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# The effects of auditory and visual distracters on the toleration of background noise in normal hearing listeners

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# The Effects of Auditory and Visual Distracters on the Toleration of Background Noise in Normal Hearing Listeners

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# ABSTRACT

The primary objective of this study was to evaluate the effect of auditory and visual cognitive loads on the preferred background noise levels in normal-hearing listeners. This study investigated the preferable background noise levels (primary task) when normal hearing listeners were presented with auditory and/or visual cognitive distractions (secondary task). It was hypothesized that normal hearing listeners' preferable background noise level would decrease in the presence of either distracter and that the synergistic effect of the two distracters would result in even lower preferable background noise level. Preferable background noise levels were measured on 24 normal-hearing listeners under four conditions. A 2x2 repeated measure ANOVA was performed with auditory and visual distraction (two levels each) as within-subject factors and the test order as a between-subjects factor. The results of the repeated measure ANOVA indicated significant main effect of auditory distraction. None of the interactions between auditory distraction, visual distraction and test order were reported to be significant. The interaction between auditory distraction and test order however, was near significant. Tests between subjects effects revealed no significant effect of test order. Pairwise comparison with Bonferroni correction revealed significantly higher preferable noise levels in the visual task and lower noise level in the auditory task. Results indicated that while attending to a visual cognitive task, normal hearing listeners were willing to put up with a higher background noise level than attending to an auditory task.

# INTRODUCTION

The Acceptable Noise Level (ANL) test (Nabelek, Tucker, and Letowski, 1991) is a clinical tool to measure how much background noise a listener will accept in the presence of speech; the ultimate use of the ANL test is to determine user success with hearing aids. Using continuous discourse and background noise, the listener's most comfortable listening level (MCL) is obtained first and background noise is later introduced to assess the most noise a listener is willing to tolerate. This maximum amount of tolerable noise is referred to as the background noise level or BNL (Nabelek et al., 1991; Franklin, Thelin, Nabelek, and Burchfield, 2006). To calculate the listener's ANL, the listener's BNL to background noise is subtracted from the MCL and the resulting value is listener's ANL score. Research has shown that the ANL is very reliable and useful. Studies have primarily been completed on hearing impaired subjects due to the test's ability to predict hearing aid success. It has been reported that ANL is not influenced by the listener's age, gender, or hearing threshold levels (Fisher-Smiley, Muenchen, and Konrad, 2006; Freyaldenhoven, Rogers, Harkrider, Burchfield, and Nabelek, 2003; Nabelek et al., 1991; Nabelek et al., 2004). ANL can be influenced by stimulant medication and focus has been placed upon medications such as those used to treat attention deficit/hyperactivity disorder (ADHD) and how they impact a listener's performance on the ANL test (Freyaldenhoven et al., 2005).

ANL scores are used to predict the success of hearing aid use for listeners with hearing loss as well as future hearing aid success for normal hearing listeners. The computed scores can range from less than 0 dB to greater than 25 dB (Franklin et al., 2006). ANL scores under 8 dB are considered low and suggest that listeners tolerate more background noise in the presence of speech; scores greater than 8 dB suggest the opposite in which listeners tolerate less background noise (Plyler, Alworth, Rossini, and Mapes, 2011; Nabelek et al., 1991; Nabelek, et al., 2004). The tolerance of background noise directly relates to hearing aid use and success because a common reason why many individuals do not use their hearing aids is due to the amount of background noise they can hear as a result of amplification.

An important component in measuring a listener's ANL is background noise. The amount of background noise that a listener tolerates directly relates to their success as a hearing aid user. In the original study by Nabelek et al. (1991) it was proposed that background noise is an entertaining novelty and as a result, the listener might accept less of the speech stimulus (as cited in Gordon-Hickey and Moore, 2007). To investigate this claim, they looked at the novelty of background noise in normal hearing subjects and its impact upon speech acceptance. They concluded that the type of background noise may impact ANL scores (Gordon-Hickey and Moore, 2007). Plyler et al., 2011, have proposed that the amount of background noise a listener accepts is related to the characteristics of the speech stimulus such as content and speaker gender. They suggest that speech presented by male speakers significantly impacts some listeners' MCL levels and if the speech is interesting or unique, less background noise is tolerated (Plyler et al., 2011). In addition, it was found that MCLs were higher when speech was presented by a male speaker (Plyler et al., 2011). Additionally, a greater tolerance of background noise occurs when the speech stimulus is presented at a low intensity level, regardless of hearing threshold level (Franklin et al., 2006; Freyaldenhoven, Plyler, Thelin, and

Hedrick, 2007; Tampas and Harkrider, 2006, as cited in Plyler, Madix, Thelin, and Johnston, 2007).

When BNL is being measured, it is important to instruct the listener that they are not determining their Uncomfortable Listening (UCL) level instead. Studies have measured the relationship between MCL and UCL and it has been found that UCL influences higher MCL levels when UCL is tested first (Stephens, Blegvad, and Krogh, 1977, as cited in Punch, Rakerd, and Joseph, 2004). Normal hearing listeners are more susceptible to the influence of UCL upon MCL due to "prior auditory experience" (Punch et al., 2004) which can result in greater reported levels.

