM errors were observed in the control group under spatial audio conditions. For the focus group, while no significant positive differences were noted, the lack of negative impacts implies a favourable influence of binaural 3^{rd} order Ambisonics in maintaining cognitive performance without introducing distractions.

7.8.2 Personalised Soundscape - Integrated Auditory Indicators

In the within-group comparison, a significant effect was identified by the focus group evaluation when auditory indicators were incorporated into the soundscape content (SS-AI), as compared to SLN. This effect was manifested by a substantial reduction in COM errors, pointing towards an improvement in impulsivity control (refer to Table 7.5). The data supports the efficacy of dynamically introduced auditory cues as a method for providing temporary increased stimulation without causing distraction.

The presence of SS-AI provided additional benefits to the control group, with significant differences in *d'*, COM, and OM errors when compared to all other sound conditions. This decrease in OM errors and improved *d'*, relative not only to SLN and PN but also to mono reproduction, indicated a partial improvement in attention (qv Table 7.4). At the same time, a decrease in COM errors observed across all other sound conditions implies enhancements in impulsivity control. Such enhancements underscore the potential role of the interactive soundscape in offering supplementary temporal stimulation. Furthermore, these findings provide support to the second hypothesis of this study, affirming the advantageous impact of spatialized soundscapes compared to mono soundscapes.

The between-groups comparison revealed a mixed pattern of effects for SS-AI, echoing SS-BN but slightly more pronounced. All metrics, except HRT, demonstrated significant interactions between the groups (qv Table 7.9). In the focus group, an improvement in OM errors was observed, indicative of enhanced attention. However, a contradiction arises from the reduction of COM errors, which coincides with an increase in Preservation errors, leading to unclear implications for impulsive control (qv Table 7.8). Similarly, within the control group, an interesting contradiction is observed. An increase in the HRT-related metrics of SD and CV is noted, signifying an inconsistency in attention. Concurrently, an enhancement in the *d'* metric is detected, suggesting partial enhancements in attention.

In the examination of the behavioural response metrics during exposure to SS-AI, a significant decrease in TM_{HEAD} was identified for the control group in the within-group analysis relative to the SS-MN approximately equalising the head movement with the SLN condition, as illustrated in Tables 7.13 and 7.17. Conversely, the focus group exhibited increased head movement compared to the SLN condition, as revealed by the between-group interactions. For a detailed comparison, refer to Table 7.18. Concurrently, the diminished TM_{HAND} behavioural response observed in SS-MN and SS-BN was also maintained in SS-AI, indicating a regulation of hyperactivity.

The observed increase in head movement in both groups indicates participants' responsiveness to auditory cues, raising questions about their role in enhancing attention. However, this heightened head movement contradicts the decrease in hand movement, making it challenging to draw conclusions about its impact on hyperactivity. This might be attributable to the dynamic audio indicators, which maintained an elevated level of alertness, leading to improvements in impulsivity (cf reduced COM errors in the focus group). Concurrently, these cues acted as distractors, causing a tendency towards hyperactivity. Notably, auditory cues were frequently interpreted by participants as game-like or activity enhancers, adding engagement to what was typically a monotonous routine. Comments like "it was given to me as something to do" underscored this engagement.

The third hypothesis of study II, proposed that integrating auditory cues into a personalized immersive soundscape, in comparison to silence, would enhance cognitive performance and behavioural traits in participants with ADHD. The findings confirm its acceptance, with some nuanced outcomes warranting further exploration. The introduction of auditory cues into the personalized immersive soundscape significantly improved impulsivity control in participants with ADHD, as indicated by the reduced COM errors. Additionally, improvements in hyperactivity control were observed, indicated by a decrease in hand movements. However, the analysis of behavioural metrics revealed mixed results, notably the contradiction between the decrease in hand movements and the increase in head movements.

Additionally, cognitive metrics presented a contradiction, showcasing a reduction in COM errors alongside an increase in Preservation errors. These conflicting findings indicate a complex interplay between auditory cues and participants' responses. This complexity underscores the multifaceted nature of cognitive and behavioural reactions to auditory stimuli in individuals with ADHD. Consequently, these findings underline the necessity for further research to deeply investigate these nuances and better understand the implications of auditory cues on attention and hyperactivity in ADHD populations.

7.8.3 Stimulation - Distraction

Finally, the discussion touches upon the influence of spatialised sonic representation and dynamic auditory cues as stimulation or distractions.

The findings suggest that SS-BN enhanced certain aspects of attention and impulsivity performance when compared to SLN for both control and focus groups, with no inclination towards hyperactivity being observed. Conversely, the significant decrease in TM_{HAND} in SS-MN, SS-BM, and SS-AI indicated suggesting hyperactivity control, thereby illustrating the beneficial effect of spatialised sonic environments on behaviour. This further reinforces the recommendations for positive stimulation.

The retention of such cognitive and behavioural improvements, particularly for the control group, when compared with mono reproduction, leads to the conclusion that the spatialised sonic representation of soundscapes facilitates stimulation without engendering distraction. Although notable benefits arose from the within-subject comparing binaural to mono, and silence conditions, the between-group comparisons of SS-BN outcomes yielded mixed results, primarily due to variations in HRTs. An explanation for these HRT variations has been provided, but questions persist regarding whether the spatialised sound improved alertness through a sense of presence yet simultaneously introduced a distraction.

Building on this analysis, the comparison between SS-BN and SS-AI reveals that the integration of dynamic elements into soundscape design does not induce additional distractions or impact the performance of the control group. Conversely, the focus group, while showing improved detectability, did not retain the significant difference in SS-AI as previously seen in the comparison between SS-BN and SLN. This suggests that dynamic elements might serve as a distraction for children with ADHD. This potential distraction is also manifested in the behavioural responses, as indicated by the increase in the TM_{HEAD}, suggesting an escalated tendency towards hyperactivity.

Another suggestion looks at the level reduction from 78 dB(A) in SS-BN to 72 dB(A) in SS-AI could potentially lead to sub-optimal stimulation. This aligns with the optimal stimulation theory and the MBA model (qv 2.3.1), which both propose that the addition of extra-task stimulation, shaped like an inverse 'U', is likely to enhance cognitive functioning in ADHD or otherwise, too little stimulation could lead to sub-stimulation. While this appears to be a plausible explanation, the overall SPL remained unchanged, pointing to the dynamic sonic elements being perceived as a distractor as the more likely reason for the diminished detectability.

7.8.4 Discussion - Duration Over-Limit Head Movement

The metric related to duration was designed to reveal differences among the soundscape sound conditions (MN, BN, AI) and the SLN, with the PN response included for comparative purposes.

A general observation showed that all sound conditions had a negative impact on the time duration for which participants diverted their gaze from the screen (qv Fig.7.29, 7.30). This is underscored in the within-group analysis, where significant differences are noticeable in all sound conditions for both groups when compared to SLN, as indicated in Tables 7.15 and 7.16. Particularly in the focus group, there is a linear increase in duration starting from SLN at 10.16 secs and progressing to PN at 19.1 secs, SS-MN at 41.7 secs, SS-BN at 63.23 secs, and finally reaching SS-AI at 73.24 secs (qv Table 7.17. A similar effect is also substantiated in the between-groups analysis, highlighting the significant increase in duration for the focus group (qv Table 7.18). This could suggest that any supplementary sonic stimuli may encourage visual exploration of the space and the more spatially descriptive the stimuli, the greater the need for participants to familiarise themselves with the sonic environment.

A partial contradiction with the TM_{HEAD} was observed, wherein the within-group analysis indicated a trend towards decreased head movement in the focus group, reference to Table 7.17. The PN scored an equivalent to SLN of 1.62 displacement, while the SS-MN recorded a reduced 1.304 and the SS-BN had 1.45. An increase was observed at SS-AI, registering 1.666 displacements, yet no significant differences were provided in any of these instances. Notably, a significant increase in the TM_{HEAD} displacement was only demonstrated by the PN in the control group, reference to Table 7.13.

To clarify the above, additional research is being conducted to explore the association between the duration of head movement exceeding the predefined limits and the potential reduction in horizontal head movement resulting from audio indicator guidance. Specifically, the investigation seeks to determine if these indicators function as sensory alarm mechanisms and additional stimulation methods that ultimately lead to a reduction in head movement. Consequently, only the horizontal head movement (Azimuth plane, yaw angle) is utilised for this comparison, as illustrated in Figure 7.31. It is a dual y-axis graph, with the duration on the left axis, represented by dot markings and the Azimuth displacement on the right axis, indicated by dash markings. The focus group is denoted by the colour green, while the control group is represented in blue.

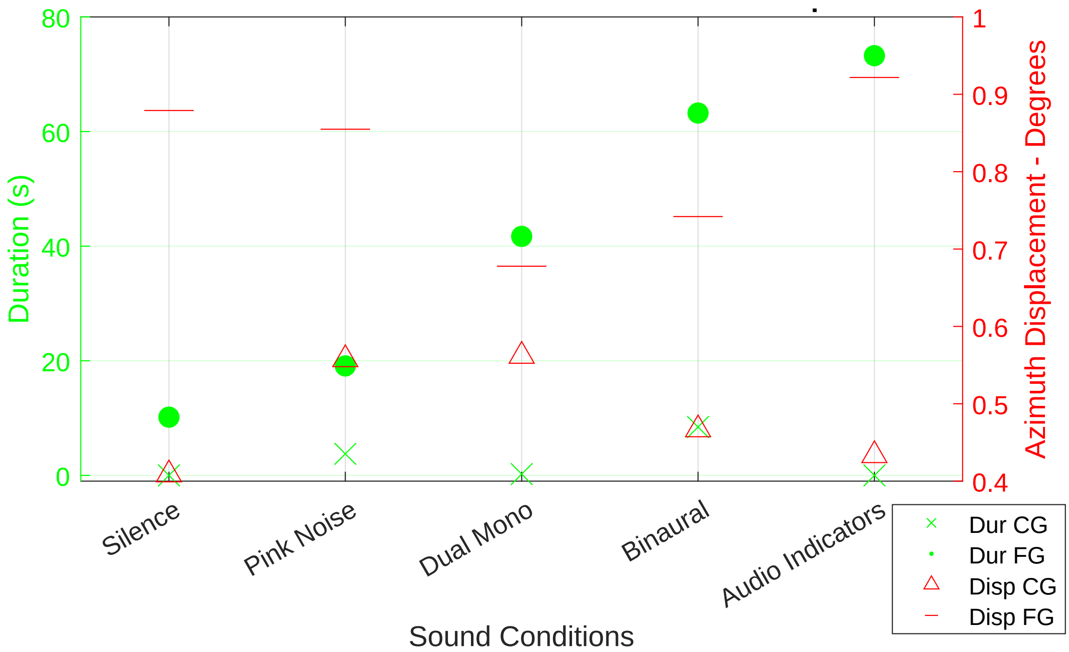


Figure 7.31: Duration of Head-Movement Beyond Limits: The left axis depicts the time duration for which the participants' heads exceeded the boundary of $\pm 25°$ in the horizontal plane, represented by dot markings. The right axis presents the total displacement solely within the horizontal plane (Azimuth), indicated by dash markings. The focus group is denoted by the colour green, while the control group is represented in blue.

As can be observed, the head movement in the horizontal plane acts inconsistently from the duration the participants divert their gaze from the screen.

Specifically, some instances show steady, possibly relaxed, long-duration off-limits but short-displacement gaze aversions, as exemplified by the focus group cases of SS-BN. Conversely, there are cases where continuous minor movements (long displacement) occur while participants maintain their gaze on the screen (short duration), as evidenced in the focus group cases of SLN, PN and in the control group in PN and SS-MN. The remaining cases, such as the focus groups SS-MN and SS-AI and similarly for the control in SLN, SS-BN and SS-AI, exhibit expected behaviour with both duration and displacement demonstrating similar trends.

The behaviour under consideration can be comprehended by referring to the focus group in SLN, where participants are observed to maintain their gaze on the screen for the majority of the 15-minute session, with only a brief 10-second span spent looking away. Concurrently, the horizontal head movement approaches its maximum extent, which is anticipated considering the hyperactivity aspect of that population.

A slight decrease in head movement is recorded with the introduction of PN, whereas the duration spent looking away from the screen doubles to 20 seconds. Notably, this allows for the differentiation of concentration from movement, as significant improvement in *d'* and COM errors is observed in the focus group.

As the complexity of the sound content escalates with SS-MN, the duration spent off-screen doubles again to 40 seconds, although head movement reaches its minimum. This could be interpreted as a potential distraction triggered by the complex sound content. However, it could also indicate a form of relaxation brought about by the familiar soundscape, resulting in a calming effect on movement.

With the introduction of spatially presented soundscapes, complexity escalates, largely due to the 3D representation of the content. This leads participants to engage in more extensive exploration and familiarisation with the sonic environments, resulting in an increase in both head movement and instances of looking away from the scene.

The highest form of complexity is reached with the incorporation of dynamic auditory indicators, as found in the SS-AI sound condition. Here, a more pronounced version emerges, with both displacement and duration registering the highest values. This could possibly be attributed to participants being occupied with the task of interacting with the auditory cues, as previously discussed.

In discussing ADHD hyperactivity, Gawrilow et al. [352] refer to the theoretical *State Regulation Model*. In terms of hyperactivity, it is proposed that the levels are not consistently stable across various situations. Instead, they are hypothesized to increase significantly during low activation states, serving as a form of self-stimulation, and during high activation states, acting as a behavioural indication of overactivation. In line with this hypothesis, the SLN is suggested to induce an under-aroused state and the SS-AI a high activation state, both allegedly resulting in augmented head movement.

A general inference could be drawn suggesting that with increasing complexity, expressed in terms of sound content, 3D sound representation, or dynamic auditory cues, there emerges a need to understand and familiarise oneself with the intricate stimulus. This sense of 'wonder' might manifest as extended periods of exploration. Concurrently, the diminished head movement observed in the SS-MN might indicate that personalised soundscape content could instil a sense of calm and comfort.

7.9 Discussion - Personal Content Selection

Upon the completion of the soundscape selection game, the facilitator initiated a brief discussion with the participants regarding their choices. The observation was made that the majority of selections appeared to be grounded on elements such as feelings, memories, disturbances, and escapism. Soothing sounds, including the 'crackling of fire', 'gentle rainfall', 'wind rustling through leaves', and 'ocean waves', were favoured by a majority of the participants. These participants constructed their soundscapes predominantly around sentiments of "calmness," "relaxation," and "comfort & cosiness," or they selected sounds that they simply "liked," found "pleasant," or "go together, complement each other." Participants' comments are provided in Appendix D.

'Familiarity' was a discernible factor in several instances where participants justified their preference for specific sound content based on memories and experiences, such as "listening to the heavy raindrops on my home's window" or landscape conditions they found enjoyable, such as being "next to the river and the campfire with our caravan" or "on the ocean beach with my father by the campfire." A couple of participants described their soundscapes as an escape, referring to them as "sounds of nature, being away from the every day." The less popular sounds were often described as "too loud," "too fast," "annoying" or "overwhelming." Intriguingly, two participants from the focus group expressed a preference for "intense," "cool, loud, and noisy sounds", underlining the influence of personal preference or need.

7.10 Summary: Main Experiment

This chapter delves into a comprehensive analysis of two studies designed to investigate the impact of auditory stimuli on cognitive and behavioural responses in children with ADHD and TDC. It explores the influence of personalized soundscapes, spatialized audio representation, and dynamic auditory cues on attention, impulsivity, and hyperactivity.

In Study I, the effects of different sound conditions are compared, including pink noise (PN), personalized soundscapes in mono (SS-MN), and silence (SLN), on cognitive responses and behavioural outcomes. The findings revealed that PN positively influenced cognitive performance, particularly reducing COM errors and enhancing attention. SS-MN, on the other hand, showed nuanced improvements in cognitive metrics and controlled hyperactivity. The results supported the hypothesis that these auditory stimuli could positively impact cognitive and behavioural traits in children with ADHD.

Study II extends the investigation by introducing binaural 3^{rd} order Ambisonic rendering (SS-BN) and integrated auditory indicators (SS-AI) into the sound conditions. SS-BN exhibits positive effects on attention and impulsivity for both groups, notably reducing hand movement and indicating improved hyperactivity control in the ADHD group. However, SS-AI demonstrates nuanced effects, improving impulsivity control, but the increase in head movement suggests potentially acting as a distraction for children with ADHD.

The chapter also explores the relationship between the duration of head movement beyond predefined limits and auditory cues, highlighting the complexity of participant responses. It discusses the potential role of auditory cues as sensory alarm mechanisms and the need for further research to understand their impact fully.

Furthermore, the investigation into participants' personal content selection revealed that preferences were often driven by emotions, memories, and a desire for calmness and relaxation. It underscores the importance of considering individual preferences when designing auditory stimuli.

Overall, this chapter provides valuable insights into the multifaceted nature of cognitive and behavioural responses to auditory stimuli in children with ADHD and TDC. It underscores the importance of considering individual differences and content complexity when designing auditory interventions. These findings set the stage for a deeper understanding of how auditory stimuli can be harnessed to improve cognitive functioning and quality of life for individuals with ADHD.

8 Conclusions and Future Work

8.1 Conclusions

This research employed an interdisciplinary experimental approach, integrating elements from several scientific domains, including psychology, cognitive science, audio engineering, and neurodiversity research. Through a series of methodically designed experiments, the potential impacts of a variety of soundscape conditions, including mono noise, binaural noise, and auditory indicators on children with ADHD, were analysed. The central hypothesis, which was specified in Section 1.1 and forms the central motivation for the research presented in this thesis is as follows:

Personalised, immersive soundscapes therapy

will positively affect the cognitive and behavioural performance

of children with Attention Deficit Hyperactivity Disorder.

The investigations presented in this thesis confirm this primary hypothesis through significant evidence found in the studies conducted. Soundscapes, curated based on personal preferences and experiences of children with ADHD, were observed to have not only a positive cognitive impact, marked by reduced impulsivity, indicating an enhancement in inhibitory control, but also demonstrated behavioural improvements, especially in the form of decreased hand movements. This latter observation emphasizes the potential of sound as a behavioural regulator, signifying a notable advancement in ADHD research.

The introduction of binaural sound reproduction as a novel aspect of immersive soundscapes was a significant aspect of this study. It was associated with improved cognitive responses, as evidenced by better *d'* and COM error rates, and also with improved sensory-motor control, indicated by reduced hand movements. These findings suggest a potential role for binaural soundscapes in supporting cognitive and behavioural control in children with ADHD. However, mixed interactions revealed in the between-group comparison indicated an inverse association between improved error metrics (*d'*, COM, and OM errors) and declined HRT-related metrics (SD, CV, Preservation errors). According to Conner's analysis, the initial characteristic under consideration is the participant's *response style*, which embodies a trade-off between speed and accuracy. A *liberal* style prioritises speed over accuracy, while a *conservative* style values accuracy over speed [1]. The observed variations in HRT-related metrics, along with improvements in certain error metrics, might suggest a shift towards a more *conservative* response style in some participants, emphasizing accuracy over speed. This observation, while intriguing, is speculative and not directly tested in the study. This prompts questions about how individual response styles might collectively manifest in group settings and influence overall outcomes. Future research could delve into the complexities of how individual traits, such as response style, aggregate in group dynamics, particularly when interacting with auditory stimuli, and their impact on cognitive and behavioural outcomes.

When comparing binaural soundscapes with dual mono reproduction, a notable enhancement in attention and impulsivity for the control group is observed. However, its neutral impact on children with ADHD ensures that it is not considered a distractor. This emphasizes its potential as a viable audio rendering method in ADHD contexts, even if it doesn't necessarily enhance performance.

This research also provided noteworthy insights into the influence of pink noise on children with ADHD. Addressing inconsistent findings in existing literature, this study investigates further the effects of pink noise. It was demonstrated that pink noise could be a beneficial sonic stimulation for children with ADHD, primarily by reducing impulsivity.

The research findings support the primary hypothesis, suggesting that immersive soundscapes can have a positive impact on children with ADHD. However, the evidence also reveals certain variability in outcomes. Despite standardized procedures and controlled experimental conditions, efforts to minimize biases and uphold consistency, inherent variations in cultural context and socioeconomic factors across different countries might subtly influence the study's outcomes. For instance, Study II highlighted improvements in certain attention measures, notably the reduction of OM errors, while impulsivity metrics displayed diverse trends, including a decrease in COM errors alongside an increase in Preservation errors. Acknowledging these influencing factors, it's crucial to interpret the results with consideration for potential diversities arising from cultural contexts. These nuances may influence the broader applicability or generalizability of the findings across varied cultural settings.

