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# Acceptance & Efficacy of Biophilic Soundscaping in An Open-Plan Office

Joint Research Report

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### Executive Summary

The purpose of this study was to test biophilic soundscaping for its efficacy in reducing speech intelligibility in an open plan office and for its user acceptance by the employees in that space.

**Specific Aims**

The results of this study are intended to extend existing evidence for the efficacy of a biophilic soundscaping solution in comparison to traditional sound-masking systems or when no masking system is employed. The two-part study consisted of an in-situ field study to determine acceptance of biophilic soundscaping and explore perceptions of efficacy. The lab experiment sought to determine if there are performance effects of biophilic soundscaping during two types of focus work: automated (easier) and deliberate (more effortful).

**Key Findings**

**In-Situ Efficacy & Satisfaction Study**

Biophilic soundscaping is perceived to be more effective at masking overheard conversations than other sound-masking conditions in real world applications.

Most participants were either neutral or more satisfied with biophilic soundscaping, when properly deployed, over traditional sound-masking.

**Performance Effects Experiment**

Biophilic soundscaping is more effective, on average, in mitigating speech distraction effects caused by continuous conversation for automated (easier) focus tasks compared with traditional sound-masking. It also is nearly as effective as traditional sound-masking in mitigating speech distractions effects caused by continuous conversation for deliberate (difficult) focus tasks.

Measures of attention, stress, and perceived performance revealed, on average, these were either similar or better in biophilic soundscaping compared to traditional sound-masking.

**What This Means**

When properly deployed via change management, people in an open-plan office environment find working in the biophilic soundscaping as satisfying or more so, and as effective or better than traditional sound-masking.

In terms of performance and attention, working on any focus task without distraction from auditory events is best. Not having any sound-masking in the presence of task-irrelevant auditory events degrades performance and attention on focus tasks. When working without auditory events is not possible, evidence from this study suggests that biophilic soundscaping masks overheard conversation enough to perform as well as or better than when traditional sound-masking is employed on easier and more difficult focus tasks.

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## Background

*Excerpt from Why We Can't Focus at Work*[1]

### How We Focus

When we want to complete a task, we control our attention toward that task – picking up *task-relevant information* (or external stimuli) to guide our actions. We "focus" on what's necessary to complete our task. But how much attention we need is dependent upon how much we already know about the task. *And*, how long we need to sustain that controlled attention (task-vigilance) depends on how well that task can tolerate breaks in sustained attention. The challenge is that we have limited resources[2] and capacities,[3] so our brain also is designed to be efficient as possible.[4] In what ways is our brain efficient? When we are about to experience something, our brain takes in outside information, combines it with what we already know, and makes "educated" guesses at what is to come next.

Consider this: our brain acts something like a "prediction engine."[5] Newer research is providing evidence that our brain continuously gathers and assesses information from our senses to make sense out of ourselves, our world, and our place in it as we move through each day – *much of it under awareness*.[6] It is hypothesized, when WHAT our senses are gathering easily fits with what we already know, we can move through our world with relative ease – we're better at predicting what is about to occur and need less outside information to achieve our goal.[7]

What happens when we're presented with *task-irrelevant information* (stimuli)? Well, our prediction engine still does its job; if task-irrelevant information is easy to predict, it doesn't require much attention. Here's an interesting phenomenon: when working on effortful, difficult tasks (tasks that need deliberate, sustained attention), we can start to suppress highly predictable irrelevant information from even entering awareness.[8] Think about that for a moment: the more difficult the task, the easier it is to ignore information irrelevant to the task. How does that work? Remember that our "prediction engine" is efficient, so when I need to be more deliberate about my task, I'm using more processing and resources and there is less "room" for more *predictable* task-irrelevant stimuli to reach awareness.

### What Constitutes a Distraction

However, when *task-irrelevant stimuli* are different, outside of our expectations, or *unpredictable*, they create prediction errors. Quite often we then focus on the error to see if action is needed and to learn to predict similar stimuli in the future. Don't forget, this new information is irrelevant to our current task, so it's pulling resources away from that. Some research indicates that "attentional capture" during a task slows task processing, regardless of its content.[9] It's the unpredictable nature of it that is distracting – the more different the task-irrelevant information is, the larger the prediction error, and the more likely it is to capture attention and pull resources away from our current task.

How long it takes to resume the original task after attention has been captured can range, on average, from a few seconds to up to a full minute.[10] While relatively short per instance, *the accumulation of multiple distractions* can have profound effects on work performance.

*NOTE: Deviation from expectations – what constitutes a large prediction error – varies widely among people. E.g., those with anxiety and Autism Spectrum Disorder are found to respond to very small differences between new stimuli and what they have already experienced, resulting in a higher sensitivity to stimuli than average. Both may be flooded with prediction errors, where those with anxiety are taxed with resolving the flood of errors and those with ASD aren't able to resolve the errors.[11] People sensitive to stimuli easily get "overloaded" by flooding awareness with events that need further attention.[12] Today's challenge may lie in how complex modern life is and the likely increase for sensory overload. As life continues to increase in complexity, the more we all will need to manage potential overload.

### What Constitutes Interference

Sometimes, even after the onset of a distraction, the new information that captured our attention continues to sustain some of our attention and resources – despite being unwanted information. In these instances, we'll call it *interference*, after the initial distraction there may be a conflict with the original task in that it engages in similar types of

1. Johnson et al., 2019
2. Thomson, Besner, and Smilek, 2015
3. N. Cowan, 2001; Nelson Cowan, 2010
4. Christie and Schrater, 2015
5. Euler, 2018; Cepelewicz, 2018
6. Friston and Frith, 2015; Alexander and Brown, 2018
7. Heeger, 2017; de Lange, Heilbron, and Kok, 2018
8. Buschman and Kastner, 2015; Zelazo, 2015
9. Hughes, 2014; Parmentier, 2014; Everett, Labonte, and Marsh, 2017; Cheyne et al., 2009
10. Monk, Trafton, and Boehm-Davis, 2008
11. Menon and Uddin, 2010; Menon, 2015; Van de Cruys, 2014
12. Aron, Aron, and Jagiellowicz, 2012; Acevedo et al., 2018

processing,[13] having overlapping characteristics with the information needed to complete our original task.[14]

Interference occurs when task-irrelevant information processing competes with task-relevant information processing. An example of this is when someone starts talking to you while you're composing an email, and you suddenly find yourself typing what they're saying to you instead of what you intend to include in the email. Unfortunately, autocorrect isn't likely to catch those kinds of errors. We end up having difficulty coordinating the task-relevant information with our actions, and the quality of that work declines.[15]

### The Challenge with Overheard Speech

As seen in this example, language is particularly problematic – newer research provides evidence that our prediction engine, in its efficiency, does such a fantastic job of identifying sounds that are associated with language that it starts to comprehend semantic qualities of words (word sounds) *before* they reach awareness.[16] Put simply, our brain starts processing language sounds and attempts comprehension of speech before we are aware of it. The more difficult it is to comprehend speech – say when listening to only half of a phone conversation – the more processing needed, and the more disruptive that speech is to our current task.[17]

### Reducing Speech Intelligibility via Sound-Masking

One tactic to reduce the effects of speech distraction and interference in an open-office plan is to deploy sound-masking. Sound-masking works to reduce speech intelligibility by introducing enough tolerable background "noise" so that the intruding speech signal is lower than the background noise. This is where speech privacy occurs. Standards have been developed which define levels of speech intelligibility and privacy in terms of a measure called the Privacy Index,[18] with levels validated through extensive prior research.[19] In terms of the Privacy Index, more difficult focus work may need space traditionally described as that needed for "Confidential" speech; for easier focus work, spaces traditionally described as "Non-Intrusive" should still work well. See Figure 1.

