**The Comparative Effects of Silence, Birdsong, Music, and a Medical Soundscape on Cognitive Performance and Perceived Workload**

Sasha Silberberg

Student number: 1606158

s.s.silberberg@students.uu.nl

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TU Delft Faculty of Industrial Design Engineering

Critical Alarms Lab

Dr. Elif Özcan Vieira

Utrecht University Faculty of Social and Behavioural Sciences

Dr. Martijn Mulder

Dr. Sjoerd Stuit

## Abstract

Medical soundscapes (e.g., rattling trolleys, alarms) may degrade cognitive performance in a hospital setting. “Positive” soundscapes (e.g., birdsong and music) have been suggested and used as positive sound interventions to mask unpleasant medical soundscapes and boost cognitive performance, both inside and outside of a hospital setting. Here, I assess the impact of medical, birdsong, and music soundscapes on the recall of numerals projected on a monitor for 210 ms before being masked. Recall of such briefly presented items may tap into “immediate” or “iconic” memory (Sperling, 1960). Participants completed the memory task while being exposed to one of three pre-recorded soundscapes: birdsong, a Mozart sonata, or a medical soundscape. A 2x3 design was used, where sound condition (sound versus silence) was the within-participant manipulation and the between-group variable was the soundscape type. Following task completion, participants completed a questionnaire asking about their perceived workload of the task in silence versus sound, and their pleasantness rating of their respective soundscape. The questionnaire also included items that addressed individual sensory-processing sensitivity, prior experience listening to soundscapes while working, and prior experience in a hospital setting. A repeated measures analysis of variance showed no statistically significant difference in accuracy scores between all three groups of soundscapes and no interaction effect between the score difference in silence versus sound and soundscape type. Despite the medical soundscape’s rating as the most unpleasant soundscape, its perceived workload scores were the lowest. This finding may be attributable to the type of task or auditory stimuli used.

# Contents

## Introduction

Canadian composer and educator Raymond Murray Schafer coined the term 'soundscape' (Schafer, 1977), defining it as "[a]n environment of sound (or sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society" (Truax, 1978). Since its inception, 'soundscape' has been redefined, often simply likened to "the auditory equivalent of landscape" (Brown, 2012). More recently, the International Organization for Standardization (ISO) aimed to establish an international consensus using the following definition: "[the] acoustic environment as perceived or experienced and/or understood by a person or people, in context" (ISO, 2014).

Soundscape research is flourishing as policy makers, urban planners, and other decision makers recognize the potential for soundscapes to be impactful in both negative and positive ways (Jiang et al., 2022). One major area of interest is hospital soundscapes (e.g., rattling trolleys, alarms, hospital staff conversation, and cleaning machines). It is well-established that these soundscapes, particularly those found in Intensive Care Units (ICUs) and operating rooms (ORs), can negatively affect patients' and hospital staff's physical and mental health (Iyendo, 2016; Topf, 2000). Studies on patient physiology have shown that hospital acoustics can influence cardiovascular arousal, reduce sleep quality, and induce anxiety and feelings of hopelessness, leading to higher incidences of re-hospitalization and extended hospital stays (Bliefnick et al., 2019). Similarly, hospital staff have reported increased fatigue, occupational burnout, and emotional exhaustion (Iyendo, 2016; Joseph & Ulrich, 2007; Topf, 2000).

While there has been a considerable focus on how hospital acoustics impact patient and staff health and well-being, only a few studies have looked into their impact on cognitive performance within an experimental setting (Busch-Vishniac, 2019; Erne et al., 2022; Murthy et al., 1995; Reinten, 2020; Schmidt et al., 2020). Further, few, if any, studies have compared such potential effects against those of natural soundscapes (e.g., birdsong, rainfall, and ocean waves) and music, which have been suggested and used as positive sound interventions to mask unpleasant medical soundscapes and boost cognitive performance, both inside and outside of a hospital setting (Iyendo, 2017; Mackrill et al., 2014; Proverbio et al., 2018; Saadatmand et al., 2013; Spence & Keller, 2019).

The aim of this study is to compare the effects of “positive” soundscapes (natural soundscapes and music), “negative” soundscapes (medical soundscapes), and silence on cognitive performance and perceived workload. I hypothesized that 1) medical soundscapes will reduce cognitive performance as compared to silence, birdsong, and music and 2) the pleasantness of birdsong and music will mitigate perceived workload scores regardless of performance.

In this study, cognitive performance will be measured by accuracy levels on Inoue and Matsuzawa’s (2007) limited-memory hold task. Given this study’s focus on medical soundscapes, it can be argued that the limited-hold memory task is akin to computer tasks performed by doctors and nurses in a hospital on a daily basis, most notably using simple counting and immediate visual working memory in their work. This task tests iconic memory, which has never been studied within the domain of soundscapes and cognitive performance. In this sense, using this task is an attempt to expand this area of research into iconic memory and potentially identify a new domain in which soundscapes may have a robust effect on performance. Unlike short-term memory or long-term memory, iconic memory is a form of sensory memory which refers to the immediate, brief (less than one second) memory of a visual image (Dick, 1974). George Sperling (1960) was the first to confirm the existence of this type of memory within an experimental setting and define its capacity and duration. Iconic memory requires attention and is used in a variety of daily tasks, especially those that require change-detection (Clarke & Mack, 2015; Persuh et al., 2012).

