MEMOSOUND—Mechanistic pathways of memory retrieval from urban soundscapes

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Introduction

Memory retrieval (MR) refers to accessing stored information, and the sonic environment plays a crucial role in influencing how efficiently and effectively we can retrieve memories [1]. Environmental sounds, music, or familiar auditory cues can serve as powerful triggers for memory recall, and the interaction between our cognitive processes and sonic stimuli can either enhance or hinder memory performance [2]. Several studies have separately demonstrated the impact of both positive [3-5] and negative [6-8] sounds on the health and well-being of MR processes. However, no mechanistic pathway study has demonstrated how auditory cues influence the MR process in urban soundscapes across different contexts, activities, and user profiles.

A traditional mechanistic pathway approach typically illustrates the step-by-step process of biochemical reactions in humans or animals [9]; however, the concept of mechanistic pathways has also been recently considered in the context of interactions between the physical and biological domains, as demonstrated by Engel et al. [10].

The proposed project offers a novel perspective on investigations in soundscape studies and employs a mixed-methods design to investigate how MR occurs concerning different urban soundscapes. The mixed-methods design integrates qualitative and quantitative data collection, enabling a comprehensive understanding of the direct and indirect processes associated with MR. Triangulating procedures enable a detailed interpretation and synthesis of the results, as outlined by Creswell [11]. This methodology aligns with the holistic framework proposed by ISO/TS 12913 – Part 2, which emphasises the use of multiple data collection techniques to better understand the perceived sonic environment [12-13]. This approach enables a deeper exploration of how urban sounds impact human memory recall (MR), supported by neurophysiological data, psychoacoustic modelling of sound sources, and a comprehensive analysis of user profiling and contextual interactions. To advance the mechanistic pathway of this study, a structured methodological approach will be employed, subdivided into sequential sub-steps. These sub-steps are designed to identify the most effective instruments for collecting subjective and objective data. This includes the development of audiovisual experiments featuring various urban scenes to investigate short-, mid-, and long-term MR while tracking responses through neurophysiological measurements. Additionally, experiments will be conducted with diverse target groups, including those with and without cognitive and auditory impairments, to examine how user profiles affect MR processes. In addition to the audiovisual experiments, a citizen science-based app will facilitate data collection, identifying the types of memories triggered in different urban environments daily, thereby allowing for mid-term MR data collection. This app will also be connected to the cloud via the Internet of Things (IoT) and can assist with mapping and urban planning purposes. Finally, the analysis of all employed sounds using signal processing and psychoacoustic modelling helps comprehend the signals used in all phases of the work and their influence on the cognitive processes related to MR.

Methods

The MEMOSOUND project comprises seven phases, measuring the acute to chronic impacts on MR, as illustrated in Figure 1, following a mixed-methods design. Inside this approach, some phases follow specific design procedures. In the phases shown in light grey, a convergent parallel design (CPD) will be adopted. CPD is when quantitative and qualitative data co-occur and are analysed separately. At the same time, the violet-indicated phases follow an embedded design, where one dataset is embedded within another. The primary data can be qualitative or quantitative, and the secondary data is used to support or expand the primary data. The salmon-indicated phase analyses the previous phases in more depth. It follows an explanatory design, aiming to provide a more detailed explanation of the observed trends from the collected quantitative data [11].

Before conducting auditory experiments, a **preliminary step of fitting taxonomies** is necessary to measure the impact of short- and long-term memory noise and how restorative environments can enhance memory restoration (MR). The taxonomies of MR, affective content and perceived restorative scale will be adjusted. This phase counts on existing affective and retrieved memory response datasets from Dr. Engel's PhD studies [14] and soundscape studies related to restorative environments collected in Brazil [15-16]. A further step, involving the combination of neurophysiological tests with cognitive assessments, while soundscape scenes are played in the background, is also essential. This step involves **a pilot study**, during which both subjective and objective instruments are refined for data collection in subsequent steps. In this step, the audiovisual scenes will also be recorded and used during the MEMOSOUND project.

The **impacts of short-term MR** responses will be collected through the **"MIND—Memory Impact of Noise Disturbance"** experiment. This experimental phase aims to determine the effect of urban noise on MR in educational settings, focusing on both learning and work environments. The next phase will be using a mobile phone app called **Sound Diary App.** The app will be developed to determine the impact of **mid-term MR** and allow data collection through the Citizen & Science modality. Participants will

contribute their experiences by listening to various urban sounds in their environment and answering questions about how those sounds affect their memories or evoke specific recollections. The app can send reminders to the user, encouraging repeated reports and aiding in the determination of mid-term MR impacts on the sonic environments. The data collected can be sent to the cloud through the Internet of Things (IoT), producing impact maps of the MR of urban soundscapes. These maps are helpful tools that can aid in managing urban settings and enhancing urban planning related to the sonic environment. The impact of short- and long-term noise on MR will be investigated through the "SOUNDS – Sensory Overload and Unwanted Noise Disruption of Soundscapes" audiovisual experiments, which aim to explore how individuals with varying degrees of hearing impairment experience MR in response to urban soundscapes and unwanted sounds. Restorative soundscapes will be tested by the "**RESME – Restorative Soundscape for Memory Enhancement**" audiovisual experiments. This experiment aims to investigate how exposure to restorative soundscapes (natural, soothing sounds such as water flowing, birdsong, or rustling leaves) influences both short-term and long-term memory recall (MR) and the potential benefits of neurophysiological recovery through restorative soundscapes.