13. Jahncke, Hongisto, and Virjonen, 2013; Marsh et al., 2017; Marsh, Yang, et al., 2018
14. Lutfi-Proctor, 2016
15. Pinotsis, Buschman, and Miller, 2018
16. Parmentier and Kefauver, 2015
17. Emberson et al., 2010; Marsh et al., 2017; Marsh, Ljung, et al., 2018
18. ASTM E1130-16, 2016
19. Goodchild and Johnson, 2018

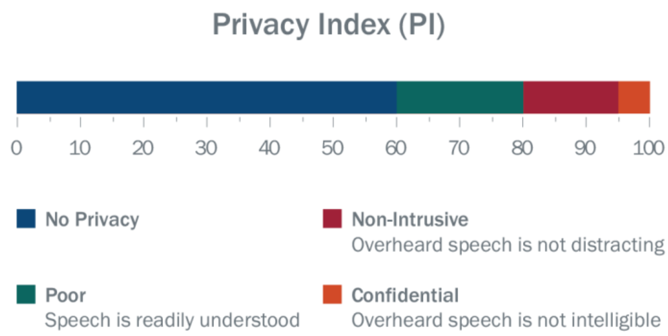


*Figure 1. Privacy Index Rating Scale*

Recommended sound-masking consists of the use of a pink-noise-generated background masking signal, with tuned spectrum and level[20] is a representation of a typical, well-designed sound-masking spectrum in common use.

Biophilic soundscaping, different from traditional sound-masking, leverages natural sounds (like ocean waves, babbling brooks, waterfalls, wind, etc.), within which there can be naturally occurring sound at higher frequencies.[21] There is some preliminary evidence that these natural sounds may be better and preferred for covering speech to improve performance.[22] However, other studies indicate that biophilic soundscaping may not provide an improvement over traditional sound-masking, especially if people find the biophilic soundscaping annoying.[23]

Not only does sounds-masking need to reduce speech intelligibility, but it also needs to be accepted. Therefore, two studies were proposed to assess benefits of biophilic soundscaping. Such benefits include perceived efficacy of biophilic soundscaping in masking speech, satisfaction with the content of the biophilic soundscaping, and improved performance with biophilic soundscaping in the presence of overheard speech.

### In-Situ Study Predictions

An in-situ field study was conducted to determine acceptance of biophilic soundscaping and explore perceptions of its efficacy. Based on mixed results of biophilic soundscaping in an open office, the following was predicted:

20. Bradley, 2003
21. Watts et al., 2009
22. Haapakangas et al., 2011; Watts et al., 2009; Renz, Leistner, and Liebl, 2018
23. Hongisto et al., 2017

**H1:** Perception levels of overheard conversations will be equal to or reduced in the biophilic soundscaping compared to traditional sound-masking.

**H2:** When deployed through change management techniques, satisfaction with the subjective experience of biophilic soundscaping will be equal to or better than traditional sound-masking.

#### Experiment Predictions

The lab experiment seeks to determine if there are performance effects of biophilic soundscaping during two types of focus work: automated (easier) and deliberate (more effortful).

There is evidence that with the accumulation of predictions errors (many distractions) during a task can lower performance on focus tasks, especially tasks that are more difficult.[24] However, the more predictable task-irrelevant information is, the less prediction errors will occur. This is helpful for performance on difficult tasks but could cause interference for easier tasks. Introducing sound-masking to reduce speech intelligibility of overheard conversations may improve task performance in comparison to no sound-masking. Since biophilic soundscaping uses sounds with naturally occurring sounds at higher frequencies, it may be better at masking speech. Therefore, the following was predicted:

**H3:** Performance and attention on automated (easier) focus tasks during an overheard conversation with sound-masking will be better than without sound-masking.

**H4:** Performance and attention on deliberate (more difficult) focus tasks during an overheard conversation with sound-masking will be better than without sound-masking.

**RQ:** How effective and accepted is the biophilic soundscaping compared to traditional sound-masking?

## Methods

#### Subjective In-Situ Study Participants

The participant pool consisted of knowledge workers at a large mid-western manufacturer at the corporate headquarters. In a designated bay of the open office biophilic soundscaping was deployed and a group that has similar workstyles in a different location acted as a control group with traditional sound-masking.

#### Experiment Participants

The participant pool consisted of knowledge workers at a large mid-western manufacturer and was asked to participate in an experiment testing performance and stress for a focus task. Participants were assigned to one of four conditions based on convenience:

- no sound-masking with a continuous conversation
- traditional sound-masking with a continuous conversation
- biophilic soundscaping with a continuous conversation
- control group with no conversation in an enclosed office with no sound-masking

#### In-Situ Manipulation: Acoustical Conditions

The acoustical conditions were controlled and/or manipulated. For the treatment group, after the pre-test baseline (survey) of the current traditional sound-masking condition, the sound-masking generated by biophilic soundscaping system were modified a minimum of 2 weeks in a steady-state traditional-spectrum (Bradley) sound-masking, and an optimized waterfall biophilic soundscaping. Objective tests for all conditions in both locations were conducted comparing the effect of different background sound conditions as defined below.

- Control & Baseline: Dynasound under-floor masking system with filtered pink-noise. Baseline level ranged from 43dBA to 49dBA with average of 46.5 dBA.
- Traditional-Spectrum Steady State (Bradley) Sound-masking: Use the pink-noise-generated background masking signal, with tuned spectrum and level as prescribed by Bradley in the study "The Acoustical Design of Conventional Open-Plan Offices,"[25] as a representation of a typical, well-designed sound-masking spectrum in common use. Level is set at 45 dBA, ±0.5 dB in ea. 1/3 octave band distributed through the ceiling speakers.
- Custom Biophilic Soundscaping "Waterfall" Theme: Full acclimation program deployed with system optimized for the space, occupants, and activities distributed through the ceiling speakers.

Masking signals were delivered through the ceiling speaker system such that the effects of spatial and

24. Johnson and Richardson, 2018

25. Bradley, 2003

temporal variations arising due to speaker placement would be experienced consistently across the traditional and biophilic masking test conditions.

### In-Situ Measurement: Acoustical Experience

On designated data collection days per condition, participating members completed a survey assessing their experience of the acoustics in their workspace as well as the ways in which they work on Likert-type scales.[26]

### Experiment Measurement: Biometrics

#### Galvanic Skin Response (GSR)

GSR measures the electrical activity of skin. Skin conductance is governed by autonomic sympathetic activity, independent of cognitive control, and indicates emotional/nervous system arousal.[27] The sensor was placed on the non-dominant hand.

#### Facial Expressions

The Facial Action Coding System identifies and analyzes macroexpressions, microexpressions, and categorizes subtle expressions into Action Units which relate to more complex emotional responses as well as level of intensity.[28]

#### Eye-Tracking

Saccades (directional movement of gaze) and fixations (duration of gaze in one location) can indicate attention and interest.[29] Gaze and fixations were tracked in Areas of Interest (AOI) specific to each cognitive test.

### Experiment Measurement: Cognition

#### Task-Switching & Response Inhibition

Performance was measured via errors on tasks. Both the Task-Switching program and the Go/No-Go program records errors in the test. More errors indicate lower accuracy. The Task-Switch program takes less than 10 minutes and tests the stable ability and speed in switching between rule sets as a measure of cognitive control, which requires high working memory load and sustained attention – attentional control.[30] The Go/No-Go program takes less than 5 minutes and tests the ability to inhibit response to specific stimuli while randomly presented with stimuli that requires a response.[31] Likewise, this program is also a good measure of sustained attention.

### Experiment Measurement: Perceptual Outcomes

#### Self-Reported Measures of Focus Task Difficulty or Ease

After each test, perceptions of ease or difficulty was measured for task instructions, the task itself, and ability to focus on a 7-point scale (1 = extremely easy to 7 = extremely difficult).

### Experiment Manipulation: Auditory Distraction Variable

Experiment testing was in a semi-controlled environment within the soundscaping area where the auditory track of task-irrelevant conversation was played from a location in the room that provided a Privacy Index rating of at least 85 for the biophilic soundscaping condition.

#### Manipulation Check: Perceived Auditory Distraction

After both tests, an acoustical distraction manipulation check was measured in terms of comprehension, relevance, and interest in the overheard conversation.

### Experimental Manipulation: Acoustical Conditions

Objective tests for all conditions in all locations were conducted comparing the effect of different background sound conditions as defined below.

A. Steady State Soundscaping "Whispering River" Theme: This includes the biophilic sound of running water. Non-adaptive level and spectrum set 3dB below GSA maximum levels.
B. Traditional-Spectrum Steady State Sound-masking*: Use the pink-noise-generated background masking signal, with tuned spectrum and level as prescribed by Bradley in the study "The Acoustical Design of Conventional Open-Plan Offices,"[32] as a representation of a typical, well-designed sound-masking spectrum in common use. Level is set at 45 dBA, ±0.5 dB in ea. 1/3 octave band. *note: set 3dBA below GSA specifications
C. No Sound-masking: No masking of any type.
D. Control Condition: Complete experiment with no auditory distractions.