Given that the experience of soundscapes "entails [the] psychological analysis of a collection of sounds", it is important to take into account certain psychological factors that may influence how one is impacted by a given soundscape and how one perceives that soundscape (Özcan et al., 2022). In the context of this study, such factors include the perceived pleasantness of soundscapes and individual sensory-processing sensitivity. The perceived pleasantness of soundscapes is considered to be a key dimension in soundscape appraisal (Aumond et al., 2017; Bogdanov et al., 2022; Erfanian et al., 2021). This factor is particularly relevant to this study as perceived pleasantness can influence stress levels, which in turn could impact perceived workload (Medvedev et al., 2015; Said et al., 2020). Likewise, differing levels in individual sensory-processing sensitivity have been linked to both soundscape appraisal and cognitive performance (Aletta et al., 2018; Gao et al., 2023; Johansson et al., 2016; Mackersie & Calderon-Moultrie, 2016; Song et al., 2022). Such factors were included in this study in order to shed light on their potential influence on cognitive performance and perceived workload across different soundscape types.

## Medical Soundscapes and Cognitive Performance

The few studies that have looked into the impact of medical soundscapes on cognitive performance within an experimental setting have mixed findings. On the one hand, Murthy et al. (1995) found twenty anesthesia residents performed worse on short-term memory and mental efficiency tests while exposed to pre-recorded OR sounds as opposed to no ambient sounds. Echoing Murthy et al.'s findings, Erne et al. (2022) found that ICU sounds led to significantly reduced information retention among healthcare professionals (HCPs) after a simulated ICU ward round. On the other hand, Schmidt et al. (2020) found that ICU noise had no significant effects on HCPs' working memory performance. They compare these results with those of Murthy et al., describing them as potentially attributable to their study's design, noting factors such as their use of a less sensitive task, participants' exposure to ICU noise for a shorter period of time, and their use of pink noise as a control background sound as opposed to silence. Furthermore, they mention that similar studies (Moorthy et al., 2004; Ryherd et al., 2012) that use job-specific tasks instead of mental efficiency tests fail to produce significant effects, potentially because healthcare workers are accustomed to the sounds in ICUs; therefore their performance is not affected. These studies used different cognitive tasks: the Benton Visual Retention Test, answering a free recall questionnaire about an auditory simulation of a ward round, and a 2-back object-location task. For this reason, it is difficult to identify the variable responsible for these different experimental outcomes.

In sum, research on the relation between medical soundscapes and cognitive performance is sparse and the findings obtained are not in agreement. Nevertheless, self-assessments by hospital staff support the view that medical soundscapes degrade cognitive performance (Folscher et al., 2014; Lo Castro et al., 2022). Higher OR noise levels are correlated with higher anxiety and perceived workload scores and decreased attention among surgical staff, impacting surgical performance and patient outcomes (Arabaci & Önler, 2020; Fu et al., 2021; Keller et al., 2018; Kennedy-Metz et al., 2022; Mcleod et al., 2021). However, when it comes to hospital acoustics, noise levels are not the only cause of reduced performance and increased anxiety, stress, and perceived workload among OR and other hospital staff. Factors such as alarm fatigue, frequent disruptions, speech intelligibility, and distressing patient sounds also play a role in degrading performance (Mackrill et al., 2013; Özcan et al., 2018).

## Background Music and Cognitive Performance

In 1993, Rauscher et al. published "Music and Spatial Task Performance," igniting a conversation in the scientific community and popular media around the potential for music to enhance cognitive performance. They claimed that participants' spatial reasoning skills were significantly enhanced for 10-15 minutes after listening to a Mozart sonata for 10 minutes as compared to listening to a relaxation tape or silence. Many studies were conducted to evaluate this "Mozart effect." However, as noted in a meta-analysis of this work (Pietschnig et al., 2010), replication of this effect has been inconsistent, and the significant, yet small effects that have been observed were not substantially different from the effects of other types of music compared to no stimulus. This similarity could be explained by "well-known mechanisms of general arousal," which, in this context, suggest that more arousing music stimulates the cerebral cortex, potentially boosting performance on spatial tasks (Pietschnig et al., 2010; Thompson et al., 2001).

The Mozart effect specifically refers to enhanced performance on reasoning tasks *following* listening to Mozart. Left unanswered is whether task performance would be enhanced were music to play *concurrently* in the background. Cheah et al.'s (2022) review of 154 experiments looking to answer this question showed that research in this area is largely inconclusive. Paradoxically, the authors did find that background music generally reduced performance on memory and language-related tasks. Despite this finding, many people continue to listen to background music while studying or working. Within a hospital setting, surgeons often play background music, claiming that it improves their performance and reduces stress (Fu et al., 2021). The literature supports the notion that outside of memory and language-based tasks, music reduces stress and improves performance among surgical staff (Co et al., 2022; El Boghdady & Ewalds-Kvist, 2020; Iyendo, 2016; MacLean et al., 2013). Some studies have also shown that music may lower perceived workload among OR staff, although findings are mixed (Gao et al., 2018; Narayanan et al., 2022; Tseng et al., 2022). Outside of the OR, music has been used to mask unpleasant hospital acoustics and create a calmer working environment, reducing stress and inducing positive feelings in patients and staff, and bettering patient outcomes (Iyendo, 2016; Mackrill et al., 2013; Trappe, 2012).

## Natural Soundscapes and Cognitive Performance

Like music, natural soundscapes have been suggested and used as a positive sound intervention to mask medical soundscapes, which, as previously mentioned, are notoriously unpleasant and stressful for patients and hospital staff (Iyendo, 2017; Mackrill et al., 2014; Saadatmand et al., 2013; Spence & Keller, 2019). Numerous studies have shown that natural soundscapes reduce stress and improve psychological and physical well-being in not only hospital staff and patients, but other populations, including office workers and students (Alvarsson et al., 2010; Benfield et al., 2014; Cerwén et al., 2016; Iyendo, 2017; Largo-Wight et al., 2016; Luo et al., 2021; Saadatmand et al., 2013). This phenomenon is in line with Stress Reduction Theory, which posits that natural stimuli promote recovery from stress (Ulrich et al., 1991).