Background noise has been shown to impact a listener's performance based upon the level of annoyance it presents as well as how much distraction it can provide. The most common listener response to loud background noise is annoyance (Landström, Kjellberg, and Byström, 1995). In particular, intermittent rather than constant noise has a greater impact upon a listener's performance and level of annoyance (Cohen, 1980; Glass and Singer, 1972, as cited in Landström et al., 1995). In the irrelevant sound paradigm, a sound is presented at a conversational level which the listener is instructed to ignore while completing a visual distracter task. When the sound is present, it interrupts the listener's performance on the distracter task (Jones, Hughes, and Macken, 2010). For normal hearing listeners, the interaction between auditory distracters and performance on a computer-based task found that at MCL, listeners tolerated auditory distraction more and had better task performance whereas UCL performance was noticeably poorer (LaPointe, Heald, Stierwalt, Kemker, and Maurice, 2007). Auditory selective attention, a variation of the irrelevant sound paradigm, is attributed to the listener's cognitive ability to either focus on a particular stimulus or repress extraneous stimuli (Rao, Zhang, and Miller, 2010). In a study examining the cognitive systems involved with auditory selective attention in normal hearing listener, a significant interaction between test condition and performance task was found which suggests that stable background noise yields better subject performance compared to unstable background noise (Rao et al., 2010).

The present study aims to examine the effects of both auditory and visual distraction upon a normal hearing listener's toleration of background noise. More specifically, this study intends to evaluate the effect of visual distraction on a listener's tolerable background noise level in the presence or absence of a speech stimulus. More will be understood regarding how much background noise a listener is willing to tolerate at a level that does not cause fatigue or discomfort. The research is anticipated to provide information regarding a normal hearing listener's tolerable background noise levels in different experimental conditions relative to different distracters. It will be seen whether the presence of auditory distraction, visual distraction, or both have an impact upon what the listener tolerates for background noise. The listener's UCL will be obtained to provide a comparison between these values and their tolerable BNL in the test conditions. By obtaining UCL, the range between the UCL and tolerable BNL can be assessed in order to determine the subject's Dynamic Range of loudness.

The research questions for this study are:

1. Does a listener's tolerable BNL change in the presence of competing visual and/or auditory distracters?
2. How does tolerable background noise relate to UCL?

Based upon the first research question regarding tolerable BNL and distracters, the hypotheses are:

$H_0$: There will be no significant difference in tolerable background noise level when the subject is attending to the noise stimulus compared to when the subject is distracted.

$H_1$: There will be a difference in tolerable background noise levels when the subject is attending to the noise stimulus compared to when the subject is distracted.

The hypotheses for the second research question regarding the relationship between tolerable BNL and UCL are:

$H_0$: There will be no significant difference between tolerable background noise level and UCL.

$H_1$: There will be a significant difference between tolerable background noise level and UCL.

# METHODS

## Participants

Twenty-four adult, normal-hearing, native speakers of American English were recruited to participate in this study. All subjects were female with a mean age of 20 years (range of 19-22 years); only female participants took part in this study since previous findings have indicated no gender differences in normal-hearing listeners' ANL levels. Normal hearing sensitivity was defined as 25 dB HL hearing threshold from 250 Hz through 8000 Hz, clear otoscopy and normal middle ear function (Type A tympanogram). Exclusion criteria included self-report of cognitive or learning deficits or a diagnosis of attention deficit disorder/attention deficit hyperactivity disorder which was being medically treated by stimulant medication.

Prior to testing, all participants were informed about the research and any risks or benefits. All subjects signed informed consent forms approved by the James Madison University Institutional Review Board. Subjects were assigned code numbers and placed in one of four groups to determine test order using a Latin-square design. The subject assignment for the order of testing based on the Latin-square design can be referred to in Appendix A.

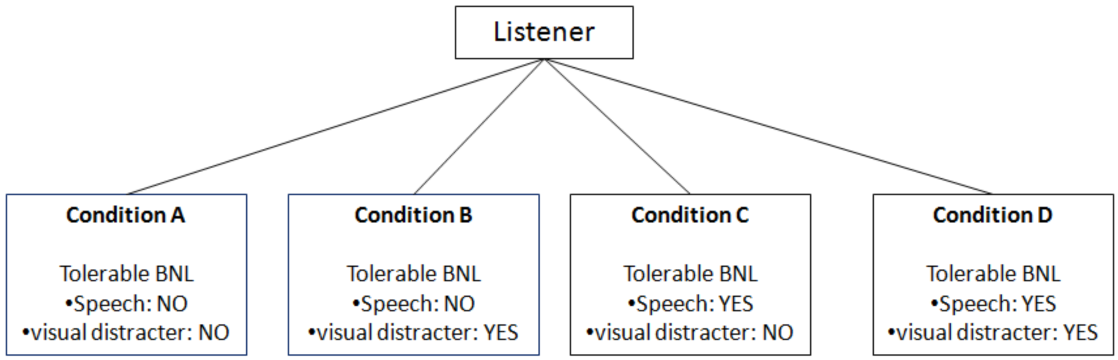
## Procedure

Each participant completed a practice condition prior to actual testing. During the practice condition, subjects were encouraged to ask any questions they had about determining MCL and BNL; the practice condition was performed as many times as necessary for the participant to become comfortable with the task.