#### Manipulation Check: Speech Intelligibility

Play 10 phrases from The IEEE Recommended Practice for Speech Quality Measurement,[33] pausing between each, while participant attempts to listen,

26. Plantronics, 2017
27. iMotions, 2016c
28. iMotions, 2016b
29. iMotions, 2016a
30. Kiesel et al., 2010
31. Criaud and Boulinguez, 2013
32. Bradley, 2003
33. IEEE, 1969

comprehend, and then type what they hear. Accuracy of sentences were calculated.

### Procedures

For the in-situ study, participants were asked to complete the informed consent document on the first survey. Surveys were deployed via email on a designated day for each condition. Participants were allowed 5 days to respond with a reminder email on the last day.

### Cognitive Testing in Experiment Procedure

Upon arrival to the appointment, the researcher reviewed/collected the informed consent from each participant. The participant was instructed on what to expect.

Once the biometric instruments were collecting data, the participant completed one of two cognitive web-based tests. At the onset of the first test, an audio track of a conversation was played at the designated testing position. For the biophilic soundscaping and traditional sound-masking conditions, objective measurement of the experiment site was within the "non-intrusive" range with a Privacy Index rating of ~85. Test order was randomly assigned to prevent ordering effects. Upon completion of both tests, the participant answer questions about demographics and perceptual information.

## In-Situ Study Results

### Demographics

The data set for the In-Situ study involved 93 participants, 44% men and 56% women with an average age of 37.9 years, and 2.3% non-regular staff, 69% regular staff, 24.1% managers, and 4.6% leaders. Demographics did not confound any of the in-situ study outcomes. See Figure 2.

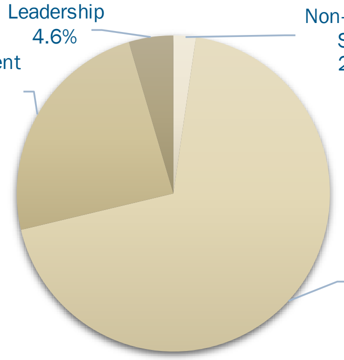


*Figure 2. Percentage of Participant Roles in Organization*

### Acceptance & Perceived Efficacy

The optimized biophilic soundscaping was perceived to be more effective at masking overheard conversations than other sound-masking (baseline & Bradley/traditional sound-masking) conditions in real world applications in terms of others overhearing own conversation and overhearing others' conversation, with the experience of noise significantly lower than traditional sound-masking and baseline. NOTE: Participants use of headphones increased slightly when in the traditional (Bradley) sound-masking condition. So, effects seen for the Bradley/traditional group may be confounded by that increase in headphone use. See Table 1 for ANOVA results and Figures 3-5 for mean difference bar charts.

| Being Overheard (1 = not well at all; 5 = extremely well) | | |
|---|---|---|
| F(3,89)=4.695**; p=.004 | Mean | Std. Deviation |
| Control | 3.73 | 1.280 |
| Baseline | 3.68 | .791 |
| Traditional† | 3.17 | .937 |
| Biophilic | 2.88 | .741 |
| **Overhearing Others (1 = not well at all; 5 = extremely well)** | | |
| F(3,89)=4.034**; p=.010 | Mean | Std. Deviation |
| Control | 3.73 | 1.280 |
| Baseline | 3.68 | .791 |
| Traditional† | 3.17 | .937 |
| Biophilic | 2.88 | .741 |
| **Experience of Noise (1 = extremely quiet; 5 = extremely loud)** | | |
| F(5,141)=3.676**; p=.004 | Mean | Std. Deviation |
| Control | 2.33 | 1.175 |
| Baseline | 3.62 | .815 |
| Traditional† | 3.35 | .885 |
| Biophilic | 3.04 | .751 |

*Table 1. ANOVA Differences (*p<.10; **p<.05) †Increase in headphone use neared statistical significance, p<.10. Interpret with caution.*

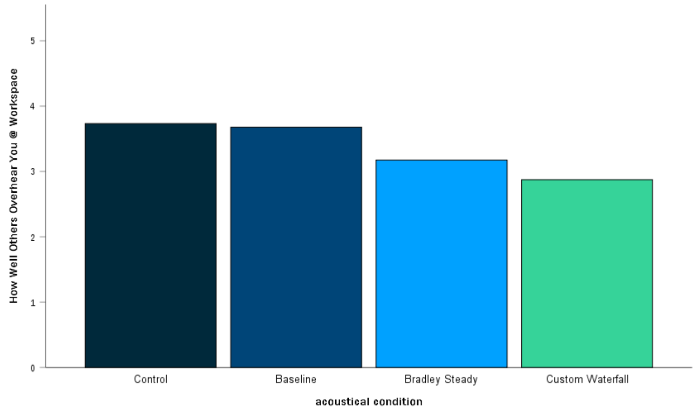


*Figure 3. How Well Others Overhear Your Conversations. (0 = not at all well; 5 = extremely well)*

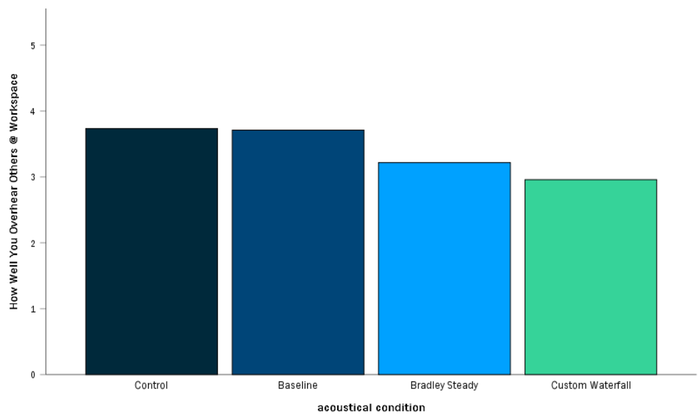


*Figure 4. How Well You Overhear Others' Conversations. (1 = not at all well; 5 = extremely well)*

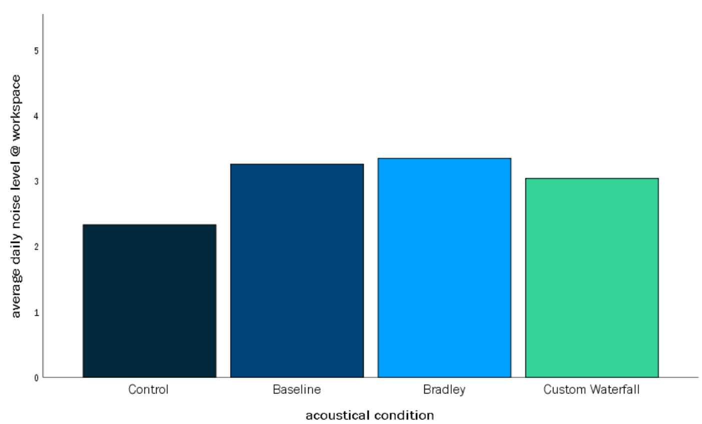


*Figure 5. Average Daily Noise Level. (1 = extremely quiet; 5 = extremely loud)*

ANOVAs revealed satisfaction with the biophilic "Waterfall" optimized theme either was as satisfactory or more satisfactory than all other conditions on the various aspects of the workspace acoustics: noise at their workspace, masking content, masking volume, and the masking effect on their work. See Table 2 for ANOVA results and Figures 6-9 for mean difference bar charts.

| Satisfied w/Noise (1 = strongly disagree; 5 = strongly agree) | | |
|---|---|---|
| F(3,86)=2.58*; p=.059 | Mean | Std. Deviation |
| Control | 3.38 | .961 |
| Baseline | 2.70 | 1.236 |
| Traditional† | 3.00 | 1.044 |
| Biophilic | 3.46 | .977 |
| Satisfied with Masking Content (1 = strongly disagree; 5 = strongly agree) | | |
| F(3,85)=4.82**; p=.004 | Mean | Std. Deviation |
| Control | 3.08 | .760 |
| Baseline | 3.24 | .739 |
| Traditional† | 3.00 | 1.000 |
| Biophilic | 3.88 | .900 |
| Satisfied with Masking Volume (1 = strongly disagree; 5 = strongly agree) | | |
| F(3,86)=4.21**; p=.008 | Mean | Std. Deviation |
| Control | 3.15 | .899 |
| Baseline | 3.40 | .932 |
| Traditional† | 3.00 | 1.206 |
| Biophilic | 4.00 | .976 |
| Satisfied with Masking Effect on Work (1 = strongly disagree; 5 = strongly agree) | | |
| F(3,86)=2.53*; p=.062 | Mean | Std. Deviation |
| Control | 3.00 | .707 |
| Baseline | 3.33 | .884 |
| Traditional† | 3.09 | .900 |
| Biophilic | 3.67 | .816 |

