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THE RELATIONSHIP OF DICHOTIC LISTENING ABILITIES AND SOUND SENSITIVITY FOR OLDER ADULTS

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THE RELATIONSHIP OF DICHOTIC LISTENING ABILITIES AND SOUND SENSITIVITY FOR OLDER ADULTS

by

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DEDICATION

This dissertation is dedicated to my loving family, my enthusiastic friends, and the countless members of the University of Memphis faculty who have given me guidance and encouragement. I would also like to dedicate this dissertation to my husband, the endless support of whom has given me the time, energy, and willpower to craft this dissertation. Finally, I would like to dedicate it to my late grandfather, Billie Bonner, who inspired me more than he could ever know.

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PREFACE

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ABSTRACT

While amplification is the most prevalent treatment for mild to moderately severe hearing loss, many individuals with hearing loss report discomfort with amplified sounds. Despite attempts to resolve these issues with digital sound processing, adverse effects continue to be reported. It is possible these adverse effects are due to sound sensitivity rather than over amplification. Sound sensitivity has been found to relate to personality traits, emotionality, anxiety, depression, and self-reported hearing disability. One way to evaluate sound sensitivities is to explore how individuals accept sound. Sound acceptability is a holistic construct that attempts to evaluate a sound’s aversiveness, pleasantness, annoyance, and other factors.

Relationships between personality traits and emotional reactivity and their possible impact on sound acceptability have not been explored. Therefore, a survey study with 53 adults aged 18 to 30 was conducted to evaluate if those with more negative personality traits and emotionality would report less sound acceptability. Results suggested that those with higher negative emotionality and lower agreeableness in their personality reported less acceptability of everyday sounds. The implications of these relationships are discussed.

The factors individuals consider when judging sound acceptability have also not been evaluated previously. It was hypothesized that individuals would consider loudness, duration, and pitch to judge sound acceptability. A study using multi-dimensional scaling was completed with 53 adults aged 18 to 30 to further understand the individual perceptions of the acceptability of everyday sounds. Spatial plots of the resulting data suggested that individuals did in fact consider loudness, although the duration component was more complicated to evaluate. Implications of these findings are discussed.

Reduced dichotic listening ability also results in adverse listening outcomes. Yet, the relationship between dichotic listening and sound sensitivity has not been explored. It was hypothesized that those with poorer dichotic listening ability would have more sound sensitivity than those with normal dichotic listening abilities. The final study examined this hypothesis in a group of 36 adults aged 65-79 years old through a cross-sectional survey. The survey evaluated measures of personality, emotional reactivity, anxiety/depression, cognitive ability, sound sensitivity, and dichotic listening ability. Relationships between anxiety/depression, dichotic listening, and sound sensitivity were evaluated. There was a significant relationship between poorer dichotic listening and increased sound sensitivity. However, this effect was fully mediated by anxiety/depression, suggesting that those with poorer dichotic listening ability are likely to have higher anxiety/depression, which results in more sound sensitivity. This may affect clinical outcomes with amplification for this population. Implications of these results are discussed.

Table of Contents

Chapter Page

List of Tables ix

List of Figures x

1. General Introduction 1

2. Exploring the relationships between sound acceptability, emotional reactivity, and personality 4
    - Materials and methods 8
        - Participants 9
        - Materials 9
            - Personality 10
            - Emotional Reactivity 10
            - Sound Acceptability 11
        - Procedures 13
        - Data analyses 15
    - Results 15
        - Personality and Emotional Reactivity 15
        - Sound Acceptability Ratings 17
        - Associations between Personality, Emotional Reactivity, and Sound Acceptability 17
    - Discussion 20
    - Conclusions 24

3. Acoustic-perceptual Dimensions Underlying Real-world Sound Acceptability Judgments by Young Adults with Typical Hearing 26
    - Materials & Methods 29
        - Participants 29
        - Materials 30
            - Personality 30
            - Emotional Reactivity 30
            - Sound Acceptability 31
        - Procedure 32
        - Data analyses 34
    - Results 34
    - Discussion 38
    - Conclusion 41

4. The Relationship Of Dichotic Listening Abilities And Sound Sensitivity For Older Adults 42
    - Materials & Methods 54
        - Participants 54