At the completion of the practice test, the subjects then began the testing as determined by their assigned groupings. A visual representation of the assigned groupings can be referred to below in Figure 1. The groupings for the treatment conditions based upon a Latin square design were ABCD, BADC, CDAB, and DCBA. The conditions were as follows:

A. Determine tolerable BNL without a spoken message and no visual distraction
B. Determine tolerable BNL without a spoken message and with visual distraction
C. Determine tolerable BNL with a spoken message and no visual distraction
D. Determine tolerable BNL with a spoken message and without visual distraction

Figure 1. Visual representation of treatment conditions.



Additional testing was also completed for each subject, including measuring the Most Comfortable Listening level (MCL), as well as two different Uncomfortable Listening levels (UCL) – with and without visual distraction.

The Acceptable Noise Level Test CD (Frye Electronics, Tigard, OR) was chosen as the stimuli. This pre-recorded CD has running speech by a male talker (Arizona Travelogue) on one track and multi-talker babble on the other track.

All testing was performed in a 3 × 2.8 × 2 meters double walled sound attenuating booth (Industrial Acoustics Company, Bronx, NY). Prior to the presentation of any auditory stimulus, the volume unit (VU) meter on GSI-61 Clinical Audiometer was set to zero using the calibration tone in the test CD. Both the Arizona Travelogue speech stimulus and the multi-talker speech babble were channeled to one loud speaker and presented at 0° azimuth. A research assistant was seated in the sound attenuating booth for providing instructions.

The visual distraction task for this study was a driving simulation application (Volkswagen Touareg Challenge 1.0.2 by Volkswagen) which was downloaded onto an iPad. The application required the user to drive a vehicle through a racecourse while accelerating, braking, and steering the vehicle as necessary. To accelerate or apply the brake on the vehicle, the user was required to use their thumb while the steering mechanism of the game was controlled by the user turning the iPad towards the left for a left turn and towards the right for a right turn similar to operating a steering wheel in a car.  The subject was instructed to drive without straying from the track.

Instructions

Prior to completing any of the tasks, all participants completed a practice test. This practice test was both the ANL test and treatment condition C. The speech stimulus by the male talker was first introduced at 20 dB HL and increased in 2 dB steps. The participant was instructed to indicate to the researcher when the speech reached a level that was most comfortable for them to listen to for a prolonged period of time. The subject was encouraged to increase or decrease the level of the speech as many times as necessary to find a comfortable listening level. The subject indicated the MCL to the researcher by saying "stop." This MCL level was recorded by the researcher for future conditions. After the participant determined their MCL level, background noise was introduced at 20 dB HL. The noise was increased in 2 dB steps and the subject was asked to indicate when the background noise level reached the maximum level they were willing to tolerate by saying "stop." The written instructions for this practice test were as follows:

> *I am going to present ongoing speech by a male talker. The speech will slowly get louder. I want you to* ***tell me when the speech is the most comfortable for you*** *as if you were listening to the radio. You may turn the loudness up and down as needed to help select the most comfortable level.*
>
> *Now I am going to present a background noise conversation of several people talking at the same time. The* ***level of the background noise conversation will slowly increase and I want you to tell me when it is the most you are willing to accept or put up with****. You may turn the loudness of the background noise*

*conversation up and down as needed to help you select the level you are most willing to accept.*

Task A required the subject to determine their tolerable BNL in the absence of a speech stimulus and no visual distraction. The background noise was the sole stimulus for this condition and was introduced at 20 dB HL. The noise level increased in 2 dB steps until the subject verbalized "stop." The participant was encouraged to ask for the background noise to be increased or decreased as many times as necessary in order to determine their tolerable BNL. The written instructions for this condition were as follows:

*Imagine you are engaged in a conversation. I am going to present a background noise conversation of several people talking. The level of the background noise will slowly increase. I want you to* ***monitor the level of the conversation and tell me when it is the most you are willing to accept or put up with while imagining you are still engaged in that conversation****. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.*

Condition B introduced a visual distracter, the iPad application, to the background noise presentation. Prior to the start of this condition, the research assistant gave the iPad to the subject. The subject was instructed to pay attention to the game while monitoring the background noise level. Again, the background noise was introduced at 20 dB HL and increased in 2 dB steps. The subject was instructed to tell the researcher when the background noise level reached a maximum level they were willing to tolerate by saying "stop." The subject was encouraged to increase or decrease the level to help determine their tolerable BNL level as many times as necessary by saying "up" or "down." At the conclusion of this task, the research assistant collected and reset the iPad for future conditions. The written instructions for this condition were as follows:

> *You are going to play a game on the iPad. I am going to present a background noise conversation of several people talking. Imagine you are engaged in conversation.* ***Your task is to play the game while monitoring the level of the background noise.*** *The background noise conversation of several people will get louder.* ***Tell me when it reaches a level that you are most willing to accept or tolerate*** *while imagining you are still engaged in that conversation. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.*

Test condition C was the actual ANL test and a repeat of the practice task. This condition introduced the speech stimulus by the male talker at the level the participant had determined to be their MCL during the practice task. After the participant was listening to the speech stimulus for several seconds, the background noise was introduced at 20 dB HL. The noise was increased in 2 dB steps and the subject was asked to indicate when the background noise level reached the maximum level they were willing to tolerate by saying "stop." The written instructions for this condition were as follows:

> ***There will be ongoing speech by a male talker.*** *The speech will be at the level you decided was most comfortable for you to listen to during the Practice Task.*
>
> *A background noise conversation of several people talking will be presented and will slowly get louder.* ***Tell me when the noise reaches a level that you are most willing to accept or put up with while still listening to speech by the male talker.*** *You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.*

In the final condition, D, the subject was required to determine their BNL to a speech stimulus with visual distraction. Prior to the start of this condition, the research assistant gave the iPad to the participant. The participant was instructed to pay attention to the game while monitoring the background noise level. This condition introduced the speech stimulus by the male talker at the subject's previously established MCL. After the participant was listening to the speech stimulus for several seconds, the background noise was introduced at 20 dB HL. The noise was increased in 2 dB steps and the subject was asked to indicate when the background noise level reached the maximum level they were willing to tolerate by saying "stop" while playing the iPad application. At the conclusion of this task, the research assistant collected and reset the iPad for future conditions. The written instructions for this condition were as follows:

> *There will be ongoing speech by a male talker. The speech will be at the level you decided was most comfortable for you to listen to during the Practice Task.*

*I am going to present a background noise conversation of several people talking and you are going to be playing a game on the iPad.* ***Your task is to focus on playing the game while monitoring the level of the noise.*** *The background noise conversation will slowly get louder and* ***I want you to tell me when the noise has reached a level you are willing to accept or put up with****. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.*

After the four tasks were completed in the order determined by the Latin-square design, the subject's UCL was obtained in two final conditions. The first UCL condition was measured to background noise only as this is a true clinical measure of the subject's UCL. The background noise was introduced to the subject at 20 dB HL and increased in 2 dB steps until the subject said "stop." The written instructions for this condition were as follows:

*Your task is to listen to the background noise. This noise will slowly get louder. I want you to listen to the noise and* ***tell me when the noise reaches a loud level that is uncomfortable for you to tolerate****.*

In the second UCL task, the participant was instructed to play the iPad application while the background noise was introduced at 20 dB HL and slowly increased in 2 dB steps. The subject again needed to indicate to the researcher by saying "stop" when the background noise level reached a level where it was uncomfortably loud. The written instructions for this condition were as follows:

> ***Your task is to play a game on the iPad*** *while I present background noise. This background noise will slowly get louder.* ***I want you to tell me when the noise reaches a loud level that is uncomfortable for you to tolerate****.*

Data Analysis

The individual raw data from all participants was arranged in Microsoft Excel format and later imported to SPSS 20 for statistical analysis to test the previously stated hypothesis. A repeated measures analysis of variance (ANOVA) was performed to evaluate the differences in subjects' tolerable background noise level (BNL) scores across the four test conditions.

RESULTS

Tolerable background noise levels for the four conditions were analyzed in a 2 x 2 design. A repeated measure ANOVA was performed using SPSS 20 with auditory and visual distraction (two levels each) as within-subject factors and the test order as a between-subjects factor. The 2 x 2 design is summarized in Table 1 below.

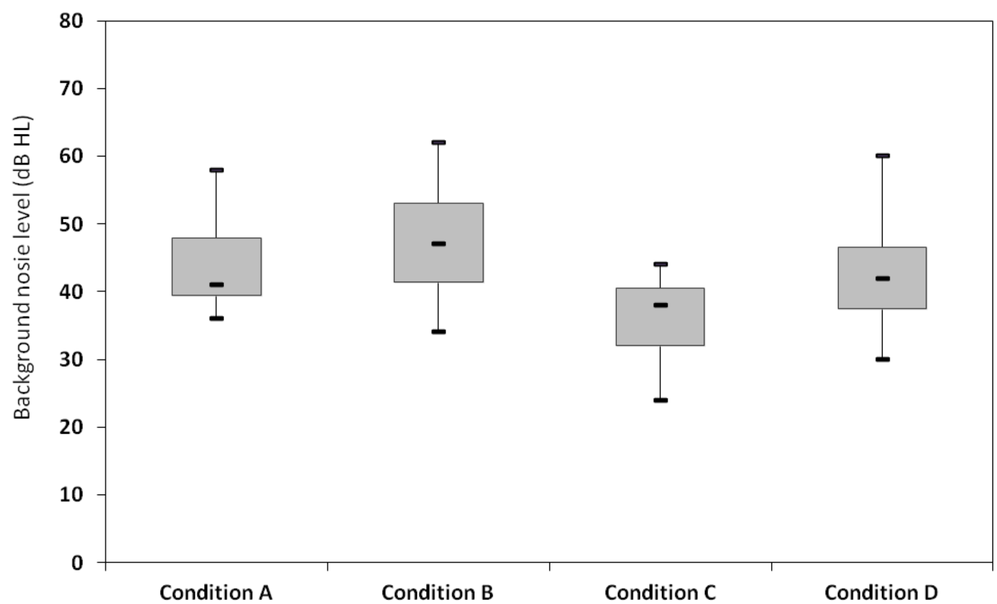
Table 1. 2 x 2 design for four conditions.

| Auditory Distraction | Visual Distraction: Yes | Visual Distraction: No |
|---|---|---|
| Yes | Condition D | Condition C |
| No | Condition B | Condition A |

Tolerable background noise levels with visual and auditory distraction

Mean background noise levels for each of the four conditions were calculated. When the subjects were instructed to indicate their tolerable background noise level without any auditory or visual distracters (Condition A), the mean noise level was 43.2 dB HL (SD = ±6.05). The second task involved subjects monitoring the tolerable background noise while playing a simulated driving video game (Condition B). Under this condition, the average background noise level was measured at 47.3 dB HL (SD = ±8.01). When the subjects were asked to indicate the tolerable noise level while listening to a competing story from the same azimuth as that of the speech (Condition C), the mean tolerable noise level decreased to 36.5 dB HL (SD = ±5.45). The final condition included both visual and auditory distracters (Condition D) where the mean background noise level was 41.8 dB (SD = ±7.2). The box plot of the group data (n = 24) is shown in Figure 2.