Whether natural soundscapes improve cognitive performance in a hospital setting is an open question, as little work has been done on this topic. However, it can be argued that the stress reduction induced by listening to natural soundscapes may be presumed to improve performance, as numerous studies have demonstrated the link between excessive stress and poor performance among hospital staff (Davey et al., 2019; Khamisa et al., 2015; Vahedian-Azimi et al., 2017).

More data on stress reduction through listening to natural soundscapes exist outside the hospital. Many people find that such soundscapes improve their mood and help them focus by masking distracting sounds (Newbold et al., 2017). Most studies investigating the effect of natural soundscapes on cognitive performance are based on Attention Restoration Theory (ART), which asserts that concentration improves after exposure to natural environments (Kaplan & Kaplan, 1989). In these experiments, participants are exposed to nature via a nature walk, nature-based soundscapes, images, or films after completing a task that presumably depletes attention capacity. Following exposure to nature-based stimuli, participants repeat the attention task again and their performance is compared to performance prior to exposure to nature-based stimuli. Proponents of ART argue that nature-based stimuli are restorative because they enable “soft fascination” by “put[ting] an individual in an effortless mode of attention, thereby giving attention a relative opportunity to rest and replenish itself” (Joye & Dewitte, 2018). Although several restoration studies have demonstrated improved performance on attention tasks following exposure to nature-based stimuli, directed attention capacity has not been operationalized in a consistent manner across this research (Joye & Dewitte, 2018). For example, previous tasks used include proofreading, the Trail Making Test, the Stroop Task, the Sustained Attention to Response Task, or the Digit Span Backward/Forward (Berman et al., 2008; Berman et al., 2012; Berto, 2005; Faber Taylor & Kuo, 2009; Hartig et al., 1991; Joye & Dewitte, 2018; Shin et al., 2011). Further, ART research has been criticized for its lack of support for its underlying assumptions (i.e., “that nature effects are restorative effects” and “restoration is – or derives from – an ancient evolved adaptive response”) and ambiguous theoretical concepts (e.g., “soft fascination”) (Joye & Dewitte, 2018).

While a number of ART studies have investigated the impact of listening to natural soundscapes prior to performing a cognitive task, research on the effects of background natural soundscapes on concurrent cognitive tasks is scarce and findings are mixed. For example, Proverbio et al. (2018) found participants performed better and faster on difficult arithmetic operations while listening to heavy rain or classical music than when no sounds were presented. They speculated that this is due to an “enhanced cerebral alertness” initiated by the auditory stimuli. Another recent study investigating the efficacy of natural soundscapes in masking office noise found that natural soundscapes limited distractions and “protected” performance on a serial recall task (Jahncke et al., 2016). This finding is in line with another office study where participants performed cognitive tasks under different acoustic conditions used to mask distracting speech: pink noise, ventilation noise, instrumental music, vocal music, and the sound of spring water. Compared to silence, decrements in short-term memory performance and increases in perceived workload were observed in most acoustic conditions. However, performance and perceived workload improved in the spring water condition as compared to the speech only condition, making it “the most optimal speech masker” (Haapakangas et al., 2011).

On the other hand, Lee et al. (2020) found that participants performed worse on cognitive assessments while listening to spring water and office noise as compared to silence, office noise, and white noise plus office noise, an outcome they attributed to increased mental effort and sensory overstimulation. Unlike the study by Proverbio et al. (2018), where “enhanced cerebral alertness” improved performance, Lee et al. claimed this same factor led to performance decrement in their study. Possibly there is a non-monotonic relationship between alertness and performance– when alertness is increasing from low to moderate levels, performance improves; but when alertness is increasing from moderate to high levels, performance gets worse. Such a result describes the predictions of the Yerkes Dodson Law (Yerkes & Dodson, 1908). Complicating matters further, the type of natural soundscapes used to boost performance must also be considered: natural soundscapes with high acoustic variation, like birdsong, may be more detrimental to performance than, for example, rainfall, which has low acoustic variation (Lee et al., 2020; Newbold et al., 2017).

## Do Different Soundscapes Impact Cognitive Performance Differently?

Evidently, a wide variety of soundscapes exist, and each one can play a role in how we perceive and interact with our environment. In comparing the effects of birdsong, a medical soundscape, and music on cognitive performance, this study may shed light on potential positive sound interventions that can be used to improve cognitive performance or perceived workload in hospital settings. Further, it will provide more data to this understudied area of research, potentially showcasing a negative impact that medical soundscapes may have on cognitive performance and perceived workload.

# Method

## Participants

Sixty participants (35 women and 25 men) with a mean age of 24.79 years (min = 19, max = 33, SD = 2.54) volunteered for the study. All participants self-reported healthy or corrected-to-normal hearing and vision. All participants were given the option to receive academic credit for their participation. The experiment was conducted with ethical approval from Utrecht University's Ethics Review Board of the Faculty of Social and Behavioural Sciences.

