Auditory visual perception: acoustic distractions in mass timber versus concrete office spaces

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ABSTRACT

Designing for acoustics in relation to human health is becoming an increasingly relevant topic in the architectural profession. In an office environment, auditory stimuli such as the sound of traffic, office chatter, or impact noises (including as footfall or a chair dragging) from the floor above may cause small distractions throughout the course of the day. Based on research studies reviewed and compiled by the World Health Organization (WHO), the repetition of auditory stimuli could have compounding effects on occupants' health and productivity. This study looks at the implications that auditory stimuli can have on office workers in two different building typologies; a mass timber building constructed of nail laminated timber (NLT), and a traditional masonry building. The comparison of these two typologies allowed us to assess if being surrounded by a biophilic elements such as wood gave users an "acoustic forgiveness factor" when exposed to the same types of auditory stimuli. Three biometric data sets were gathered to analyze unconscious emotional and physical responses to auditory stimuli: Galvanic Skin Response (GSR), heart rate, and emotional response (measured as valence) through the novel use of a facial recognition software.

This small pilot study showed users of the conventional, masonry building were more likely to have a physical and emotional response to auditory stimuli in comparison to the inhabitants of the mass timber building. Further research with more participants and more controls in the study are needed; however, the results of this study imply that working in a mass timber building may provide an "acoustic forgiveness factor" to its occupants.

KEYWORDS: Acoustics, health, mass timber, auditory stimuli, biometric response

INTRODUCTION

The issue of acoustic performance in architecture is expanding from solely focusing on user satisfaction or code requirements to growing concerns of the impact of acoustics on human health and workplace performance (Manuj, 2017). It is important for office environments to provide optimal acoustic environments to reduce distractions and improve productivity (Campbell, 2005). The sources of sound pollution can vary greatly from building to building and even room to room. Acoustic stimuli can range from outside street noise such as traffic and sirens, to potential indoor stressors like people chatting, ongoing noise from the mechanical systems of a building, or footfall from adjacent floors. To control or suppress these sounds can be a huge economic expense, particularly when retrofitting a building; therefore, finding cost-effective means to mitigate the impact of these environmental stressors is extremely important.

To assess the effects these acoustic stimuli have on the user, this study analyzed the distraction and stress level of people in a mass timber building versus a masonry building to see if there may be an *acoustic forgiveness factor* that occurs when an occupant is in a building with exposed wood instead of without. If the biophilic effects of wood have an impact on reducing stress from acoustics, this will be a strong case to utilize a more natural aesthetic such as mass timber wood structure or implement elements like wood paneling during a retrofit of an existing building.

Acoustics & Health

The impact of environmental noise can have a significant impact on human health and well-being. As cities around the world begin to densify, the noise associated with urban environments will continue to increase with population growth. The United Nations Department of Economic and Social Affairs has projected that by 2050, 68% of the world's population will be living in urban areas. As a result, it is critical to understand the impact of the urban soundscape on mental and physical health as well as overall occupant well-being. Current information on the impact of environmental noise on human health is limited, largely due to the lack of longitudinal studies on the subject. However, through a systematic review of the impact of environmental noise and human health completed by the World Health Organization (WHO) in 2018, there is sufficient evidence on the potential for negative health outcomes resulting from environmental noise (Van Kempen, 2018).

The report released by WHO focuses on sources of environmental noise in the European region and primarily consists of studies on transportation noise (road, air, and rail). The report concludes that increased noise exposure can result in cognitive impairment, sleep disturbance, cardiovascular disease, and a reduction in overall quality of life. Additionally, the World Health Organization recommends policy suggestions to limit the adverse effects of environmental noise. This includes reducing daytime road traffic noise to below 53 decibels (dB) and nighttime below 45 dB (Van Kempen, 2018).

Unwanted exposure to long term environmental noise has proven to have the most significant impact on human health, resulting in both auditory impairments and non-auditory impacts. Auditory impairments can include hearing loss and tinnitus, while non-auditory impacts are broader ranging impacting both psychological and physiological health. While the effects of environmental noise are increasingly being studied, there is little information regarding the impact of smaller acoustic stimuli that are often dealt with in working environments and public buildings. More research is needed to understand the significance of unexpected less predictable acoustic interrupters such as a neighbor talking, a phone ringing or harsh HVAC sounds on an individual's health.