The incorporation of auditory indicators within personalized soundscape content brings forth an exciting paradigm shift in addressing ADHD-related challenges. The observed decrease in COM errors indicates their potential in enhancing impulsivity control. Additionally, the reduction in hand movements suggests a role in behavioural regulation, particularly in managing hyperactivity. Interestingly, the auditory cues seemed to evoke an increase in head movement, suggesting the participants' effective response to the cues and potentially enhancing their attention. This apparent contradiction indicates that the dynamic auditory indicators, while contributing to impulsivity improvements, might also act as distractors, leading to possible attention deficits.

A key secondary finding was the variation in participants' head movement in response to soundscape complexity. Specifically, Mono personalised soundscapes (SS-MN) led to a balance between screen focus and minimal head movement, hinting at a calming effect due to familiarity and personal preference with the content. In contrast, more complex spatial soundscapes (SS-BM) prompted greater exploratory head movement while maintaining screen focus, indicating deeper engagement. This distinction highlights how soundscape complexity and personalization affect engagement and behaviour in children with ADHD.

The research also highlighted the value of personal content selection, revealing how this feature could enhance the individual's connection with the soundscape, a crucial factor in its efficacy. The selection of familiar sounds based on participants' preferences and memories may enhance the immersive quality of the soundscape, thereby enhancing its beneficial effects.

In the assessment of a spatial audio game, both the focus and control groups displayed comparable patterns, indicating that children with ADHD share similar spatial perception abilities with their TDC, without any noticeable tendencies or deficits. This pivotal evaluation not only provides insights into the spatial auditory perception of participants but also underscores the potential implications of immersive audio experiences.

While the primary focus of this research centred on children with ADHD, the interventions yielded notable benefits within the TDC group as well. Surprisingly, the personalized and immersive soundscapes, initially tailored for the ADHD population, resulted in significant cognitive enhancements among the TDC participants. Notably, while Mono personalized soundscapes (SS-MN) showed neutral effects on the TDC group, substantial cognitive improvements were evident with spatially presented soundscapes (SS-BN and SS-AI). These improvements encompassed enhanced *d'*, reduced COM and OM errors, and decreased head movement in SS-AI compared to Mono. These outcomes underscore the substantial impact and universality of personalized and immersive binaural auditory environments. The significant benefits observed in both ADHD and TDC groups not only validate the effectiveness and versatility of these soundscapes but also suggest their potential broader applications. The extended scope of these findings highlights the promise of these immersive soundscapes, indicating their potential usefulness not only in ADHD-specific scenarios but also in broader educational or therapeutic contexts.

In conclusion, this research has contributed to the growing body of literature on the therapeutic uses of sound in children with ADHD. It underscores the potential and promise of personalised, immersive soundscapes and binaural reproduction in improving the cognitive performance of children with ADHD. The mixed results, while presenting a challenge, also highlight avenues for further research and nuanced understanding. These findings open a new door to employing soundscapes as a potential tool to aid children with ADHD, emphasising the importance of individualising interventions to harness the full benefit of these techniques.

8.2 Limitations

While this work provides significant contributions to our understanding of the effects of personalised, immersive soundscapes on children with ADHD, it is not without limitations that future research may address.

Sample Size: The number of participants in this study, particularly in the control groups, was relatively small. A larger sample size would provide a more robust test of the hypotheses and allow for a more diverse representation of children with ADHD.

Individual Differences: This study relied heavily on the personalisation of soundscapes. While this is one of the study's strengths, it also introduces individual differences as a potential confounding factor. Future research might want to explore standardised measures to control for the effects of individual differences.

Population Consistency: The studies were conducted in different environments (UK and Greece) with differences in recruitment. These might have introduced biases in the experiment despite efforts made to minimize them. Future research could focus on maintaining consistency across all aspects of the experiment.

Silence Condition: This study employed a sequential approach to present the sound conditions, starting with silence as a baseline and then introducing the other sound conditions in a random order. This choice was driven by the desire to measure the participants' cognitive and behavioural state in their 'natural' condition before exposure to any auditory stimuli. Furthermore, it allowed participants to first focus on the visual component of the game, ensuring a consistent starting point for all subjects. However, it is essential to acknowledge that this sequential introduction of silence as a baseline may have introduced certain limitations to the experimental design. The absence of counterbalanced randomization for the initial silence condition implies that order effects, practice effects, or participant fatigue could have influenced the subsequent comparisons between silence and the other sound conditions. Participants might have become more experienced with the game or more accustomed to the experimental process over time. These factors should be considered when interpreting the study's outcomes. Future studies could explore alternative randomization methods or counterbalancing to address these limitations.

Lack of Longitudinal Data: This study provides a snapshot of the effects of personalised, immersive soundscapes on the cognitive and behavioural performance of children with ADHD. However, it does not offer insights into the long-term effects of this intervention. A longitudinal study could provide information on whether the observed effects persist over time.

While these limitations must be acknowledged, they do not detract from the study's significance but instead point towards directions for future research. The research journey that this thesis has embarked upon opens new horizons in understanding the therapeutic possibilities of sound in managing ADHD symptoms, setting the stage for exciting future research in this arena.

8.3 Future Work

1. Advancing Personalized Therapeutic Soundscapes

Future work should aim to further refine the personalization aspect of Therapeutic Immersive Soundscapes. Incorporating psychophysiological data of individuals can provide crucial inputs to craft soundscapes more effectively. For instance, physiological markers like heart rate or skin conductance levels could offer valuable insights into the participant's state of arousal or stress, which could be used to calibrate the soundscape accordingly. A wider variety of sound content should be provided for participants, enabling them to express themselves and construct a preferred soundscape. Combining naturalistic sounds with abstract, synthesized elements could offer an enhanced auditory experience. This intersection could potentially lead to varied impacts on cognitive and behavioural performance, worth exploring in depth.

2. Expanding Immersion in Therapeutic Soundscapes

To further augment the immersion in Therapeutic Soundscapes, future research could also delve into furthering our understanding of immersive soundscapes. This could involve investigating the effects of spatial sonic movement and source distance on the individual's cognitive and behavioural responses. For instance, do sounds that appear to move around the listener have a different effect than sounds that are static? Does the perceived distance of the sound source have an impact on the listener's level of immersion or focus? These questions may also provide elements for personalised scenarios in building spatial auditory environments. Additionally, it might be beneficial to incorporate the use of virtual acoustics to create more realistic, immersive soundscapes.

3. Pioneering Interactive Therapeutic Soundscapes

A promising avenue for future research is the development of interactive soundscapes. These soundscapes, driven by real-time psychophysiological data, can dynamically adapt to the individual's current state, making the therapeutic experience more effective and personalized. Various sensor technologies, including bio-sensors and cameras, can be employed to continuously monitor these responses. Notably, the incorporation of an AI observer can further transform these soundscapes. This intelligent agent, continuously monitoring the participant's responses, can adjust the soundscape in real time. With the capacity to take into account the participant's past interactions and any therapist guidelines, this AI observer could contribute to creating a highly personalized, adaptive therapeutic soundscape, offering an exciting new horizon in cognitive and behavioural support for individuals with ADHD.

8.4 Final Remarks

The core motivation of this thesis has been to study the unexplored potential of personalized immersive soundscapes as a therapeutic intervention for children with ADHD. This journey was initiated with the belief that by marrying the emerging technologies of spatial sound with the complexities of cognitive neuroscience, could contribute to creating more effective, engaging, and individualized support for those navigating the challenges of ADHD.

The findings of this thesis have shed light on the significant influence of personalized and immersive soundscapes on the cognitive and behavioural performance of children with ADHD. These carefully tailored soundscapes can offer meaningful improvements in attention and impulsivity control, partially confirming the initial hypothesis and lending weight to the promising role of auditory interventions for ADHD.

Unveiling the diverse impacts of different sound elements, this research emphasized the critical role of personalisation, immersion, and interactivity. These insights contribute to the development of Therapeutic Immersive Soundscapes, closely linked to the ongoing technological evolution and our expanding comprehension of human cognition's response to sound.

Looking forward, the promising results from this thesis offer intriguing implications, with potential applications extending beyond the realm of research. Personalized immersive soundscapes could find a place in various practical contexts. From educational environments to therapeutic settings, these soundscapes could play a pivotal role in fostering learning and development. This approach stands to offer advantages not only to individuals with ADHD but also to a broader spectrum of individuals with diverse cognitive needs.

With a sense of measured optimism and anticipation, gazing into the future of this research area through the interplay of sound, space, and cognition. The field of therapeutic sound interventions is vast, intricate and largely uncharted. By persistently pursuing exploration, innovation, and refinement, we are drawn nearer to future designs in which the synergy of technology and neuroscience might provide more bespoke and efficacious therapeutic support, thus aiding in the improvement of the lives of individuals with ADHD.

Appendices

A

Scoping Review: Additional Material

A.1 Sound Contribution Categories: Detailed Tables

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[259]	Self-Regulate anxiety and stress	Auditory-Display	Sound variation relative to respiration.
[202]	self-awareness control-relax oneself	Speech	Guided imagery experience Relaxing narrative.
[285]	Bring attention into the present moment	Auditory-Feedback	Sound response to the movement of the figure.
		Soundscape	Ocean waves and bird songs tuned around one chord.
[260]	High level of awareness and concentration	Auditory-Display	Agent responds sonically (inhale-exhale) at the same pace as the participant.
		Music Stim.	Calm music.
		Speech	Meditation instruction
[193]	Focus users attention to their breathing	Auditory-Display	Respiration data guides audio generation breathing patterns (eventfulness).
[194]	Control breathing, rhythmic behavior, enhancing calm-focus	Auditory-Display	Represent humans breathing sounds.
[198]	Reflects emotional state	Auditory-Display	Responsive audio to users bio metrics.
[203]	Eliciting breath awareness	Soundscape	Urban and forest sonic environments.

Table A.1: Sound contribution category "Body and Mind", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics.
Stim.: Stimulus

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[223]	Emotional Stimulation	Soundscape	Virtual rooms: a waiting room and natural env.
		Sp. Audio	5.1 surround sound system.
[262]	Affect emotional state	Sound Stim.	Sounds from IADS database related to anger, fear, joy etc.
[248]	Relaxation	Soundscape	Nature sounds (waves/wind).
[171]	Create emotional connection	Sound Stim.	Audio feedback associated to movement.
[175]	Increase positive affect	Soundscape	Underwater sonic environment.
[188]	Relaxation: lack of fear response	Soundscape	Natural environment: forest or beach.
[263]	Mind relaxation	Music Stim.	Relaxing background music.
		Speech	Audio narration: breathing control.
[195]	Change in vitality and mood	Soundscape	Forest ambient sounds.
[196]	Relax-Refresh	Music Stim.	Relaxing or louder music during refreshment stage˙
[221]	Relaxation	Music Stim.	Soft music
[228]	Relaxation-Engagement	Speech	Narration by the therapist.
		Music Stim.	Ambient music, relaxing sounds.
		Soundscape	Brain activity controls ambient sounds.
[199]	Elicit awe	Music Stim.	Instrumental musical score.
		Sp. Audio	Binaural sound over H/P.
[95]	Relaxation	Music Stim.	Calm Ambient music.
[179]	Provoke emotions	Sound Stim.	Crying and moaning.
[200]	Relaxation	Soundscape	Underwater sounds.
[185]	Craving induced by paraphernalia, smoking env. cues	Soundscape	Sound of a drug use scene. Natural environment.
[177]	Cue induced craving	Soundscape	Voices to lure/invite participants to drug use.

Table A.2: Sound contribution category "Emotions", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics. Stim.: Stimulus, Sp. Audio: Spatial Audio

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[235]	Enhance interest motivation	Music Stim.	Musical Sequence
[102]	Increase motivation to exercises	Soundscape	Interactive soundscape natural env.
[248]	Positive reinforcement, morale boosters	Sound Stim.	Auditory rewards: applause, cheering.
[256]	Motivation to exercise	Auditory-Display	Sonified stepping actions.
[250]	Improve motivation	Auditory-Feedback	responsive sounds to hand positioning.
[249]	Increase motivation	Auditory-Feedback	Respond to target achieved.
[201]	Encourage exercise and motivation	Sound Stim.	Respond to target achieved.
		Music Stim.	Background music/songs.

Table A.3: Sound contribution category "Encouragement and Motivation", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics. Stim.: Stimulus

Citation	Sound Assisting	Sound Components	Sound Component Details
[192]	Cue exposure - smoke craving	Soundscape	Nature sounds; party scene cues such as cigarettes and lighters, interacting smokers.
[242]	Control amount of difficulty/anxiety	Soundscape	Destructive noises as phone rings, talking, keys.
[183]	Influencing emotional state	Sound Stim.	Sounds from IADS.
[176]	Feer of heights: improve tolerance	Speech	Virtual coach asking questions and setting tasks with increasing difficulty.
[184]	Control level of difficulty-content	Speech	Semi-structured dialogues controlled by the therapist.
[188]	Control level of difficulty	Sound Stim.	Destructive sounds, noise level, people speaking phone ringing.
[207]	Control exposure by the therapists	Speech	Semi-scripted dialogues with virtual humans.
[190]	Improve tolerance to phobia/trauma	Sound Stim.	Sound exposure controlled by the therapist: sound of fire.

Table A.4: Sound contribution category "Exposure", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[102]	Improve users attention on events	Soundscape	Interactive Soundscape: natural environment.
[248]	Improve Focusing	Auditory-Feedback	Responsive musical drum game.
[191]	Distraction intervention	Music Stim.	Music Therapy: Relaxing music.
		Soundscape	Natural sounds.
[186]	Stimulate curiosity, capture attention	Music Stim.	Neutral music to avoid personal memories.
		Speech	Story narration, excite imagination-memory.
[197]	Focus on task. Remove worries-distractions.	Auditory-Feedback	Dynamically create music from body movement.
[260]	Improve awareness, concentration.	Music Stim.	Calming background music.
		Speech	Meditation Instructions.
[180]	Remove cognitive distraction.	Music Stim.	Background music
[91]	Sustain attention	Music Stim.	Classical piano music.
		Spatial Audio	Binaural audio delivered over headphones.
[246]	Draw user's attention	Auditory-Feedback	Use audio ques.
[97]	Improve focus	Soundscape2	Natural sound env.

Table A.5: Sound contribution category "Focus-Concentration", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[102]	Improve presence	Soundscape	Natural envs: forest, lake, etc.
[167]	Promote natural communication	Sp. Audio	Binaural 3rd orderAmbs audio delivered over headphones
[196]	Increase immers.	Auditory-Feedback	Sound changes along with movements
		Soundscape	Natural sounds change to motion pictures.
[240]	Increase immers.	Sp. Audio	8 Speakers system.
	Engaging user experience	Soundscape	Creation of immersive therapeutic soundscape.
[251]	Feel immersed	Soundscape	City noises: cars, people, etc.
[241]	Improve immersion	Auditory-Feedback	Providing the user with visual, auditory and haptic feedback.
[180]	Enhance presence	Auditory-Feedback	Video game sounds like shooting, splashing.
[185]	Improve immersion	Sp. Audio	Binaural audio over headphones.
[206]	Escapism	Sound Stim.	Snowy sleigh ride elicited soft-gentle sounds.
		Music Stim.	Christmas scenery and music.
[178]	Increase realism	Soundscape	Ambient realistic and event sounds.
		Sp. Audio	Spatial audio over headphones.
[177]	Improve immersion	Sp. Audio	Binaural audio over headphones.
[181]	Enhance presence	Auditory-Feedback	Game sounds.
[243]	Immersive user experience	Auditory-Display	Biofeedback data modulate sound synthesis procedures.
		Soundscape	Dynamic various nature sounds.
[200]	Support immersion	Soundscape	Underwater sounds.

Table A.6: Sound contribution category "Immersion", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics. Stim.: Stimulus, Sp. Audio: Spatial Audio

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[156]	Perform exercise.	Speech	Audio guide, instructions.
[256]	Audio guide	Speech	Audio instructions
[176]	Virtual coach	Speech	Virtual coach gives info and guidance for fear of heights.
[264]	Inform	Speech	Information on location, navigation, tasks.
[261]	Spatial info	Soundscape	Sound sources added to help VIP participants detect space around them.
		Sp. Audio	Binaural audio over headphones.

Table A.7: Sound contribution category "Informative", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[248]	Improve auditory memory	Sound Stim.	Corresponding sound to image.
[220]	Stimulate memories	Music Stim.	Personalized music content.
[91]	Sustain sort memory	Soundscape	Natural sound environments.
[258]	Symbolic representations	Music Stim.	Music from the time of personal deployment or traumatic events.

Table A.8: Sound contribution category "Memory", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics

Citation	Sound Assisting Characteristics	Sound Components	Sound Component Details
[167]	Promote natural communication	Soundscape	Distinguish between sound sources; effect of background sound level in locating virtual sound characters.
[170]	Promote social communication skills	Speech	Storytelling
[169]	Improve social communication skills	Speech	Narration of personal stories.
[166]	Encourage social interaction	Sound Stim.	Create sonorous attractive-creative stimulus.
[254]	Virtual community	Music stim.	Music therapy room; a bi-directional activity.

Table A.9: Sound contribution category "Social Skills", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics. Stim.: Stimulus

Table A.10: Sound contribution category "Interactivity", presenting the required Sound Assisting Characteristics and the Sound Components implementing these characteristics

Citation	Sound Assisting Characteristics	Sound Component	Sound Component Details
[223]	Emotional stimulation	Soundscape	Interactive Soundscape: dynamic natural env.
[102]	Increase motivation for exercise	Soundscape	Interactive Soundscape: 4 natural sciences.
[248]	Relaxation	Soundscape	Interactive Soundscape affecting natural envs.
[189]	Maintain active engagement.	Soundscape	Alternating soundscapes to reduce auditory repetition.
	Warning, possitive reinforcement	Auditory-Display	
[242]	Control amount of difficulty/anxiety	Soundscape	Interactive Soundscape with dynamic sound sources.
[256]	Navigate through control menus	Auditory Feedback	Audio messages according to button selection.
[253]	Provide info and guide the process	Auditory Display	Real time feedback on numerous movement parameters: reach trajectory, hand velocity.
[257]	Engagement-Involvement	Sound Stim.	Sounds range from unpleasant pain sensation to pleasant and quiet env.
[167]	Promote natural communication	Soundscape	Moving sound objects spatially, virtual sound characters.
[188]	Relaxation	Soundscape	Natural env. forest or beach.
[263]	Media immersion	Auditory Feedback	Audio feedback controlling sound effects
[250]	Sustain engagement	Auditory Display	Sound reappears to correct hand positioning.
[196]	Increase immersion	Soundscape.	Interactive Soundscape: sound changes along with movement.
[240]	Increase interactivity, engagment	Auditory Display	Transform external parameters into musical relevant event.
	Establish a sense of agent	Soundscape	Dynamic Soundscape: sounds emitted by the child (vocalisation, clapping).
		Sound Stim.	Responsive abstract sounds.

Citation	Sound Assisting Characteristics	Sound Component	Sound Component Details
[251]	Support immersion	Soundscape	Interactive city sounds.
[228]	Relaxation	Soundscape	Dynamically ambient sounds.
[95]	Enhance engagement	Auditory Feedback	Video Game sounds.
[247]	Divert attention by engagement	Sound Stim.	Auditory Stimuli supporting visual content.
[249]	Quality of performance	Auditory Feedback	Sound displays position and quality of movement.
[238]	Cognitive stimulation	Auditory Feedback	Response: plays notes.
[252]	Interact with virtual objects	Auditory Feedback	Audio feedback is acquired in the task.
[255]	Support post stroke to improve gait	Auditory Feedback	Sound effects when targets appear, disappear or hit.
[178]	Enhance engagement	Auditory Feedback	Relative to the hand actions of the participant.
[233]	Enhance inter/tion	Sound Stim.	Responsive Animal sounds.
[243]	Improve immersive, engaging experience	Soundscape	Effecting audio parameters like volume, frequency, or reverb affecting nature sounds.
[97]	Improve focus, recover from stress	Soundscape	Change natural environmental by physiological response and working activities.
[156]	Positive feedback		Speed indication without the patient looking at the screen.
[236]	Provide guidance	Auditory Display	Pitch and rhythm distortion, indicating erroneous decisions.
[237]	Provide guidance	Auditory Display	Sound guidance relative to correct hand movement path.
[227]	Increase arousal	Auditory Feedback	When hitting the target.
[182]	Improve immersion, isolation	Soundscape	Peaceful setting with audio features and sounds from nature.
[175]	Provide distraction	Auditory Feedback	Responsive game sounds.
		Soundscape	Interactive underwater env.

