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Cognitive effects of noise on hospital emergency department staff

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Abstract

Hospital emergency departments today are undoubtedly noisy, and this noise can cause human error, adverse medication events, and limit the ability of clinicians to provide high-quality and safe patient care. The average sound pressure levels, analyzed in previous studies for hospitals around the world, substantially exceed the World Health Organization guidelines. These sounds–emitting from sources ranging from monitor alarms, ring binders, overhead paging, trash bins, and echogenic surfaces, to patients crying out–can be abrupt, yet not sustained. The problem of hospital noise requires deep learning and insight beyond those provided by mere sound pressure level measurements and even loudness evaluations. In order to evaluate how noise impacts hospital staff distraction and performance, and its subsequent propensity for human error, we conducted study at a busy, urban hospital emergency department. The effects on physician cognitive load and working memory due to various sonic occurrences within the hospital emergency department were assessed using cognitive executive function evaluations with binaurally-augmented acoustic environments as the backdrop. The paper will discuss the methods deployed for cognitive testing using binaural augmentation, share initial results, and offer meaningful interpretations as well as potential recommendations which address these results.

Keywords: Noise, Hospital, Cognition, Patient Safety

1 INTRODUCTION

Noise in hospitals has long been a topic of discussion and concern, especially as it relates to the ability for patients to heal. However, hospital noise does not only affect the patients' healing; it also impacts the ability of medical staff to perform their tasks reliably. Multiple recent studies have found sound pressure levels (including weighted, peak, and equivalent measures) in hospitals to be significantly exceeding the 35-45 dB(A) range recommended by the World Health Organization (WHO) guidelines. For instance, in operating rooms at Johns Hopkins Hospital, all $L_{A,eq}$ levels observed were higher than 58 dB(A), and the unweighted L_{peak} levels exceeded 90 dB over 65% of the time in each surgery category [1]. Another study, conducted at a Swedish neurological intensive care unit (ICU) and which surveyed perception of staff regarding alarms, aimed to investigate the growing concern of alarm fatigue. The most troubling outcome was almost half (49%) of the staff admitted to adjusting alarm levels so they became inaudible [2].

This paper aims to apply cognitive executive function evaluations in order to determine if the sound pressure level and Loudness metrics of hospital sound environments do correlate with the results of distraction and cognitive load assessments. We need to consider using a new metric, which is not based on sound pressure level or Loudness, in order to properly determine if hospital noise negatively impacts staff concentration and becomes detrimental to patient safety.

2 BINAURAL AUGMENTATION

Sound files were created to emulate different situations within an emergency department setting in order to conduct repeatable distraction and cognitive load tests to adequately assess hospital staff cognitive performance.

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Figure 1. Source and dummy head receiver locations for binaural room impulse response measurements [3].

Short segments (about five minutes) of sound are required as the auditory backdrop for each distraction and cognitive test cycle, since subjects cannot be expected to take multiple tests each lasting much longer than this. Binaurally augmenting anechoic recordings of typical hospital emergency department sounds onto these short segments of the field recordings grants the authors more control over the Loudness and sound pressure levels of each sound file tested. The following sections will describe the two initial components of the sound files and the process used for binaural augmentation for some of the sound files.

2.1 BRIR and field recording collection

We conducted unoccupied and occupied measurements in a busy, urban hospital emergency department as part of Master's thesis research in 2015. The unoccupied measurements consisted of 13 binaural room impulse responses (BRIRs) taken with a HEAD Acoustics Binaural Dummy Head at the center of the emergency department and using 13 different source positions. As shown in Figure 1, the source positions include the entrances as well as inside patient rooms, at the nurses' station, along an interior hall, and at the entrance to the emergency department [3].