Acoustics & Energy Performance

Energy performance and thermal comfort are often of primary consideration when designing building enclosures, often leaving the acoustics of a building as a side effect of those design decisions instead of specifically designing for optimal acoustic performance. Acoustic decoupling is the process of separating materials to minimize sound vibration transfer and increase the Sound Transmission Class (STC) rating of an assembly. From an energy standpoint, decoupling materials also reduces heat transfer through an assembly and results in a higher performing thermal enclosure (Warnock, 1984). Materials used for thermal insulation are typically the same materials used to minimize sound transmission and control vibrations. This includes materials such as mineral wool, fiber glass, or cellulose insulation. Overall, many strategies that increase the energy performance of a building typically result in improved sound isolation.

BACKGROUND

Sound Measurement Categories

In architectural assemblies sound is typically measured in one of three ways. The Outdoor Indoor Transmission Class (OITC) measures the rate of transmission between indoor and outdoor spaces. The Sound Transmission Class (STC) measures the airborne sound transfer through a building partition (Warnock, 1984). The Impact Insulation Class (IIC) measures the transmission of sound transfer via impact (such as footsteps) through a building assembly (Warnock, 1999).

Mass Timber and Stress Reducing Properties of Wood

The use of mass timber and cross-laminated timber (CLT) construction are gaining prevalence in the US "due to concerns about climate change, resource sustainability, the need for construction efficiencies and the human biophilic affinity for wood" (Fell, 2010). As the majority of the population spends an increasing amount of their time indoors, it is important to recognize the benefits nature has on human psychological and physiological health. Studies have shown that nature has the ability to be both psychologically and physiologically restorative after high stress events. Hence, bringing more natural elements into interior environments is beginning to gain traction as a strategy to improve human health and reduce stress levels (Burnard, 2015).

The growing prevalence of exposed wood structures in mass timber buildings is an effective way to bring natural elements into the interior of a building. "Using wood for interior treatments in indoor environments has been shown to have positive impacts on occupants, especially related to indicators of human stress." (Burnard 2015). In one study, subjects were exposed to a decorative wood wall and white walls. Although there was a small sample size, when people were exposed to the wood walls their heart rate and blood pressure decreased. (Burnard 2015). Moreover, a different field study compared four different office environments: one without wood or plants for control, one with only wood furniture and no plants, another with wood furniture and plants and one with plants and non-wood furniture. The subjects were asked to take a lightly stressful test and were monitored before, during and after to assess their stress levels. The rooms with wood furniture were the most effective for reducing stress levels during and after even compared to the room with just plants and non-wood furniture.

EXPERIMENTAL APPROACH

The study was carried out over a two week period between two separate architecture firms – one in a newly constructed nail laminated timber (NLT) building and the other in a historic, masonry building. The workers were exposed to a range of auditory stimuli to assess their distraction and stress levels in response to the sounds. A comparative analysis was performed to determine if there is an *acoustic forgiveness factor* that exists due to the presence of exposed wood in the mass timber building.

CORE HYPOTHESES

1. Office workers performing focused work in a mass timber building are less distracted and show a lower stress response from footfall than in a masonry structure.

2. Office workers performing focused work in a mass timber building are less distracted from and show a lower stress response from outside traffic noise than in a masonry structure.

3. Office workers performing focused work in a mass timber building are less distracted from and show a lower stress response from other people talking than in a masonry structure.

METHODS

Both architecture firms were studied over the course of four hours during the morning. The first was FFA Architecture and Interiors, located in downtown Portland, OR in a historic conventional, masonry building. The second was Mackenzie Architecture, which is located in downtown Vancouver, WA in a newly constructed exposed NLT building. For each group, the same controlled 30-minute soundscape was created with the following stimuli added randomly throughout: ambient noise, brown noise, footfall from above, traffic, sirens, chatter, and coughing or sneezing (*see figure 1*).