## Auditory Conditions

The stimuli were selected from Spotify software and transformed into MP3 files to be normalized by Adobe Audition (Build 23.2.0.68) software with a Programme Loudness Level set to a Target Level of -23.0 LUFS with a tolerance of +/- 0.5 LU and a dB True Peak (dbTP) of -1.0 dBTP. A Voltcraft SL-100 decibel meter was used to measure the perceived loudness of each stimulus, which varied between 55 and 70 dB. All decibel readings were measured from where the participants were seated. The selected stimuli were as follows:

- "Good Night, White Noise" by Linus Xio (https://t.ly/BQMi)
- "Spring Birds Calling" by Birds On Television (https://t.ly/bZ36)
- "Piano Sonata No. 18 in D Major, K. 576, 'Hunt': II. Adagio" by Wolfgang Amadeus Mozart, Mao Fujita (https://t.ly/ixiA)
- "Hospital, E.R. - Emergency Room: Busy Ambience Hospital Ambiences" by Sound Effects Library (https://t.ly/lB62)
- "General Nurses Station Ambience with Pa Announcements" by Sound Ideas (https://t.ly/uSds)

"Hospital E.R…" and "General Nurses Station…" were melded into a single 10-minute MP3 file, with "Hospital E.R…" playing first and then imperceptibly fading into "General Nurses Station…". All other stimuli were similarly extended to make them into 10-minute long MP3 files. These adjustments were made in order to ensure that the stimuli persisted without disruption through the participant's completion of the task.

## Visual Stimuli for the Cognitive Task

In this version of the limited-hold memory task (Inoue and Matsuzawa, 2007), participants were presented with five random non-repeating single-digit numerals (one through nine) in a random configuration on a screen (40 different positions in an 8-by-5 array). Following a latency of 210 ms, the numerals were masked. Participants used a mouse to click on the masked numerals in ascending order as they remembered them. Each session consisted of 50 trials, with each individual trial completed correctly only if every numeral was identified correctly in ascending order. The background color over which the numerals were presented was black, while the numerals were white and superimposed onto gray square blocks. The numerals were masked with white square blocks that matched the size of the gray square blocks exactly. Performance metrics (number correct and incorrect) were presented on the screen, but were covered by an opaque, red Post-It note for the duration of the task to ensure that participants could not see them.

## Questionnaire

The questionnaire used in the present study consisted of 17 items, 12 of which were 7-point Likert scales which asked participants to rate their level of agreement with various statements ranging from "strongly disagree" to "strongly agree". Participants who were in the medical soundscape condition were asked an additional question (question eight) at the end of the questionnaire, making their questionnaires 18 items in length. Perceived workload, pleasantness scores of the sounds played during their task, and prior experience listening to other soundscapes were operationalized via Questions 4, 5, and 7, respectively. Question 6 included seven 7-point Likert scale items, which were taken from the Highly Sensitive Person (HSP) Scale (Aron & Aron, 1997) to measure individual sensory-processing sensitivity. Please see the Appendix for the full questionnaire.

## Study Design

A 2x3 design was used, where sound condition (sound versus silence) was the within-participant manipulation and the between-group variable was soundscape type (birdsong, a medical soundscape, and [Mozart] music). Participants were randomly assigned to one of the three soundscape types, with the sound condition being counterbalanced across all participants.

## Procedure

Participants sat in front of a laptop PC screen in an experimental cubicle. Two speakers, angled at 45° with each placed on either side of the computer screen, formed an equilateral listening triangle with the participant. Participants were given a consent form and a participant information sheet to sign before beginning the experiment. Afterward, they were given instructions on how to complete the limited-memory hold task and were told that they would perform the task both in silence and while sounds were playing in the background. Participants were told to ignore the sounds playing on the speakers. All participants completed at least one 50-trial practice session, moving onto the experimental sessions only if they reached a criterion of 20% (10/50) correct responses in one of two potential practice sessions. White noise was used as the control sound condition playing on the speakers during the practice session(s). White noise was chosen as the control sound condition because it is thought to act as a “steady state” noise, producing little if any disruption as compared to silence (Hughes, 2014). Following the practice session(s), the participant completed four experimental sessions, two of which were in silence, while the other two were performed while their respective soundscape type played in the background. Each session consisted of 50 trials and took approximately four to six minutes to complete. Following these four experimental sessions, all participants answered an online questionnaire, which took less than five minutes to finish. The duration of the experiment was between 25 and 35 minutes, depending on how many practice sessions the participant did.

## Statistical Analysis

All data were collected using Excel 2019 software (Build 2.70.1) and Qualtrics software (www.Qualtrics.com). All data were subsequently imported into JASP software (Build 0.17.1) to be analyzed.

Likert-derived questionnaire items (Questions 4, 5, and 6) were treated as continuous, with the presumption that the distances between categories ("strongly agree" to "strongly disagree") were not equal. In line with this, these items were transformed into a scoring continuum of seven to zero, where "strongly agree" was given a score of seven and "strongly disagree" was given a score of zero. Further, post-hoc adjustments to the scoring procedures for Questions 4 (pertaining to perceived workload) and 5 (pertaining to perceived pleasantness of the sound condition) were made in order to reduce redundancy caused by experimenter error and to simplify the analysis. Initially, Question 4 contained three sub-questions and Question 5 contained two sub-questions. For Question 4, it was reasoned that the three data points obtained from these three sub-questions could be reduced into a single data point by subtracting the perceived workload score of the silent condition from that of the sound condition. This produced a single score which represented the perceived difference in workload across both conditions. Question 5's two data points were transformed into a single data point by simply ignoring the first sub-question ("*The sounds playing on the speakers while I performed the task were unpleasant*") and using the second sub-question ("*The sounds playing on the speakers while I performed the task were pleasant*") as the representative measure of pleasantness. These post-hoc adjustments were made across all participant data.