The occupied measurements are field recordings taken over 12 hours within the same hospital emergency department. The L_{eq} and Loudness were calculated over each hour of the measurements. The A-weighted L_{eq} for each hour were found to be in excess of the World Health Organization (WHO) guidelines recommended for hospital settings. This excess is significant, at about 20 dB(A) higher than the 35-45 dB(A) WHO recommended values for each hour of the field recordings [3].

2.2 Creation of binaurally-augmented acoustic environments

Using the binaural room impulse responses, anechoic signals of various typical hospital emergency department sound events can be convolved together to create a binaural signal (see Figure 2). Some anechoic signals used include coughing, sneezing, heart rate monitor beeping, and other alarm sounds. Convolving the anechoic signal with a BRIR with the source position inside a patient room to the left of the dummy head will convey information to the listener that the sound is coming from a place far off to the left. Adjusting the levels of

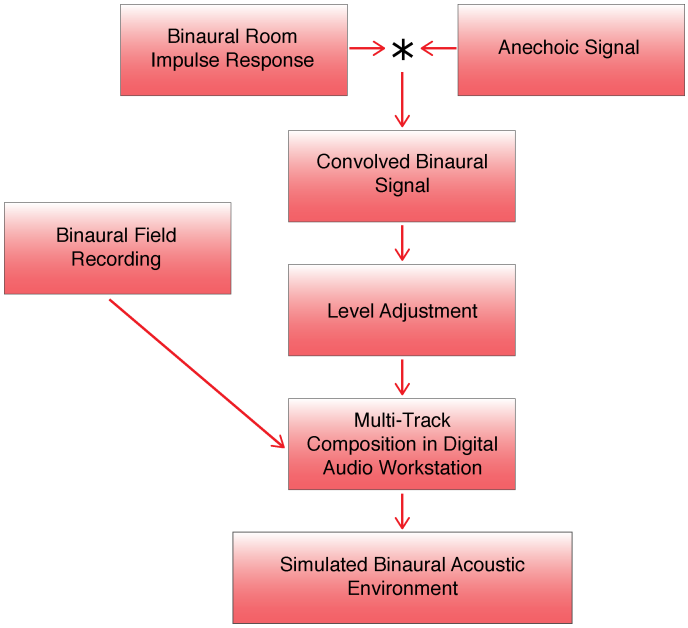

Figure 2. Graphical representation of the process using binaural augmentation to create simulated binaural acoustic environments as sound files for testing.

each convolved binaural signal is imperative, so that each sound will seem as though it belongs within the base binaural field recording. The adjusted, convolved binaural signals can then be placed within the binaural field recording using a digital audio workstation (DAW) as a multi-track composition. From here, the composition can be exported as a single sound file of a simulated binaural acoustic environment.

3 ASSESSING COGNITIVE PERFORMANCE

Two different tests were conducted to assess the cognitive performance with various simulated binaural acoustic environments. A subjective test was employed to assess the degree of distraction, and an objective test was used to investigate the impacts on cognitive load and working memory.

3.1 Distraction

The degree of distraction was assessed subjectively using a visual analog scale (VAS), where participants were asked to place a mark along a line from “not at all distracting" to “most distracting imaginable" based on how they felt after listening to each sound file. Using a VAS allows participants to rate their degree of distraction based on two extremes, rather than forcing them to discretize their responses to fit certain categories. This makes for a much larger “sampling frequency" of participants’ responses, rather than only the discrete scale intervals of 1, 2, 3, 4, and 5, for example [3].

3.2 Cognitive load

The n-Back task with an n value of 3 was determined to have a difficulty level correlating with the cognitive level required by hospital emergency department staff. The n-Back task is a sequential memory task used to measure working memory capacity, since it has been shown that brain activity during the test reflects neural correlates of working memory. Additionally, between-trial factors (like the sound environment) affect cognitive control required for accurate task performance [4].