	Description	**Timing (mm:ss)**	**Related Sound Class**
Stimuli #1	Ambient Traffic	2:05-3:32	OITC
Stimuli #2	Chair Drag	4:57-5:02	IIC
Stimuli #3	Police Siren	7:20-7:50	OITC
Stimuli #4	Female Cough	12:02-12:09	N/A
Stimuli #5	Footsteps Above #1	16:08-16:20	IIC
Stimuli #6	Office Scanner	18:46-19:56	N/A
Stimuli #7	Footsteps Above #2	23:02-23:11	IIC
Stimuli #8	Truck Idle	25:52-26:08	OITC
Stimuli #9	Cut off ambient air conditioner soundtrack (silence)	27:51-30:00	N/A

Figure 1: Chart of auditory stimuli and timing

Five workers in each of the different office environments were asked to work for 30 minutes each with the custom audio sample, while they faced a facial-recognition camera, paired with software to detect mood and distraction level (by examining eye movement, head movement, and facial expression), as well as a monitor to analyze stress levels.

Equipment

Noise-canceling headphones were used to block most of the exterior sound and play the created soundscape with the applied auditory stimuli. A camera was placed in front of the participant in order to gather data on facial expression through the iMotions software (version 7.2). This provided data on the intensity and length of emotions being caused by each particular acoustic stimulus.

A Shimmer3 GSR+ monitor was also connected to the participants wrists, pointer, middle, and ring finger to further analyze the emotional impact and stress level of the soundscape. This was hooked up to a participant's left or right wrist, middle and ring finger to measure the electrodermal activity (EDA) or galvanic skin response (GSR). These measure the electrical activity conducted through the sweat glands in the skin and gives an indication of the intensity of the particular emotion being experienced at the time.

Acoustic Stimuli

In the course of the 30-minute study, nine acoustic stimuli were played through noise canceling headphones. Eight stimuli were played over a 28-minute long track simulating ambient air conditioning to limit interference from outside noises (*see figure 2*). At the end of the 28 minutes, two additional minutes of silence on the audio track were added, so the subjects could be monitored for a biometric response to the removal of the ambient air conditioning. Of the eight stimuli, three represented various common outside noises and relate to the Sound Transmission Class (STC), the next three stimuli represented noises from the floor above and relate to the Impact Isolation Class (IIC), and two represented noises common to the work environment. The figure below represents the timeline of the study along with the decibel level and duration of the stimuli.

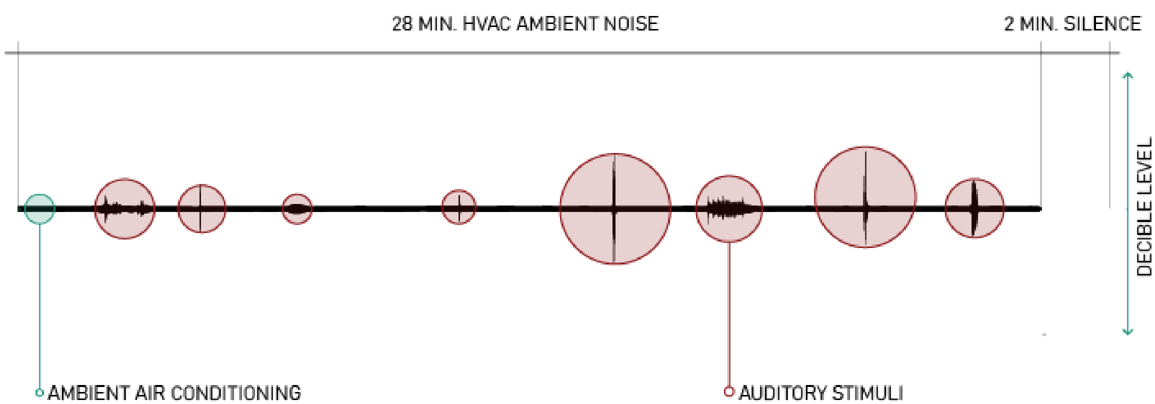

Figure 2: Timing and decibel level of acoustic stimuli

Participants

Five workers volunteered from each office to participate in the study (*see figure 3)*. The sample size was limited to those willing to participate; however, in both offices it was possible to perform the study across a range of locations throughout each space.