Subsequently, the assumption of homogeneity of variance was confirmed. Descriptive statistics were then obtained across the following variables: task performance in silence, task performance with each background soundscape, sex, prior experience listening to soundscapes while working, prior experience in a hospital setting (for participants exposed to the medical soundscape), perceived difference in workload (in sound versus silence), pleasantness score, and HSP score. Age was excluded from this analysis as its standard deviation was low (2.54 years). Paired *t*-tests were used to determine whether order effects were present, to compare overall task performance in silence versus sound, to compare task performance in females versus males, and to compare participants with differing levels of experience ("yes" or "no") in listening to soundscapes while working. One-way ANOVAs were used to determine if there were significant differences in 1) task performance (while listening to the medical soundscape) depending on the participants' level of experience in a hospital setting, 2) pleasantness scores of all soundscape types , and 3) perceived differences in workload across all acoustic conditions.

Task performance was defined by accuracy scores, with accuracy being a perfect recall of the order of numerals presented in a given trial. Group differences in performance (total percentage of correct trials across sessions) were first analyzed using a repeated measures analysis of variance (ANOVA), with sound condition (silence versus sound) as a within-subjects variable and soundscape type (birdsong, music, and medical soundscape) as a between-subjects variable. A second exploratory repeated measures ANOVA was performed to test whether potential task performance differences were dependent on the following covariates: HSP scores, pleasantness scores, and perceived workload scores. Further exploratory correlation analyses were run to test different potential correlations across the following variables: accuracy score difference (in sound versus silence), perceived difference in workload (in sound versus silence), and pleasantness score. The accuracy score difference was produced by subtracting the silence score from its corresponding sound score. All statistical tests were conducted against a level of $\alpha = 0.05$.

# Results

## Task Performance

*Table 1*. Table showing the mean (standard deviation) accuracy scores in all soundscapes (birdsong, medical soundscape, and music) against their respective silence scores by order of presentation ("silence then soundscape" versus "soundscape then silence").

| Order Effects on Accuracy: Soundscapes versus Silence | | | | |
|---|---|---|---|---|
| | **Silence then Soundscape** | | **Soundscape then Silence** | |
| **Soundscape Type** | Silence Score | Soundscape Score | Soundscape Score | Silence Score |
| Birdsong | 0.30 (0.17) | 0.31 (0.16) | 0.44 (0.20) | 0.42 (0.19) |
| Medical | 0.39 (0.15) | 0.42 (0.18) | 0.39 (0.17) | 0.37 (0.21) |
| Music | 0.38 (0.17) | 0.38 (0.18) | 0.26 (0.20) | 0.29 (0.19) |

Table 1 shows the mean (standard deviation) accuracy scores across all soundscapes presented and the potential order effects of their respective sound condition (silence versus sound). Two paired *t*-tests were used to determine whether order effects were present. There were no statistically significant differences between mean accuracy scores (from sound conditions) from when sound was presented first versus when sound was presented second ($t(29) = 0.16$, $p = 0.87$). Likewise, there were no statistically significant differences in mean accuracy scores (from silent condition) when silence was presented first versus when silence was presented second ($t(29) = -0.05$, $p = 0.96$). These results show no evidence for a practice effect.

*Table 2*. Table showing the mean (standard deviation) accuracy scores in each acoustic condition (birdsong, medical soundscape, and music) against their respective mean accuracy scores in silence, regardless of the order of presentation (“silence then soundscape” versus “soundscape then silence”). This table also includes an “overall” score, the mean accuracy score in silence and in sound across all acoustic conditions.

| Mean Accuracy Scores: Soundscapes versus Silence | | |
|---|---|---|
| **Soundscape Type** | Silence Score | Soundscape Score |
| Birdsong | 0.36 (0.18) | 0.37 (0.19) |
| Medical | 0.37 (0.18) | 0.38 (0.17) |
| Music | 0.34 (0.18) | 0.32 (0.19) |
| Overall | 0.36 (0.17) | 0.36 (0.17) |

Table 2 shows the mean (standard deviation) accuracy scores in each acoustic condition against their respective mean accuracy scores in silence. The mean (standard deviation) accuracy scores in silence and in sound across all acoustic conditions are 0.36 (0.17) and 0.36 (0.17), respectively. A paired *t*-test was used to compare these “overall” measures, indicating no significant difference in performance in silence versus sound ($t(59) = 0.34$, $p = 0.73$).

A repeated measures ANOVA was used to compare the effect of soundscape type (birdsong, medical soundscape, and music) on accuracy scores across sound conditions (silence versus sound). There was no statistically significant difference in accuracy scores between all three groups of soundscapes ($F_{(2,1)} = 0.41$, $p = .67$) and there was no interaction effect between the score difference (in silence versus sound) and soundscape type ($F_{(2,1)} = 0.92$, $p = .41$). Given this lack in statistical significance, a second exploratory repeated measures ANOVA was performed to compare the effect of soundscape type on task performance across sound conditions given the following covariates: HSP score, pleasantness score, and perceived workload score. This analysis showed no statistically significant between-subjects effects in task performance across the three soundscape groups considering these three covariates: HSP score ($F_{(1,1)}$ = 0.63, *p* = .43), pleasantness score ($F_{(1,1)}$ = 0.44, *p* = .51), and perceived workload difference ($F_{(1,1)}$ = .01, *p* = .91). With regards to within-subjects effects, there were no statistically significant interaction effects in accuracy score difference (the difference between scores in silence versus sound) x HSP score ($F_{(1,1)}$ = 0.10, *p* = .75). However, a statistically significant interaction effect in accuracy score difference x perceived workload difference was observed ($F_{(1,1)}$ = 5.95, *p* = .02). The interaction effect between accuracy score difference x pleasantness score is irrelevant because the pleasantness score was only based on the participant's pleasantness rating of sound, not silence.