Materials 52
Dichotic Listening Test 52
Questionnaires 53
Sound Sensitivity 53
Personality 53
Emotional Reactivity 54
Anxiety and Depression 54
Cognitive Assessment 55
Procedure 60
Data analyses 61
Results 62
Prevalence 62
Participant Factors 62
Cognition 63
Sound Sensitivity 63
Dichotic Listening 64
Dichotic Listening, Sound Sensitivity, and Anxiety/Depression 64
Discussion 67
Limitations 69
Conclusion 70

5. General Conclusion 71

References 74

Appendix A: Sound Acceptability Concept 86

Appendix B: Sound Comparison Instructions 87

Appendix C: IRB Approval - PRO-FY2021-24 88

Appendix D: IRB Approval - PRO-FY2022-349 89

List of tables

Table Page

1. Characteristics of participants 9

2. Measured Intensity Levels of D-SAT Sounds, Relative to the CST Carrot Passage at 67 dB SPL 13

3. Personality and Emotional Reactivity: Responses to IMM and PERS-S 16

4. Relationship between Personality and Emotional Reactivity 17

5. Sound Acceptability Test Sound Category Average Ratings 17

6. Pearson Correlations Between Personality, Emotional Reactivity, and Sound Acceptability 19

7. Regression Analyses with General Negative Reactivity and Agreeableness Predictors 19

8. Demographics of the Sample 29

9. SAT Sounds by Intensity and Duration 31

10. Similarity Matrix of Sound Acceptability Ratings Input to MDS 35

11. Final MDS Dimension Coordinates 35

12. Characteristics of the Sample 55

13. Internal Traits of the Sample 63

List of figures

Figure Page

1. Loudness contour anchors established by Cox et al. 1997 14

2. MDS spatial plot of sound acceptability ratings 36

3. ALSCAL visualization of the individual participants' weights for dimension 1 and dimension 2 37

4. The mediation model with X=R-Ear DL Score and the effect of each pathway 66

5. The mediation model with X=Ear difference DL Score and the effect of each pathway 66

6. The mediation model with X=Total DL Score and the effect of each pathway 67

Chapter 1

GENERAL INTRODUCTION

While hearing aids are a common approach to treating hearing loss, many individuals report aversiveness to amplified sounds (Picou, 2020), and researchers have found that individuals with more sound sensitivity are more likely to have poorer outcomes with hearing aids (e.g., Nabelek et al., 2006; Palmer et al., 2006). Despite attempts to reduce the adverse effects of amplified sound digitally (Bentler et al., 2008; Brons et al., 2013, 2014; Chung, 2018; Liu et al., 2012; Palmer et al., 2006), some users continue to report adverse outcomes with amplification (Lindley et al., 2001). While there is still a lack of understanding as to why these individuals continue to have adverse outcomes, it is possible these adverse effects are due to sound sensitivity. Sound sensitivity has been found to relate to negative attributes, such as anxiety, depression, neuroticism, and negative emotionality (Jastreboff & Jastreboff, n.d.; Miedema & Vos, 2003).

Researchers have demonstrated that subjective real-world loudness discomfort of amplified sounds is not directly related to sounds generated in the clinical laboratory or traditional loudness measures (Filion & Margolis, 1992; Keidser et al., 2010; Lindley et al., 2001). In fact, loudness perception has been found to have a large inter-individual variability (R. A. Bentler & Cooley, 2001; Sherlock & Formby, 2017), and there is great variability in individuals' tolerance for sounds (R. A. Bentler & Cooley, 2001; Thomas & Jones, 1982). However, loudness is only one facet of sound. Therefore, to evaluate individuals' perception of everyday sounds, the concept of sound acceptability has been established (Huber & Johnson, accepted). Sound acceptability is a holistic construct that has individuals consider the annoyance, aversiveness, pleasantness, the emotional reaction to the sound, and other features.

Emotional reactivity characterizes the emotional response in terms of activation, intensity, and duration, and can be measured as general positive and general negative reactivity (Preece et al., 2018). While emotional reactivity has been found to associate with some personality traits (Costa & McCrae, 1992, Watson & Clark, 1984), emotional reactivity and personality traits' direct relation to sound acceptability is still unknown.

Additionally, the acoustic-perceptual factors that individuals consider when judging a sound's acceptability, or if individual factors influence these decisions, has yet to be determined. Previous research suggests that loudness, duration, and pitch are used when individuals categorize sets of sounds (Allen & Bond, 1997); however, it is unknown if these are the same factors used when judging sound acceptability. Understanding what factors an individual considers when judging sound can impact the strategies a clinician uses to adjust amplification devices.