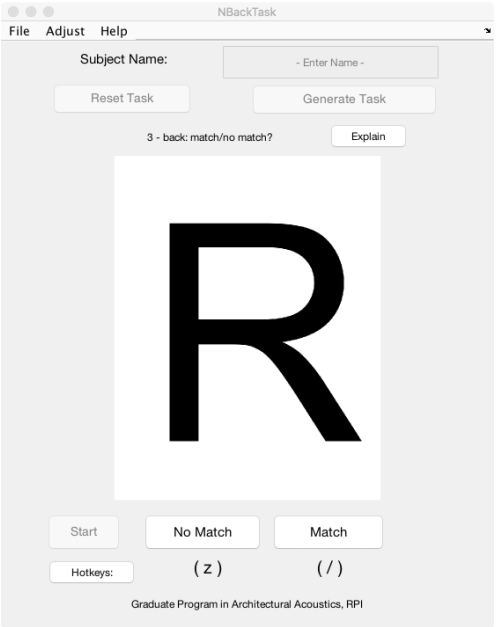

Figure 3. *n*-Back task graphical user interface at one instance during a 3-Back test. Each letter appears individually on the screen, forcing subjects to remember the letters shown previously.

The *n*-Back task was adapted into a graphical user interface (GUI) in MATLAB. While a sound file plays in the background, the subject must correctly identify whether the letter appearing on the screen is a “match" or “no match." The letter is a match if it is the same as the letter that appeared three times previously, since the version of the task employed is the 3-Back. Figure 3 shows the GUI at one instance during a 3-Back task. Given a sequence of letters B R K **B** J **K** R N R **R**, each letter in bold would be a match.

Effective executive control is required to reject lures successfully, where a lure is a letter that is the same as the letter that appeared 2 or 4 instances previously. In the example used above, the subject must be careful to correctly choose “no match" for the 2-Back lure in bold: B R K B J K R N **R** R. The responses to the 3-Back test can be analyzed by accuracy and time. The average percent incorrect and the average response time of each participant can be examined to reveal patterns in the impacts of the sound environments on cognitive load and working memory [4].

4 INITIAL EXPERIMENTS

In order to test the hypothesis that the physical parameter of sound pressure level and the psychoacoustic parameter of Loudness correlate with distraction and cognitive load, six sound files were created as auditory backdrops for the initial experiment. Three sound files were unaltered binaural field recordings, and three sound files were augmented from each of those field recording segments. The files each varied in $L_{A,eq}$ and Loudness.

4.1 Degree of distraction

This test was conducted through two loudspeakers arranged at the front of a room within the emergency department where measurements were taken. All 18 participants in this study were working medical doctors specializing in emergency department care.

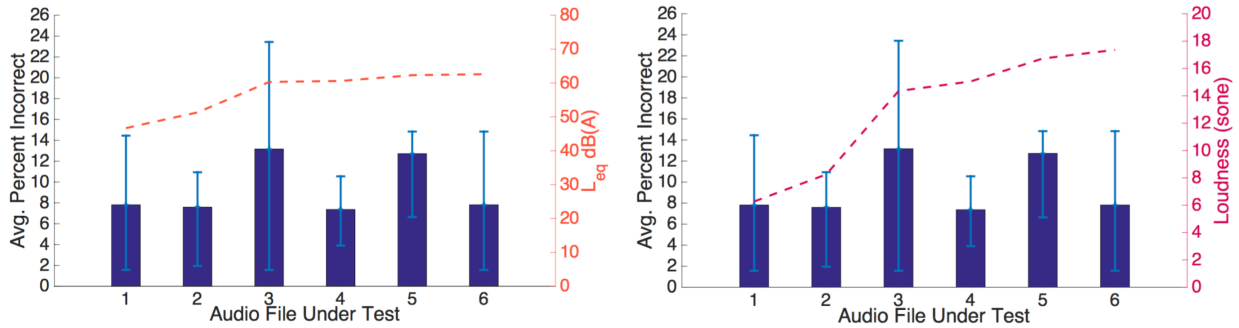

Figure 4. 3-Back task results showing average percent incorrect and standard deviation for all participants for six sound files, presented against $L_{A,eq}$ (orange, left) and average instantaneous Loudness (pink, right) [3].