## Pleasantness and Perceived Workload

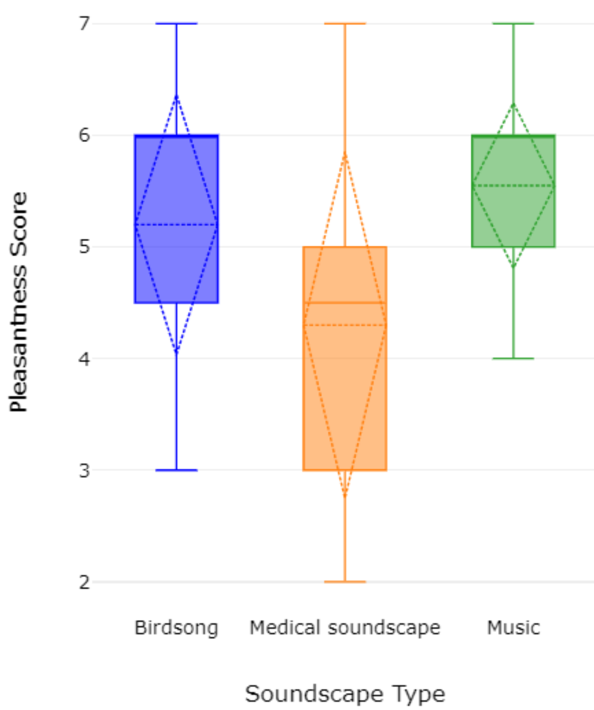


*Figure 1*. Boxplot showing pleasantness scores by soundscape type. Each box starts at the first quartile and ends at the third quartile of accuracy scores, with the mean value represented as a dashed horizontal line and the median value represented as a solid horizontal line. The standard deviation is displayed as a dashed rhombus. The whiskers define the interquartile range of the dataset. The higher the pleasantness score, the more the participant deemed the soundscape as pleasant as opposed to unpleasant.

As depicted in Figure 1, the pleasantness scores of birdsong (mean = 5.20, SD = 1.20) and music (mean = 5.55, SD = 0.76) were higher than those of the medical soundscape (mean = 4.30, SD = 1.59). The medical soundscape is characterized by a wider distribution of pleasantness scores, while the pleasantness scores for music were less dispersed. A one-way ANOVA confirmed statistically significant differences in pleasantness scores of all soundscapes ($F_{(1,1)}$ = 5.49, $p$ = .007). A paired $t$-test showed that this statistically significant difference occurred only between music and the medical soundscape ($t$(19) = 2.92, $p$ = .009).

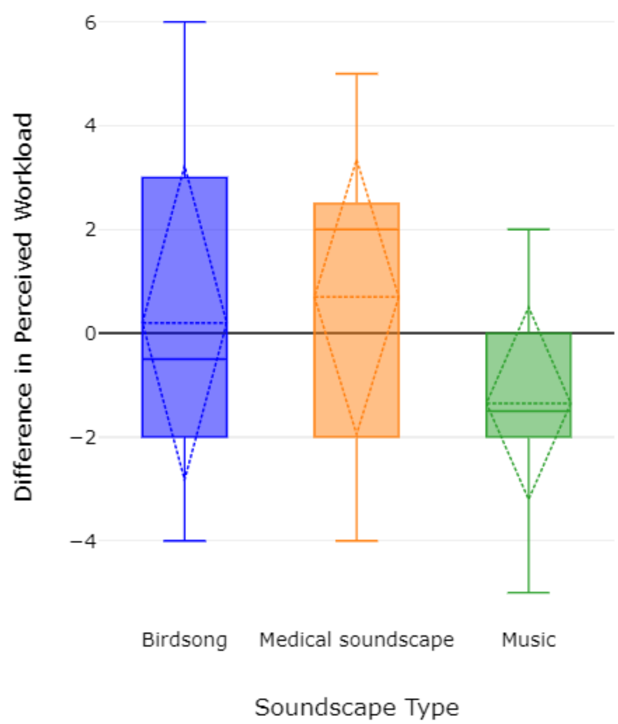


*Figure 2*. Boxplot showing the differences in perceived workload across sound conditions (silence versus sound) by soundscape type. This difference was produced by subtracting the perceived workload score of the silent condition from that of the sound condition. The more positive the perceived workload difference, the lower the perceived workload of the task during the sound condition as compared to silence.

Figure 2 shows the differences in perceived workload across sound conditions (sound versus silence) by soundscape type: birdsong (mean = 0.20, SD = 3.11), medical soundscape (mean = 0.70, SD = 2.72), and music (mean = -1.35, SD = 1.90). On average, the medical soundscape's perceived workload scores were the lowest, although dispersion of data was high in all acoustic conditions. A one-way ANOVA confirmed statistically significant differences in the differences in perceived workload (across sound conditions) in all acoustic conditions ($F_{(2,1)} = 3.32$, $p = .04$). A paired *t*-test showed that this statistically significant difference occurred only between music and the medical soundscape ($t(19) = -2.44$, $p = .03$).