A.2 Bidirectional Table: Therapeutic Tasks - Sound Contribution

Table A.11: Bidirectional data arrangement connecting the Therapeutic Tasks with the Sound Contribution requirements and the Sound Components that implement these contributions. Abbreviations: **Au.Dsp**: Auditory Display, **Au.Fdb**: Auditory Feedback, **Mu.Stm**: Music Stimulus, **S.Stm**: Sound Stimulus, **Sp.Au**: Spatial Audio, **Spch**: Speech, **SS**: Soundscape

Therapeutic Task	Sound Contribution	Sound Components
Anxiety/Stress	Body&Mind, Emotions, Exposure, Immersion	Au.Dsp. - Spch. - Mu.Stm. - SS. - Sp.Au.- S.Stm. - Au.Fdb
Autism (ASD)	Interactivity, Social Skills	S.Stm. - Au.Dsp. - M.Stm. - Sp.Au. - Spch.
Concentration/ Focus/ Attention	Body&Mind, Encouragement, Focus, Interactivity	Au.Fdb. - SS. - Au.Dsp. - S.Stm
Cybersickness	Emotions, Immersion	Au.Fdb. - S.Stm. - Spch
Drug Dependences	Emotions, Exposure	SS.
Elicit Awe	Emotions	M.Stm. - Sp.Au.
Experiencing Flow	Focus	Au.Fdb.
Memory-Cognitive Rehab.	Focus, Immersion, Memory, Interaction	M.Stm. - S.Stm. - SS. - Spch.
Mindfulness	Body & Mind, Emotions, Focus	Au.Dsp. - M.Stm. - S.Stm. - Spch.
Mood Repair	Body &Mind, Emotions, Immersion, Interaction	Au.Dsp. - Au.Fdb. - M.Stm. - SS.
Pain Reduction	Emotions, Focus, Immersion, Interaction	M.Stm. - S.Stm. - Au.Fdb. - SS.
Dementia (PwD)	Emotions, Focus Encouragement, Interactivity, Memory	M.Stm. - S.Stm. - Au.Fdb. - Au.Dsp. - SS.
Phobias	Emotions, Exposure, Immersion	S.Stm. - M.Stm. - Spch. -.SS

Therapeutic Task	Sound Contribution	Sound Components
Physical Rehab.	Emotions, Informative Encouragement, Focus, Interactivity	M.Stm. - S.Stm. - Au.Fdb. - Au.Dsp. - Spch. - SS.
Post Traumatic-PTSD	Exposure, Memory	M.Stm. - S.Stm.
Visually Impaired People-VIP	Informative	Sp.Au. - Spch. - SS.

A.3 Supplementary Material

Supplementary material associated with this Scoping Review can be found in the online version and at: https://sites.google.com/view/tie-scoping-review/home

B Behavioural Characteristics: Hand & Head Movement Response Graphs

B.1 Hand Movement

The following graphs depict the displacement of hand movement over time in relation to all sound conditions. To facilitate comparison, the graphs displaying the responses of the control and focus groups are presented side by side.

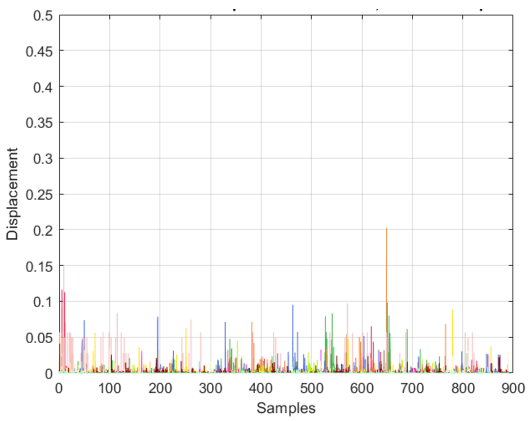


Figure B.1: Hand movement displacement of the control group responses in Silence condition.

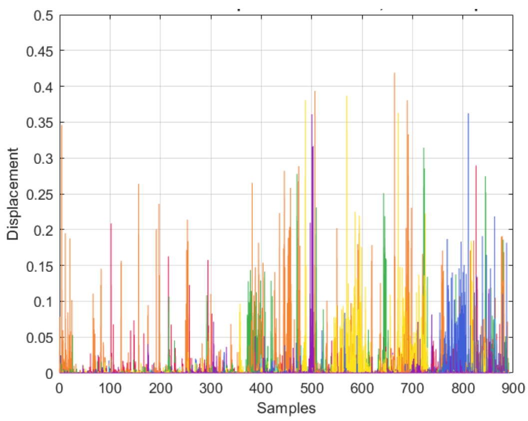


Figure B.2: Hand movement displacement of the focus group responses in Silence condition.

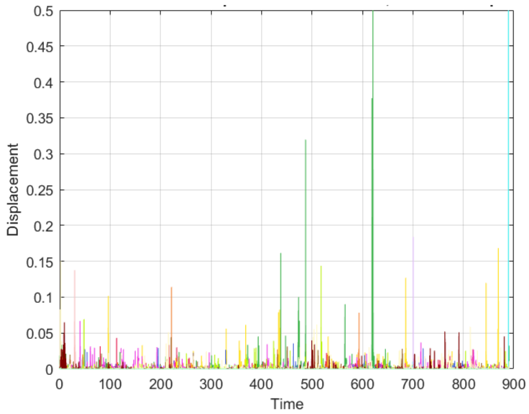


Figure B.3: Hand movement displacement of the control group responses in Pink Noise condition.

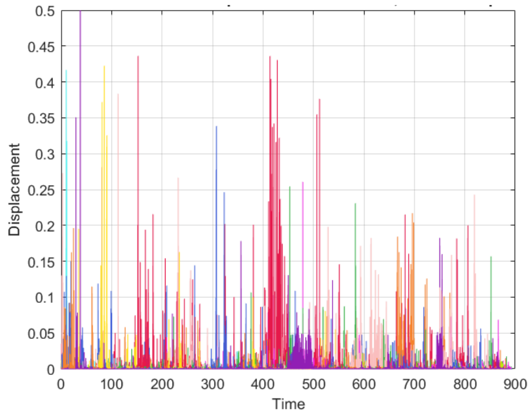


Figure B.4: Hand movement displacement of the focus group responses in Pink Noise condition.

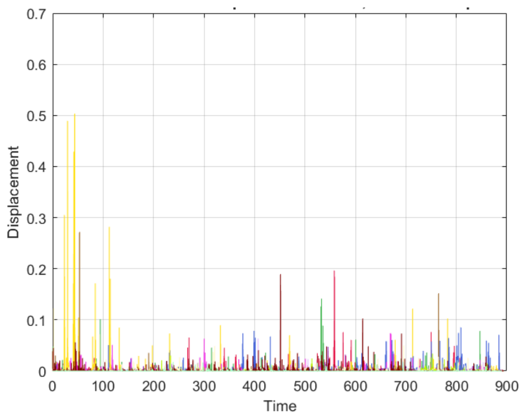


Figure B.5: Hand movement displacement of the control group responses in Dual Mono condition.

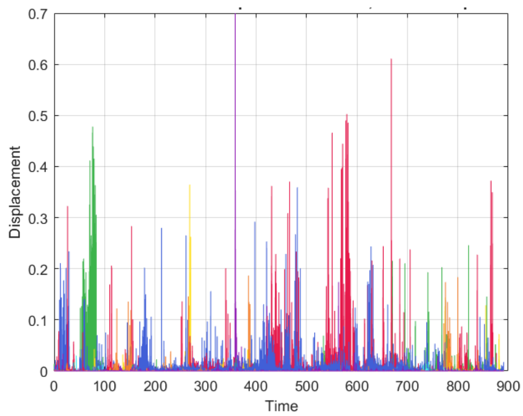


Figure B.6: Hand movement displacement of the focus group responses in Dual Mono condition.

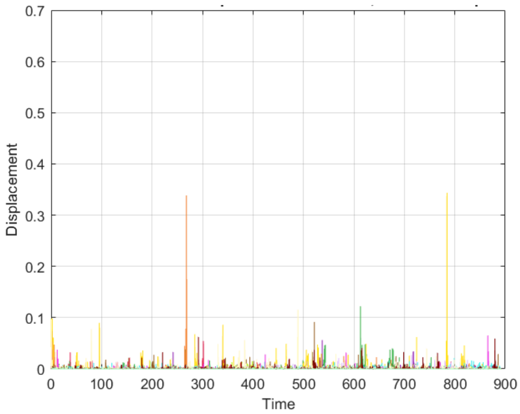


Figure B.7: Hand movement displacement of the control group responses in Binaural condition.

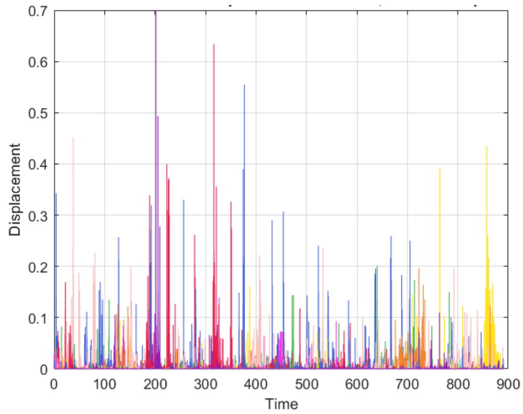


Figure B.8: Hand movement displacement of the focus group responses in Binaural condition.

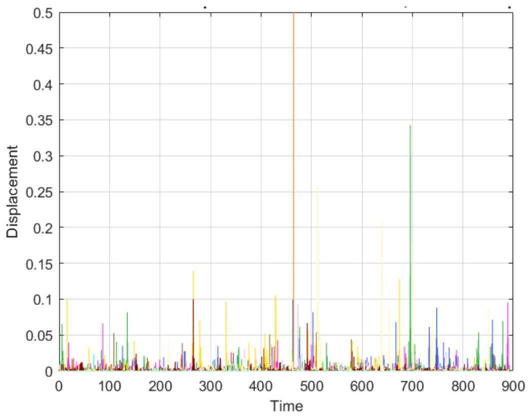


Figure B.9: Hand movement displacement of the control group responses in Audio Indicators condition.

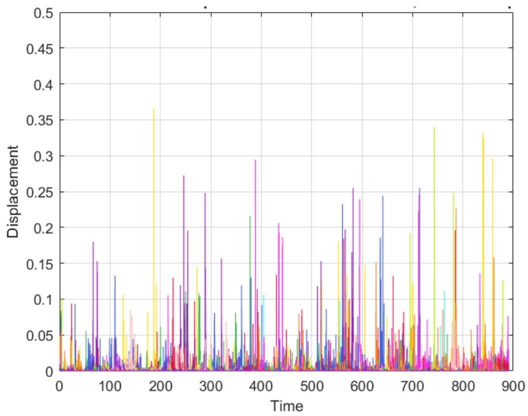


Figure B.10: Hand movement displacement of the focus group responses in Audio Indicators condition.

B.2 Total Head Movement

The graphs showcased in this section illustrate the participants' response movements in *yaw, pitch,* and *roll* across all sound conditions, measured in degrees over time. These responses capture the angle at which the participants' heads deviate from the origin, calibrated at the centre of the screen. The graphs are presented in pairs, grouping the control and focus groups together, enabling easy comparison. Additionally, the cumulative *total-head-movement* over time is displayed, representing the sum of the displacement in movement.

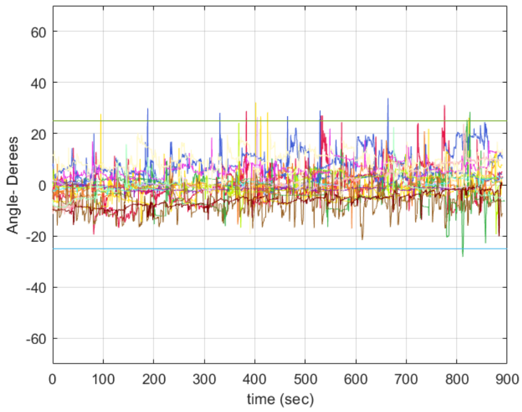


Figure B.11: Head movement: Yaw, of the control group responses in Silence condition.

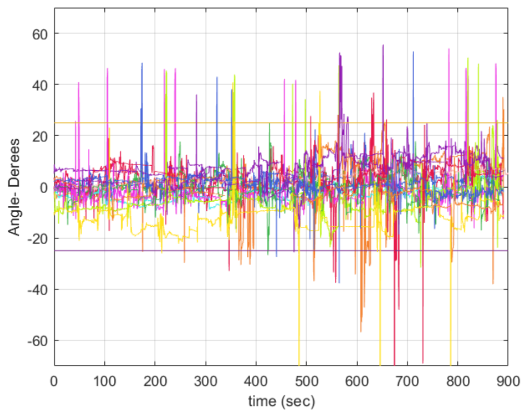


Figure B.12: Head movement: Yaw, of the focus group responses in Silence condition.

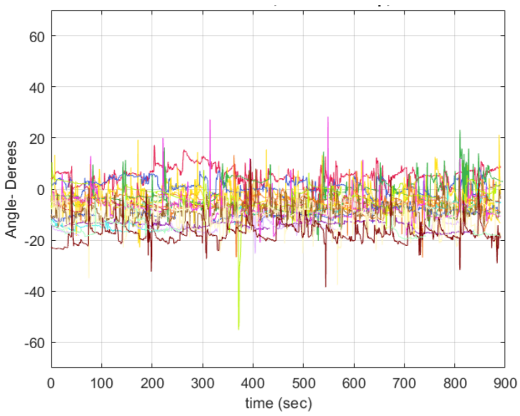


Figure B.13: Head movement: Pitch, of the control group responses in Silence condition.

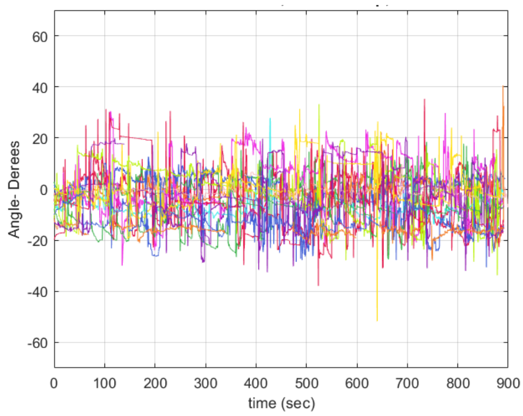


Figure B.14: Head movement: Pitch, of the focus group responses in Silence condition.

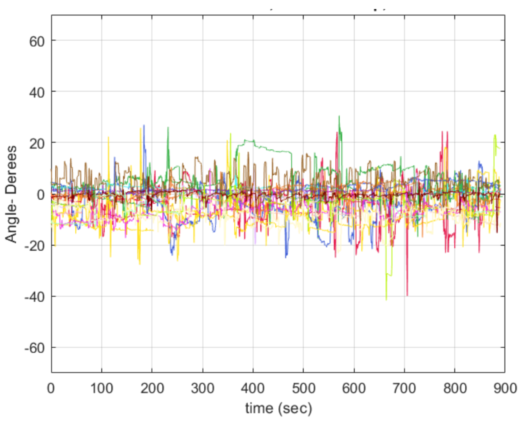


Figure B.15: Head movement: Roll, of the control group responses in Silence condition.

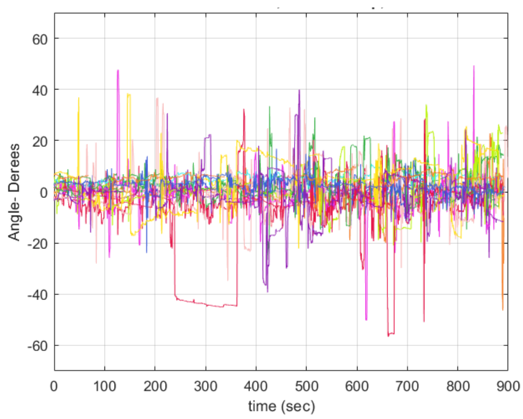


Figure B.16: Head movement: Roll, of the focus group responses in Silence condition.

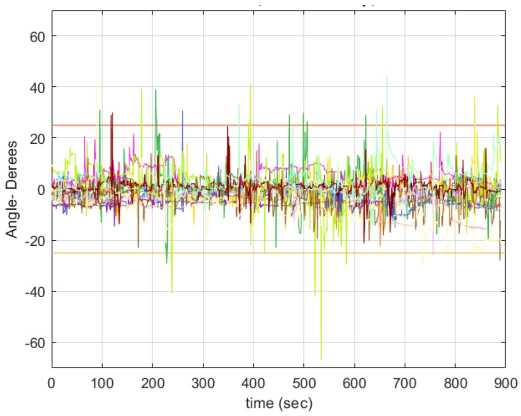


Figure B.17: Head movement: Yaw, of the control group responses in Pink Noise condition.

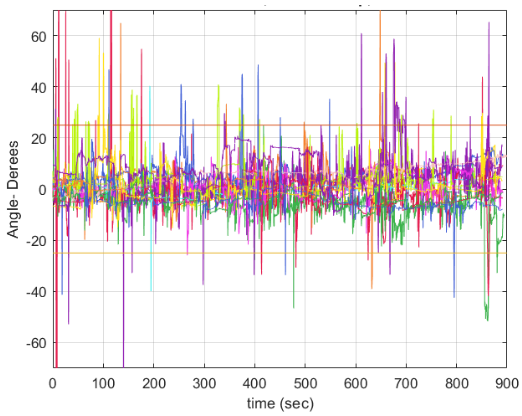


Figure B.18: Head movement: Yaw, of the focus group responses in Pink Noise condition.

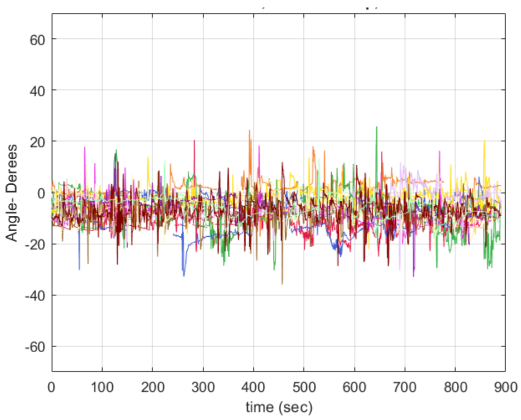


Figure B.19: Head movement: Pitch, of the control group responses in Pink Noise condition.

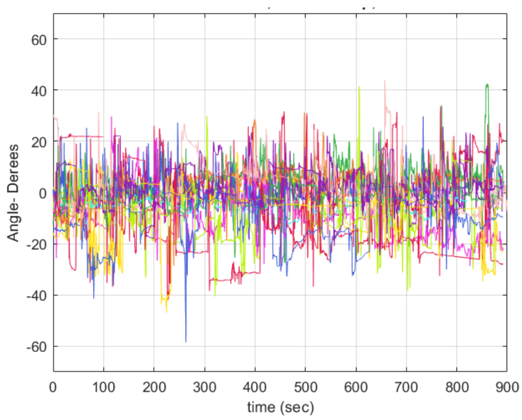


Figure B.20: Head movement: Pitch, of the focus group responses in Pink Noise condition.

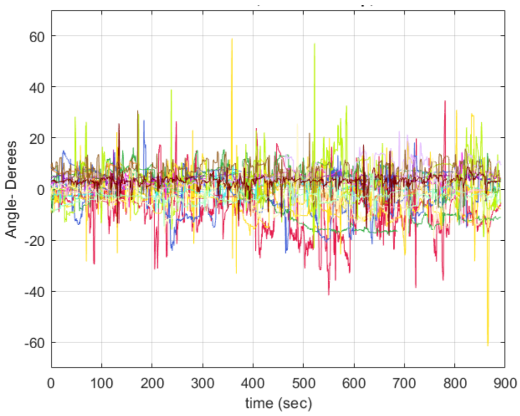


Figure B.21: Head movement: Roll, of the control group responses in Pink Noise condition.