*Table 2. ANOVA Differences (*p<.10; **p<.05) †Increase in headphone use neared statistical significance, p<.10. Interpret with caution.*

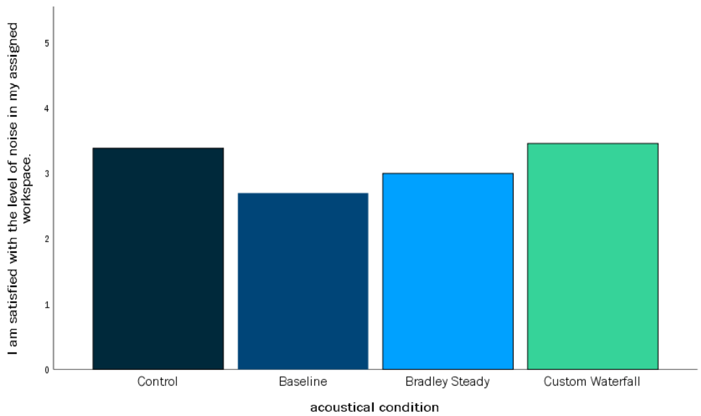


*Figure 6. Satisfied with Noise at Workspace. (1 = strongly disagree; 5 = strongly agree)*

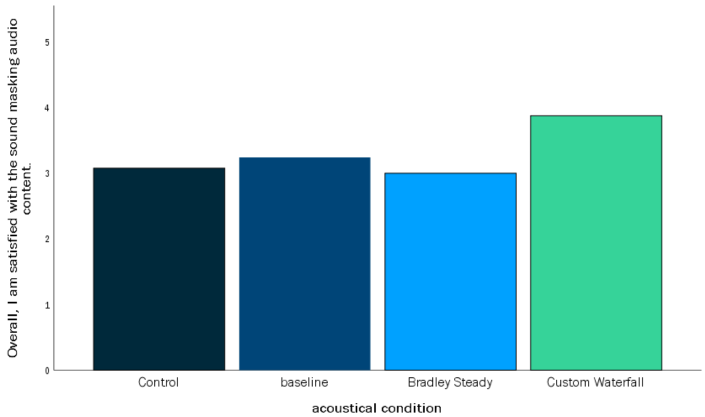


*Figure 7. Satisfied with Sound-masking Content. (1 = strongly disagree; 5 = strongly agree)*

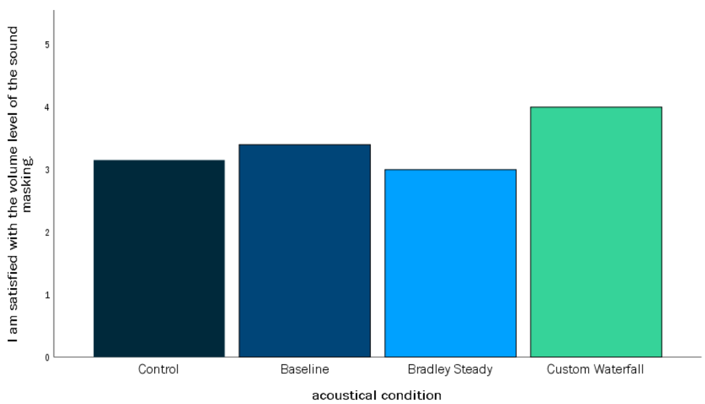


*Figure 8. Satisfied with Sound-masking Volume. (1 = strongly disagree; 5 = strongly agree)*

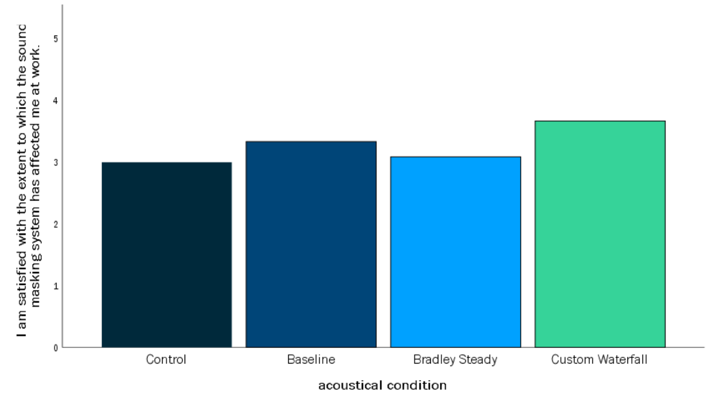


*Figure 9. Satisfied with How Masking Affects Work. (1 = strongly disagree; 5 = strongly agree)*

## Experiment Results

### Demographics

The final data set for the experiment involved 39 participants, 41% men and 59% women with an average age of 39.91 years, and 81.6% regular staff, 15.8% managers, and 2.6% leaders. Demographics did not confound any of the experiment outcomes. Power analysis for the deliberate focus task requires a minimum of 8 participants per condition. This was met. See Figure 10.

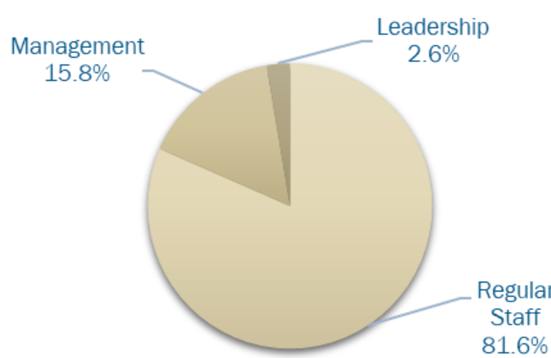


*Figure 10. Percentage of Participant Roles in Organization*

### Effects on Focus Performance Experiment

T-test results revealed that there was no ordering effect as average scores on the Go/No-go test ($t = .559$; $p = .580$) and the Task Switch test ($t = .914$; $p = .367$) were the same. Completing one cognitive test before the other did not cause any differences in performance on either test.

| Go/No-go Test Means | Mean Correct |
|---|---|
| Task Switch first | 179.17 |
| Go/No-go first | 179.00 |
| Task Switch Test Means | |
| Task Switch first | 113.58 |
| Go/No-go first | 115.36 |

*Table 3. No Ordering Effect for Tasks*

### Experiment Manipulation Check

Speech intelligibility of each condition was tested using 10 phrases from The IEEE Recommended Practice for Speech Quality Measurement.[34] Accuracy of comprehension of each phrase was calculated and dropped in the presence of both sound-masking conditions.

| | No Masking | Whispering River | Bradley |
|---|---|---|---|
| Accuracy | 77.9% | 31.3% | 30.0% |

*Table 4. Intelligibility Manipulation Check for Each Condition*

### Automated Focus Task Performance

Biophilic soundscaping is effective in mitigating speech distraction effects caused by continuous conversation for automated (easier) focus tasks. Less errors occurred in the control condition when not exposed to continuous conversation. See Table 5 and Figure 11.

| Avg. Errors in Automated Task | | | |
|---|---|---|---|
| No Masking (M = 1.13) | Mean | t-test Value | P-Value |
| Whispering River | .25 | 1.904** | .046 |
| Bradley | .50 | 1.211 | .126 |
| Control | .33 | 1.680* | .063 |

*Table 5. Average Error Rates for Automated Focus Task per Condition (1-tailed; *p<10; **p<.05)*

The error rate is low for the automated task in a control condition (.002%). However, the rate of errors dropped in the biophilic soundscaping from the error rate in the no-masking condition – from .006% to .001%. The biophilic soundscaping allowed people to perform at least as well as, if not better than the control group for automated tasks.