While sound sensitivity may explain continuing adverse outcomes with amplification, another possibility is poor dichotic listening. Dichotic listening has been found to relate to hearing ability and is impacted by aging. There seem to be several notable relationships among factors involved in sound sensitivity and dichotic listening abilities. For instance, poorer dichotic listening abilities have been seen in those with clinical depression (Bruder et al., 2001, 2004). Additionally, those reporting higher depression and anxiety tend to have lower dichotic listening abilities (Gadea et al., 2011), greater sound sensitivity (Jüris et al., 2013), and self-report more hearing disability (Kim et al., 2017; Tremblay et al., 2015). Greater self-reported hearing disability also correlates with greater sound sensitivity. However, the relationship between dichotic listening ability and sound sensitivity has not been explored.

The first study explored the relationships between personality, emotional reactivity, and sound acceptability (Chapter 2). To further understand the how individuals use acoustic-perceptual dimensions when judging sound acceptability, a second study was completed. This study used multi-dimensional scaling to evaluate individual perceptions of the acceptability of everyday sounds (Chapter 3). The third study aimed to explore the relationship between dichotic listening and sound sensitivity, and to determine if anxiety and depression affect this relationship (Chapter 4).

Chapter 2

EXPLORING THE RELATIONSHIPS BETWEEN SOUND ACCEPTABILITY, EMOTIONAL REACTIVITY, AND PERSONALITY

Currently, the most common treatment for mild to moderate sensorineural hearing loss is amplification with hearing aids (Picou, 2020). These devices amplify environmental sounds into a listener's audible range. Although clinical measures of pure-tone audiometric threshold levels, speech recognition abilities, and uncomfortable loudness levels can assist in determining whether a person is a candidate for hearing aids, these measures do not give information about how well an individual might adjust to amplified sound in daily listening. Historically, low hearing aid acceptance and satisfaction reported on standardized questionnaires such as the Abbreviated Profile of Hearing Aid Benefit (APHAB; Cox et al., 2007), Satisfaction with Amplification in Daily Life (SADL; Cox & Alexander, 1999; Uriarte et al., 2005), and Profile of Aided Loudness (PAL; Shi et al., 2007) has highlighted the deleterious effects of amplification on users' sound tolerance.

Studies have demonstrated that there is a great deal of variability in people's tolerance for sounds (R. A. Bentler & Cooley, 2001; Thomas & Jones, 1982). Disruptive decreases in sound tolerance are associated with defined medical diagnoses. For instance, hyperacusis is a negative reaction to sound based on acoustical factors such as pitch or loudness, and misophonia is a strong negative reaction to a sound with a specific pattern and meaning to the individual (Jastreboff & Jastreboff, n.d.). Yet, the diagnostic criteria and etiologies for sound or noise "sensitivity" have not been clearly defined. Individuals with noise sensitivity have been defined as those with high scores on noise sensitivity questionnaires, having a pervasive and negative attitude towards sound in general, or having strong reactions to specific noise situations (Anderson, 1971; Miedema & Vos, 2003). Additionally, the etiologies of noise sensitivity might vary. Noise sensitivity has been attributed to a person's internal physiological, psychological, or lifestyle-related states which increase the amount of reactivity to noise in general (Job, 1999), and it has been commonly found in those with psychological disorders such as anxiety disorder, major depressive disorder, and traumatic brain injury (Shepherd et al., 2015). While the definitions vary, findings within the literature consistently support the finding that people with noise sensitivity tend to report more negativity in regards to sound (Jastreboff & Jastreboff, n.d.; Miedema & Vos, 2003). Research has demonstrated that individuals with more sound sensitivity are more likely to have poorer outcomes with hearing aids (e.g., Palmer et al; Nabelek et al.). Despite attempts to resolve aversiveness of amplified sound, sound sensitivity is an unsolved issue in audiology, and there is little evidence-based information to guide clinical practices to ameliorate it (Fackrell et al., 2017).

Perhaps the most salient acoustic dimension of amplified sound that impacts acceptability is perceived loudness. Yet loudness perception has large inter-individual variability (R. A. Bentler & Cooley, 2001; Sherlock & Formby, 2017). Even when audiologists fit hearing aids using evidence-based protocols that take loudness into account, the majority of hearing aid wearers continue to experience some loudness discomfort with amplified sound (Keidser et al., 2010). Researchers have demonstrated that sounds generated in the clinical laboratory, and traditional loudness measures are not directly related to subjective real-world loudness discomfort of loud unamplified sounds (Filion & Margolis, 1992; Keidser et al., 2010; Lindley et al., 2001). This suggests that loudness is only one facet of sound that individuals consider when making judgements about discomfort. Indeed, research has shown that even soft and average-level sounds may be rated as annoying or adverse to some, especially those new to using hearing aids (Hernandez et al., 2006).