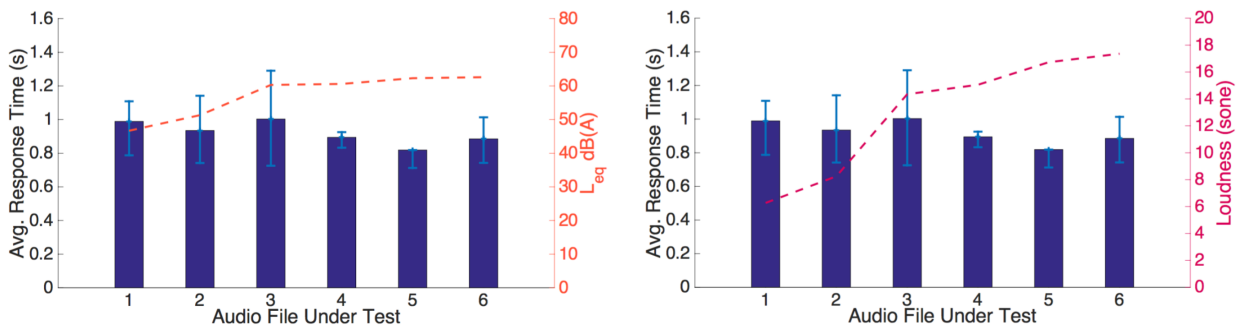

Figure 5. 3-Back task results showing average response time and standard deviation for all participants for six sound files, presented against $L_{A,eq}$ (orange, left) and average instantaneous Loudness (pink, right) [3].

4.2 *n*-Back test

This test was conducted with a GUI through a laptop in the hearing chamber on the Rensselaer Polytechnic Institute campus. The auditory component was administered through headphones. A different set of subjects was used for this test, with a total of 7 participants.

4.3 Initial results

The average percent incorrect and the average response time results from the 3-Back task are shown in Figures 4 and 5, respectively. The orange dotted line on the left graph in these two figures represents the increasing $L_{A,eq}$ values of the audio files. The pink dotted line on the right graph in the two figures represents the increasing Loudness values of each sound file. In comparison to the $L_{A,eq}$ and Loudness of the six sound files, it is obvious that no clear correlations can be discerned between the test results and the sound file attributes of $L_{A,eq}$ and Loudness.

5 CONCLUDING REMARKS

The degree of distraction and the cognitive load show no obvious correlations with $L_{A,eq}$ and Loudness of the sound environments. The authors will be conducting subsequent experiments to assess both the degree of distraction and cognitive load with a new group of about 18 participants, incorporating an increased variety of unaltered and augmented sound files. The results could also be compared to different measurements of sound pressure level, like $L_{A,max}$ and $L_{A,min}$ for example. These further experiments will be used to improve our

knowledge on the impacts of hospital noise and to eventually create better working and healing environments in hospitals.

REFERENCES

[1] Kracht, J.M.; Busch-Vishniac, I.J.; West, J.E. Noise in the operating rooms of Johns Hopkins Hospital. J. Acoust. Soc. Am., Vol 121 (5), 2007, pp 2673-2680.

[2] Ryherd, E.E.; Waye, K.P.; Ljungkvist, L. Characterizing noise and perceived work environment in a neurological intensive care unit. J. Acoust. Soc. Am., Vol 123 (2), 2008, pp 747-756.

[3] Dodds, P. The effects of noise on the cognitive performance of physicians in a hospital emergency department [thesis]. Troy (NY): Rensselaer Polytechnic Institute; 2015.

[4] Ralph, J. Statistical manipulation and control strategies of the n-Back task [dissertation]. Troy (NY): Rensselaer Polytechnic Institute; 2014.