Since the audiovisual experiments will be tracked through neurophysiological measurements, it is possible to verify how the stimuli trigger the auditory brain response and the activation of MR. These changes will be observed in the time domain, and the corresponding sound sources will be analysed through **signal processing and psychoacoustic modelling** techniques [17-18], providing a detailed explanation of how the sound sources interfere with humans' health and well-being.

Expected Results

The expected results of the MEMOSOUND project regarding MR applied in urban soundscapes are 1) identification of sonic cues and MR links, 2) contextual influence on MR, 3) impact of user profiles on MR, 4) identification of short-, mid-, and long-term MR, 5) neurophysiological insights; 6) citizen science data collection and mapping, 7) signal processing and psychoacoustic modelling, and 8) holistic understanding of MR in urban soundscapes.

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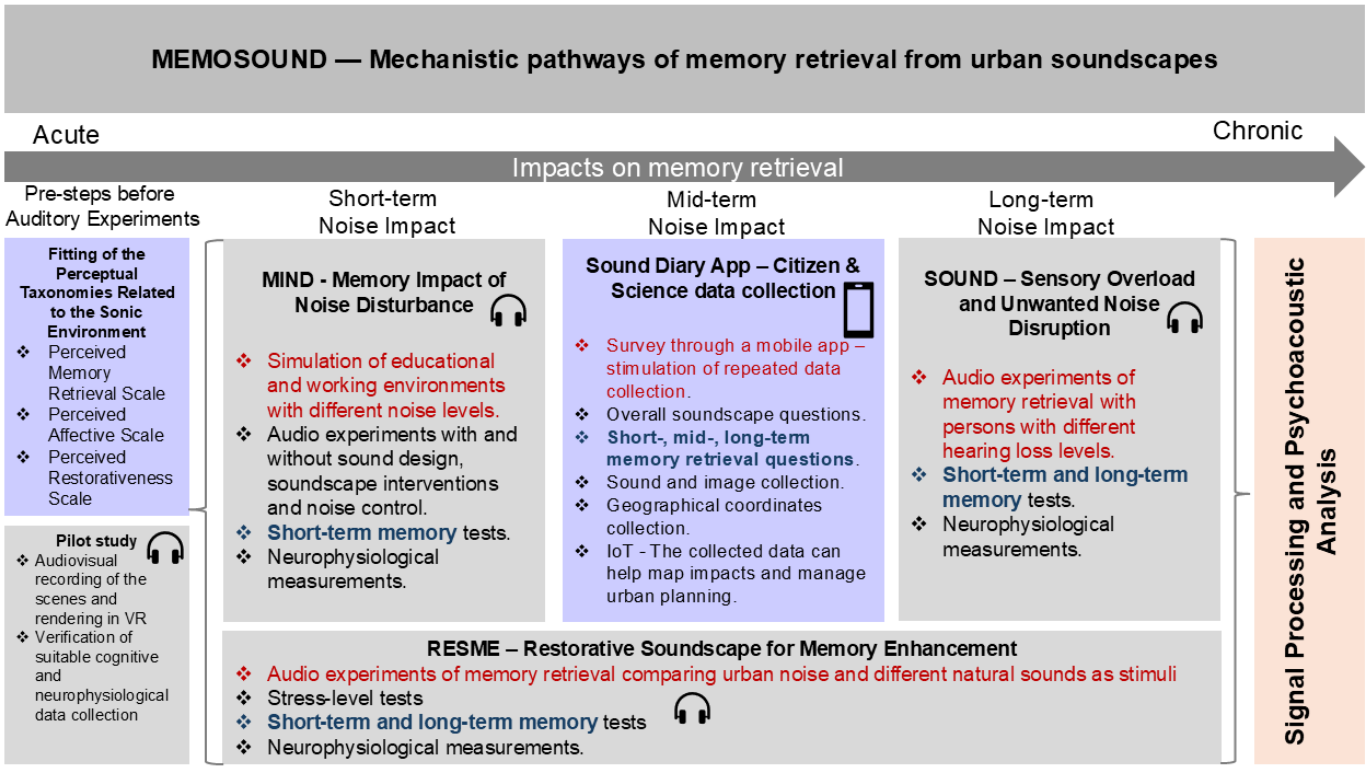

Figure 1: **Framework of the MEMOSOUND project**

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