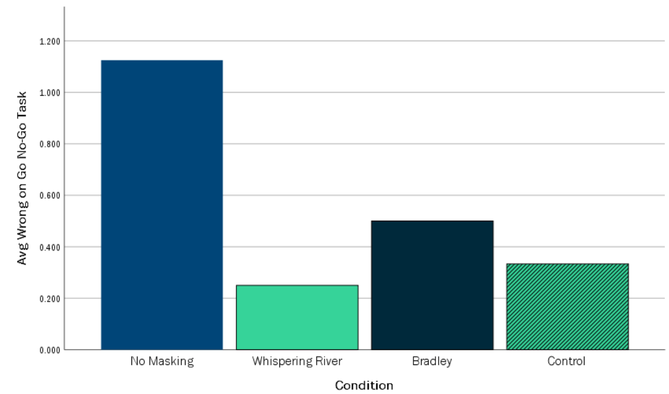


*Figure 11. Average Errors for Automated Focus Task*

### Task Switch Deliberate Focus Task Performance

Biophilic soundscaping is somewhat effective in mitigating speech distraction effects caused by continuous conversation for deliberate (more difficult) focus tasks. See Table 6. and Figure 12.

| Avg. Errors in Deliberate Task | | | |
|---|---|---|---|
| No-Masking (M = 7.75) | Mean | t-test Value | P-Value |
| Whispering River | 4.83 | 1.318* | .102 |
| Bradley | 2.30 | 2.638** | .009 |
| Control | 3.44 | 1.862** | .041 |

*Table 6. Average Error Rates for Deliberate Focus Task per Condition (1-tailed; *neared significance; **p<.05)*

The deliberate task error rate in the no masking condition was 6.5%. Less wrong answers neared significance for Whispering River where the error rate dropped to 4.8%. Wrong answers were significantly lower for control where the error rate dropped to 3.4%. Wrong answers were significantly lower for Bradley where the error rate dropped to 2.3%.

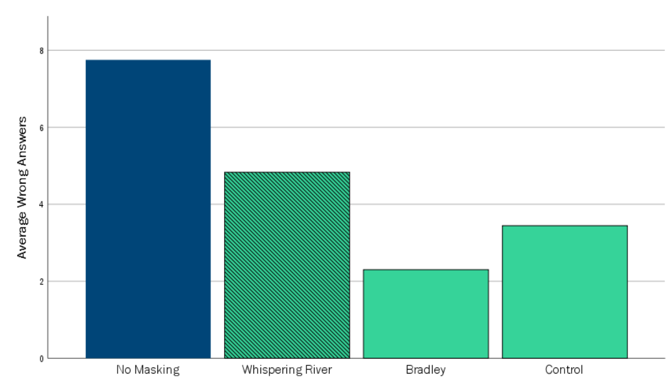


*Figure 12. Average Errors for Deliberate Focus Task*

34. IEEE, 1969

### Interest in Overheard Conversation for Both Tasks

For the conditions exposed to the continuous conversation, interest levels vary. The no masking condition was most interested in the conversation as compared to the biophilic soundscaping condition ($t = 2.599$; $p = .015$**) and in the Bradley condition ($t = 1.586$; $p = .066$*). (1-tailed p-values; *p<.10; **p<.05; See Figure 13.)

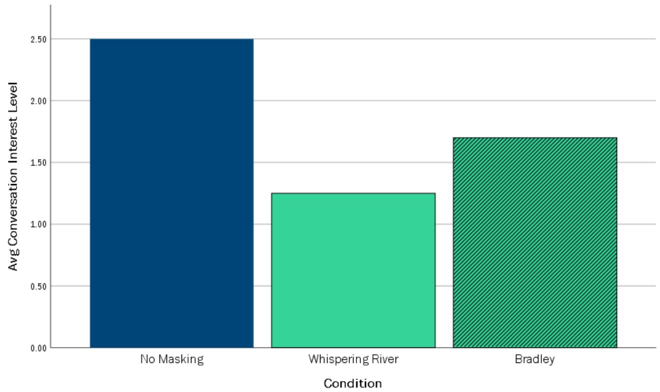


*Figure 13. Average Interest in Overheard Conversation During Automated Tasks per Condition (1 = not at all; 3 = moderate; 5 = extremely)*

### Comprehension of Overheard Conversation for Automated Focus Task

The no masking condition self-rated comprehension of the conversation was high (M = 73.86%, SD = 26.935). People comprehended more of the conversation in the no-masking condition compared to the biophilic soundscaping, Whispering River condition and in the Bradley condition. See Figure 14.

| Avg. % Conversation Comprehension in Automated Task | | | |
|---|---|---|---|
| No-Masking (M = 73.86%) | Mean | t-test Value | P-Value |
| Whispering River | 34.45% | 3.017** | .005 |
| Bradley | 44.78% | 2.371** | .015 |

*Table 7. Average % Comprehension for Automated Focus Task per Condition (1-tailed; **p<.05)*

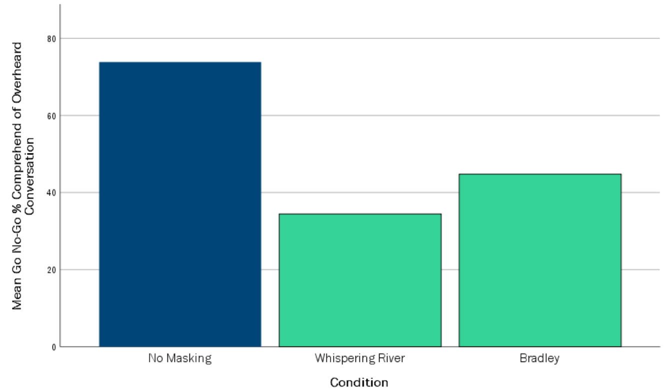


*Figure 14. Average Percent Comprehended of Overheard Conversation for Automated Focus Task*

### Comprehension of Overheard Conversation for Deliberate Focus Task

The no masking condition self-rated comprehension of the conversation was low (M = 33.14%, SD = 27.86) for the deliberate task. This is significantly lower than the automated task comprehension ($t = 3.867$, $p = .004$, 1-tailed) even though the acoustical conditions were identical. This could be further evidence for an engaged cognitive suppression mechanism for difficult tasks.[35]

People comprehended more of the conversation in the no-masking condition compared to the Bradley condition. Comprehension in the biophilic soundscaping, Whispering River condition did NOT differ significantly from the no masking condition. See Table 8 and Figure 15.)

| Avg. % Conversation Comprehension in Deliberate Task | | | |
|---|---|---|---|
| No-Masking (M = 33.14%) | Mean | t-test Value | P-Value |
| Whispering River | 22.18% | 1.002 | .165 |
| Bradley | 15.70% | 1.372* | .080 |

*Table 8. Average % Comprehension for Deliberate Focus Task per Condition (1-tailed; *p<.10)*

35. Hughes, 2014; Sörqvist, Stenfelt, and Rönnberg, 2012; Hughes et al., 2013

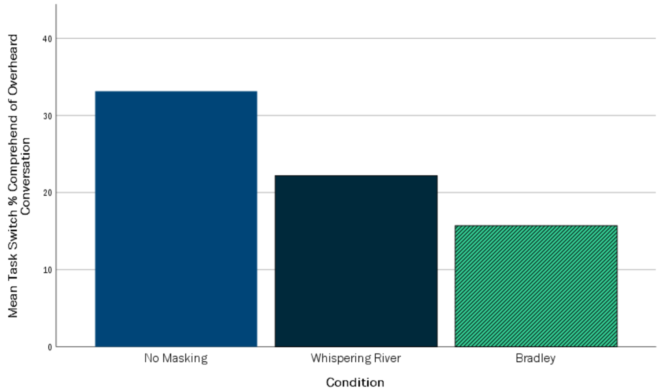


*Figure 15. Average Percent Comprehended of Overheard Conversation for Deliberate Focus Task*

## Ease of Task Instruction, Task, & Focusing

### Ease of Task Instruction, Task, and Focusing for Automated Focus Task

A series of t-tests revealed one nearly significant difference between the no masking condition and each of the other conditions for ease of the task itself and focusing (1-tailed p-levels). Task instruction ease for the automated (Go/No-go) task did not differ significantly among any of the conditions with all average responses between moderately easy (2) and extremely easy (1). For task and focusing ease, all average responses were between slightly easy (3) and extremely easy (1) with Whispering River rated slightly easier than no masking and is less likely due to chance, or nearly significant.