Participant	**Firm**	***Age***	***Gender***	***Location***	***Notes***
A1	FFA	*37*	*Female*	*Hallway*	*Glasses*
A2	FFA	*31*	*Male*	*Corner*	*Facial Hair / Glasses*
A2	FFA	*38*	*Female*	*Back Office*	*Glasses*
A4	FFA	*34*	*Male*	*Back Office*	*Standing*
A4	FFA	*42*	*Male*	*Corner*	*Facial Hair*
B1	Mackenzie	*+/- 30*	*Female*	*Right*	
B2	Mackenzie	*+/- 30*	*Male*	*Left*	*Held hand over face at times*
B3	Mackenzie	*+/- 30*	*Male*	*Right*	*Glasses / Facial hair / Primarily working on monitor not facing camera*
B4	Mackenzie	*+/- 30*	*Male*	*Left*	
B5	Mackenzie	*+/- 30*	*Male*	*Left*	*Glasses*

Figure 3: Participant profile for those in the masonry building (FFA) and mass timber building (Mackenzie).

RESULTS

Three biometric datasets were gathered to analyze the level of emotion and stress levels related to the acoustical stimuli: Galvanic Skin Response (GSR), heart rate, and emotional response (measured as valence) through the use of a facial recognition software. The GSR and heart rate provided the occupants' physical response to the stimuli, while the facial recognition captured emotional response from nonconscious facial expression. In the iMotions software, valence measures whether or not participants had any emotional response. Instead of individually monitoring emotions (including contempt, joy, anger, fear) valence was measured to determine if there was any biometric response from the acoustic stimuli as a whole. However, due to unreliable data collected from one of the equipment, only the iMotion facial recognition software data was taken into account for this analysis.

The level of responses were measured from the valance data gathered from the facial recognition software, showing whether the participants had a positive or negative emotional reaction to the stimuli introduced. The balance for each participant was set at 0% and a threshold of 20% was set up to filter milder reactions to stimuli or other exterior reactions. Any emotional response above 20 (positive or negative) then was accounted for as a response and incorporates into the average level of response as shown below.

The analysis first looks at the results per building type to find any significant trends of each participant group It later continues to compare both buildings to find whether there's a significant level of response from both participant groups that could either prove or disprove the hypothesis.

Mass Timber Building Results

The participants from Mackenzie Architects who work in the mass timber building had varying degrees of exposure to biophilic elements, but all of them had direct views to an exposed wood ceiling or column within their sightline while running the experiment. Five participants were exposed to the soundtrack, while they continued to work on their own personal tasks.