Figure 2. Box plots of the tolerable background noise levels (in dB HL) for each of the four conditions. Each box shows the median, first and third quartiles and the whiskers represent the extremes.




The results of the repeated measure ANOVA indicated significant main effect of auditory distraction [F (1, 20) = 34.626, p < 0.001] and visual distraction [F (1, 20) = 56.709, p < 0.001]. None of the interactions between auditory distraction, visual distraction and test order were reported to be significant. The interaction between auditory distraction and test order however, was near significant [F (3, 20) = 2.610, p =

0.080]. A summary of the test effects and their interactions are shown in Table 2. Significant effects are highlighted with an asterisk.

As described in the methods section, the orders of presentation of the four test conditions were balanced using a Latin square design. Tests of between-subjects effects revealed no significant effect of test order [F (3, 20) =0.151, p=0.928). The descriptive statistics with means and standard deviations for each condition is summarized in Table 3.

Table 2. Summary of the repeated measures ANOVA. Significant effects (p< 0.05) are highlighted with an asterisk.

| **Effects** | ***df*** | ***F*** | **Significance** |
|---|---|---|---|
| Auditory distraction | (1, 20) | 34.626 | **0.000*** |
| Auditory distraction * test order | (3, 20) | 2.610 | 0.080 |
| Visual distraction | (1, 20) | 56.709 | **0.000*** |
| Visual distraction * test order | (3, 20) | 0.398 | 0.756 |
| Aud distraction * Visual distraction | (1, 20) | 0.798 | 0.385 |
| Aud distraction * Visual distraction* test order | (3, 20) | 2.152 | 0.126 |

Table 3. Means and standard deviations of the group scores for each of the test condition as a function of test order. For example, Condition D (auditory + visual distraction) was presented at four different sequences to six subjects each based on the Latin square design. Columns 3 and 4 show the mean and standard deviation of performance on condition D for each presentation sequence.

| | Test order | Mean (dB HL) | ±1 Std. Deviation | N (24) |
|---|---|---|---|---|
| Auditory + Visual Distraction | ABC**D** | 39.3 | 7.55 | 6 |
| | BA**D**C | 41.0 | 7.01 | 6 |
| | C**D**AB | 44.0 | 9.38 | 6 |
| | **D**CBA | 43.0 | 5.47 | 6 |
| Auditory Distraction only | AB**C**D | 36.6 | 5.31 | 6 |
| | BAD**C** | 34.6 | 6.65 | 6 |
| | **C**DAB | 37.6 | 4.63 | 6 |
| | D**C**BA | 37.3 | 6.02 | 6 |
| Visual Distraction only | A**B**CD | 48.3 | 8.52 | 6 |
| | **B**ADC | 50.6 | 9.35 | 6 |
| | CDA**B** | 46.6 | 9.09 | 6 |
| | DC**B**A | 43.6 | 4.63 | 6 |
| No Distraction | **A**BCD | 41.3 | 5.60 | 6 |
| | B**A**DC | 45.6 | 6.50 | 6 |
| | CD**A**B | 44.3 | 7.73 | 6 |
| | DCB**A** | 41.6 | 4.45 | 6 |

Pairwise Comparison between the four conditions

The analysis of variance indicated a significant main effect of auditory as well as visual distraction. It was also of interest to find out if there were any significant pairwise differences between the four conditions (A, B, C, and D). Results (see Table 4 below) indicated significant differences between mean scores in the pairs A-B, A-C, B-C, B-D, and C-D. There was no significant difference between condition A and D.

Table 4. Pairwise comparison of the differences between the four conditions. Significance was tested at an alpha level of 0.05 and adjustments for multiple comparisons were done with Bonferroni correction.

| (I) | (J) | Mean Difference (I-J) | ± 1 Std. Error | Significance[b] | 95% Confidence Interval for Difference [b] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Boundary | Upper Boundary |
| A | B | -4.08* | 0.82 | .000 | -6.45 | -1.71 |
| | C | 6.66* | 1.01 | .000 | 3.74 | 9.58 |
| | D | 1.41 | 1.37 | 1.000 | -2.53 | 5.37 |
| B | A | 4.08* | 0.82 | .000 | 1.71 | 6.45 |
| | C | 10.75* | 1.19 | .000 | 7.31 | 14.18 |
| | D | 5.50* | 1.59 | .013 | 0.88 | 10.11 |
| C | A | -6.66* | 1.01 | .000 | -9.58 | -3.74 |
| | B | -10.75* | 1.19 | .000 | -14.18 | -7.31 |
| | D | -5.25* | 1.01 | .000 | -8.17 | -2.32 |
| D | A | -1.41 | 1.37 | 1.000 | -5.37 | 2.53 |
| | B | -5.50* | 1.59 | .013 | -10.11 | -0.88 |
| | C | 5.25* | 1.01 | .000 | 2.32 | 8.17 |