| Task Instruction Ease | | | |
|---|---|---|---|
| No-Masking (M = 1.57) | Mean | t-test value | P-Value |
| Whispering River | 1.00 | 1.000 | .178 |
| Bradley | 1.00 | 1.000 | .178 |
| Control | 1.11 | .894 | .193 |
| Task Ease | | | |
| No-Masking (M = 1.86) | Mean | t-test value | P-Value |
| Whispering River | 1.00 | 1.549* | .086 |
| Bradley | 1.11 | 1.322 | .116 |
| Control | 1.11 | 1.322 | .116 |
| Focusing Ease | | | |
| No-Masking (M = 2.29) | Mean | t-test value | P-Value |
| Whispering River | 1.64 | .896 | .192 |
| Bradley | 2.00 | .421 | .340 |
| Control | 2.89 | .788 | .222 |

*Table 9. Average Ease of Task Instructions, Task, and Focusing for Deliberate Task (1-tailed; *p<.10)*

### Ease of Task Instruction, Task, and Focusing for Deliberate Focus Task

A series of t-tests revealed some differences from the no masking condition on ease of task instruction, the task itself, and focusing during the task. The ratings ranged between slightly easy (3) to moderately difficult (6). Although, understanding task instructions (processing language) was easier in both masking conditions than when in the no masking condition, Whispering River was easier and statistically significant whereas Bradley wasn't rated nearly as easy and only approached significance. This aligns with existing evidence that the language in the conversation interfered less with ability to understand the instructions.[36] In terms of task and focusing ease, the biophilic soundscaping, rated easier on both, neared significance whereas the other conditions were not significantly different than the no masking condition.

36. Parmentier and Kefauver, 2015; Marsh, Hughes, and Jones, 2009

| Task Instruction Ease | | | |
|---|---|---|---|
| No-Masking (M = 4.86) | Mean | t-test value | P-Value |
| Whispering River | 3.27 | 2.098** | .026 |
| Bradley | 3.50 | 1.550* | .071 |
| Control | 4.67 | .221 | .414 |
| Task Ease | | | |
| No-Masking (M = 5.43) | Mean | t-test value | P-Value |
| Whispering River | 4.73 | 1.682* | .056 |
| Bradley | 5.00 | .910 | .136 |
| Control | 1.11 | 1.322 | .116 |
| Focusing Ease | | | |
| No-Masking (M = 4.57) | Mean | t-test value | P-Value |
| Whispering River | 3.45 | 1.675* | .056 |
| Bradley | 3.0 | .921 | .137 |
| Control | 2.89 | .788 | .222 |

*Table 10. Average Ease of Task Instructions, Task, and Focusing for Deliberate Task (1-tailed; *p<.10; **p<.05)*

### Stress, Emotion, and Attention Outcomes

#### Stress Outcomes Per Condition for Automated Focus Task

An ANOVA looking at the galvanic skin response peaks participants experienced while completing the automated focus task reveal no significant differences among all conditions exposed to the continual conversation. Traditional sound-masking nor biophilic sound scaping provide any benefit in terms of reducing nervous system arousal: $F(3,20) = 1.221$, $p = .331$.

#### Stress Outcomes Per Condition for Deliberate Focus Task

An ANOVA looking at the galvanic skin response peaks participants experienced while completing the deliberate focus task reveal no significant differences among all conditions exposed to the continual conversation. Traditional sound-masking nor biophilic sound scaping provide any benefit in terms of reducing nervous system arousal: $F(3,23) = 1.204$, $p = .330$.

#### Expression of Emotion: Sustained Attention

In terms of expressions of emotion, there were no significant nor practical differences between conditions for either task. The emotions most often expressed in both conditions were expressions of attention and neutral expressions. Remaining emotional expressions were very low or negligible.

These results are to be expected based on the nature of both tasks requiring sustained attention. Therefore, these results support the manipulation of both cognitive tasks requiring sustained attention.

Engagement expressions appear slightly higher during the deliberate task, but this is logical since more deliberate effort occurs to complete that task.

#### Eye-Tracking Outcomes for Attention

Attention in eye-tracking is measured in gaze and fixations for the area of interest on the screen. Two measures of eye-tracking were used to determine attention:

- % time spent in fixations – how much time within the area of interest was spent in fixations for the entire task
- gaze revisits to the area of interest – how many times eyes left and returned to the area of interest

#### Automated Focus Task Eye-tracking Outcomes

ANOVA revealed there was no significant differences the proportion of time spent in fixations ($F = .056$, $p = .491$) for the Go/No-go automated task across all conditions, including the control.

| % Time Spent in Fixation (ms) | | |
|---|---|---|
| | Mean | Std. Deviation |
| Whispering River | 37.20 | 50.514 |
| No Masking | 45.00 | 41.103 |
| Bradley | 35.83 | 39.595 |
| Control | 42.40 | 36.841 |

*Table 11. Avg. % Time Spent in AOI in Fixation for Automated Focus Task*

T-tests revealed the difference in number of times one's gaze left and returned to the area of interest approached significance. Less occurred in the biophilic soundscaping, Whispering River, condition ($M = 31.60$, $SD = 35.50$) than the control condition ($M = 83.80$, $SD = 60.30$; $t = 1.668$, $p = .067$*). This condition afforded people the ability to keep their attention within the area of interest compared to all other conditions, even though there were no differences in fixations. (1-tailed p-values; *p<.10. See Figure 16.)

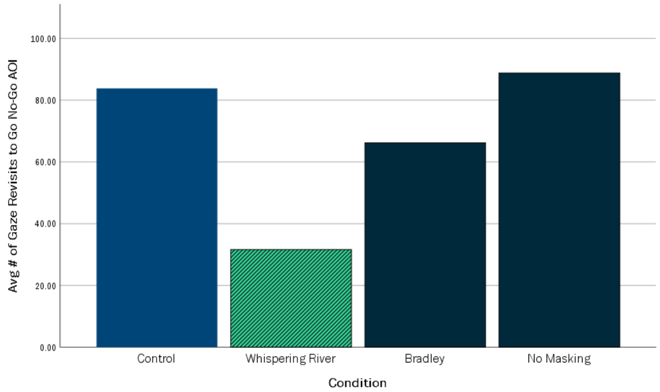


*Figure 16. Average Number of Times Gaze Left and Returned to AOI for Automated Focus Task.*

## Deliberate Focus Task Eye-tracking Outcomes

A series of t-tests revealed the proportion of time spent in fixations for the deliberate Task Switch focus task was significantly less in all conditions exposed to continuous conversation as opposed to the control group, with the no masking condition having the smallest proportion of time spent in fixations. (See Figure 17.)

| % Time Spent in Fixation (ms) | | | |
|---|---|---|---|
| Control (M = 62.80) | Mean | t-test Value | P-Value |
| Whispering River | 39.57 | 1.954** | .039 |
| No Masking | 33.40 | 1.969** | .045 |
| Bradley | 32.20 | 2.264** | .026 |

*Table 12. Avg. % Time Spent in Fixation for Deliberate Focus Task (1-tailed; **p<.05)*

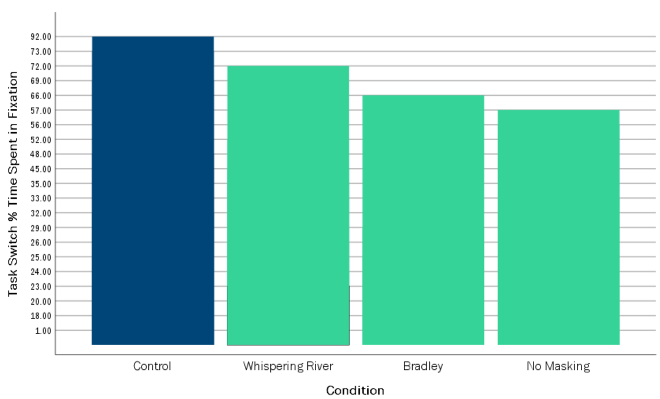


*Figure 17. Avg. % Time Spent in AOI in Fixation for Deliberate Focus Task*

ANOVA revealed there was no significant differences across all conditions in the number of times one's gaze left and returned to the area of interest for the deliberate Task Switch focus task (F = .192, p = .450).

| Avg. # of Times Gaze Left and Returned to AOI | | |
|---|---|---|
| | Mean | Std. Deviation |
| Whispering River | 72.71 | 33.811 |
| No Masking | 71.80 | 43.286 |
| Bradley | 58.40 | 17.008 |
| Control | 71.60 | 42.682 |

*Table 13. Average Number of Times Gaze Left and Returned to AOI for Deliberate Focus Task.*

# Conclusions

The evidence presented suggests support for all four hypotheses:

**H1:** Perception levels of overheard conversations will be equal to or reduced in the biophilic soundscaping compared to traditional sound-masking.