Hearing aid manufacturers have developed digital signal processing features to help reduce the negative impact of amplified unwanted sounds. These generally examine acoustic aspects of sounds to classify them as speech and noise and reduce varying types of sounds characterized as noise. These features have been demonstrated to aid in the reduction of noise annoyance and increase satisfaction (Bentler et al., 2008; Brons et al., 2013, 2014; Palmer et al., 2006). Additional types of digital noise reduction have been developed to target specific types of unwanted sounds such as short, transient sounds (Chung, 2018; Liu et al., 2012), wind (Chung, 2018), noise in reverberant spaces (Picou & Ricketts, 2019), and hearing aid whistling (T. A. Ricketts & Hornsby, 2005). Even with these highly specialized features, some hearing aid users continue to report adverse outcomes with amplification, suggesting that some people may be more sensitive to sound than others and that typical adjustments to gain and noise reduction features are not enough for some individuals (Lindley et al., 2001).

In addition to acoustic aspects of sounds, individual characteristics of the listener also are likely to contribute to perceptions about different sounds. For example, when presented with loud, real-world sounds in a laboratory setting, some hearing aid wearers who reported that sounds were “uncomfortably loud” indicated that they provided this rating because they disliked or had negative prior experiences with the sounds, suggesting that some hearing aid users are unable to separate discomfort due to loudness from other negative aspects of everyday noises (Keidser et al., 2010). Researchers have attempted to determine how patient personality profiles might impact self-reported noise sensitivity. Measures of neuroticism and openness traits improve the ability to predict preference for basic and premium hearing aids from sound acceptability ratings (Sarangi and Johnson, 2019), and neuroticism is related to reported aversiveness with hearing aids (Cox et al., 2007). Additionally, those with lower scores for the openness personality trait and those with higher conscientiousness scores have less willingness to accept background noise (Franklin et al., 2013).

In addition to personality traits, past experiences and internal states also are integral to sound sensitivity. For example, regardless of personality type, people with a heightened level of anxiety (Milenković & Paunović, 2015; Stephens, 1970) and more life stress (Nivison & Endresen, 1993; Shepherd et al., 2015) have been found to have less noise acceptability. Individuals with higher anxiety and stress levels have also demonstrated higher overall negative emotional reactivity (Becerra et al., 2017; Preece et al., 2018). Emotional reactivity characterizes the emotional response in terms of activation, intensity, and duration. Although emotion and moods are considered temporary states that are distinct from personality traits, research results do indicate a strong dispositional component of emotionality, so that even transient moods reflect a general level of emotional reactivity (Watson et al., 1988). For example, positive emotionality generally corresponds to the extraversion personality factor but does not share the same emphasis on excitement and sensation-seeking that is common for extraversion (Costa & McCrae, 1992). Negative emotionality is highly correlated with the neuroticism personality factor. Individuals with both of these characteristics are likely to experience psychological distress and negative emotions and mood states (Watson & Clark, 1984). Individuals with higher negative emotionality, scores for the neuroticism personality trait, or stress are also more likely to experience tinnitus or hyperacusis (Durai et al., 2017; Jastreboff & Jastreboff, n.d.; Jüris, Andersson, et al., 2013; Villaume & Hasson, 2017) and many of those with an anxiety or psychiatric disorder will experience hyperacusis (Jüris, Andersson, et al., 2013).

To address the multifaceted nature of satisfaction with amplified sound, Johnson and Cox (2012) posited that a valuable metric may be obtained through evaluating the acceptability of everyday non-speech sounds. This holistic construct is based on a person's overall impression of a sound and includes considerations of each sound's aversiveness, annoyance, pleasantness, loudness, perceptions of sound quality, and emotional reactions to the sound. These qualities weighed together creates an overall impression of the acceptability of the sound.