Based on estimated marginal means

* The mean difference is significant at the 0.05 level

[b] Confidence interval adjustment for multiple comparisons: Bonferroni

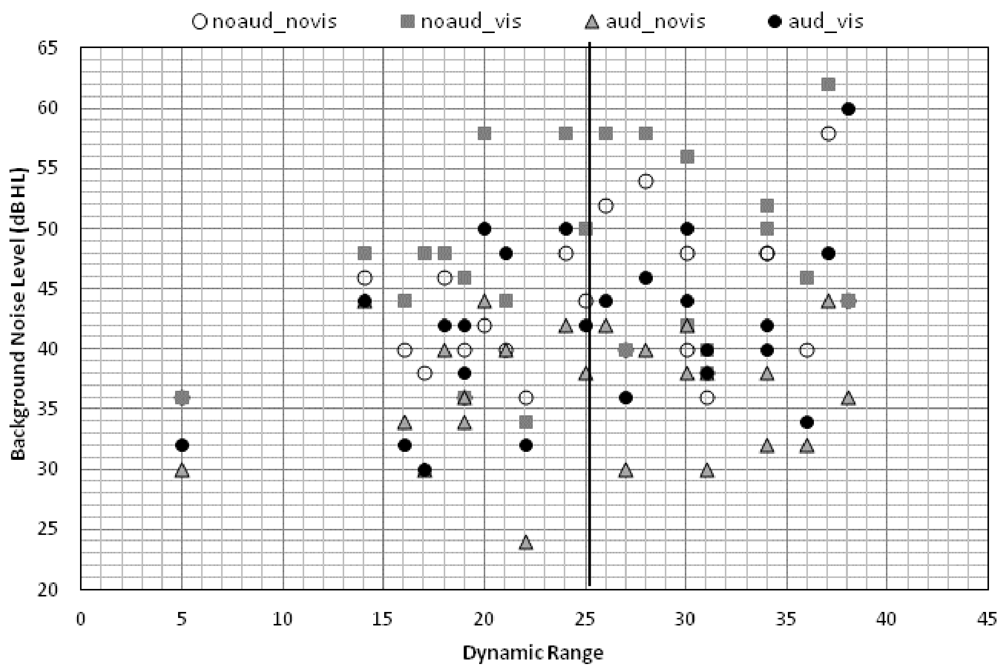
Relationship between subjects' tolerable BNL and UCL

It was important to verify if the subjects were selecting the level of background noise they were willing to put up with (tolerable BNL) as opposed to their uncomfortable level (UCL) for noise. Although the differences between the two measures were discussed and explained to the subjects to verify understanding, it is still possible that subjects inadvertantly reported their tolerable background noise level as a UCL. The mean for UCL was found to be significantly higher than that of the BNL [$t(23)=10.643$, $p<0.0001$].

Dynamic Range was calculated as the difference between UCL and MCL. In Figure 3, the Dynamic Ranges for each of the 24 subjects is plotted for all four conditions. The data shows a large variation in the distribution of the background noise level as a function of the Dynamic Range. Upon further analysis, it was found that there was a marginal interaction between Dynamic Range and visual distraction.

In summary, the results from a group of 24 normal hearing subjects indicated that as a whole they were willing to tolerate more background noise while engaged in a visual distraction task. However, when they were engaged in an auditory distraction task, they were only willing to put up with a lower level of noise. In the presence of a combined auditory and visual distraction task, the tolerable background noise level was in between the levels for either distracter task.

Figure 3. Scatter plot of the tolerable background noise at each of the four conditions as a function of Dynamic Range (UCL – MCL). The Dynamic Range was spread across a wide range for the 24 subjects with one individual outlier. The vertical line shows median Dynamic Range splitting the group into low and high (12 subjects each).



# DISCUSSION

The purpose of this study was to determine if normal hearing subjects would tolerate less background noise in the presence of competing auditory and/or visual distraction. The presence of the auditory and visual distracters could increase the cognitive load upon the listener's system and therefore, this load may impact how much background noise a listener was willing to tolerate. In particular, it was questioned if a listener's tolerable background noise level would change in the presence of competing visual and/or auditory distracters. It was hypothesized that when distracters were present, there would be a significant difference in the listener's tolerable background noise levels. The results of the study indicated that subjects were willing to tolerate more background noise with the visual distracter and less noise with the auditory distracter. Furthermore, ANOVA results yielded a significant main effect of auditory distraction and visual distraction when presented in isolation and not in combination.

Condition B, in which the subjects tolerated the most background noise, it is likely that the subjects focused solely on the driving simulation task and their mental resources were primarily allocated to the driving task. It is possible that when they were given the choice between the driving task and the background noise, the subjects favored the driving task more because of the novelty and excitement it provided. For Condition C, where the subjects were not provided with the driving simulation task, they had a much harder task to separate the auditory distracter (running speech in this case) from the target signal (background noise). This resulted in a lower tolerable background noise level. Condition D maximized the amount of stress upon the listeners' cognitive load when they were presented with both the auditory and visual distracters simultaneously and were required to divide their attention between both as well as monitoring the background noise. Based on the performance of subjects on condition B and C, one would expect the tolerable background noise levels for condition D to be much lower when two distracters were presented simultaneously, but that was not the case. The subjects as a group tolerated more noise in condition D than auditory distraction alone and less noise when compared to visual distraction alone.

