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AUDITORY PROCESSING-DRIVEN SOUNDSCAPE DESIGN FOR DEMENTIA: A SYSTEMATIC FRAMEWORK FOR ENVIRONMENTAL INTERVENTION

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ABSTRACT

Auditory neuroscience research has uncovered distinctive patterns of auditory processing deficits across dementia variants, underscoring the urgent need for targeted soundscape interventions in indoor spaces and specifically for dementia care design. This paper develops a systematic framework linking dementia-specific auditory deficits to soundscape design principles. By examining both bottom-up and top-down auditory processing mechanisms, we elucidate how different forms of dementia affect auditory scene analysis. We present a functional block diagram that maps specific auditory deficits to distinct dementia types, including Alzheimer's disease, frontotemporal dementia, and posterior cortical atrophy. This mapping guides the development of soundscape interventions that address both energetic and semantic masking while promoting temporal and spatial orientation. Our study reveals how strategic indoor soundscape augmentation can compensate for specific auditory processing deficits. Based on our findings, we present evidence-based guidelines for soundscape augmentation in indoor environments, emphasizing personalized approaches and environmental context. This work advances both the theoretical understanding of auditory processing in dementia and practical applications for creating supportive acoustic environments, ultimately enhancing the quality of life for people with dementia.

Keywords: *ASA, Appraisal, Soundscape, Dementia.*

1. INTRODUCTION

Dementia presents unique challenges in perceiving and processing auditory information, with distinct patterns of impairment across different variants of the condition [1, 2]. While visual aspects of environmental design have received considerable attention, the acoustic environment remains relatively unexplored despite its profound impact on cognition, behaviour, and quality of life. The brain's auditory system analyzes, evaluates, and interprets complex acoustic events—a process known as Auditory Scene Analysis (ASA) [3], although Appraisal should be added to this process [4] (ASA&A). The ASA&A allows individuals to make sense of their auditory environment, identify crucial sounds, and respond appropriately to acoustic information. However, in dementia, this fundamental cognitive process becomes compromised [5]. Soundscape augmentation showed promising results in helping people with dementia navigate their daily lives and lower their behavioural and psychological behaviour [6-8]. Knowing that various forms of dementia exhibit specific auditory deficits, it is essential to tailor soundscape augmentation to individuals depending on their specific auditory impairments.

This paper presents a systematic framework connecting specific auditory deficits in different dementia types to targeted soundscape design interventions. By understanding how dementia affects auditory processing at higher cognitive

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levels, we can develop evidence-based approaches to create supportive acoustic environments that compensate for these deficits and enhance quality of life.

2. AUDITORY SCENE ANALYSIS AND APPRAISAL IN DEMENTIA

Auditory scene analysis operates through two primary mechanisms: bottom-up and top-down processing [9]. Bottom-up processing involves analyzing basic acoustic signals based on their physical characteristics, including frequency, amplitude, temporal features, and spatial location. It is data-driven and essential for initial sound processing. Top-down processing involves applying past knowledge, expectations, and cognitive frameworks to interpret auditory information, filling gaps and resolving ambiguities. Figure 1 shows the relation between top-down and bottom-up processing.

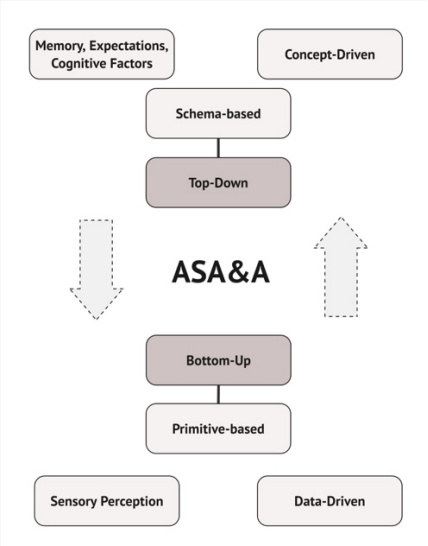

Figure 1: A diagram of ASA & A and the top-down and bottom-up relation

Different forms of dementia disrupt these processes in distinct ways. Alzheimer's disease primarily affects temporoparietal cortical areas and presents auditory disorientation, increased sound sensitivity, and tracking in complex acoustic environments [2,10]. Posterior Cortical Atrophy presents auditory agnosia and even more severe deficits in ASA&A segregation and grouping [11]. Frontotemporal Dementia variants show agnosia for environmental sounds, impairments in rhythm, pitch, and timbre perception, and disrupted emotional processing of sounds [2]. Lewy Body Dementia often presents with auditory hallucinations and broad disruptions of auditory processing [2].

These impairments can affect primitive-based (bottom-up) or schema-based (top-down) processing. Conditions impacting temporoparietal regions, such as Alzheimer's Disease, predominantly affect primitive-based processing. At the same time, Frontotemporal Dementia variants show greater impairment in schema-based processing that relies on existing knowledge and expectations.

3. FRAMEWORK DEVELOPMENT

To systematically address these auditory deficits, we developed a functional block diagram (FBD) that maps specific types of dementia to their associated auditory symptoms and processing deficits. Diagram 1 shows the overall concept of this framework and provides a structured approach to understanding the relationship between neurological deterioration and auditory impairment, offering a foundation for targeted interventions.