Although it seems likely that emotional reactivity plays a role in moment-to-moment assessments of sound acceptability in a manner that is independent of personality, this relationship has not been studied. Although the long-term goal of this research is to explore these relationships for hearing aid wearers, the current research study aimed first to evaluate the relationships between emotional reactivity, measures of personality, and noise acceptability in young adults with typical hearing and to determine whether emotional reactivity and specific personality traits were related to overall sound acceptability.

Hypothesizing that sensation-seekers would be more receptive to a variety of sound stimuli, we expected a positive correlation between positive emotionality and extraversion but anticipated that extraversion would have a stronger linear relationship with sound acceptability than positive emotionality. Given the relationships between anxiety and stress and sound sensitivity, we anticipated a strong positive correlation between negative emotionality and neuroticism, and a strong negative correlation between these factors and sound acceptability. Overall, this research aimed to provide insight into the important factors of personal traits and perceived sound quality that predict hearing aid acceptability.

MATERIALS AND METHODS

This cross-sectional exploratory survey study was approved by the University of Memphis Institutional Review Board, FY2021-24. Participants were compensated $10 for their time (about 30 minutes) and effort.

Participants

The 53 typically-hearing participants (39 female) in this study were age 18-30 years old (*x*=22.36 years, *sd*=2.89). Participants were recruited via social media and word of mouth. Other demographic characteristics, including age, gender, race, ethnicity, education level, and neighborhood noise levels are described in Table 1.

Table 1. Characteristics of Participants

Characteristic	*n*
Gender	
Female	39
Male	14
Race	
White or Caucasian	37
Black or African American	10
Asian	3
Pacific Islander	2
Other	1
Ethnicity	
Non-Hispanic	47
Hispanic or Other	6
Education	
Less than high school diploma or GED	1
High school diploma or GED	3
Some college	12
Associate degree	8
Bachelor's Degree	27
Master's Degree	2
Neighborhood Noise Level	
Very Quiet	15
Somewhat Quiet	24
Neither Quiet nor Noisy	7
Somewhat Noisy	7

Materials

Predictor variables were measures of personality and emotional reactivity, and the outcome was sound acceptability.

Predictor variables

International Mini-Markers

The International Mini-Markers (IMM; Thompson, 2008) responses are used to determine the magnitude of each of five personality traits: agreeableness, extraversion, neuroticism, conscientiousness, and openness. The IMM was developed as a brief version of the Big Five personality trait set (Thompson, 2008), and has been used previously in audiology literature (Benfield et al., 2014; Cox et al., 1999, 2005; Franklin et al., 2013; Miedema & Vos, 2003). The IMM presents 40 descriptor words to participants with instructions to “describe yourself as accurately as possible. Describe yourself as you see yourself at the present time, not as you wish to be in the future.” Participants were given a scale to rate each trait from 1 (extremely inaccurate) to 9 (extremely accurate), with 5 being a neutral center point. Some items were reversed items. Ratings for items were summed for each of the five personality traits.

Perth Emotional Reactivity Scale

The Perth Emotional Reactivity Scale Short form (PERS-S; Preece et al., 2018) was used to evaluate participants’ emotional reactivity. The PERS-S is a validated scale designed to measure aspects of how a person typically reacts to experiencing emotional events with 18 questions divided evenly among domains (Preece et al., 2018). Emotional Reactivity can be measured as a general positive and general negative overall value, or with subscales evaluating activation, duration, and intensity in the positive and negative direction. We chose to sum the responses for general negative reactivity and general positive reactivity scales for this study, as recommended by Preece et al. (2018) and Hurriyati et al. (2020). Higher scores indicate higher levels of reactivity in the domain.

Outcome variable

Sound Acceptability Test

A modified version of the Sound Acceptability Test (SAT; Johnson, 2012) was used to quantify participants' acceptability of everyday sounds. The SAT was developed in the Hearing Aid Research Lab to quantify the effectiveness of hearing aid features that, when used alone or in combination, are intended to improve the acceptability of real-world non-speech sounds. This holistic construct is based on a person's overall impression of a sound and includes considerations of each sound's aversiveness, annoyance, pleasantness, loudness, perceptions of sound quality, and emotional reactions to the sound (Johnson, 2012). The current format includes 21 everyday real-world sounds in nine different duration and intensity domains. These domains were evaluated and categorized following the methods recommended by Hernandez et al. (2006). Presenters traditionally present each sound twice in person, resulting in 42 total presentations per assessment. Participants are asked to rate the acceptability of the sound from 0-"not-at-all-acceptable" to 10-"very much acceptable." Presentations of each sound are made at specific heights and distances from the participant (e.g., 25" directly in front of the participant at head-level, and 35" in front of the participant at the level of the floor, depending on how the sound would naturally occur. Qualities weighed together create an overall impression of the acceptability of the sound.