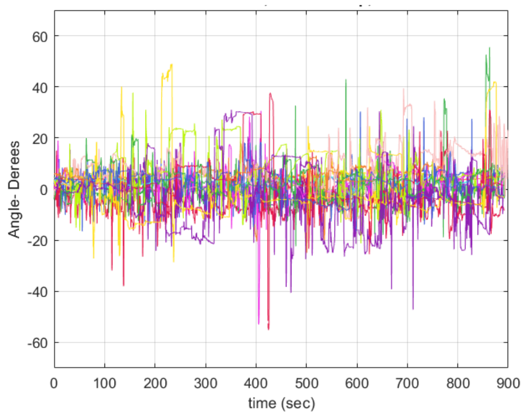


Figure B.22: Head movement: Roll, of the focus group responses in Pink Noise condition.

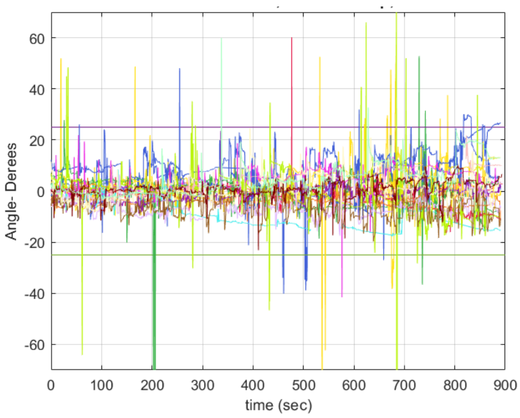


Figure B.23: Head movement: Yaw, of the control group responses in Dual Mono condition.

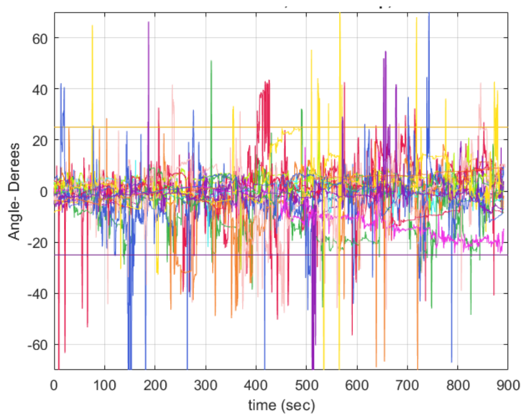


Figure B.24: Head movement: Yaw, of the focus group responses in Dual Mono condition.

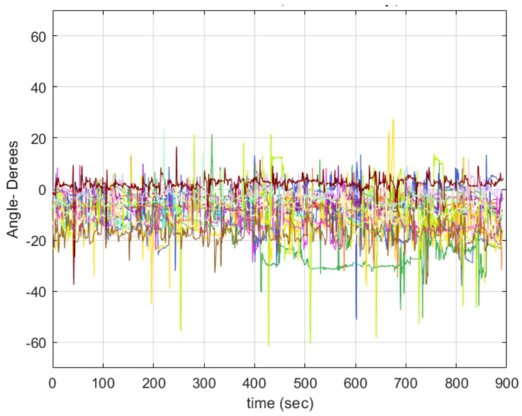


Figure B.25: Head movement: Pitch, of the control group responses in Dual Mono condition.

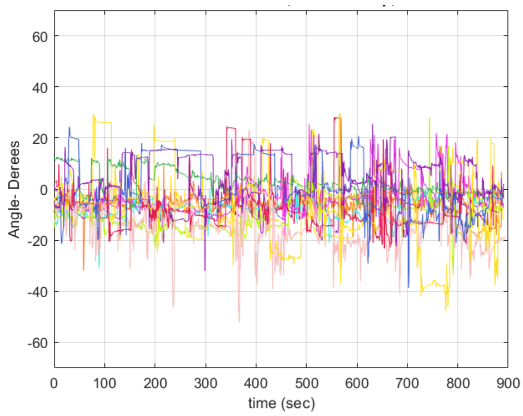


Figure B.26: Head movement: Pitch, of the focus group responses in Dual Mono condition.

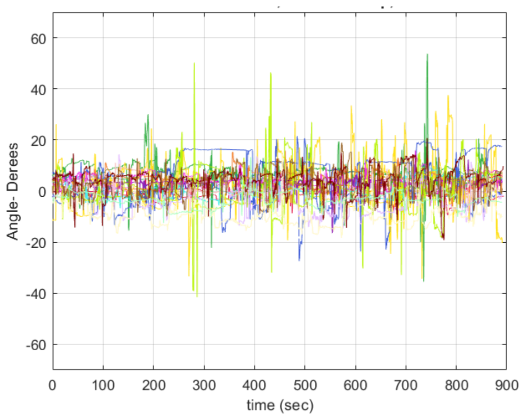


Figure B.27: Head movement: Roll, of the control group responses in Dual Mono condition.

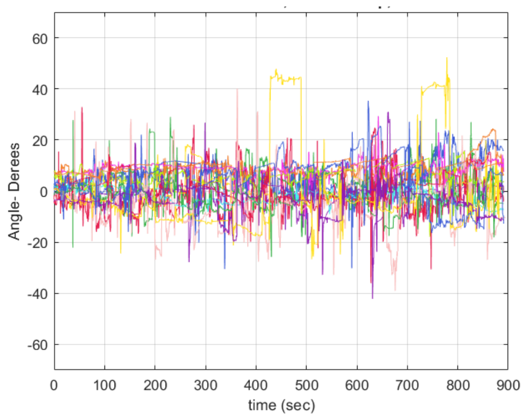


Figure B.28: Head movement: Roll, of the focus group responses in Dual Mono condition.

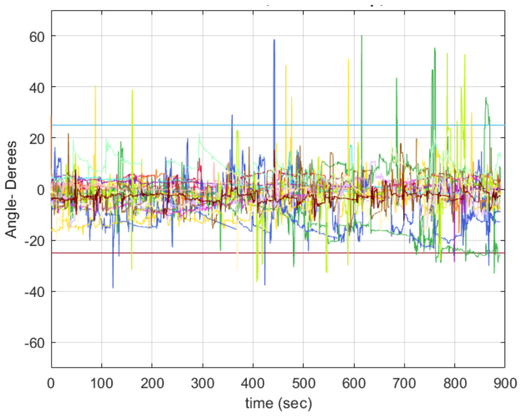


Figure B.29: Head movement: Yaw, of the control group responses in Binaural condition.

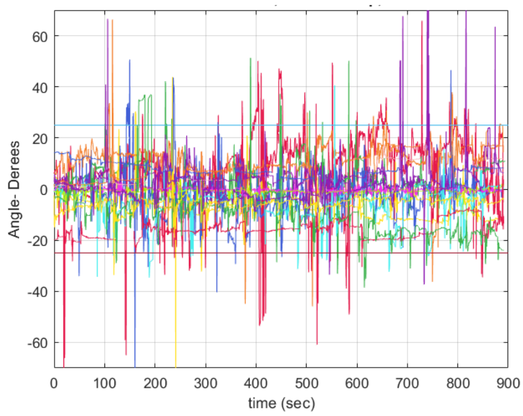


Figure B.30: Head movement: Yaw, of the focus group responses in Binaural condition.

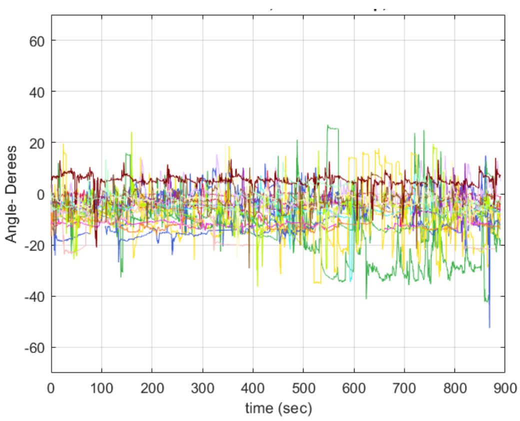


Figure B.31: Head movement: Pitch, of the control group responses in Binaural condition.

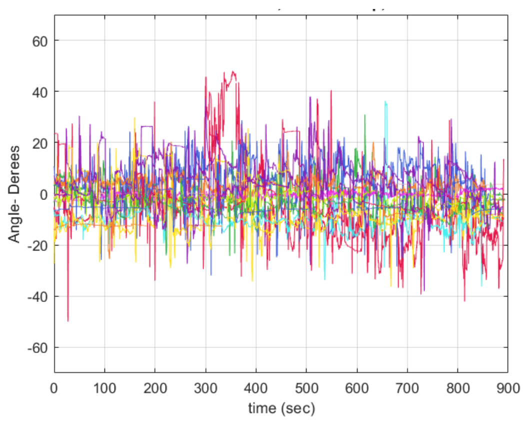


Figure B.32: Head movement: Pitch, of the focus group responses in Binaural condition.

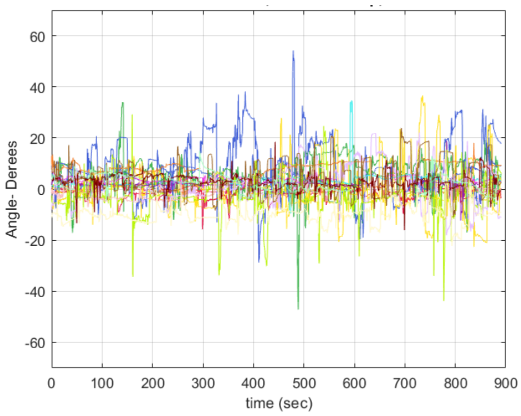


Figure B.33: Head movement: Roll, of the control group responses in Binaural condition.

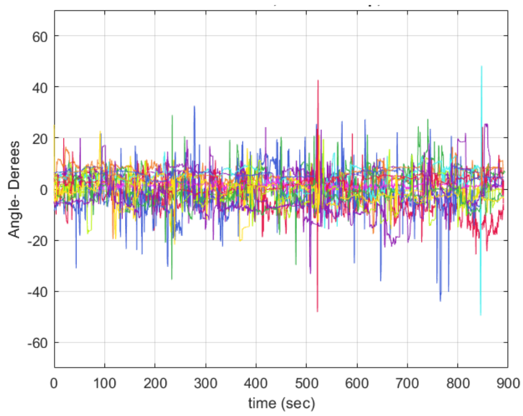


Figure B.34: Head movement: Roll, of the focus group responses in Binaural condition.

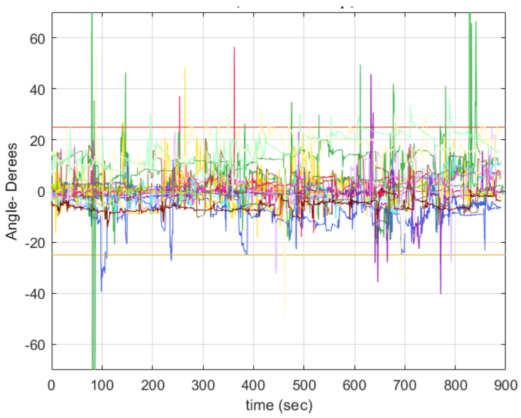


Figure B.35: Head movement: Yaw, of the control group responses in Audio Indicators condition.

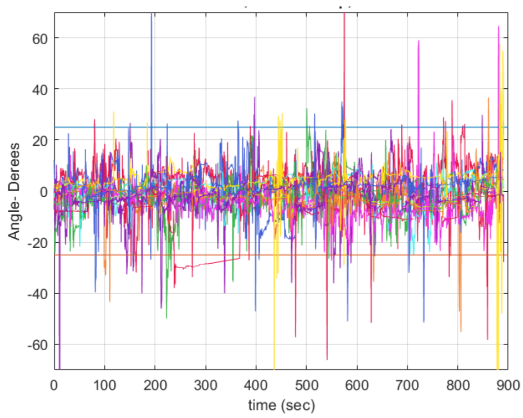


Figure B.36: Head movement: Yaw, of the focus group responses in Audio Indicators condition.

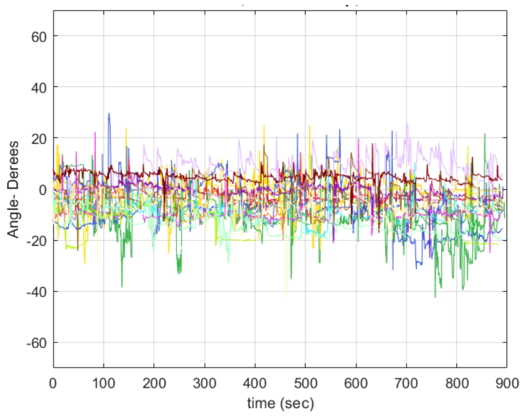


Figure B.37: Head movement: Pitch, of the control group responses in Audio Indicators condition.

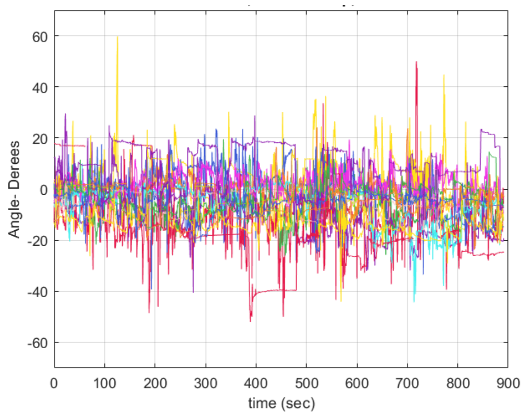


Figure B.38: Head movement: Pitch, of the focus group responses in Audio Indicators condition.

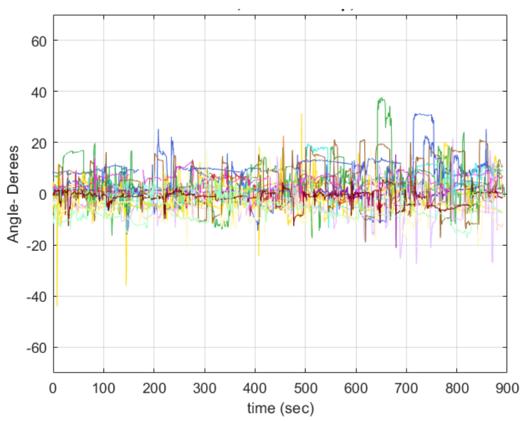


Figure B.39: Head movement: Roll, of the control group responses in Audio Indicators condition.

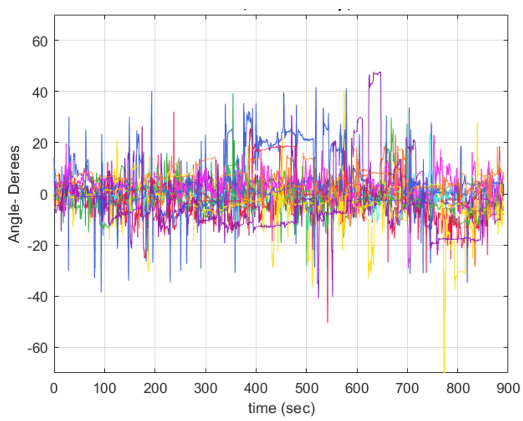


Figure B.40: Head movement: Roll, of the focus group responses in Audio Indicators condition.

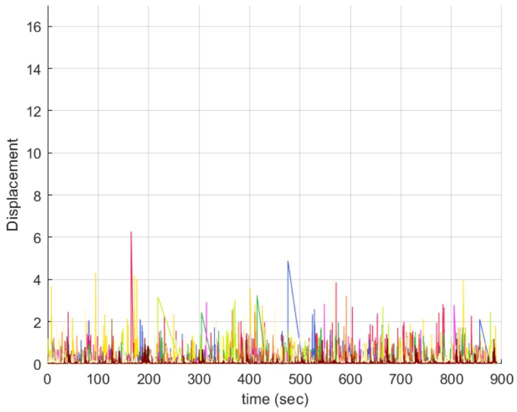


Figure B.41: Total-Head-Movement of the control group responses in Silence condition.

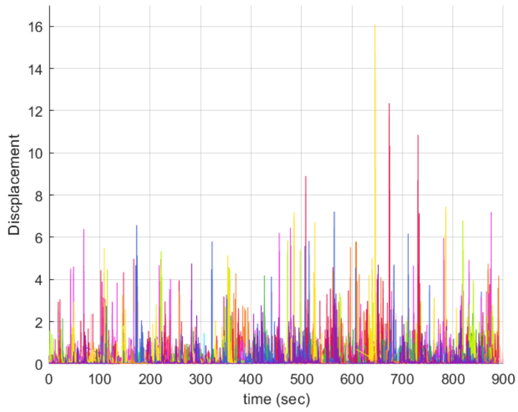


Figure B.42: Total-Head-Movement of the focus group responses in Silence condition.

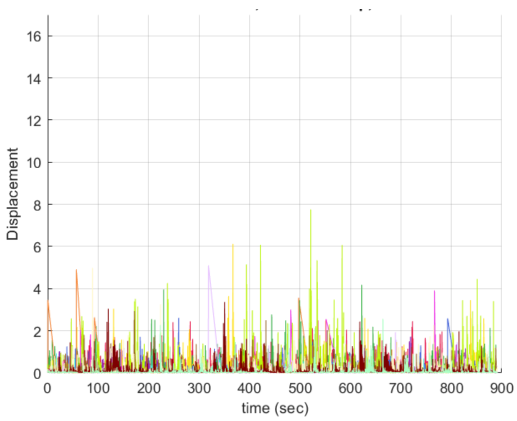


Figure B.43: Total-Head-Movement of the control group responses in Pink Noise condition.

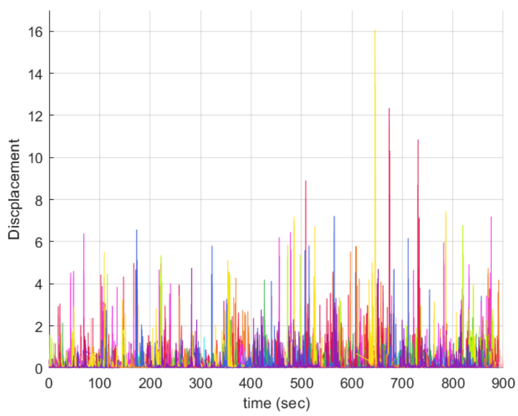


Figure B.44: Total-Head-Movement of the focus group responses in Pink Noise condition.

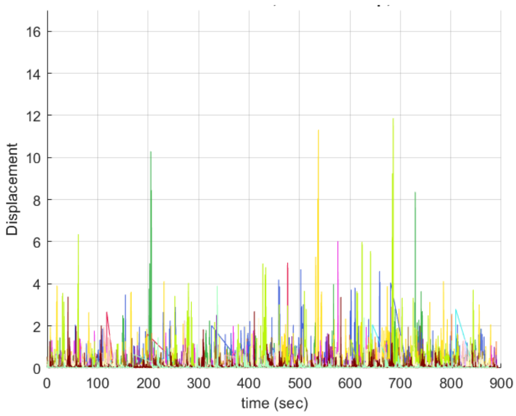


Figure B.45: Total-Head-Movement of the control group responses in Dual Mono condition.

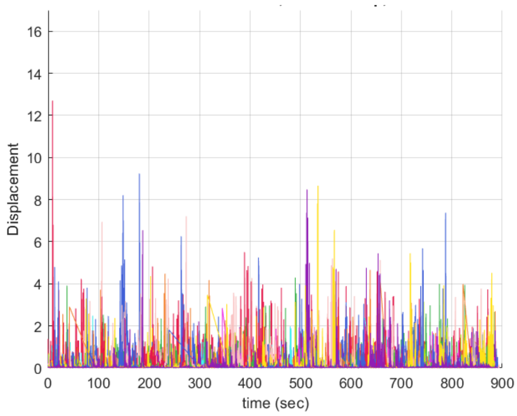


Figure B.46: Total-Head-Movement of the focus group responses in Dual Mono condition.

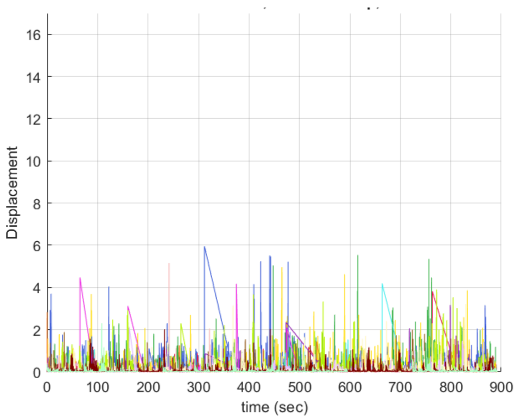


Figure B.47: Total-Head-Movement of the control group responses in Binaural condition.