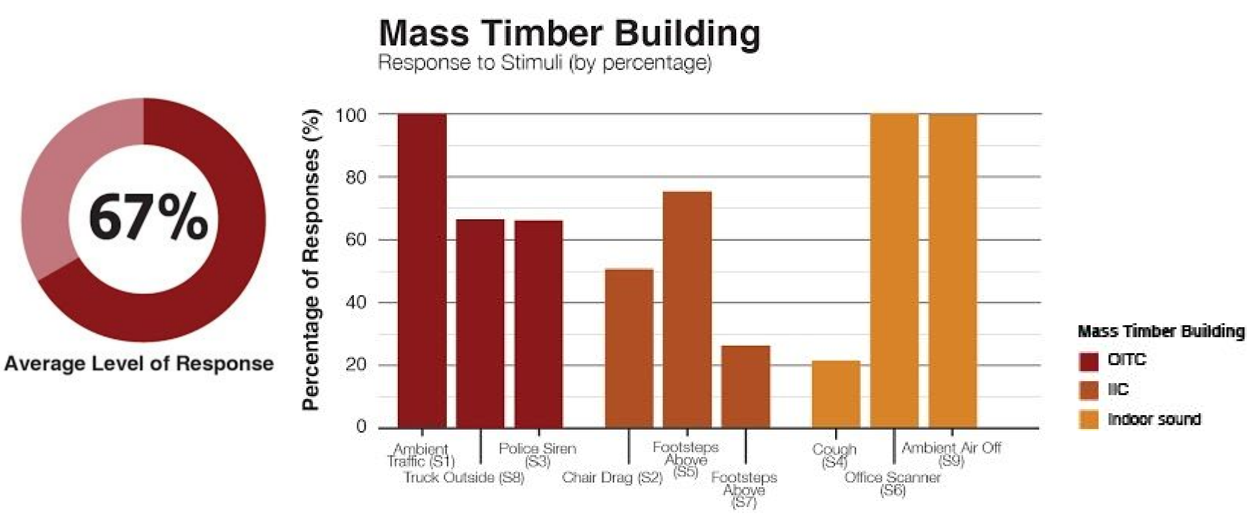

Figure 4: Average Percentage of Responses to Auditory Stimuli in Mass Timber Building.

The results show an average response rate of 67% when exposed to the controlled stimuli (*see figure 4)*. The responses were evaluated to detect whether participants had an emotional response during the timeframe they were exposed to the stimuli. Examining the results of all five participants there was only a positive emotional response 12% of the time, while there was a negative response 61% of the time, and no response 27% of the time. The average level of response rate of 67% is due to the 20% threshold, mentioned above, for determining whether an emotional response is valid. As shown in *Figure 4*, the responses are broken down by sound category to evaluate any trends in reactions but no conclusive evidence was drawn out from the comparison. Participants seemed to be equally distracted from OITC sounds, IIC sounds, and internally generated sounds, with no significant difference from one to another.

Masonry Building Results

Five participants from FFA Architects were exposed to the soundtrack, while they conducted their work in their conventional, masonry building.

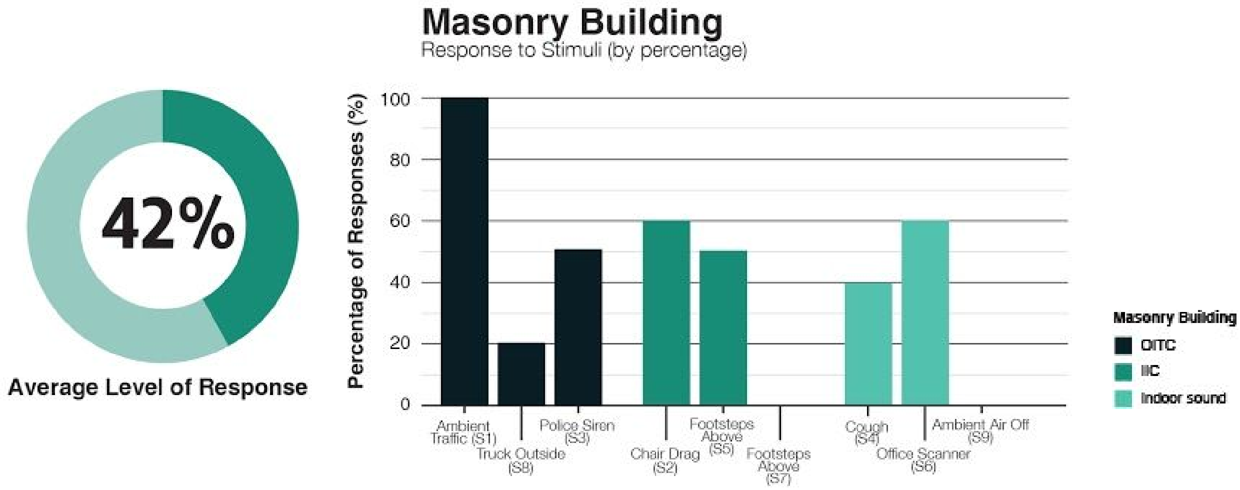

Figure 5: Average Percentage of Responses to Auditory Stimuli in Masonry Building.

On average respondents showed an emotional response rate of 42% from the introduced noises, showing a significantly lower reaction from the participants at the masonry building (*see figure 5)*. The evaluated responses from the data gathered of emotional reaction showed 11% positive response, 62% negative response, and 25% no response. From the 73% (positive and negative response) 31% had an emotional response below the 20% threshold of the study. As shown in figure 4, OITC sounds seemed to have a higher level of response from IIC and internally generated noises, however, not a big enough sample was evaluated to be able to come up with conclusive results.