**H2:** When deployed through change management techniques, satisfaction with the subjective experience of biophilic soundscaping will be equal or better than traditional sound-masking.

**H3:** Performance and attention on automated (easier) focus tasks during an overheard conversation with sound-masking will be better than without sound-masking.

**H4:** Performance and attention on deliberate (more difficult) focus tasks during an overheard conversation with sound-masking will be better than without sound-masking.

The research question, "how effective and accepted is the biophilic soundscaping compared to traditional sound-masking?" is addressed in the conclusion.

### Efficacy Perceptions & Satisfaction with Biophilic Soundscaping

People perceive others overhearing their own conversations less and perceive overhearing others' conversations less than in traditional sound-masking. When properly deployed, they also tend to be more satisfied with the biophilic soundscaping than traditional sound-masking. Proper deployment includes transparency about changes to sound-masking and soliciting input into selection of theme – common change management tactics.

### Performance Outcomes for Automated Focus Tasks in Biophilic Soundscaping

On average, when people are exposed to continuous conversation, they made less errors during the automated focus task while in the biophilic soundscaping than when no sound-masking is deployed. They performed similarly to those not exposed to conversation. In addition, those in the traditional sound-masking did not perform better than those with no sound-masking at all.

Measures of attention in the form of visual attention and expressed emotion of attention were consistent across all conditions except for how often gaze drifted outside the visual area of interest. In this case, on average, the gaze of those in the biophilic soundscaping condition stayed within the area of interest more than the other conditions. Attention was improved in this respect. Similarly, there were no differences in experience of stress during the experiment.

Perceived task ease and focus during the task were, on average, improved in comparison with the no-sound-masking condition, except for the control group that experienced the same level of ease in focusing as the no sound-masking condition. All participants deemed the task instructions easy regardless of the condition. Lastly, participants exposed to the continuous conversation reported, on average, comprehending less of the conversation during the automated task while in both the biophilic soundscaping and the traditional sound-masking conditions.

| Outcomes for Automated Tasks When Exposed to Continuous Conversation as Compared to No Sound-Masking Condition | | | |
|---|---|---|---|
| Outcome Type | Biophilic | Traditional | Control |
| Task Accuracy | | | |
| Errors | less | same | nearly less |
| Attention | | | |
| AOI % Fixations | same | same | same |
| AOI Revisits | less than no masking and control | similar, but less than no masking | same |
| % Expressed | same | same | same |
| Stress | | | |
| GSR Peaks | same | same | same |
| Perceived Ease | | | |
| Task Instruction | same | same | same |
| Task | easier | easier | easier |
| Focusing | easier | easier | same |
| Comprehension | | | |
| % Perceived | less | less | NA |

*Table 14. Summary of Automated Task Performance Outcomes*

### Performance Outcomes for Deliberate Focus Tasks in Biophilic Soundscaping

On average, when people are exposed to continuous conversation, they made less errors during the deliberate focus task while in the traditional sound-masking condition than when no sound-masking was deployed. They performed like those not exposed to conversation. Lastly, improved performance for those in the biophilic soundscaping while overhearing a conversation approached significance.

Measures of attention in the form of visual attention and expressed emotion of attention were consistent across all conditions except for how much time within the AOI was spent in fixation – or steady visual attention. In this case, on average, the proportion of fixation within the AOI of those in the control condition was higher than the other conditions. This form of attention was improved in the absence of overheard speech only. Lastly, there were no differences in experience of stress during the experiment.

All participants deemed the task itself and focusing, on average, slightly difficult regardless of the condition. Perceptions of the ease of task instructions were, on average, easier than the no sound-masking condition with the biophilic soundscaping condition finding them easiest.

The no masking condition self-rated comprehension of the conversation was much lower for the deliberate task than for the automated task even though the acoustical conditions were identical across both types of tasks. NOTE: These results are potentially confounded by the cognitive suppression mechanism for difficult tasks.[37] Therefore any differences found here are likely minimized and confounded by this process – any differences should be interpreted cautiously.

Outcomes for Deliberate Tasks When Exposed to Continuous Conversation as Compared to No Sound-Masking Condition

| Outcome Type | Biophilic | Traditional | Control |
|---|---|---|---|
| Task Accuracy | | | |
| Errors | nearly less | less | less |
| Attention | | | |
| AOI % Fixations | similar, but more than traditional | similar, but more than no masking | higher than no masking |
| AOI Revisits | same | same | same |
| % Expressed | same | same | same |
| Stress | | | |
| GSR Peaks | same | same | same |
| Perceived Ease | | | |
| Task Instruction | easiest | easier | easier |
| Task | same | same | same |
| Focusing | same | same | same |
| Comprehension | | | |
| % Perceived | same | nearly less | NA |

*Table 15. Summary of Deliberate Task Performance Outcomes*

Lastly, of what people could understand *during both tasks*, those in the biophilic soundscaping were less interested in the conversation than in the traditional sound-masking, which was slightly less than when no masking was used.

In terms of the research question, the biophilic soundscaping allows people, on average, to perform as well as when in traditional sound-masking, if not better, depending on the task. Considering noise and overheard speech in the open-plan office is one of the top complaints, these findings are encouraging in terms of a better solution for managing acoustics to reduce auditory events that can capture attention and interfere with cognitive performance.[38]

37. Hughes, 2014; Sörqvist, Stenfelt, and Rönnberg, 2012; Hughes et al., 2013

38. Johnson et al., 2019

## Contributors

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**James Waddell**, EVP Cognitive WX Services, Cognitive Corp. has over 25 years of experience dedicated to workplace optimization. James is a proven leader in the creation and direction of successful technology and real estate strategies, workplace technology optimization, and operational processes improvements within companies of all scales and type. He focuses on leveraging the integration of converged technology systems to enrich and enhance the human experience within the built environment.

**Leah Gussenbauer** holds a B.Sc. and an M.S. in Mechanical Engineering. She started her career performing safety analysis and research testing to support nuclear power plants, transitioning to manufacturing 3 years ago. She is a Product Engineer where she designs, prototypes, and tests components for Movable Walls at Haworth.

## References


Acevedo, Bianca, Elaine Aron, Sarah Pospos, and Dana Jessen. 2018. "The Functional Highly Sensitive Brain: A Review of the Brain Circuits Underlying Sensory Processing Sensitivity and Seemingly Related Disorders." *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 373 (1744): 20170161.

Alexander, William H., and Joshua W. Brown. 2018. "Frontal Cortex Function as Derived from Hierarchical Predictive Coding." *Scientific Reports* 8 (1): 3843.

Aron, Elaine N., Arthur Aron, and Jadzia Jagiellowicz. 2012. "Sensory Processing Sensitivity." *Personality and Social Psychology Review* 16 (3): 262–82.

ASTM E1130-16. 2016. "Standard Test Method for Objective Measurement of Speech Privacy in Open Plan Spaces Using Articulation Index." West Conshohocken, PA.

Bradley, John S. 2003. "The Acoustical Design of Conventional Open Plan Offices." *Canadian Acoustics* 27 (3): 23–31.

Buschman, Timothy J., and Sabine Kastner. 2015. "From Behavior to Neural Dynamics: An Integrated Theory of Attention." *Neuron* 88 (1): 127–44.

Cepelewicz, Jordana. 2018. "To Make Sense of the Present, Brains May Predict the Future | Quanta Magazine." Quanta Magazine. 2018.

Cheyne, J. Allan, Graydenj F. Solman, Jonathan S.A. Carriere, and Daniel Smilek. 2009. "Anatomy of an Error: A Bidirectional State Model of Task Engagement/Disengagement and Attention-Related Errors." *Cognition* 111: 98–113.

Christie, S Thomas, and Paul Schrater. 2015. "Cognitive Cost as Dynamic Allocation of Energetic Resources." *Frontiers in Neuroscience*, no. 289: 1–15.

Cowan, N. 2001. "The Magical Number 4 in Short Term Memory. A Reconsideration of Storage Capacity." *Behavioral and Brain Sciences* 24: 87–186.