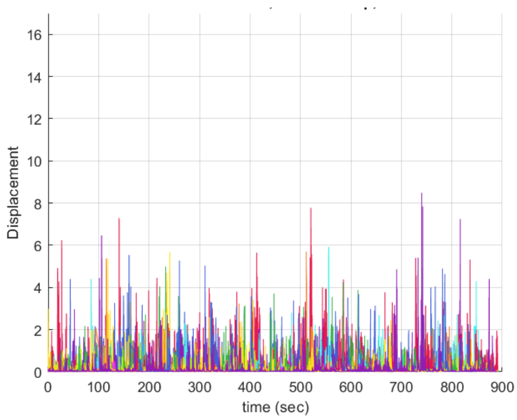


Figure B.48: Total-Head-Movement of the focus group responses in Binaural condition.

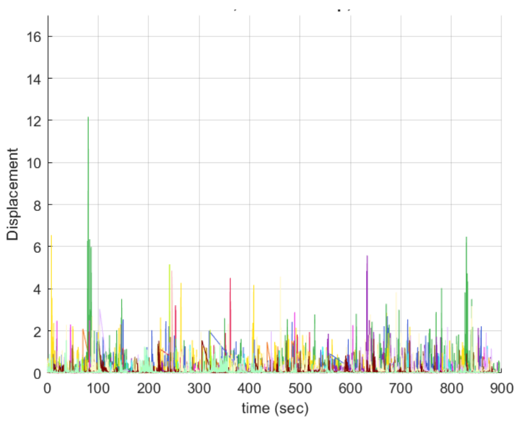


Figure B.49: Total-Head-Movement of the control group responses in Audio Indicators condition.

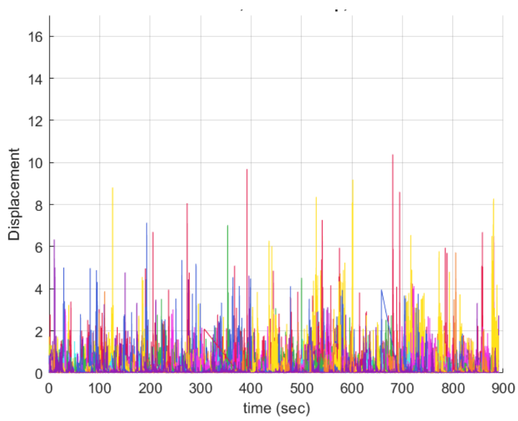


Figure B.50: Total-Head-Movement of the focus group responses in Audio Indicators condition.

C

Ethics: Relevant Documentation

C.1 Application Form for Physical Sciences Ethics Committee Approval

THE UNIVERSITY of York

Application Form for Physical Sciences Ethics Committee Approval

Advice for applicants on completing the form *Please ensure that the information provided is:* • *Accurate and concise* • *Clear and simple and easily understood by a lay person* • *Free of jargon, technical terms and abbreviations* *Further advice and information can be obtained from your departmental representative on the PSEC and at: http://www.york.ac.uk/admin/aso/ethics/cttee.htm*

Please return completed (typed) form to your departmental representative via email to:

elec-ethics@york.ac.uk

Title of project: Immersive Soundscapes supporting children with ADHD.

SECTION 1 DETAILS OF APPLICANTS

Details of principal investigator (name, appointment and qualifications)

Panos Tsagkarakis PhD Research Student in Electronic Engineering Email: Panagiotis.tsagkarakis@york.ac.uk, mob.: +44 (0)7444427660

Names, appointments and qualifications of additional investigators *(student applicants should include their project supervisor(s) here)*

Dr Gavin Kearney, Associate Professor in Audio and Music Technology University of York, AudioLab Email: gavin.kearney@york.ac.uk , phone: +44 (0) 1904 32 2374 Professor Chris Barlow, Head of Research and Innovation KP Acoustics Research Labs Email: cb@kpacoustics.com, phone: +44 (0) 238 254 4965

Location(s) of project

AudioLab,
Department of Electronic Engineering,
Genesis 6, Church Lane, Innovation Way, Heslington, York,
YO10 5DQ, United Kingdom

SECTION 2 FUNDERS

What is the funding source(s) for the project?

Funding is provided by the KP Acoustics Research Labs.
1 Galena Rd, London W6 0LT

Please answer the following:

(i) Does the express and direct aim of the research or other activity raise ethical issues?

YES [ ] NO [x]

(ii) Is there any obvious or inevitable adaptation of research findings to ethically questionable aims?

YES [ ] NO [x]

(iii) Is the work being funded by organisations tainted by ethically questionable activities?

YES [ ] NO [x]

(iv) Are there any restrictions on academic freedoms – notably, to adapt and withdraw from ongoing research, and to publish findings?

YES [ ] NO [x]

If you answered **Yes** to any of the above, please give details below:

SECTION 3 DETAILS OF PROJECT OR OTHER ACTIVITY

Aims (100 words max)

This project aims to develop and evaluate a low-cost implementation of personalised, immersive soundscapes that will positively affect the cognitive performance of children with attention deficit hyperactivity disorder (ADHD). It is based on cross-modal sensory interaction providing a therapeutic soundscape while the participant performs visual tasks.

Background (250 words max)

ADHD is a neurodevelopmental disorder characterised by behavioural impairments in the domains of inattention, impulsivity, and/or hyperactivity [1]. ADHD affects approximately 5% of the children in the UK [2]. Stimulant medication is currently the primary treatment with several parental concerns about the side effects and not lasting results. Cognitive Behaviour Therapy (CBP) is limited in training patients to control their symptoms through education and talking through issues [3].

Noise Therapy (NT) supports an alternative treatment based on the significant impact the immediate environment has on the expression of ADHD symptoms. Controlled introduction of noise as a reinforcing stimulus in the environment has demonstrated a positive effect on cognitive performance [4], reading and writing skills [5], and working memory [6]. However, there are still improvements to be made in impulsivity and reaction time.

This research extends the scope of Noise Therapy by introducing immersive soundscapes both as alternative content (natural noise environments such as rain, wave, fire etc.) and audio reproduction techniques whilst retaining the therapeutic quality of sound (noise). Presenting the soundscape content spatially, enhances the sense of immersion which constitute a crucial element in the participant's engagement [7]. The Continuous Performance Task (CPT) framework is used to evaluate participants' Response Time, Omission and Commission errors as indications of inattention, impulsivity, Sustain attention and vigilance. The research outcome provides a step forward for cross-modal, personalised non-pharmacological ADHD treatment for everyday applications.

1. American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders (DSM-5R); American Psychiatric Publishing: Washington, DC, USA, 2013.
2. NHS - Greater Manchester Combined Authority. (2018). *Delivering Effective Services for Children and Young People with ADHD*. https://www.england.nhs.uk/north-west/wp-content/uploads/sites/48/2019/03/GM-wide-ADHD-guidance.pdf.
3. Pickens, T. A., Khan, S. P., & Berlau, D. J. (2019). White noise as a possible therapeutic option for children with ADHD. Complementary Therapies in Medicine, 42(October 2018), 151–155. https://doi.org/10.1016/j.ctim.2018.11.012
4. Söderlund, G. B. W., & Sikström, S. (2008). Positive Effects of Noise on Cognitive Performance: Explaining the Moderate Brain Arousal Model. Proceedings from ICBEN, International Comission on the Biological Effects of Noise, 1–9
5. Berlau, D. J. (2019). White noise as a possible therapeutic option for children with ADHD. Complementary Therapies in Medicine, 42(October 2018), 151–155. https://doi.org/10.1016/j.ctim.2018.11.012
6. Söderlund, G. B. W., Åsberg Johnels, J., Rothén, B., Torstensson-Hultberg, E., Magnusson, A., & Fälth, L. (2021). Sensory white noise improves reading skills and memory recall in children with reading disability. Brain and Behavior, 11(7), 1–15. https://doi.org/10.1002/brb3.2114
7. Emily Brown and Paul Cairns. 2004. A grounded investigation of game immersion. In <i>CHI '04 Extended Abstracts on Human Factors in Computing Systems</i> (<i>CHI EA '04</i>). Association for Computing Machinery, New York, NY, USA, 1297–1300. https://doi.org/10.1145/985921.986048

Brief outline of project/activity (250 words max)

The project will take place in the United Kingdom and Greece. Participants include 20 children with ADHD (unmedicated) and 20 Typically Developed Children (TDC) aged 8-14 years old. The children with ADHD will require an existing diagnosis of ADHD from their local NHS Trust or authorized children psychologist according to the guidelines of DSM-5 criteria [1]. Recruiting will take place through schools, community groups and private ADHD support centres in the greater York (UK) and Athens (GR) area.

The project requests the children to participate in two sessions on separate days. They will use the application (video game presented on monitor screen) two times (14 min each) on the first and three times on the second session. They are invited to respond to visual targets (CPT: go-nogo task) while exposed to a variety of sonic environments. At the beginning of the first session, the participants are invited to select sonic material to build their own, personalised soundscape. We will ask them their opinions on their selections. Each session will be completed with a VR entertaining demonstration using a head-mounted device (HMD). The participant will have the chance to relax, play and interact with virtual worlds.

The principal investigator will run each session with a single participant and their parents-gradient present. At the beginning of the session, the participant will be instructed about the details of the experimental procedure verbally and the use of an information sheet. The experiment is designed with minimal and portable apparatuses (monitor screen, VR headsets and headphones). The data collection sessions will run in the laboratory space of the Genesis 6 building or locally implemented at specialised (ADHD) privet centres and schools fulfilling the predefined experimental conditions.

1. Reynolds CR, Kamphaus RW. DSM-5 diagnositic criteria - attention-Deficit/Hyperactivity disorder (ADHD). Diagnostic and statistical manual of mental disorders. 5th editio. American Psychiatric Association; 2013https://doi.org/10.1542/pir.31-2-56.

Study design *(if relevant – e.g. randomised control trial; laboratory-based)*

This is an experimental repeated measurement study.

If the study involves participants, how many will be recruited?

40 participants, consisting of 20 children with ADHD and 20 TDC for two sessions on separate days.

If applicable, what is the statistical power of the study, i.e. what is the justification for the number of participants needed?

Not applicable – this is a feasibility study aimed at developing the intervention. The current number of participants is sufficient to allow us to develop the application and test it for acceptability and usability.

SECTION 4 RECRUITMENT OF PARTICIPANTS

How will the participants be recruited?

Participants will be recruited from community settings such as schools, local support groups, children's centres, and charities such as "MIND" or "Accessible Arts & Media". We are already collaborating with two clinical psychologists providing us guidance and networking.

What are the inclusion/exclusion criteria?

Children with ADHD: All participants must be between the ages of 8 and 14 years with an existing diagnosis of ADHD from an NHS Trust or authorized children psychologist according to guidelines of DSM-5 criteria. They must be at normal IQ and physically able to move freely around the experiment area. The participants on stimulant medication or diagnosed with Autistic Spectrum Disorder or photosensitive epilepsy will not take part.

Control Group: All participants must be typically developed children, between the ages of 8 and 14 years with normal IQ.

Will participants be paid reimbursement of expenses?	YES	x	NO	
Will participants be paid?	YES	x	NO	

If yes, please obtain signed agreement

Will any of the participants be students?	YES		NO	x

SECTION 5 DATA STORAGE AND TRANSMISSION

If the research will involve storing personal data, including sensitive data, on any of the following please indicate so and provide further details (answers only required if *personal* data is to be stored).

Manual files	Consent forms
University computers	
Home or other personal computers	
Laptop computers, tablets	All digital information
Website	

Please explain the measures in place to ensure data confidentiality, including whether encryption or other methods of anonymisation will be used.

All data will be anonymised. Paper copies of any obtained information will be stored securely in a locked room and inside locked storage cabinets. Digital information will be stored on secure, encrypted devices which are password protected. Only the direct research team will have access to the data.

Please detail who will have access to the data generated by the study.

Panos Tsagkarakis
Gavin Kearney
Christopher Barlow

Please detail who will have control of and act as custodian for, data generated by the study.

Panos Tsagkarakis

Please explain where, and by whom, data will be analysed.

All data will be analysed by Panos Tsagkarakis at the Audio Lab, Innovation Way, York.

Please give details of data storage arrangements, including where data will be stored, how long for, and in what form.

Data will be anonymised and will be stored in excel, .csv and .mat form on a password protected drive for 2 years after the project duration.

SECTION 6 CONSENT

Is written consent to be obtained?

YES	x	NO	

If yes, please attach a copy of the information for participants

The consent forms and information sheets are attached to this amended application. These are:

Information Sheets for parents:
02 Parent PIS V1 26.05.22

Information sheets for Children with ADHD:
03a Children with ADHD PIS V1 26.05.22

Information sheets for Control Group (TDC):
03b Control Group PIS V1 26.05.22

Consent Form
04 Parent Consent Form V1 26.05.2022

If no, please justify

Will any of the participants be from one of the following vulnerable groups?

Children under 18	YES	x	NO	
People with learning difficulties	YES	x	NO	
People who are unconscious or severely ill	YES		NO	x
People with mental illness	YES		NO	x
NHS patients	YES		NO	x
Other vulnerable groups (if ‘yes’, please give details)	YES		NO	x

If so, what special arrangements have been made for getting consent?

Parents and children will receive information sheets and will be given at least 48 hours to read through, ask the research team any questions, and decide if they want to participate. If they are happy to proceed, then parents will be asked to complete consent forms prior to the study commencing.

SECTION 7 DETAILS OF INTERVENTIONS

Indicate whether the study involves procedures which:

Involve taking bodily samples	YES		NO	x
Are physically invasive	YES		NO	x
Are designed to be challenging/disturbing (physically or psychologically)	YES	x	NO	

If so, please list those procedures to which participants will be exposed:

The game is designed to occasionally expose children to noisy auditory stimuli that might disturb them. However, the exposure to the challenging stimuli is implemented in a highly controlled and safe manner concerning both the content and sound level.

List any potential hazards:
Wearing the VR headset will remove the participant’s ability to see the surrounding area during the game. Participants will be accompanied by a responsible adult to ensure adequate spacing and safety.

List any discomfort or distress:
Duration. Some participants may find the duration of the experiments challenging.
Sensory sensitivities. Those with sensory sensitivities may find wearing a VR headset difficult. We will give young people the option of holding the VR set over their face rather than using a strap and will assess the acceptability of their use.
On both occasions, the participants will have the opportunity to withdraw at any time.

What steps will be taken to safeguard

(i) the confidentiality of information
Participant data will remain confidential, participant information will be anonymised with the use of individual identification codes. Personal data will only be accessible via password-protected software.

(ii) the specimens themselves?

What particular ethical problems or considerations are raised by the proposed study?

Involving children, but this will be mitigated by full informed consent procedures, including consent from parents etc. Game interacting with sensory stimuli that participants might find difficult, however this will be implemented in a safe/fun way and participants can stop at any time.

What do you anticipate will be the output from the study? ***Tick those that apply:***

Peer-reviewed publications	x
Non-peer-reviewed publications	
Reports for sponsor	
Confidential reports	
Presentation at meetings	x
Press releases	x
Student project	

Is there a secrecy clause to the research?
If yes, please give details below

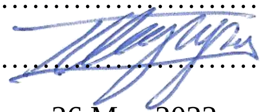
YES		NO	x

SECTION 8 SIGNATURES

The information in this form is accurate to best of my knowledge and belief and I take full responsibility for it.

I agree to advise of any adverse or unexpected events that may occur during this project, to seek approval for any significant protocol amendments and to provide interim and final reports. I also agree to advise the Ethics Committee if the study is withdrawn or not completed.

Signature of Investigator(s): ……………………………………………………………



……………………………………………………………

Date: …………26 May 2022………………………………

> ***Responsibilities of the Principal Researcher following approval***
> - If changes to procedures are proposed, please notify the Ethics Committee
> - Report promptly any adverse events involving risk to participants

C.2 Parents/Guardian Consent Form

THE UNIVERSITY *of York*

Study Number:

Patient Identification Number:

Title: Immersive Soundscapes supporting children with ADHD

Consent form

Please initial to consent

1	I have read and understand the information sheet dated 26.05.22, version V1, for the above study.	☐
2	I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
3	I understand that taking part in this research study is voluntary and I know that I can withdraw from the study at any time. I am aware that I do not need to give any reason for withdrawing. I know this will not affect any support my child receives. If my child does not want to be involved I know that my child can withdraw from the study at any time without giving any reason.	☐
4	I agree to be contacted if needed for further information on the forms I complete as part of the research.	☐
5	I am aware that when the results of the study are published, children/ young people and families will not be identified. All the information will be kept strictly confidential.	☐
7	I agree with my child taking part in this research.	☐
8	I understand that my contact information will be kept securely on the database when the study has finished and agree that the research team can share my anonymised data (data with any identifiable information removed) with other researchers and mental health professionals.	☐
9	I agree that the research team can contact me in the future to follow up on this research.	☐
10	I agree that the research team can contact me to let me know about other upcoming research.	☐

Parent/guardian name:
Contact number:
Contact email:
Sign: Date:

Researcher name:
Sign: Date:

C.3 Parent/Guardian Information Sheet

PARTICIPANT INFORMATION SHEET: PARENTS/GUARDIANS

Version 1: 26/05/2022

Immersive Soundscapes Supporting Children with ADHD

We would like to invite your child to take part in our research study. Before you decide we would like you to understand why the research is being done and what it will involve.

Please read through this information and take the time to decide whether you want your child to take part. Feel free to ask us if there is anything that is not clear or if you would like more information – our contact details can be found toward the end of this information sheet.

Background

ADHD is a neurodevelopmental disorder characterized by behavioural impairments in three domains: inattention, impulsivity, and/or hyperactivity. While the signs and symptoms vary between individuals, children with ADHD tend to daydream a lot, forget or lose things a lot, talk too much, make careless mistakes or take unnecessary risks, have a hard time resisting temptation or have difficulty getting along with others. This causes them to experience difficulties in the learning process and educational performance as well as in their social interactions.

ADHD is directly related to low dopamine release, which leads to working memory deficits and the reduced activation of the reward centre. Consequently, an increase in reward seeking is often expressed as impulsivity and hyperactivity. According to the Moderate Brain Arousal model, external noise from the environment can compensate for the hypo-functioning dopamine system in ADHD.

Noise Therapy supports an alternative treatment based on the significant impact the immediate environment has on the expression of ADHD symptoms. The controlled introduction of white noise as a reinforcing stimulus in the environment has demonstrated a positive effect on cognitive performance, reading and writing skills, and working memory. However, there are still improvements to be made in impulsivity and reaction time.

This research extends the scope of Noise Therapy by introducing immersive soundscapes both as alternative content (natural noise environments such as rain, wave, fire etc.) and audio reproduction techniques whilst retaining the therapeutic quality of sound (noise). We are developing an application using headphones as a possible solution to help children with ADHD improve focus and engagement while performing cognitive tasks. The research outcome provides a step forward for cross-modal, personalised non-pharmacological ADHD treatment for everyday applications.

Our aims

We are now hoping to improve the application by inviting input from children with ADHD, finding out the effect of content variations, and immersively presenting natural soundscapes on their cognitive performance.

Why have I been approached?

Your child:

- Has an existing diagnosis of ADHD
- Experiences learning difficulties
- Is between the age of 8 and 14 years old

- Is physically able to move freely using the equipment (headphones, headset, and controllers)
- Does not have photosensitive epilepsy

What happens during the research?

We recruit 20 children with ADHD matching the above criteria to participate in a two-session trial (on separate days). We will ask them to play a simple hitting targets type of game presented on a monitor screen while listening to various sound environments presented over headphones. The game does not require any alphabetical or arithmetical knowledge. The duration of the game is 14 min, and the participant is requested to play it twice on the first day and three times on the second day. At the beginning of the first session, the participants are invited to select sonic material to build their own, personalised soundscape. We will ask them their opinions on the different materials and their selections. Instructions will be communicated to participants and their parents/guardians prior to study commencement.

We will look at the effect of sonic environments on the participants' response to the targets over time. The information gathered from all participants will reveal if the use of the application shows promise in the improvement of attention and restriction of impulsivity.

Each session will be completed with a VR entertaining demonstration using a head-mounted device (HMD). The participant will have the chance to relax, play and interact with virtual worlds.