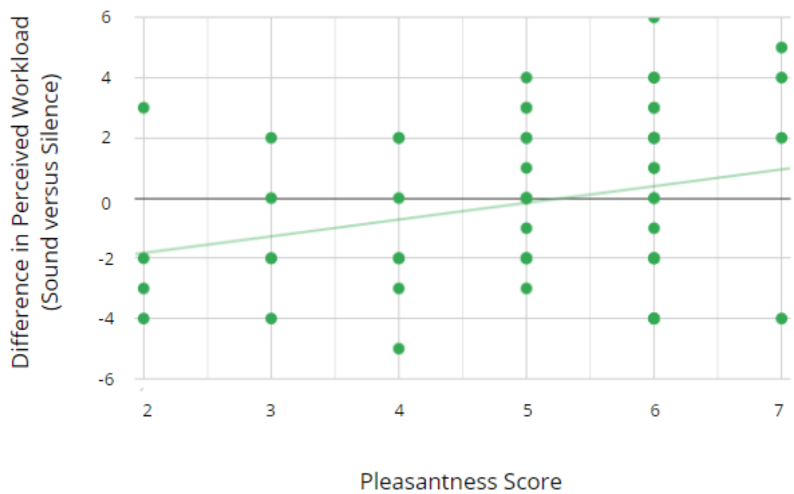


*Figure 3*. Scatterplot showing the positive, yet weak correlation between the differences in perceived workload scores across sound conditions (sound versus silence) and the pleasantness scores of all soundscapes.

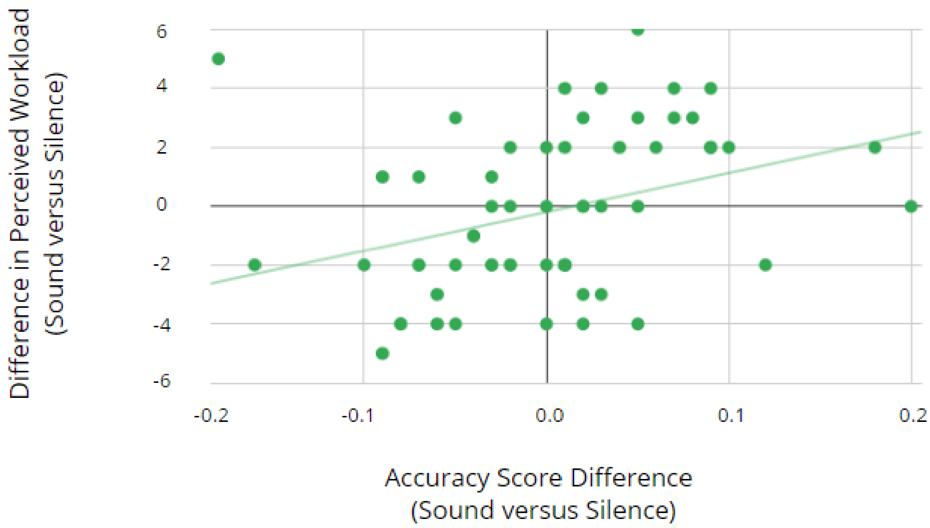


*Figure 4*. Scatterplot showing the positive, yet weak correlation between the differences in perceived workload scores (in sound versus silence) and the differences in mean accuracy scores (in sound versus silence). The differences in mean accuracy scores were produced by subtracting the silence scores from their corresponding sound scores. The more positive the accuracy score difference, the better the sound score as compared to the silent score, and vice versa.

As previously mentioned, the second repeated measures ANOVA showed no statistically significant between-subjects effects in the perceived workload differences across soundscape groups. However, a statistically significant within-subjects interaction effect was observed in accuracy score difference x perceived workload difference. This finding is supported by a correlation analysis (Figure 3), which demonstrated a statistically significant, yet weak positive correlation between accuracy score difference and perceived workload difference ($r(58) = .37$, $p = .007$). Further correlation analyses (Figure 4) showed another statistically significant, yet weak positive correlation between perceived workload difference and pleasantness score ($r(58) = .29$, $p = .02$).

### Sex Differences, Prior Experience Listening to Soundscapes, and Prior Experience in a Hospital Setting

Participants' sex and responses to Questions 7 (prior experience listening to soundscapes while working) and 8 (prior experience in a hospital setting) were also included in the analysis. A paired *t*-test ($t(24) = -0.53$, $p = 0.60$) showed no statistically significant differences in task performance by sex (females: mean = 0.36, SD = 0.16; males: mean = 0.35, SD = 0.19). With regards to Question 7, another paired *t*-test ($t(15) = 0.64$, $p = 0.53$) showed no statistically significant differences in task performance between participants with prior experience listening to soundscapes while working (mean accuracy score in silence = 0.35, SD = 0.19; mean accuracy score with sound = 0.36, SD = 0.19) participants without prior experience (mean accuracy score in silence = 0.37, SD = 0.12; mean accuracy score with sound = 0.35, SD = 0.14). A one-way ANOVA was used for Question 8, which was only posed to participants who were exposed to the medical soundscape condition. The ANOVA showed no statistically significant difference in task performance during the medical soundscape condition ($F_{(2,1)} = 0.43$, $p = 0.66$) in participants with "a little" experience (mean accuracy score in silence = 0.39, SD = 0.17; mean accuracy score in sound = 0.41, SD = 0.16), "a moderate amount" of experience (mean accuracy score in silence = 0.46, SD = 0.32; mean accuracy score in sound = 0.43, SD = 0.25), and "none at all" (mean accuracy score in silence = 0.36, SD = 0.10; mean accuracy score in sound = 0.37, SD = 0.13). Only one participant responded to Question 8 by saying they had "a great deal" of experience in a hospital setting, so this data point was excluded from the analysis.