Cowan, Nelson. 2010. "The Magical Mystery Four: How Is Working Memory Capacity Limited, and Why?" *Current Directions in Psychological Science* 19 (1): 51–57.

Criaud, Marion, and Philippe Boulinguez. 2013. "Have We Been Asking the Right Questions When Assessing Response Inhibition in Go/No-Go Tasks with FMRI? A Meta-Analysis and Critical Review." *Neuroscience & Biobehavioral Reviews* 37 (1): 11–23.

Cruys, Sander Van de. 2014. "To Err and Err, but Less and Less: Predictive Coding and Affective Value in Perception, Art, and Autism."

Emberson, Lauren L, Gary Lupyan, Michael H Goldstein, and Michael J Spivey. 2010. "Overheard Cell-Phone Conversations : When Less Speech Is More Distracting." *Psychological Science* 21 (10): 1383–88.

Euler, Matthew J. 2018. "Intelligence and Uncertainty: Implications of Hierarchical Predictive Processing for the Neuroscience of Cognitive Ability." *Neuroscience & Biobehavioral Reviews* 94 (November): 93–112.

Everett, John, Katherine Labonte, and John Marsh. 2017. "Attentional Capture by Deviant Sounds: A Non-Contingent Form of Auditory Distraction?" *Journal of Experimental Psychology: Learning, Memory, & Cognition* 43 (4): 622–34.

Friston, Karl, and Christopher Frith. 2015. "A Duet for One." *Consciousness and Cognition* 36 (November): 390–405.

Goodchild, Jim T., and Beck Johnson. 2018. "Workplace Acoustical Performance: Designing for Privacy." Holland, MI: Haworth, Inc.

Haapakangas, A., E. Kankkunen, V. Hongisto, P. Virjonen, D. Oliva, and E. Keskinen. 2011. "Effects of Five Speech Masking Sounds on Performance and Acoustic Satisfaction. Implications for Open-Plan Offices." *Acta Acustica United with Acustica* 97 (4): 641–55.

Heeger, David J. 2017. "Theory of Cortical Function." *PNAS* 114 (8): 1773–82.

Hongisto, Valtteri, Johanna Varjo, David Oliva, Annu Haapakangas, and Evan Benway. 2017. "Perception of Water-Based Masking Sounds—Long-Term Experiment in an Open-Plan Office." *Frontiers in Psychology Front. Psychol* 8 (8): 11773389–1177.

Hughes, Robert W. 2014. "Auditory Distraction: A Duplex-Mechanism Account." *PsyCh Journal* 3 (1): 30–41.

Hughes, Robert W, Mark J Hurlstone, John E Marsh, François Vachon, and Dylan M Jones. 2013. "Cognitive Control of Auditory Distraction: Impact of Task Difficulty, Foreknowledge, and Working Memory Capacity Supports Duplex-Mechanism Account." *Journal of Experimental Psychology Human Perception & Performance* 39 (2): 539–53.

IEEE. 1969. "IEEE Recommended Practice for Speech Quality Measurements." *IEEE Transactions on Audio and Electroacoustics* 17 (3): 225–46.

iMotions. 2016a. "Eye Tracking: Pocket Guide."

———. 2016b. "Facial Expression Analysis: Pocket Guide."

———. 2016c. "GSR Pocket Guide The Pocket Guide."

Jahncke, Helena, Valtteri Hongisto, and Petra Virjonen. 2013. "Cognitive Performance during Irrelevant Speech: Effects of Speech Intelligibility and Office-Task Characteristics." *Applied Acoustics* 74 (3): 307–16.

Johnson, Beck, Jim T. Goodchild, Brad Burrows, and Danny Viator. 2019. "Why We Can't Focus at Work." Holland, MI: Haworth, Inc.

Johnson, Beck, and Paul J. Richardson. 2018. "Haworth Human Performance Lab: Visual & Auditory Distraction Effects on Deliberate Focus Work." Holland, MI: Haworth, Inc.

Kiesel, Andrea, Mike Wendt, Kerstin Jost, Marco Steinhauser, Michael Falkenstein, Andrea M Philipp, and Iring Koch. 2010. "Control and Interference in Task Switching: A Review." *Psychological Bulletin* 136 (5): 849–74.

Lange, Floris P. de, Micha Heilbron, and Peter Kok. 2018. "How Do Expectations Shape Perception?" *Trends in Cognitive Sciences* 22 (9): 764–79.

Lutfi-Proctor, Danielle A. 2016. "The Mechanisms of Auditory Distraction: The Roles of Interference-by-Process and Attention Capture." Louisiana State University.

Marsh, John E., Robert W. Hughes, and Dylan M. Jones. 2009. "Interference by Process, Not Content, Determines Semantic Auditory Distraction." *Cognition* 110 (1): 23–38.

Marsh, John E., Krupali Patel, Katherine Labonté, Emma Threadgold, Faye C. Skelton, Cristina Fodarella, Rachel Thorley, et al. 2017. "Chatting in the Face of the Eyewitness: The Impact of Extraneous Cell-Phone Conversation on Memory for a Perpetrator." *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale* 71 (3): 183–90.

Marsh, John E, Robert Ljung, Helena Jahncke, Douglas MasCutcheon, Florian Pausch, Linden J Ball, and François Vachon. 2018. "Why Are Background Telephone Conversations Distracting?" *Journal of Experimental Psychology: Applied*, no. March.

Marsh, John E, Jingqi Yang, Pamela Qualter, Cassandra Richardson, Nick Perham, François Vachon, and Robert W Hughes. 2018. "Post-Categorical Auditory Distraction in Serial Short-Term Memory: Insights from Increased Task-Load and Task-Type." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 44 (6): 882–97.

Menon, Vinod. 2015. "Salience Network." *Brain Mapping: An Encyclopedic Reference* 2: 597–611.

Menon, Vinod, and Lucina Q. Uddin. 2010. "Saliency, Switching, Attention and Control: A Network Model of Insula Function." *Brain Structure & Function* 214 (5–6): 655–67.

Monk, Christopher A, J Gregory Trafton, and Deborah A Boehm-Davis. 2008. "The Effect of Interruption Duration and Demand on Resuming Suspended Goals." *Journal of Experimental Psychology: Applied* 14 (4): 299–313.

Parmentier, Fabrice B. R. 2014. "The Cognitive Determinants of Behavioral Distraction by Deviant Auditory Stimuli: A Review." *Psychological Research* 78 (3): 321–38.

Parmentier, Fabrice B.R., and Miriam Kefauver. 2015. "The Semantic Aftermath of Distraction by Deviant Sounds: Crosstalk Interference Is Mediated by the Predictability of Semantic Congruency." *Brain Research* 1626: 247–57.

Pinotsis, Dimitris A, Timothy J Buschman, and Earl K Miller. 2018. "Working Memory Load Modulates Neuronal Coupling." *Cerebral Cortex*, March.

Plantronics. 2017. "Managing Noise Survey Results." Santa Cruz, CA.

Renz, Tobias, Philip Leistner, and Andreas Liebl. 2018. "Auditory Distraction by Speech: Can a Babble Masker Restore Working Memory Performance and Subjective Perception to Baseline?" *Applied Acoustics* 137 (March): 151–60.

Sörqvist, Patrik, Stefan Stenfelt, and Jerker Rönnberg. 2012. "Working Memory Capacity and Visual-Verbal Cognitive Load Modulate Auditory-Sensory Gating in the Brainstem: Toward a Unified View of Attention." *Journal of Cognitive Neuroscience* 24 (11): 2147–54.

Thomson, David R., Derek Besner, and Daniel Smilek. 2015. "A Resource-Control Account of Sustained Attention: Evidence from Mind-Wandering and Vigilance Paradigms." *Perspectives on Psychological Science* 10 (1): 82–96.

Watts, Greg, Rob Pheasant, Kirill Horoshenkov, Laura Ragonesi G Corresponding, and R Watts. 2009. "Measurement and Subjective Assessment of Water Generated Sounds." *Acta Acustica* 95 (6): 1032–39.

Zelazo, Philip David. 2015. "Executive Function: Reflection, Iterative Reprocessing, Complexity, and the Developing Brain." *Developmental Review* 38: 55–68.

Haworth research investigates links between workspace design and human behavior, health and performance, and the quality of the user experience. We share and apply what we learn to inform product development and help our customers shape their work environments. To learn more about this topic or other research resources Haworth can provide, visit haworth.com.