What are the possible benefits of taking part?

By taking part, children and their parents/guardians will have the opportunity to support the development of an application that may potentially improve cognitive performance and quality of life for children with ADHD. The results will provide insides regarding the participant's learning style, which can be used to enhance their learning processes. Finally, the participants will have the opportunity to enjoy spatial audio and VR experiences.

Are there any risks to taking part?

During the video game, noisy sound elements will be included in the soundscape that might disturb the participant. However, the exposure to the challenging sounds is implemented in a highly controlled and safe manner concerning both the content and sound level.
During the entertainment section, the VR game participants with sensory sensitivities may find wearing a VR headset difficult. We will give young people the option of holding the VR set over their face rather than using a strap and will assess the acceptability of their use. They will have the option to stop at any time if they feel uncomfortable.

What happens if we want to take part?

If you and your child would like to take part in this study, please return the enclosed Contact Details form at the end of this information sheet to the research team. You can also contact the team via email or telephone (details below) for more information or if you have any questions.

If you decide you want to take part, we will then ask you and your child to complete a consent form. You will be able to keep a copy of the information sheet and consent form. You can still withdraw at any point after this, without needing to give a reason. This will not affect the support your child receives.

Does my child have to take part?

No. There is no obligation for your child to participate. This is entirely voluntary, and you and your child can withdraw at any point without needing to give a reason. If you decide you don't want to take part this will not affect the health or education support your child receives in the future.

Is the study confidential?

Yes, participation in this study is entirely confidential and anonymous. You and your child will not be named in any reports produced from this study. Confidentiality will be maintained throughout the study, and any information kept by the research team will be done so using participant numbers rather than names. Our procedures for handling, processing, storage and destruction of data are compliant with the Data Protection Act 2018.

How will our data be used?

As a university, we use personally identifiable information to conduct research to improve health, care and services. As a publicly funded organisation, we must ensure that it is in the public interest when we use personally identifiable information from people who have agreed to take part in the research. This means that when you agree to take part in a research study, we will use your data in the ways needed to conduct and analyse the research study. Your rights to access, change or move your information are limited, as we need to manage your information in specific ways for the research to be reliable and accurate.

If you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally identifiable information possible. Information collected will only be used for the purpose of health and care research in accordance with the UK Policy Framework for Health and Social Care Research, or to contact you about future opportunities to participate in research. It will not be used to make decisions about future services available to you, such as insurance.

What will happen to the results?

Following data analysis, we will provide a brief overview of our findings to participants and involved mental health professionals. We intend for our findings to be published in an academic, peer-reviewed journal and aim to disseminate our findings via conferences. All data will be anonymised, and any personally identifiable data held will not be shared.

Who has reviewed this study?

As well as internal review within our research team, this study has been reviewed by the Physical Sciences Ethics Committee at the University of York "Tsagkarakis270522".

Who is funding the research?

This study is being funded by KP Acoustics Research Labs, London. The views expressed are those of the author(s) and not necessarily those of the funding company.

Who can I contact if I want to learn more about the study?

If you wish to discuss this study in further detail or have any specific questions, please contact:

Panos Tsagkarakis – PhD Researcher
panagiotis.tsagkarakis@york.ac.uk / 07444427660
or
Dr. Gavin Kearney – Associate Professor in Audio and Music Technology
Gavin.kearney@york.ac.uk / 01904 32 2374

Who can I contact if I want to complain?

If you wish to make a complaint (or talk about making a complaint) you can contact the PALS (Patient Advice and Liaison Service) team. They offer confidential and free service to guide you through the different services available at Leeds York Partnership Foundation Trust.

Patient Advice and Liaison Service (PALS)
The Becklin Centre
Alma Street
Leeds, West Yorkshire
LS9 7BE
Tel: 0800 052 5790
Email: pals.lypft@nhs.net

If you wish to raise a complaint on how we have handled your personal data, you can contact our Data Protection Officer who will investigate the matter.

Durham Burt - Data Protection Officer
dataprotection@york.ac.uk

If you are not satisfied with our response or believe we are processing your personal data in a way that is not lawful you can complain to the Information Commissioner's Office (ICO) https://ico.org.uk/your-data-matters/

Thank you for taking the time to read this leaflet.
If you have any questions, please do get in touch.

C.4 Participant Information Sheet

PARTICIPANT INFORMATION SHEET: Participant (ADHD)
Version 1: 26/05/2022

Immersive Soundscapes Supporting Children with ADHD

We would like to ask you to take part in our research study. You can choose if you want to take part or not. This leaflet explains what the study is about and what will happen if you choose to take part. If you have any questions, you can ask us before you choose if you want to take part.

What is the study about?

There are lots of children with ADHD in England and the rest of the world. They all have their own personalities, likes and dislikes, but might have some things in common such as:

- Liking to daydream a lot
- Forget or lose things a lot
- Make careless mistakes
- Take unnecessary risks
- Finding it difficult getting along with others

Some people with ADHD find it difficult to concentrate on a single task or experience this undefinable urge to move. This is caused by the limited dopamine release in the brain. We want to help these people be more able to retain their focus on a task without feeling upset or uncomfortable.

We examine how sound can improve your concentration. We made a simple video game that you will play while hearing different sounds on your headphones. We will make small changes to those sounds while you are playing and see how many targets you hit. You will also have the chance to build your own sound environment.

What will happen if I take part?

If you decide that you would like to take part, we will ask you to meet on two separate days. You will play the video game twice on the first day and three times on the second while listening to sounds on your headphones. On the first day, you will also select natural sounds you like to build your favourite soundscape and tell us your opinion about them. At the end of each day, you will relax, play, and enjoy VR entertainment using a VR headset.

Why have I been asked?

We would like to invite you to take part because you:

- Have a diagnosis of ADHD,
- Are aged between 8-14 years old,
- Face difficulty concentrating,
- We think you will enjoy participating

Do I have to take part?

No. You don't have to take part if you don't want to. If you decide to take part but then change your mind that is ok too. You can tell us at any time if you would like to stop and will not need to give a reason.

Are there any risks to taking part?

When playing the game some noisy sounds that you might not like will be played. This might feel a little strange or difficult at first. But you can stop playing at any time if you do not like it.

Are there any benefits to taking part?

We hope you enjoy participating and sharing experiences, plus you get to use a VR headset!

What if there is a problem?

If you have any problems or questions during the study, you can speak to your parents/carers or any of the adults involved. Your family can contact the research team using the details below:

Panos Tsagkarakis (panagiotis.tsagkarakis@york.ac.uk - 07444427660)
Gavin Kearney (gavin.kearney@york.ac.uk - 01904 32 2374)

What will happen with my information?

If you decide to take part, nobody else will know that the information we have is from you. Your name will not be included on any results.

Thank you for taking the time to read this leaflet.
We hope you would like to take part.
If you have any questions we are happy to answer them.

C.5 Parents/Guardian Consent Form in Greek

Αριθμός μελέτης:

Αριθμός Αναγνώρισης Συμμετέχοντα:

Τίτλος: "Εμβυθιστικά" ηχοτοπία για την υποστήριξη παιδιών με ΔΕΠΥ

Έντυπο συναίνεσης

Παρακαλώ επιλέξτε
Για συναίνεση

1	Έχω διαβάσει και κατανοήσει το φύλλο πληροφοριών γονέα της, για την παραπάνω μελέτη.	☐
2	Είχα την ευκαιρία να εξετάσω τις πληροφορίες, να κάνω ερωτήσεις και να λάβω ικανοποιητικές απαντήσεις.	☐
3	Κατανοώ ότι η συμμετοχή σε αυτήν την έρευνα είναι εθελοντική και γνωρίζω ότι μπορώ να αποχωρήσω από τη μελέτη ανά πάσα στιγμή. Γνωρίζω ότι δεν χρειάζεται να αναφέρω κανέναν λόγο για την απόσυρση. Γνωρίζω ότι αυτό δεν θα επηρεάσει την υποστήριξη που θα λάβει το παιδί μου. Εάν το παιδί μου δεν θέλει να συμμετάσχει, ξέρω ότι το παιδί μου μπορεί να αποσυρθεί από τη μελέτη ανά πάσα στιγμή χωρίς να αναφέρω κανέναν λόγο.	☐
4	Συμφωνώ να επικοινωνήσουμε μαζί μου αν χρειαστεί για περισσότερες πληροφορίες σχετικά με τις φόρμες που συμπληρώνω ως μέρος της έρευνας.	☐
5	Γνωρίζω ότι όταν δημοσιευτούν τα αποτελέσματα της μελέτης, τα παιδιά και οι οικογένειες δεν θα ταυτοποιηθούν. Όλες οι πληροφορίες θα διατηρηθούν αυστηρά εμπιστευτικές.	☐
7	Συμφωνώ με τη συμμετοχή του παιδιού μου σε αυτήν την έρευνα.	☐
8	Κατανοώ ότι τα στοιχεία επικοινωνίας μου θα διατηρηθούν με ασφάλεια στη βάση δεδομένων όταν ολοκληρωθεί η μελέτη και συμφωνώ ότι η ερευνητική ομάδα μπορεί να μοιραστεί τα ανώνυμα δεδομένα μου με άλλους ερευνητές και επαγγελματίες ψυχικής υγείας.	☐
9	Συμφωνώ ότι η ερευνητική ομάδα μπορεί να επικοινωνήσει μαζί μου στο μέλλον για να δώσει συνέχεια σε αυτήν την έρευνα.	☐
10	Συμφωνώ ότι η ερευνητική ομάδα μπορεί να επικοινωνήσει μαζί μου για να με ενημερώσει σχετικά με άλλες επερχόμενες έρευνες.	☐

Όνομα γονέα/κηδεμόνα:

Τηλέφωνο επικοινωνίας:

email:

Υπογραφή: Ημ/νια:

Όνομα ερευνητή:

Υπογραφή: Ημ/νια:

C.6 Parent/Guardian Information Sheet in Greek

“Εμβυθιστικά” ηχοτοπία για την υποστήριξη παιδιών με ΔΕΠΥ (Immersive Soundscapes Supporting Children with ADHD)

Πληροφορίες για τον Γονέα σχετικά με την έρευνα

Θα θέλαμε να προσκαλέσουμε το παιδί σας να λάβει μέρος στην ερευνητική μας μελέτη. Πριν αποφασίσετε, θα θέλαμε να καταλάβετε γιατί γίνεται η έρευνα και τι θα περιλαμβάνει.

Παρακαλούμε διαβάστε αυτές τις πληροφορίες και αφιερώστε χρόνο για να αποφασίσετε εάν θέλετε να συμμετάσχει το παιδί σας. Μη διστάσετε να μας ρωτήσετε εάν υπάρχει κάτι που δεν είναι σαφές ή εάν θέλετε περισσότερες πληροφορίες – τα στοιχεία επικοινωνίας μας βρίσκονται στο τέλος αυτού του φύλλου πληροφοριών.

Background

Η ΔΕΠΥ χαρακτηρίζεται από διαταραχές συμπεριφοράς σε τρεις τομείς: απροσεξία, παρορμητικότητα και/ή υπερκινητικότητα. Ενώ τα σημεία και τα συμπτώματα ποικίλλουν μεταξύ των ατόμων, τα παιδιά με ΔΕΠΥ τείνουν να ονειροπολούν πολύ, να ξεχνάνε ή να χάνουν συχνά πράγματα, να μιλάνε πολύ, να κάνουν απρόσεκτα λάθη ή να παίρνουν περιττά ρίσκα, να δυσκολεύονται στην επικοινωνία με άλλους ή να αντιστέκονται σε προκλήσεις. Συνέπεια αυτών είναι να αντιμετωπίζουν δυσκολίες στη μαθησιακή διαδικασία και την εκπαιδευτική απόδοση καθώς και στις κοινωνικές αλληλεπιδράσεις.

Η ΔΕΠΥ σχετίζεται άμεσα με τη χαμηλή απελευθέρωση ντοπαμίνης στον εγκέφαλο, η οποία οδηγεί σε δυσλειτουργία της μνήμης εργασίας και στη μειωμένη ενεργοποίηση του κέντρου ανταμοιβής. Ως επακόλουθο, η αύξηση στην αναζήτηση ανταμοιβής εκδηλώνεται συχνά ως παρορμητικότητα και υπερκινητικότητα. Σύμφωνα με το μοντέλο Μέτριας Διέγερσης Εγκεφάλου (Moderate Brain Arousal model), ο εξωτερικά προεχόμενος θόρυβος από το περιβάλλον μπορεί να αντισταθμίσει το υπολειτουργικό σύστημα ντοπαμίνης στη ΔΕΠΥ.

Η Θεραπεία Θορύβου (Noise Therapy) βασίζεται στη σημαντική επίδραση που έχει το άμεσο περιβάλλον στην εκδήλωση των συμπτωμάτων της ΔΕΠΥ. Η ελεγχόμενη εισαγωγή του λευκού θορύβου ως ενισχυτικού ερεθίσματος στο περιβάλλον έχει παρουσιάσει θετική επίδραση στη γνωστική απόδοση, στις δεξιότητες ανάγνωσης και γραφής και στη μνήμη εργασίας. Ωστόσο, μελετώνται περαιτέρω βελτιώσεις όπως στην παρορμητικότητα και στον χρόνο αντίδρασης.

Η παρούσα έρευνα επεκτείνει το πεδίο εφαρμογής της Θεραπείας Θορύβου εισάγοντας ηχητικά τοπία “εμβύθισης” τόσο ως εναλλακτικό περιεχόμενο (χρησιμοποιώντας περιβάλλοντα φυσικού θορύβου όπως βροχή, κύματα κ.λπ.) όσο και ως τρισδιάστατες τεχνικές αναπαραγωγής ήχου, συντηρώντας παράλληλα τη θεραπευτική ιδιότητα του θορύβου.

Σκοπός

Στοχεύουμε στην ανάπτυξη μιας εφαρμογής κατά την οποία προσκαλώντας παιδιά με ΔΕΠΥ, μελετάμε την επίδραση των παραλλαγών περιεχομένου και “εμβυθιστικών” ηχοτοπίων για την βελτίωση της εστίασης και της απερίσπαστης προσοχής κατά την εκτέλεση γνωστικών εργασιών. Τα αποτελέσματα της έρευνας συνεισφέρουν σε μια διατροπική (οπτικοακουστική), εξατομικευμένη μη φαρμακολογική θεραπεία ΔΕΠΥ για καθημερινές εφαρμογές.

Γιατί έχω επιλεχθεί;

Το παιδί σου:

- Έχει υπάρχουσα διάγνωση ΔΕΠΥ
- Αντιμετωπίζει μαθησιακές δυσκολίες
- Είναι μεταξύ 8 και 14 ετών
- Είναι σε θέση να κινείται ελεύθερα χρησιμοποιώντας τον εξοπλισμό για το πείραμα (ακουστικά και χειριστήρια)
- Δεν έχει φωτοευαίσθητη επιληψία

Τι συμβαίνει κατά τη διάρκεια της έρευνας;

Συνολικά 16 παιδιά με ΔΕΠΥ και 16 τυπικά ανεπτυγμένα παιδιά θα συμμετάσχουν σε μια δοκιμή πέντε συνεδριών (σε ξεχωριστές ημέρες). Θα τους ζητήσουμε να παίξουν ένα απλού τύπου βίντεο-παιχνίδι χτυπήματος στόχων που παρουσιάζονται στην οθόνη ενώ ακούν διαφορετικά ηχητικά περιβάλλοντα κάθε φορά. Το παιχνίδι δεν απαιτεί αλφαβητικές ή αριθμητικές γνώσεις. Η διάρκεια του παιχνιδιού είναι 14 λεπτά. Στην αρχή της πρώτης συνεδρίας, οι συμμετέχοντες καλούνται να επιλέξουν ηχητικό υλικό για να δημιουργήσουν το δικό τους, εξατομικευμένο ηχητικό τοπίο και στην αρχή τις δεύτερης θα γνωρίσουν το χωρικό ήχο μέσω εφαρμογής. Οι οδηγίες θα κοινοποιηθούν στους συμμετέχοντες και στους γονείς/κηδεμόνες τους πριν από την έναρξη της μελέτης.

Κατά την διάρκεια της εφαρμογής εξετάζουμε την επίδραση του ηχητικού περιβάλλοντος στον χρόνο απόκρισης και των αριθμό των στόχων στους οποίους ανταποκρίνονται οι συμμετέχοντες, καθώς και στο πώς μεταβάλλονται οι αντιδράσεις με την πάροδο του χρόνου. Τα αποτελέσματα θα αποκαλύψουν την δυναμική της εφαρμογής στη βελτίωση της προσοχής και τον περιορισμό της παρορμητικότητας ή της υπερκινητικότητας.

Κάθε συνάντηση ολοκληρώνεται με μια διασκεδαστική δραστηριότητα εικονικής πραγματικότητας (virtual reality-VR). Οι συμμετέχοντες θα έχουν την ευκαιρία να χαλαρώσουν, παίζοντας και αλληλοεπιδρώντας με εικονικούς κόσμους με την χρήση VR εξοπλισμού (γυαλιά και χειριστήρια).

Ποια είναι τα πιθανά οφέλη από τη συμμετοχή;

Συμβάλλοντας στην ερευνά γονείς/κηδεμόνες με τα παιδιά τους θα έχουν την ευκαιρία να υποστηρίξουν την ανάπτυξη μιας εφαρμογής που ενδέχεται να βελτιώσει τη γνωστική απόδοση και την ποιότητα ζωής παιδιών με ΔΕΠΥ. Όλες οι δράσεις κατά την διάρκεια της συνάντησης έχουν την μορφή παιχνιδιού, κάνοντάς τις ελκυστικές και ευχάριστες. Τα αποτελέσματα θα παράσχουν πληροφορίες σχετικά με το στυλ μάθησης των συμμετεχόντων τα οποίο μπορεί να χρησιμοποιηθεί για να βελτιώσει τις μαθησιακές τους διαδικασίες.

Τα παιδιά συχνά παρακινούνται από «νέες» τεχνολογίες. Μέσα από αυτές τις συναντήσεις, θα εξοικειωθούν με την ιδέα των ηχοτοπίων. Θα έχουν την ευκαιρία να κατασκευάσουν ένα προσωπικό ηχητικό τοπίο που θα αποτελείται από φυσικά ηχητικά στοιχεία όπως ήχους κυμάτων, ποταμών, φωτιάς και ανέμου. Θα έχουν επίσης την ευκαιρία να βιώσουν “εμβυθιστικές” τεχνολογίες, τόσο ακουστικά γνωρίζοντας τον χωρικό ήχο όσο και οπτικά με την ψυχαγωγία VR ως μια χαλαρωτική διαδικασία στο τέλος κάθε συνάντησης. Πιστεύουμε ότι θα είναι μια ευχάριστη εμπειρία να μοιραστούν με τους συνομηλίκους τους.

Υπάρχουν κίνδυνοι από τη συμμετοχή;

Κατά την διάρκεια του παιχνιδιού θα ακούγονται κάποιοι θορυβώδεις ήχοι που μπορεί να μην είναι ιδιαίτερα αρεστοί. Αυτό μπορεί να φαίνεται λίγο περίεργο ή δύσκολο στην αρχή. Ωστόσο, η έκθεση στους ήχους αυτούς υλοποιείται με άκρως ελεγχόμενο και ασφαλή τρόπο όσον αφορά το περιεχόμενο και το επίπεδο ήχου. Το παιδί μπορεί να σταματήσει αν νιώσει άβολα.

Τι θα γίνει αν πάρω μέρος;

Εάν εσείς και το παιδί σας θέλετε να συμμετάσχετε σε αυτή τη μελέτη, παρακαλούμε επιστρέψτε τη συνημμένη φόρμα με στοιχεία επικοινωνίας που βρίσκετε στο τέλος αυτού του φυλλαδίου στην ερευνητική ομάδα. Μπορείτε επίσης να επικοινωνήσετε με την ομάδα μέσω email ή τηλεφώνου (λεπτομέρειες παρακάτω) για περισσότερες πληροφορίες ή εάν έχετε οποιεσδήποτε ερωτήσεις.