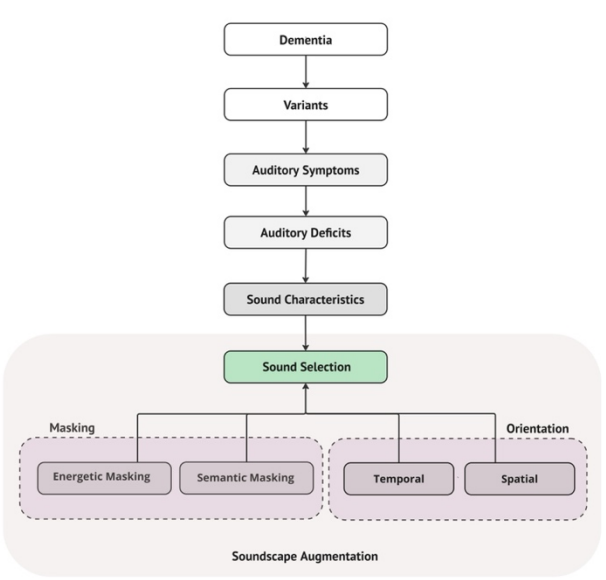

Diagram 1: Functional Block Diagram of auditory deficit in dementia and soundscape augmentation

The FBD illustrates how different dementia types (Alzheimer's Disease, Posterior Cortical Atrophy, Frontotemporal Dementia and its variants, Lewy Body Dementia, and Vascular Dementia) relate to specific auditory symptoms (such as auditory agnosia, sound

aversion, musicophilia, and word deafness) and underlying processing deficits (difficulties in localization, attention, rhythm perception, and more).
This mapping reveals patterns of impairment that inform the development of soundscape interventions. For example, Alzheimer's Disease predominantly affects auditory scene analysis and spatial processing, suggesting interventions should emphasize clear temporal patterns and distinct frequency separation. For Frontotemporal Dementia, which impacts rhythm, pitch, and emotional processing of sounds, interventions should focus on regular, simple rhythmic patterns with limited emotional complexity.

4. SOUNDSCAPE DESIGN PRINCIPLES

Based on our framework, we propose soundscape design principles that address both energetic and semantic masking while promoting temporal and spatial orientation. Energetic masking physically obstructs unwanted acoustic signals through amplitude-based interventions, reducing auditory clutter at a fundamental sensory level [12]. This approach is particularly valuable for individuals with bottom-up processing deficits, as it alleviates cognitive load by limiting competing stimuli.
Semantic masking creates cognitive interference with meaningful but distracting sounds, regulating attention through meaning-based interventions [13]. This strategy helps individuals concentrate on relevant auditory information while facilitating the cognitive processing of significant acoustic signals—especially beneficial for those with preserved bottom-up but impaired top-down processing.
For Alzheimer's Disease, effective soundscape characteristics include simple, predictable rhythmic patterns, sounds with clear spatial localization, familiar environmental sounds, reduced complexity in multi-layered sounds, and moderate tempo. For Posterior Cortical Atrophy, simplified auditory environments with single-source sounds, clear separation between sound elements, and minimal overlapping of sound sources are recommended. Diagram 2 shows the FBD focusing on Alzheimer's disease.

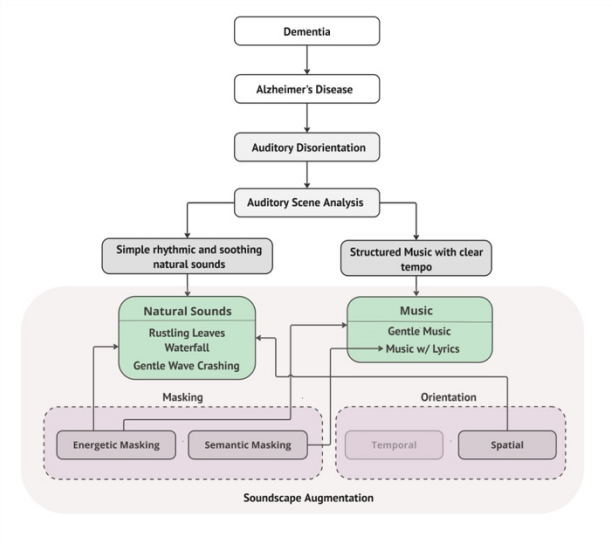

Diagram 2: Functional Block Diagram of auditory Deficit in Alzheimer's Disease and Sound Selection for Soundscape Augmentation

5. IMPLEMENTATION AND FUTURE DIRECTION

Successful implementation of this framework requires consideration of several key factors. Individual preferences and physiological responses must guide soundscape selection, with ongoing monitoring to assess effectiveness. Temporal variations throughout the day, environmental context, prevailing cognitive state, and overall sensory load all influence the optimal soundscape intervention for a given situation.
When implementing specific sound selections, natural sounds (rustling leaves, water streams, gentle rain) and anthropogenic sounds (office hum, gentle music) should be selected based on their characteristics and the specific auditory deficits they address. For example, audiobooks may benefit individuals with Semantic Variant Primary Progressive Aphasia who maintain relatively intact auditory processing capabilities but would be contraindicated for those with Parkinson's Disease/Lewy Body Dementia due to the risk of triggering hallucinations. Future research should focus on validating these soundscape interventions through controlled studies, developing technology for adaptive soundscape delivery, and integrating auditory interventions with other sensory approaches in dementia care design.

6. CONCLUSION

This paper has presented a systematic framework linking auditory processing deficits in various forms of dementia to targeted soundscape design principles. By understanding the distinct patterns of impairment associated with each dementia type, we can develop evidence-based approaches to indoor soundscape design that address specific needs.

The framework provides theoretical insights into auditory processing in dementia and practical guidelines for creating supportive acoustic environments. Through strategic soundscape augmentation that considers energetic and semantic masking along with temporal and spatial orientation, we can enhance the quality of life for people living with dementia and create more supportive indoor environments.

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