Comparison of Masonry Building to Mass Timber Building

After comparing data gathered from both the masonry and mass timber buildings, a higher level of emotional response due to the acoustic stimuli was observed in the mass timber building with a 25% difference (*see figure 6*). The most significant observed difference could have been created by a variety of factors that were not accounted for at the beginning of the study. First, the participants from FFA Architecture in the masonry building are located in a very active area of the city where long exposures of noise are common during the work day, potentially causing them to have a milder reaction to the noise introduced in the experiment (Stansfeld 2003). Second, researchers came across interference in the data gathered from participants at the masonry building (*see Discussions*), with less reliable data points available compared to those from the mass timber building. Therefore, the dissimilarity in data points skew the data gathered, making the study inconclusive. Furthermore, due to the limited amount of data collected, one participant's reaction significantly altered the percentage level of response.

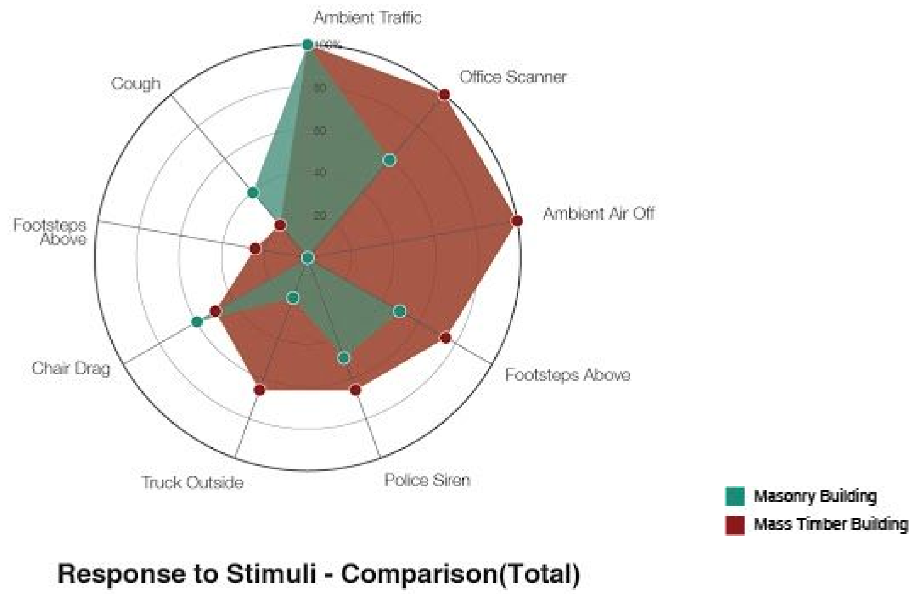

Figure 6: Comparison of Average Percentage of Responses to Auditory Stimuli in Masonry Building (blue) and Mass Timber Building (red).

Additionally, analysis was done on the acoustic stimuli to discern whether the participants had varying levels of intensity on their responses by sound class (*see figure 7)*. Two out of the three OIIC sounds produced the highest level of responses from all the participants, primarily producing negative emotional responses, with only two outliers. From the IIC sounds, two out of three ranged at an average of 35% response from the participants, while one of the sounds produced the lowest level of response at 17%. Internally generated noises produced no visible patterns of increased response, with a wide rage of responses going from negative to positive.