Εάν αποφασίσετε ότι θέλετε να συμμετάσχετε, θα ζητήσουμε από εσάς και το παιδί σας να συμπληρώσετε ένα έντυπο συγκατάθεσης. Θα μπορείτε να κρατήσετε ένα αντίγραφο του φύλλου πληροφοριών και του εντύπου συγκατάθεσης. Εάν επιθυμείτε μπορείτε να σταματήσετέ την διαδικασία οποιαδήποτε στιγμή μετά από αυτό, χωρίς να χρειάζεται να δώσετε λόγο. Αυτό δεν θα επηρεάσει την υποστήριξη που λαμβάνει το παιδί σας.

Πρέπει να πάρω μέρος;

Όχι. Δεν υπάρχει υποχρέωση συμμετοχής του παιδιού σας. Αυτό είναι εντελώς εθελοντικό και εσείς και το παιδί σας μπορείτε να αποσυρθείτε ανά πάσα στιγμή χωρίς να χρειάζεται να αναφέρετε κάποιο λόγο. Εάν αποφασίσετε ότι δεν θέλετε να λάβετε μέρος, αυτό δεν θα επηρεάσει την υποστήριξη υγείας ή εκπαίδευσης που θα λάβει το παιδί σας στο μέλλον.

Είναι η μελέτη εμπιστευτική;

Ναι, η συμμετοχή σε αυτή τη μελέτη είναι απολύτως εμπιστευτική και ανώνυμη. Εσείς και το παιδί σας δεν θα ονομαστείτε σε καμία αναφορά που θα προκύψει από αυτήν τη μελέτη. Η εμπιστευτικότητα θα τηρηθεί καθ' όλη τη διάρκεια της μελέτης και οποιεσδήποτε πληροφορίες τηρεί η ερευνητική ομάδα θα γίνεται χρησιμοποιώντας αριθμούς συμμετεχόντων και όχι ονόματα. Οι διαδικασίες μας για το χειρισμό, την επεξεργασία, την αποθήκευση και την καταστροφή δεδομένων είναι σύμφωνες με τον Νόμο για την Προστασία Δεδομένων του 2018.

Πώς θα χρησιμοποιηθούν τα δεδομένα μας;

Ως πανεπιστήμιο, χρησιμοποιούμε στοιχεία προσωπικής ταυτοποίησης για τη διεξαγωγή έρευνας για τη βελτίωση της υγείας, της περίθαλψης και των υπηρεσιών. Ως οργανισμός που χρηματοδοτείται από το δημόσιο, πρέπει να διασφαλίσουμε ότι είναι προς το δημόσιο συμφέρον όταν χρησιμοποιούμε προσωπικά αναγνωρίσιμες πληροφορίες από άτομα που έχουν συμφωνήσει να συμμετάσχουν στην έρευνα. Αυτό σημαίνει ότι όταν συμφωνείτε να λάβετε μέρος σε μια ερευνητική μελέτη, θα χρησιμοποιήσουμε τα δεδομένα σας με τους τρόπους που απαιτούνται για τη διεξαγωγή και την ανάλυση της ερευνητικής μελέτης. Τα δικαιώματά σας για πρόσβαση, αλλαγή ή μετακίνηση των πληροφοριών σας είναι περιορισμένα, καθώς πρέπει να διαχειριζόμαστε τις πληροφορίες σας με συγκεκριμένους τρόπους για να είναι η έρευνα αξιόπιστη και ακριβής.

Εάν αποσυρθείτε από τη μελέτη, θα διατηρήσουμε τις πληροφορίες που έχουμε ήδη λάβει για εσάς. Για να προστατεύσουμε τα δικαιώματά σας, θα χρησιμοποιήσουμε τις ελάχιστες δυνατές πληροφορίες προσωπικής ταυτοποίησης. Οι πληροφορίες που συλλέγονται θα χρησιμοποιηθούν μόνο για σκοπούς έρευνας για την υγεία και την περίθαλψη σύμφωνα με το Πλαίσιο Πολιτικής του Η.Β. για την Έρευνα Υγείας και Κοινωνικής Φροντίδας.

Τι θα γίνει με τα αποτελέσματα;

Μετά την ανάλυση των δεδομένων, θα παρέχουμε μια σύντομη επισκόπηση των ευρημάτων μας στους συμμετέχοντες και στους εμπλεκόμενους επαγγελματίες ψυχικής υγείας. Σκοπεύουμε τα ευρήματά μας να δημοσιευτούν σε ακαδημαϊκό περιοδικό και να ανακοινωθούν μέσω συνεδρίων. Όλα τα δεδομένα θα είναι ανώνυμα και τυχόν προσωπικά αναγνωρίσιμα δεδομένα που διατηρούνται δεν θα κοινοποιούνται.

Ποιος έχει αξιολογήσει αυτή τη μελέτη;

Η Επιτροπή Δεοντολογίας Φυσικών Επιστημών του Πανεπιστημίου του York, παρείχε την έγκριση με κωδικό "Tsagkaraki 270522".

Με ποιον μπορώ να επικοινωνήσω εάν θέλω να μάθω περισσότερα για τη μελέτη;

Εάν θέλετε να συζητήσετε αυτή τη μελέτη με περισσότερες λεπτομέρειες ή έχετε οποιεσδήποτε συγκεκριμένες ερωτήσεις, επικοινωνήστε με:

Παναγιώτης Τσαγκαράκης – Υποψήφιος Διδάκτορας
panagiotis.tsagkarakis@york.ac.uk / 07444427660
ή
Dr. Gavin Kearney – Καθηγητής στο τμήμα Audio and Music Technology
Gavin.kearney@york.ac.uk / 01904 32 2374

Με ποιον μπορώ να επικοινωνήσω αν θέλω να παραπονεθώ;

Εάν θέλετε να υποβάλετε ή να μιλήσετε για ένα παράπονο, μπορείτε να επικοινωνήσετε με την Υπηρεσία Συμβουλών και Διασύνδεσης Ασθενών (Patient Advice and Liaison Service - PALS). Οι υπηρεσίες που προσφέρουν είναι εμπιστευτικές και δωρεάν, και θα σας καθοδηγήσουν στις διαθέσιμες επιλογές μέσω του Leeds York Partnership Foundation Trust.

Patient Advice and Liaison Service (PALS)
The Becklin Centre
Alma Street
Leeds, West Yorkshire
LS9 7BE
Tel: 0800 052 5790
Email: pals.lypft@nhs.net

Εάν θέλετε να υποβάλετε ένα παράπονο σχετικά με τον τρόπο χειρισμού των προσωπικών σας δεδομένων, μπορείτε να επικοινωνήσετε με τον Υπεύθυνο Προστασίας Δεδομένων μας, ο οποίος θα διερευνήσει το θέμα.

Durham Burt - Υπεύθυνος Προστασίας Δεδομένων
dataprotection@york.ac.uk

Εάν δεν είστε ικανοποιημένοι με την απάντησή μας ή πιστεύετε ότι επεξεργαζόμαστε τα προσωπικά σας δεδομένα με τρόπο που δεν είναι νόμιμο, μπορείτε να παραπονεθείτε στο Information Commissioner’s Office (ICO) https://ico.org.uk/your-data-matters/

Σας ευχαριστούμε που αφιερώσατε χρόνο για να διαβάσετε αυτό το φυλλάδιο.
Εάν έχετε οποιεσδήποτε ερωτήσεις, παρακαλούμε επικοινωνήστε.

C.7 Participant Information Sheet in Greek

"Εμβυθιστικά" ηχοτοπία για την υποστήριξη παιδιών με ΔΕΠΥ
(Immersive Soundscapes Supporting Children with ADHD)

Πληροφορίες για παιδιά με ΔΕΠΥ
Version 1: 26/05/2022

Θα θέλαμε να σου ζητήσουμε να λάβεις μέρος στην ερευνητική μας μελέτη. Μπορείς να επιλέξεις αν θα λάβεις μέρος ή όχι. Αυτό το φυλλάδιο εξηγεί τι μελετάμε και τι θα συμβεί εάν επιλέξεις να λάβεις μέρος. Εάν έχεις ερωτήσεις, μπορείς να μας ρωτήσεις πριν επιλέξεις εάν θέλεις να λάβεις μέρος.

Τι αφορά η μελέτη;
Υπάρχουν πολλά παιδιά με ΔΕΠΥ στην Ελλάδα και στον υπόλοιπο κόσμο. Όλα έχουν τις δικές τους προσωπικότητες, τις συμπάθειες και τις αντιπάθειές τους, αλλά ίσως υπάρχουν και κοινά χαρακτηριστικά όπως:

- Τους αρέσει πολύ να ονειροπολούν
- Ξεχνάνε ή χάνουν πράγματα εύκολα
- Κάνουν απρόσεκτα λάθη
- Παίρνουν περιττά ρίσκα
- Δυσκολεύονται να τα πάνε καλά με τους άλλους

Μερικοί παιδία με ΔΕΠΥ δυσκολεύονται να συγκεντρωθούν σε μία μόνο δραστηριότητα ή νιώθουν αυτή την απροσδιόριστη επιθυμία να κινηθούν. Αυτό προκαλείται από την περιορισμένη απελευθέρωση ντοπαμίνης στον εγκέφαλο. Θέλουμε να βοηθήσουμε αυτούς τους ανθρώπους να διατηρήσουν την εστίασή τους σε μια εργασία χωρίς να αισθάνονται αναστατωμένοι ή άβολα.

Εξετάζουμε πώς ο ήχος μπορεί να βελτιώσει τη συγκέντρωσή σου. Φτιάξαμε ένα απλό βιντεοπαιχνίδι που μπορείς να παίξεις ακούγοντας διαφορετικούς ήχους στα ακουστικά σου. Θα κάνουμε μικρές αλλαγές σε αυτούς τους ήχους ενώ παίζεις και θα δούμε πόσους στόχους πέτυχες. Θα έχεις επίσης την ευκαιρία να δημιουργήσετε το δικό σου ηχητικό περιβάλλον.

Τι θα γίνει αν πάρω μέρος;
Εάν αποφασίσεις ότι θέλεις να λάβεις μέρος, θα σου ζητήσουμε να συναντηθούμε πέντε ξεχωριστές ημέρες. Σε κάθε συνάντηση θα παίξεις το βιντεοπαιχνίδι που έχει διάρκεια 14 λεπτά ενώ ακούς διαφορετικά ηχοτοπία στα ακουστικά σου κάθε φορά. Επίσης την πρώτη μέρα, θα επιλέξεις φυσικούς ήχους που σου αρέσουν για να δημιουργήσεις το αγαπημένο σου ηχητικό τοπίο και στην αρχή τις δεύτερης θα έχεις την ευκαιρία να εξοικειωθείς με τον τρισδιάστατο ήχο. Στο τέλος κάθε συνάντησής, θα χαλαρώσεις με μια διασκεδαστική δραστηριότητα εικονικής πραγματικότητας (virtual Reality-VR).

Γιατί ρωτάτε εμένα;
Θα θέλαμε να σε προσκαλέσουμε να λάβεις μέρος γιατί:

- Έχεις διάγνωση ΔΕΠΥ,
- Είσαι ηλικίας 8-14 ετών,
- Αντιμετωπίζεις δυσκολία συγκέντρωσης,
- Πιστεύουμε ότι θα απολαύσεις τη συμμετοχή σου.

Πρέπει να πάρω μέρος;
Όχι. Δεν χρειάζεται να λάβεις μέρος αν δεν το θέλεις. Εάν αποφασίσεις να συμμετάσχεις, αλλά μετά αλλάξεις γνώμη, είναι επίσης εντάξει. Μπορείς να μας πεις ανά πάσα στιγμή εάν θέλεις να σταματήσεις και δεν θα χρειαστεί να αναφέρεις κάποιο λόγο.

Υπάρχουν κίνδυνοι από τη συμμετοχή;
Όταν παίζετε το παιχνίδι θα ακούγονται κάποιοι θορυβώδεις ήχοι που μπορεί να μην σου αρέσουν. Αυτό μπορεί να φαίνεται λίγο περίεργο ή δύσκολο στην αρχή. Αλλά μπορείς να σταματήσεις να παίζεις ανά πάσα στιγμή αν δεν σου αρέσει.

Υπάρχουν οφέλη από τη συμμετοχή;
Ελπίζουμε να σου αρέσει η συμμετοχή και να μοιραστείς την εμπειρία με φίλους σου, καθώς και θα χρησιμοποιήσεις ακουστικά και εξοπλισμό εικονικής πραγματικότητας (VR)!

Τι γίνεται αν υπάρχει πρόβλημα;
Εάν αντιμετωπίσεις προβλήματα ή έχεις ερωτήσεις κατά τη διάρκεια της μελέτης, μπορείς να μιλήσεις με τους γονείς/κηδεμόνες σου ή με οποιονδήποτε από τους ενήλικες που συμμετέχουν. Η οικογένειά σου μπορεί να επικοινωνήσει με την ερευνητική ομάδα χρησιμοποιώντας τα παρακάτω στοιχεία:

Παναγιώτης Τσαγκαράκης (panagiotis.tsagkarakis@york.ac.uk - 690831928)
Gavin Kearney (gavin.kearney@york.ac.uk - +44(0)1904 32 2374)

Τι θα γίνει με τις πληροφορίες μου;
Εάν αποφασίσεις να συμμετάσχεις, κανείς άλλος δεν θα γνωρίζει ότι οι πληροφορίες που έχουμε είναι από εσένα. Το όνομά σου δεν θα συμπεριληφθεί σε κανένα αποτέλεσμα.

Σε ευχαριστούμε που αφιέρωσες χρόνο για να διαβάσετε αυτό το φυλλάδιο.
Ελπίζουμε ότι θα θελήσεις να πάρεις μέρος.
Εάν έχεις οποιασδήποτε ερωτήσεις, θα χαρούμε να τις απαντήσουμε.

D

[Notes on Participants' Responses: Transcriptions]

D.1 Focus Group

ID	CG051109	Age	10	Location
Date	221029	Sound Cond.	SLN	'Child & Family'
Date	221031	Sound Cond.	SS-MN	Edu. Support Centre
Date	230115	Sound Cond.	PN	
Date	230120	Sound Cond.	SS-AI	
Date	230223	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Spend time listening the sounds.	
Participant's Comments:			I like noisy and changing sound.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LR
2	RD	6	LR	10 C
3	L	7	LFU	11 LF
4	RU	8	L	12 R
Commetns:	Tapping figures on the table, excessive talking over the experiment.			
Preferred Rank:	Bin, Indi, Noise, Sln			
BG Sound Level:	45.5- 48.8 dBA			

ID	FG262009	Age	10	Location
Date	221025	Sound Cond.	SLN	'Child & Family'
Date	221029	Sound Cond.	PN	Edu. Support Centre
Date	230109	Sound Cond.	SS-MN	
Date	230118	Sound Cond.	SS-BN	
Date	230225	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Did not pay attention to sounds. Spent a little time listening them.	
Participant's Comments:			They sounded nice and pleasant.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	R	9 RR
2	R	6	LR	10 LR
3	LR	7	LD	11 RR
4	RR	8	LR	12 R
Comments:	Preferred silence over noise. Generally calm, yawning a lot and sleepy.			
Preferred Rank:	Did not understand the difference in SS: Sln, Noise, SS			
BG Sound Level:	45.3 - 47.9 dBA			

ID	FG160919	**Age**	9	**Location**
Date	230113	Sound Cond.	SLN	'Child & Family'
Date	230117	Sound Cond.	SS-MN	Edu. Support Centre
Date	230120	Sound Cond.	PN	
Date	230228	Sound Cond.	SS-AI	
Date	230310	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Listen the sounds and combinations carefully.	
Participant's Comments:			They sounded like the country house with rivers and a fireplace.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RD	9 LF
2	R	6	RU	10 FR
3	LU	7	RD	11 LF
4	RF	8	LF	12 R
Comments:	Preferred noise over silence. Hamming, excessive mouse clicking and foot movement.			
Preferred Rank:	Bin-Indi, Noise, Silence			
BG Sound Level:	43.7 - 48.6 dBA			

ID	FG191205	**Age**	11	**Location**
Date	230224	Sound Cond.	SLN	'Child & Family'
Date	230301	Sound Cond.	SS-MN	Edu. Support Centre
Date	230303	Sound Cond.	PN	
Date	230308	Sound Cond.	SS-BN	
Date	230310	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Spends time listening the sounds 1by1.	
Participant's Comments:			I like the sound of rain drops and the sound of the running water. They sound pleasant.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RR	9 LF
2	R	6	LD	10 RU
3	LU	7	RU	11 LU
4	RD	8	LR	12 RR
Comments:	Excessive mouse clicks, hits the foot on the floor, plays with the mouse cable.			
Preferred Rank:	Indi, Mono, Bin, Sln, Noise			
BG Sound Level:	45.2 - 48.6 dBA			

ID	FG070119	**Age**	9	**Location**
Date	230223	Sound Cond.	SLN	'Child & Family'
Date	230301	Sound Cond.	SS-MN	Edu. Support Centre
Date	230306	Sound Cond.	PN	
Date	230308	Sound Cond.	SS-AI	
Date	230323	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not spend a lot of time listening the sounds.	
Participant's Comments:			I like the noisy sound of the sea.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	R	9 L
2	R	6	LR	10 U
3	L	7	RF	11 L
4	R	8	LR	12 R
Comments:	Excessive head/body movement and talking and mouse clicks. Talks loud. Finds noise too loud.			
Preferred Rank:	Mono, Indi, Bin, Noise, Sln			
BG Sound Level:	44.9 - 47.9 dBA			

ID	FG110119	**Age**	9	**Location**
Date	230223	Sound Cond.	SLN	'Child & Family'
Date	230301	Sound Cond.	PN	Edu. Support Centre
Date	230306	Sound Cond.	SS-MN	
Date	230308	Sound Cond.	SS-AI	
Date	230309	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not spend a lot of time listening.	
Participant's Comments:			I prefer quiet and calm sounds.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LF
2	R	6	LR	10 RU
3	LR	7	RR	11 L
4	RR	8	L	12 RR
Comments:	Generally calm, excessive hand movement. Hypersensitivity to high sound levels.			
Preferred Rank:	Indi, Bin-Mono, Sln, Noise			
BG Sound Level:	44.6 - 48.5 dBA			

ID	FG141209	**Age**	14	**Location**
Date	230304	Sound Cond.	SLN	'Child & Family'
Date	230309	Sound Cond.	PN	Edu. Support Centre
Date	230311	Sound Cond.	SS-MN	
Date	231115	Sound Cond.	SS-BN	
Date	231117	Sound Cond.	SS-AI	
Notes on Soundscape Design:		Spend time listening, carefully.		
Participant's Comments:		I prefer calm sounds. Did not liked the wind - it was too loud.		
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RUF	9 L
2	R	6	L	10 R
3	LU	7	RD	11 L
4	R	8	L	12 RU
Comments:	Sensitive to loud sounds. Sbj recognised the sound of cicadas and liked as a 'game'.			
Preferred Rank:	Sln, Indi, Mono-Bin, Noise			
BG Sound Level:	44.8 - 48.3 dBA			

ID	FG200809	**Age**	10	**Location:**
Date	230223	Sound Cond.	SLN	'Child & Family'
Date	230224	Sound Cond.	PN	Edu. Support Centre
Date	230302	Sound Cond.	SS-MN	
Date	230303	Sound Cond.	SS-AI	
Date	230309	Sound Cond.	SS-BN	
Note Soundscape Design:		Listen carefully the sounds 1by1.		
Participant's comments:		I like the sound of rain, fire, water - sounds familiar and I liked it.		
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RR	9 LF
2	R	6	LD	10 R
3	LF	7	RR	11 LF
4	RR	8	L	12 R
Comments:		Hamming during the administration, relative calm.		
Preferred Rank:		Sln, Indi, Pink, Mono-Bin		
Peak BG sound Level:		45.4 - 48.1 dBA		

ID	FG330905	**Age**	12	**Location**
Date	230113	Sound Cond.	SLN	'Child & Family'
Date	230117	Sound Cond.	SS-MN	Edu. Support Centre
Date	230302	Sound Cond.	PN	
Date	230303	Sound Cond.	SS-AI	
Date	230309	Sound Cond.	SS-BN	
Note Soundscape Design:	Did not spend time listening the sounds.			
Participant's Comments:	I like them. Sounds relaxing.			
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RD	9 L
2	R	6	LR	10 RF
3	LU	7	RR	11 RU
4	RR	8	LR	12 R
Comments:	Excessive hand movement. Tapping figures on the table			
Preferred Rank:	Sln, Bin, Indi, Mono, Noise			
Peak BG sound Level:	44.3 - 48.4 dBA			