The results showed that there was a significant effect of auditory and visual distraction individually on how much background noise a subject was willing to tolerate. They were able to compartmentalize and allow the background noise level to be raised to a higher level compared to baseline. The findings of the current study concur with past literature in the area of cognitive resource allocation in the same modality and a decrease in task performance. Berggren, Hutton, and Derakshan (2011) reported that when there is an increase in the cognitive load and ultimately a greater amount of stress placed upon working memory, individuals had decreased task performance and increased errors, particularly when distracted. In studies where driving performance is measured, it has been found that cognitive load negatively impacts performance (Lee, Lee, & Boyle, 2009). In this study, an auditory task was introduced while subjects were driving and it was found that their reactions to driving obstacles such as other drivers, pedestrians, and road objects were delayed and the subjects were highly distracted.

On the other hand, when the distracter was in the same modality as the background noise, that is speech, the subjects had to use the same cognitive resources utilized in determining their tolerable background noise levels. It was also an interesting finding that when the cognitive load was in the same modality, subjects preferred less noise. This is in agreement of previous literature in cognitive psychology that healthy adults had an increase in cognitive load when noise was present as a result of increased distraction (Smucny, Rojas, Eichman, and Tregallas, 2013). In a study by Mattys, Brooks, and Cooke (2009), subjects preferred less noise when the auditory distracter was used and this is likely attributed to the masking phenomenon and increased stress upon the cognitive system. When there is a large amount of noise, it masks the competing auditory signals and ultimately negatively impacts speech understanding and cognitive processing. As a result, the subject has a high cognitive load due to the presence of two auditory stimuli and ultimately their performance decreases.

The total cognitive load put upon the system is impacted whenever there is any stimulus input, regardless of whether it is interesting or not. Research has shown that background noise negatively impacts cognitive performance for young, normal hearing listeners and age-related differences exist (Pichora-Fuller, 2003; Pichora-Fuller and Singh, 2006). If the cognitive system is further impacted by the introduction of a challenging motor task, the subject’s performance is negatively impacted due to resource allocation (Pichora-Fuller and Singh, 2006). These motor skills, coupled with the subjects’ responsibility for selecting a tolerable background noise level, introduces both working memory and motor skills. It is possible that selecting the tolerable background noise or UCL became impacted by the brain’s role in listening, remembering when to tell the researcher to stop the increasing background noise, and playing the game as well simultaneously.

The subjects tolerated more background noise while completing the driving simulation task and this might be due to a limitation in the design of the current study. The researchers did not check for either accuracy of the driving task or accuracy in the retelling of the story of the Arizona Travelogue. If the subject's performance on these tasks were measured, particularly error rates, then the results would have been analyzed as a covariate to determine the overall impact of the task upon the tolerance of background noise.

There is a clear implication of the findings of the results from this study on hearing aid use. It is worthwhile to speculate that when a hearing aid user is engaged in a real-world driving task, he or she is going to be more willing to tolerate more background noise than when he or she is driving and solely listening to the radio. These results mean that the hearing aid user is able to tolerate a greater amount of background noise than expected and still be able to perform the driving task. In such a scenario, the noise reduction circuit in digital hearing aids may not reduce the overall gain aggressively. However, if the hearing aid user is driving and listening to radio or a passenger, then the digital noise reduction circuit needs to suppress background noise as much as possible. The same concept is also applicable to an environment where a hearing aid user is watching television.

As the results indicated that the subjects were willing to tolerate more noise while engaged in a visual distraction task, it is worthwhile exploring the application of this concept to tinnitus masking treatment techniques. Peripheral masking with musical tones or broadband noise has seen renewed interest in treatment of tinnitus. Patients with tinnitus have expressed that peripheral masking is annoying. Based on the results of this study, it is possible that a simultaneous visual task might make tinnitus masking treatment more acceptable to the patients.

It is important to stress that this research was completed using normal hearing subjects. In addition, all participants in this research were college students who are used to multitasking in different modalities (e.g. texting while performing another task).

In this study, the subjects' accuracy on the visual task, the driving simulation game, was not assessed. Further research studies are necessary because it would be interesting to examine if a subject's performance, such as errors on the driving task and accuracy of retelling the Arizona Travelogue, could be quantified in relation to their tolerance to background noise. This could serve as a way to determine if there is an interaction between the distracters and task performance. It is suggested that a five-point scale be used to quantify accuracy of both driving and storytelling and it is possible that a more specific and quantifiable answer regarding why the subjects tolerated more noise in the high cognitive load situations could be found. In addition, further research is needed to test a subject group comprising of elderly hearing impaired listeners who are most likely not as adept at performing multiple tasks as young normal hearing listeners.