## Discussion

My first hypothesis was that medical soundscapes would reduce cognitive performance as compared to birdsong, music, and silence. The results from this study showed no difference in cognitive performance across all acoustic conditions, including silence. When it comes to comparing the more general impact of silence versus sound on cognitive performance, this result is not in line with the literature: prior studies have shown that cognitive performance degrades with a variety of different sounds as compared to silence (Haapakangas et al., 2021; Lee at al., 2020). However, as mentioned in the introduction of this paper, research in this area is sparse and discrepant, characterized by inconsistencies in research methodology and a lack of replicated findings. In an attempt to expand this area of research and pursue robustness of performance, an empirically novel approach was used: cognitive performance was operationalized via the limited-hold memory task, a procedure that taps into iconic memory. It may be the case that performance on this procedure is immune to degradation by acoustic stimuli. In fact, accuracy scores from this study were representative of human performance in another study using the same task without acoustic stimuli, potentially demonstrating such a phenomenon (Inoue & Matsuzawa, 2007). Perhaps future studies with this task would show acoustic stimuli would degrade performance if the masking latencies were lengthened beyond 210 ms, thereby carrying recall beyond the restricted limits of iconic memory. Of course, it is also possible that the failure to find performance degradation is not inherent in the task itself but in its underlying assumption: that acoustic stimuli disrupt recall. Despite the plausibility of such an assumption, it remains the case that robust demonstrations of acoustic degradation of memory are sparse in the literature.

My second hypothesis was that the pleasantness of birdsong and music would mitigate perceived workload scores regardless of performance. Birdsong and music indeed had higher mean pleasantness scores, which is in line with prior studies (Andringa & Lanser, 2013; Medvedev et al., 2015). Despite this finding, paradoxically, the medical soundscape was rated as the soundscape with the lowest mean perceived workload, as compared to silence. This finding is difficult to reconcile with the positive, although weak, correlation between perceived workload difference and pleasantness score. Notably, the statistically significant differences in perceived workload and pleasantness, as compared to silence, were only observed between music and the medical soundscape. In other words, music was more pleasant than the medical soundscape, while the medical soundscape was associated with a lower perceived workload than music. Given these findings and the fact that humans have a limited memory capacity, it could be argued that presenting an acoustic stimulus that is considered particularly pleasant (e.g., music) could more readily interrupt attention, absorbing attention capacity and thereby increasing the perceived workload associated with the task. It is also important to note that perceived workload scores could have been influenced by participants' awareness of their own performance, thereby giving a lower perceived workload score the better their performance, in both the silent and sound conditions. This idea is demonstrated through the statistically significant interaction effect and positive correlation between accuracy score difference (in silence versus sound) and difference in perceived workload (in silence versus sound).

## Limitations

Possibly, the task chosen for this study was insufficiently sensitive to answer the research questions. Given that it has not been empirically validated, this could indeed be the case. Further, per the ISO's definition of soundscape ("[the] acoustic environment as perceived or experienced and/or understood by a person or people, in context", 2014), it could be argued that the context of this study, a university laboratory, did not appropriately match the intention of this experiment - to analogize healthcare professionals' performance in hospital settings given "positive" sound interventions and realistic medical soundscapes (ISO, 2014). To that end, the participants in this experiment were all of a similar age and none were medical professionals (though experience in hospital settings was accounted for). Future studies in this area could address these two limitations by performing the experiment within a hospital setting with healthcare professionals. Finally, given that there are an infinite number of soundscapes to choose from, it is possible that the acoustic stimuli chosen for this study were not appropriate for the intended purpose. In order to combat this issue, future experiments could have independent raters evaluate all acoustic stimuli on a variety of different dimensions in order to ensure that they are fitting.

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# Appendix

## Questionnaire

*Basic Demographic Information*

1. Anonymous Participant ID: ____

2. Age: ____

3. Born sex:

- Female
- Male
- Other

*Perceived Workload in Sound versus Silence*

4. Please indicate how much you agree or disagree with the following statements.

*I performed (approximately) equally well on the task in silence as with sounds playing on the speakers in the background.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |

*I performed better on the task in silence than with the sounds playing on the speakers in the background.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |

*I performed better on the task with the sounds playing on the speakers in the background than in silence.*

| Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|
| | | | | | | |

## *Pleasantness Rating of Soundscape*

5. Please indicate how much you agree or disagree with the following statements.
*The sounds playing on the speakers while I performed the task were unpleasant.*

| Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|
| | | | | | | |

*The sounds playing on the speakers while I performed the task were pleasant.*

| Strongly disagree | Disagree | Somewhat disagree | Neutral | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|
| | | | | | | |

*Sensory-Processing Sensitivity (from the Highly Sensitive Person Scale)*

6. Please indicate how much you agree or disagree with the following statements.

| | | Strongly disagree | | | | | | Strongly Agree |
|---|---|---|---|---|---|---|---|---|
| 1 | Are you easily overwhelmed by strong audiovisual input? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 | Do you seem to be aware of subtleties in your environment? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3 | Do you tend to be more sensitive to pain? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 4 | Do you find yourself needing to withdraw during busy days, into bed or into a darkened room or any place where you can have some privacy and relief from stimulation? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5 | Are you easily overwhelmed by things like bright lights or sirens close by? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 6 | Are you made uncomfortable by loud noises? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 7 | Are you bothered by intense stimuli, like loud noises or chaotic scenes? | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

*Prior Experience Listening to Soundscapes While Working*

7. Do you listen to music, noise (white noise, brown noise, etc.), or other soundscapes (birdsong, rain, etc.) while you study or work?

- Yes
- No

*Prior Experience in a Hospital Setting*

8. Please indicate how much time you've spent in a hospital setting or intensive care unit (that you can still remember, i.e., not as a small child):

- None at all
- A little
- A moderate amount
- A lot
- A great deal