ID	FG321109	**Age**	11	**Location**
Date	230223	Sound Cond.	SLN	Child & Family
Date	230224	Sound Cond.	PN	Edu. Support Centre
Date	230120	Sound Cond.	SS-MN	
Date	230228	Sound Cond.	SS-BN	
Date	230310	Sound Cond.	SS-AI	
Note Soundscape Design:	Listen to sound 1b1 and combinations.			
Participant's Comments:	Calming sounds. I enjoy the gentle rainfall, and the wind passing through the trees.			
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RR	9 LR
2	R	6	LD	10 RF
3	LU	7	RU	11 LD
4	R	8	LR	12 R
Comments:	Hamming throughout the experiment. Tapping the foot on the floor. Sbj recognised the sound of cicadas and liked it as a "game'.			
Preferred Rank:	Bin-Indi, Noise, Mono, Sln			
Peak BG Sound Level:	43.9 - 48.1 dBA			

ID	FU031514	**Age**	13	**Location**
Date	221212	Sound Cond.	SLN	'Trinity Academy'
Date	221214	Sound Cond.	SS-MN	Halifax
Date	230124	Sound Cond.	PN	
Date	230123	Sound Cond.	SS-BN	
Date	230208	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Spend time listening the sounds 1by1, carefully.	
Participant's Comments:			I see a cardboard burning. We have a shed at home, and I like the sounds, familiar. The sound of fire makes me sleepy.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RU	9 LU
2	R	6	RU	10 FR
3	L	7	LD	11 LF
4	R	8	LD	12 RR
Comments:	Excessive talking over the game, excessive hand movement, jumping to his chair a few times, and tapping fingers on the table.			
Preferred Rank:	Bin, Indi, Noise, Mono, Sln			
BG Sound Level:	43.2-47.5 dBA			

ID	FU041212	**Age**	12	**Location**
Date	230202	Sound Cond.	SLN	'Trinity Academy'
Date	230206	Sound Cond.	SS-MN	Halifax
Date	230209	Sound Cond.	PN	
Date	230208	Sound Cond.	SS-AI	
Date	230209	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Listen carefully the sounds 1by1	
Participant's Comments:			Participant likes loud noises. Selection was loud and cool sounds.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RU	9 LU
2	R	6	L	10 RR
3	L	7	RU	11 LU
4	R	8	LR	12 R
Comments:	Prefers noise to silence. 'Silence is Boring'. Excessive talking and excessive body movement while sitting.			
Preferred Rank:	Mono, Bin-Indo, Noise, Sln			
BG sound Level:	45.3-48.7 dBA			

ID	FU070907	**Age**	13	**Location**	
Date	221206	Sound Cond.	SLN	Child & Family	
Date	230123	Sound Cond.	PN	Edu. Support Centre	
Date	230202	Sound Cond.	SS-MN		
Date	230207	Sound Cond.	SS-AI		
Date	230208	Sound Cond.	SS-BN		
Notes on Soundscape Design:			Did not spend any time listning to the sounds.		
Participant's Comments:			They sounded nice, and relaxing.		
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):					
1	L	5	RU	9	LU
2	R	6	LD	10	R
3	LU	7	RD	11	LU
4	R	8	L	12	RD
Commetns:		Tapping the figures on the table. He holds his hand with one hand while playing. Lays on the chair. Moves the feet while sitting. He plays with the mouse cable. The sbj recognised the sound of cicadas and liked it as a 'game'.			
Prefered Rank:		Bin, Indi, Mono, sln, Noise			
BG sound Level:		43.5-48.2 dBA			

ID	FU080118	**Age**	10	**Location**	
Date	221205	Sound Cond.	SLN	'Trinity Academy'	
Date	230130	Sound Cond.	SS-MN	Halifax	
Date	230202	Sound Cond.	PN		
Date	230207	Sound Cond.	SS-BN		
Date	230208	Sound Cond.	SS-AI		
Notes on Soundscape Design:			Spend time listening to the sounds and combinations.		
Participant's Comments:			Selection sounded calm and nice		
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):					
1	L	5	R	9	RR
2	R	6	LR	10	LR
3	LR	7	LD	11	RR
4	RR	8	LR	12	R
Comments:		Excessive movement in the chair. Subject blows off and relieves boredom.			
Preferred Rank:		Sln, bin-Indo, Mono, Noise			
BG sound Level:		44.5 -48.6 dBA			

ID	FU100105	**Age**	11	**Location**
Date	221214	Sound Cond.	SLN	'Trinity Academy'
Date	230125	Sound Cond.	PN	Halifax
Date	230131	Sound Cond.	SS-MN	
Date	230206	Sound Cond.	SS-AI	
Date	230209	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Listen carefully the sounds 1by1.	
Participant's Comments:			I live in the countryside and I like silence, the sudden fire cracks and the rain drops.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LR
2	RD	6	LR	10 C
3	L	7	LFU	11 LF
4	RU	8	L	12 R
Comments:	Played with the mouse cable. Relative relaxed. Found Indi more interesting and preferred the lower level of SS.			
Preferred Rank:	Indi, Bin, Mono, Noise, Sln			
BG sound Level:	44.3 - 47.9 dBA			

ID	FU180125	**Age**	12	**Location**
Date	221213	Sound Cond.	SLN	'Trinity Academy'
Date	230124	Sound Cond.	SS-MN	Halifax
Date	230131	Sound Cond.	PN	
Date	230206	Sound Cond.	SS-BN	
Date	230208	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Spend time listening the sounds	
Participant's Comments:			They go well together, they compliment eachoother.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RRU	9 LRD
2	R	6	LUR	10 R
3	LU	7	RRU	11 LR
4	RR	8	LD	12 RU
Commetns:	He accuses himself every time he makes a mistake. Plays with the mouse cable. Lays on the chair. Blows off and relieves boredom.			
Prefered Rank:	No difference - Noise, Bin-Indi, Mono, Sln			
BG sound Level:	45.7-48.7 dBA			

D.2 Control Group

ID	CG131109	**Age**	9	**Location**
Date	221029	Sound Cond.	SLN	Sbj Home Athens
Date	221101	Sound Cond.	PN	
Date	230115	Sound Cond.	SS-MN	
Date	230118	Sound Cond.	SS-BN	
Date	230123	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Spend time listening the sounds and combinations.	
Participant's Comments:			I enjoy the sound of fire and rain, like when we have the fire place on at home	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	R	9 L
2	R	6	LR	10 R
3	LR	7	RR	11 L
4	RR	8	LR	12 RF
Comments:	Feeling bored, yawning, moving the feet.			
Preferred Rank:	Bin, Sln, Noise			
BG Sound Level:	45.4 -45.7 dBA			

ID	CG111415	**Age**	8	**Location**
Date	221022	Sound Cond.	SLN	Sbj Home Athens
Date	221029	Sound Cond.	SS-MN	
Date	230104	Sound Cond.	PN	
Date	230114	Sound Cond.	SS-AI	
Date	230324	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not listen carefully the sounds	
Participant's Comments:			Sounds nice.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RD	9 LF
2	R	6	LU	10 RD
3	LF	7	RR	11 LR
4	RU	8	LR	12 RR
Comments:	Board, does not like noise.			
Preferred Rank:	Sln, Noise, Mono, Bin			
BG Sound Level:	43.8 - 46.7 dBA			

ID	CG131909	**Age**	12	**Location**
Date	221029	Sound Cond.	SLN	Sbj Home Athens
Date	221107	Sound Cond.	PN	
Date	230114	Sound Cond.	SS-MN	
Date	230107	Sound Cond.	SS-BN	
Date	230117	Sound Cond.	SS-AI	
Notes on Soundscape Design:			spend time listening the sounds	
Participant's Comments:			I like the sounds of rain and water; they relax me.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LU
2	R	6	LR	10 RU
3	LF	7	U	11 LR
4	RR	8	LR	12 RR
Comments:	Prefers silence over noise.			
Preferred Rank:	Sln, Bin, Mono, Noise			
BG Sound Level:	43.3 - 46.7 dBA			

ID	CG192009	**Age**	13	**Location**
Date	221025	Sound Cond.	SLN	Sbj Home Athens
Date	221025	Sound Cond.	SS-MN	
Date	230109	Sound Cond.	PN	
Date	230118	Sound Cond.	SS-AI	
Date	230123	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Spend time listening to sounds and combinations.	
Participant's Comments:			The sounds are relaxing and I feels calm.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LF
2	R	6	LD	10 RR
3	LR	7	RU	11 LU
4	RD	8	LR	12 RD
Comments:	Prefers Silence			
Preferred Rank:	Sln, Bin - Indi - Mono all sound the same, Noise			
BG Sound Level:	44.3 - 46.6 dBA			

ID	CG191415	**Age**	8	**Location**
Date	221022	Sound Cond.	SLN	Sbj Home Athens
Date	221029	Sound Cond.	SS-MN	
Date	230104	Sound Cond.	PN	
Date	230114	Sound Cond.	SS-BN	
Date	230324	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Listen the sounds 1by1.	
Participant's Comments:			Sounds calm and help me concentrate.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RR	9 LF
2	R	6	L	10 R
3	L	7	RR	11 L
4	R	8	LR	12 RU
Comments:	Preferred silence over noise. Sensitive to noise and loud sounds.			
Preferred Rank:	Sln, mono, bin, Noise			
BG Sound Level:	44.6 - 47.6 dBA			

ID	CU122509	**Age**	8	**Location**
Date	221128	Sound Cond.	SLN	'Trinity Academy'
Date	221207	Sound Cond.	PN	Halifax
Date	230125	Sound Cond.	SS-MN	
Date	230130	Sound Cond.	SS-AI	
Date	230208	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not pay attention to sounds. Just listen to a few, not all.	
Participant's Comments:			I like the sound of rain and fire. Makes me feel cosy and comfy.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LU
2	R	6	CR	10 RR
3	LU	7	RD	11 L
4	RU	8	LR	12 D
Comments:				
Preferred Rank:	Sln, Bin, Noise, Mono			
BG Sound Level:	45.9 - 48.7 dBA			

ID	CU081407	**Age**	13	**Location**
Date	221128	Sound Cond.	SLN	'Trinity Academy'
Date	221206	Sound Cond.	SS-MN	Halifax
Date	221214	Sound Cond.	PN	
Date	230125	Sound Cond.	SS-BN	
Date	230208	Sound Cond.	SS-AI	

Notes on Soundscape Design:	Did not listen all sounds. Did not spend a lot of time listening to the sounds.
Participant's Comments:	I found the sounds relaxing. I liked them.

Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):

1	L	5	R	9	LR
2	R	6	LU	10	RU
3	LUF	7	RU	11	L
4	RRU	8	LD	12	L

Comments:	Left-Handed. He preferred noise over Silence
Preferred Rank:	Silence, Binaural, Noise
BG Sound Level:	45.1 - 48.9 dBA

ID	CU010918	**Age**	14	**Location**
Date	221128	Sound Cond.	SLN	'Trinity Academy'
Date	221206	Sound Cond.	SS-MN	Halifax
Date	230125	Sound Cond.	PN	
Date	230208	Sound Cond.	SS-BN	
Date	230209	Sound Cond.	SS-AI	

Notes on Soundscape Design:	Listen to all the sounds, spent time, concentrated. Could distinguish the sounds
Participant's Comments:	Selection calm and not overwhelming

Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):

1	L	5	RF	9	LU
2	R	6	FD	10	RRU
3	LU	7	RD	11	LF
4	RR	8	LR	12	RU

Comments:	
Preferred Rank:	Noise, Indi, Bin, Mono, Sln
BG Sound Level:	45.9 - 47.2 dBA

ID	CU120525	**Age**	12	**Location**
Date	221128	Sound Cond.	SLN	'Trinity Academy'
Date	221206	Sound Cond.	PN	Halifax
Date	221214	Sound Cond.	SS-MN	
Date	230125	Sound Cond.	SS-BN	
Date	230208	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Listen carefully, one by one	
Participant's Comments:			The sounds of fire crackling helps me concentrate.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LF
2	R	6	LD	10 RR
3	LR	7	RU	11 LU
4	RD	8	LR	12 RD
Comments:	Preferred Noise from silence - less distraction.			
Preferred Rank:	Silence, Noise, Indicators, Bin, Mono			
BG Sound Level:	45.2 - 48.5 dBA			

ID	CU011514	**Age**	12	**Location**
Date	221128	Sound Cond.	SLN	'Trinity Academy'
Date	221206	Sound Cond.	PN	Halifax
Date	221214	Sound Cond.	SS-MN	
Date	230130	Sound Cond.	SS-AI	
Date	230208	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Listen to the sounds one by one and many combinations.	
Participant's Comments:			I liked the crackles from the fire and the raindrops. I remember it felt like opening the curtains to hear the rain at the window.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	R	9 L
2	R	6	LR	10 R
3	LR	7	RR	11 L
4	RR	8	LR	12 RF
Comments:	Preferred noise over silence because noise kept his mind busy and this allowed him to concentrate on the game.			
Preferred Rank:	Bin, Indi, Mono, Noise, Sln			
BG Sound Level:	42.4 - 46.9 dBA			

ID	CU031514	Age	8	Location
Date	221129	Sound Cond.	SLN	'Trinity Academy'
Date	221207	Sound Cond.	SS-MN	Halifax
Date	221212	Sound Cond.	PN	
Date	230130	Sound Cond.	SS-AI	
Date	230208	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Spent time listening the sounds 1by1.	
Participant's Comments:			I selected these sounds because they go well together. I like the sound of gentle rainfall.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RU	9 L
2	R	6	LD	10 RU
3	LR	7	RU	11 LRU
4	RF	8	LR	12 RFU
Comments:	In Binaural condition he commented that it made him sleepy.			
Preferred Rank:	Sln, Indi, Noise, Bin, Mono			
BG Sound Level:	45.3 - 46.8 dBA			

ID	CU121807	Age	8	Location
Date	221129	Sound Cond.	SLN	'Trinity Academy'
Date	221212	Sound Cond.	SS-MN	Halifax
Date	230123	Sound Cond.	PN	
Date	230208	Sound Cond.	SS-BN	
Date	230209	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Listen very carefully the sounds	
Participant's Comments:			It is a calming combination.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RF	9 LRF
2	R	6	LF	10 RDF
3	LR	7	RD	11 LU
4	RR	8	LDR	12 RU
Comments:				
Preferred Rank:	Bin, Noise, Mono, Sln			
BG Sound Level:	41.4 - 47.9 dBA			

ID	CU082505	**Age**	13	**Location**
Date	221129	Sound Cond.	SLN	'Trinity Academy'
Date	221207	Sound Cond.	SS-MN	Halifax
Date	221212	Sound Cond.	PN	
Date	230130	Sound Cond.	SS-AI	
Date	230131	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not spend time listening the sounds.	
Participant's Comments:			Survival setting: It feels like someone sitting at the beach with a camp fire.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RU	9 LU
2	RU	6	LR	10 RU
3	U	7	RU	11 LU
4	RU	8	LU	12 RU
Comments:	Prefer noise over silence because 'something was happening' except the visual task.			
Preferred Rank:	Bin, Indi, Mono, Noise, Sln			
BG Sound Level:	45.7 - 47.8 dBA			

ID	CU150525	**Age**	12	**Location**
Date	221129	Sound Cond.	SLN	'Trinity Academy'
Date	221212	Sound Cond.	PN	Halifax
Date	230123	Sound Cond.	SS-MN	
Date	230130	Sound Cond.	SS-AI	
Date	230209	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not spend time listening the sounds, went straight to the combinations.	
Participant's Comments:			I chose the ones that calm me. Some were too fast and would annoy me if I tried to concentrate. I like the sound of the wind rustling through the leaves.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	LR	5	R	9 LU
2	R	6	LR	10 RU
3	LR	7	RR	11 LD
4	LR	8	U	12 RR
Comments:	Preferred silence over noise. The noise was distracting.			
Preferred Rank:	Sln, Indi, Bin, Mono, Noise			
BG Sound Level:	45.9 - 47.9 dBA			

ID	CU221420	**Age**	8	**Location**
Date	221129	Sound Cond.	SLN	'Trinity Academy'
Date	221207	Sound Cond.	SS-MN	Halifax
Date	221212	Sound Cond.	PN	
Date	230207	Sound Cond.	SS-BN	
Date	230208	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Listen to sounds 1by1.	
Participant's Comments:			I combined sounds of fire because they sounded richer, calming and relaxing. The others sounded too loud.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	R	9 LR
2	R	6	LR	10 RLR
3	LR	7	RD	11 LU
4	R	8	LR	12 R
Comments:	Preferred silence over noise.			
Preferred Rank:	Sln, Bin, Indi, Mono, Noise			
BG Sound Level:	45.9 - 47.8 dBA			

ID	CU011204	**Age**	12	**Location**
Date	221130	Sound Cond.	SLN	'Trinity Academy'
Date	221205	Sound Cond.	SS-MN	Halifax
Date	221213	Sound Cond.	PN	
Date	230124	Sound Cond.	SS-AI	
Date	230131	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Spend time listening the sounds.	
Participant's Comments:			The section I made sounded nice!	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RU	9 LU
2	R	6	LD	10 RU
3	LR	7	RD	11 LU
4	RR	8	LR	12 RU
Comments:	Preferred noise over silence.			
Preferred Rank:	Indi, Bin, Noise, Mono, Sln			
BG Sound Level:	46.3 - 48.7 dBA			

ID	CU100308	Age	8	Location
Date	221130	Sound Cond.	SLN	'Trinity Academy'
Date	221205	Sound Cond.	SS-MN	Halifax
Date	221213	Sound Cond.	PN	
Date	230131	Sound Cond.	SS-BN	
Date	230209	Sound Cond.	SS-AI	
Notes on Soundscape Design:			Listen to sounds 1by1.	
Participant's Comments:			I like calm sounds away from the noise - city noise. I like listening to the heavy raindrops on my homes window.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	LR	5	RR	9 LU
2	R	6	LU	10 R
3	LR	7	RU	11 LU
4	RR	8	LUR	12 R
Comments:	Preferred silence over noise.			
Preferred Rank:	Bin, Sln, Mono, Noise			
BG Sound Level:	45.7 - 48.9 dBA			

ID	CU131212	Age	13	Location
Date	221130	Sound Cond.	SLN	'Trinity Academy'
Date	221205	Sound Cond.	SS-MN	Halifax
Date	221213	Sound Cond.	PN	
Date	230124	Sound Cond.	SS-AI	
Date	230206	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Spend time listening the sounds 1by1.	
Participant's Comments:			I like the sounds of the ocean and fire with the wind because it reminds me of the place where I lived with my family before and feels familiar.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	RUF	9 L
2	R	6	L	10 R
3	LU	7	RD	11 L
4	R	8	L	12 RU
Comments:	Very concentrated. The participant told me a story about his brother, playing music and enjoying listening while studying.			
Preferred Rank:	Sln, Noise, Bin, Indi, Mono			
BG Sound Level:	45.3 - 47.1 dBA			

ID	CU130425	**Age**	8	**Location**
Date	221130	Sound Cond.	SLN	'Trinity Academy'
Date	221205	Sound Cond.	PN	Halifax
Date	221213	Sound Cond.	SS-MN	
Date	230131	Sound Cond.	SS-AI	
Date	230207	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Listen carefully, 1by1 the sounds	
Participant's Comments:			They sounded relaxing.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	R	9 LU
2	R	6	LU	10 RU
3	LD	7	RD	11 LU
4	R	8	LU	12 RF
Comments:	Preferred Noise over silence			
Preferred Rank:	Noise, Sln, Indi, Bin, Mono			
BG Sound Level:	46.2 - 48.2 dBA			

ID	CU130525	**Age**	12	**Location**
Date	221130	Sound Cond.	SLN	'Trinity Academy'
Date	221205	Sound Cond.	SS-MN	Halifax
Date	221213	Sound Cond.	PN	
Date	230124	Sound Cond.	SS-AI	
Date	230208	Sound Cond.	SS-BN	
Notes on Soundscape Design:			Did not spend a lot of time listening to the sounds.	
Participant's Comments:			I selected sounds that were not loud.	
Spatial Audio Responses (Left, Right, Up, Down, Front, Rear):				
1	L	5	LF	9 LF
2	R	6	RR	10 RF
3	RR	7	LR	11 LF
4	LR	8	L	12 RF
Comments:				
Preferred Rank:	Indi, Bin, Sln, Mono, Noise			
BG Sound Level:	43.9-47.2 dBA			

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