# APPENDICES

Table 5. Condition order for subjects based on Latin-square design.

| **Subject Number** | **Condition Order** |
|---|---|
| 1 | CDAB |
| 2 | DCBA |
| 3 | ABCD |
| 4 | BADC |
| 5 | CDAB |
| 6 | DCBA |
| 7 | ABCD |
| 8 | BADC |
| 9 | CDAB |
| 10 | DCBA |
| 11 | ABCD |
| 12 | BADC |
| 13 | CDAB |
| 14 | DCBA |
| 15 | ABCD |
| 16 | BADC |
| 17 | CDAB |
| 18 | DCBA |
| 19 | ABCD |
| 20 | BADC |
| 21 | CDAB |
| 22 | DCBA |
| 23 | ABCD |
| 24 | BADC |

Table 6. Subjects' reported tolerable background noise levels for all test conditions (dB HL).

| Subject | Condition A | Condition B | Condition C | Condition D |
|---|---|---|---|---|
| 1 | 44 | 44 | 36 | 60 |
| 2 | 40 | 44 | 40 | 48 |
| 3 | 42 | 58 | 44 | 50 |
| 4 | 48 | 56 | 38 | 44 |
| 5 | 36 | 36 | 30 | 32 |
| 6 | 40 | 42 | 42 | 50 |
| 7 | 40 | 46 | 36 | 42 |
| 8 | 48 | 58 | 42 | 50 |
| 9 | 46 | 48 | 40 | 42 |
| 10 | 36 | 38 | 30 | 38 |
| 11 | 36 | 36 | 34 | 38 |
| 12 | 54 | 58 | 40 | 46 |
| 13 | 38 | 40 | 38 | 40 |
| 14 | 48 | 50 | 38 | 42 |
| 15 | 40 | 44 | 34 | 32 |
| 16 | 48 | 52 | 32 | 40 |
| 17 | 44 | 50 | 38 | 42 |
| 18 | 46 | 48 | 44 | 44 |
| 19 | 38 | 48 | 30 | 30 |
| 20 | 40 | 46 | 32 | 34 |
| 21 | 58 | 62 | 44 | 48 |
| 22 | 40 | 40 | 30 | 36 |
| 23 | 52 | 58 | 42 | 44 |
| 24 | 36 | 34 | 24 | 32 |

Table 7. Subjects' reported UCLs for both conditions (dB HL).

| Subject | UCL without Distraction | UCL with Distraction |
|---|---|---|
| 1 | 76 | 76 |
| 2 | 58 | 56 |
| 3 | 60 | 64 |
| 4 | 66 | 66 |
| 5 | 40 | 42 |
| 6 | 76 | 76 |
| 7 | 60 | 58 |
| 8 | 64 | 60 |
| 9 | 54 | 62 |
| 10 | 70 | 72 |
| 11 | 50 | 48 |
| 12 | 72 | 68 |
| 13 | 66 | 72 |
| 14 | 68 | 68 |
| 15 | 50 | 54 |
| 16 | 62 | 66 |
| 17 | 60 | 66 |
| 18 | 58 | 62 |
| 19 | 52 | 58 |
| 20 | 76 | 76 |
| 21 | 74 | 76 |
| 22 | 68 | 70 |
| 23 | 62 | 66 |
| 24 | 60 | 56 |

Instructions for all four test conditions and two UCL conditions presented to the subjects

Practice Task

I am going to present ongoing speech by a male talker. The speech will slowly get louder. I want you to tell me when the speech is the most comfortable for you as if you were listening to the radio. You may turn the loudness up and down as needed to help select the most comfortable level.

Now I am going to present a background noise conversation of several people talking at the same time. The level of the background noise conversation will slowly increase and I want you to tell me when it is the most you are willing to accept or put up with. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.

Task Condition A

Imagine you are engaged in a conversation. I am going to present a background noise conversation of several people talking. The level of the background noise will slowly increase. I want you to monitor the level of the conversation and tell me when it is the most you are willing to accept or put up with while imagining you are still engaged in that conversation. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.

Task Condition B

You are going to play a game on the iPad. I am going to present a background noise conversation of several people talking. Imagine you are engaged in conversation. Your task is to play the game while monitoring the level of the background noise. The background noise conversation of several people will get louder. Tell me when it reaches a level that you are most willing to accept or tolerate while imagining you are still engaged in that conversation. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.

Task Condition C

There will be ongoing speech by a male talker. The speech will be at the level you decided was most comfortable for you to listen to during the Practice Task.

A background noise conversation of several people talking will be presented and will slowly get louder. Tell me when the noise reaches a level that you are most willing to accept or put up with while still listening to speech by the male talker. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.

Task Condition D

There will be ongoing speech by a male talker. The speech will be at the level you decided was most comfortable for you to listen to during the Practice Task.

I am going to present a background noise conversation of several people talking and you are going to be playing a game on the iPad. Your task is to focus on playing the game while monitoring the level of the noise. The background noise conversation will slowly get louder and I want you to tell me when the noise has reached a level you are willing to accept or put up with. You may turn the loudness of the background noise conversation up and down as needed to help you select the level you are most willing to accept.

Task 6 (UCL without Distraction)

Your task is to listen to the background noise. This noise will slowly get louder. I want you to listen to the noise and tell me when the noise reaches a loud level that is uncomfortable for you to tolerate.

Task 7 (UCL with Distraction)

Your task is to play a game on the iPad while I present background noise. This background noise will slowly get louder. I want you to tell me when the noise reaches a loud level that is uncomfortable for you to tolerate.

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