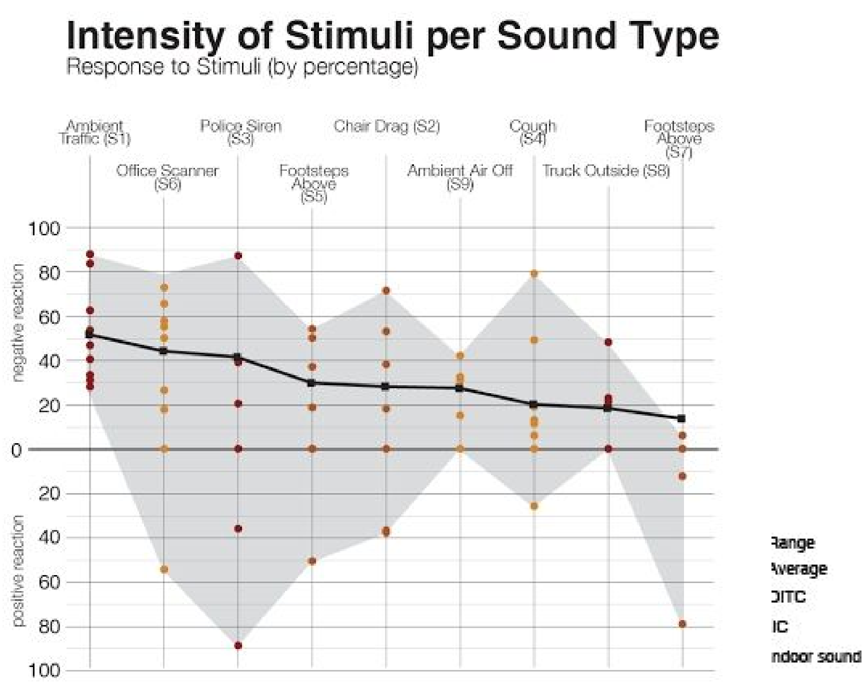

Figure 7: Varying intensities of response from introduced acoustic stimuli by sound type, with average response per stimuli.

DISCUSSION

Design Implications

The literature suggests there may be promise in using the biophilic qualities of wood to decrease stress response to distracting stimuli. The implications on the design of office and work spaces are manifold; however, the data collected in this study does not prove or refute this hypothesis. If future studies can prove the stated hypothesis, the numerous benefits of mass timber construction may be accompanied by the argument that exposed wood is a biophilic element that can carry psychological and psychological benefits that may aid in improving occupants auditory perception of the environment. An improved auditory perception could therefore lower physical and mental stress responses to auditory stimuli. This also has implications for companies looking for ways to boost worker productivity, limit sick days, and ultimately increase profits. Due to the negative impacts of noise pollution established by the World Health Organization, deploying building strategies that help to eliminate or mitigate the harmful effects of unwanted noise holds possible benefits for worker health and well-being.

Interference in Data Collection

During testing participants with facial hair or glasses had a significant decrease in the data collection of the iMotions results due to the inability of the software to effectively pick up on the users face. It was also found that many participants had a natural tendency to place their hands over their face during testing, this also resulted in the inability of the iMotions software to pick up on emotional data. Participants often worked on multiple monitors or looked at work on their desk, limiting the ability to capture facial emotions. Furthermore, if other faces came into the frame of the camera, the software would begin to analyze the new face in place of the study participants. Testing also took place in open office environments, and while the headphones used in testing were noise canceling headphones, it is possible that external auditory stimuli from the surrounding office were a variable that could not be completely eliminated. It should also be noted that due to the nature of testing in the field, it is possible that emotional responses could have been in response to things outside of the study's control, such as in response to emails, or challenges encountered in the work the participants were performing. Consistent issues were also encountered with the Galvanic Skin Response equipment. The GSR monitors had to be attached to the hand of the users, and due to the nature of the participants work (computer based), subjects were moving their hands constantly, which had a negative impact on the data collected.

CONCLUSION

With a growing concern of the effects of acoustic environments on human health, the presence of distracting auditory stimuli in work spaces and their impacts on productivity and well-being are of great importance. This study was intended to find if an *acoustic forgiveness factor* would be experienced by the employees in a mass timber building when compared to the employees in a masonry building, assuming all participants were exposed to the same auditory stimuli. Due to the inaccuracy of the biometric data sets collected, no conclusions were able to be drawn on the validity of our hypothesis. As such, further research is needed to correlate acoustic perception in a mass timber versus conventional building. While the literature shows promise in establishing a possible link between emotional and stress responses to auditory stimuli in relation to the presence of wood in the building environment, our research draws no definitive conclusions. The equipment used to collect and record data, iMotions Software and GSR monitors, may not be the most effective tools to measure and establish the data necessary in an uncontrolled setting such as an office workplace. To get a better understanding the effects of acoustic stimuli in situ, a much larger sample size would need to be utilized. It should be noted that redesigning this study in a controlled environment may have promise, and should be conducted in a lab setting with larger sample pools to replicate the results and effectively eliminate any variables.

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