D-SAT Development

For this study digital recordings were created to represent the SAT's 21 real-world everyday sounds. This choice was made to accommodate the need for remote data collection during the 2020 COVID-19 pandemic. We refer to this version of the SAT as the Digital SAT (D-SAT). In making the recordings of these sounds, we attempted to retain as many of the aspects of the in-person presentations as possible. We chose to represent these sound presentations using audio and visual information, with minimal pre-processing. Recording devices were mounted at average seated participant head-height (approximately 1 meter from the floor), at distances of 25” or 35” from the sound source, depending on which sound was presented. Recordings of the SAT stimuli were made in a 10x10-foot double walled sound treated booth. The Shure MV88 iMic was used with the Shure MOTIV Video app for iPhone version 1.3.1.191 for the recordings. The microphone gain was set to 19.5 dB with a stereo 135º polar pattern, and the equalizer was set to flat from 200-10,000 Hz. Compression and wind noise reduction was turned off, and due to the use of the front-facing camera mode for videoing, left and right channels were mirrored.

Apple iMovie version 10.1.16 was used to separate the audio and video files. Audio files were digitally edited in Adobe Audition 13.0.10.32 so that the RMS level of an average level, continuous duration sound file (in this case, “hair dryer”) was matched to approximate the RMS level of average speech. We used the “Carrot passage” from the Connected Speech Test (CST; Cox et al., 1989) presented in quiet at 67 dB SPL to represent speech. The RMS levels of the remaining SAT audio files were digitally adjusted relative to this level in an attempt to preserve the parameters of the original SAT presentations. As an exception, due to their high relative peak values, the audio files of the Bike Bell and Rattling Keys sounds could not be digitally adjusted to their intended RMS levels without excessive digital peak clipping. Therefore, these recorded sounds are 6-8 dB RMS quieter overall than when presented in person. The audio files were added back to the videos in iMovie before exporting to a saved .wav file. The sound levels resulting from this recording process were verified using a Reed SD-4023 sound level meter with A weighting and a fast response. Intensity levels of the SAT sounds were measured in relation to the calibration passage, presented at 67 dB SPL. The observed measured levels of the SAT sounds can be seen in Table 2.

Table 2. Measured Intensity Levels of D-SAT Sounds, Relative to the CST Carrot Passage at 67 dB SPL. *Due to high relative peak values, the audio files of the Bike Bell and Rattling Keys sounds could not be digitally adjusted to their intended RMS levels without excessive digital peak clipping

Expected Intensity Range	Sound	Measured Intensity (dB SPL)
Soft, < 55 dB SPL	Clicking Pen	48
	Keyboard Typing	53
	Shuffling Cards	54
	Cutting Paper	47
	Electric Fan	45
	Pen Scribble	47
Average, 55-75 dB SPL	Pen Tapping	57
	Door Bang	66
	Phone Ring	67
	Rattling Paper	66
	Hair Dryer	69
	Coffee Grinder	68
Loud, > 75 dB SPL	Clattering Dishes	77
	Hammer	77
	Desk Bell	77
	Silverware	76
	Rattling Keys*	70
	Bike Bell*	68
	Vacuum	77
	Drill	75
	Marbles	78

Survey Procedure

Participants were provided a link to an anonymous online survey developed using umSurvey Qualtrics XM^{OS} survey software (*umSurvey*, 2020), which included consent documents, demographic questions, the IMM, PERS-S, and D-SAT. If a participant did not meet the inclusion criteria of being 18-30 years old or reporting no greater than mild hearing problems, the survey was terminated. All questions required that a choice be indicated to proceed.

To set the volume levels for the D-SAT a calibration procedure was created to normalize the sound levels. Participants were presented with the Cox Loudness Contour Anchors (Cox et al., 1997; Figure 1). As participants listened to the calibration speech passage, they were asked to adjust the volume slider on the embedded YouTube video to maximum and then adjust the volume of their device until it was comfortable, indicated by a self-reported “4-comfortable” using the Loudness Contour Anchors. They were allowed to play the video as many times as necessary until they felt they had successfully set the volume of their device to “4-comfortable.” Following calibration, participants were presented the audio/video representation of each sound. Each video focused on the object being used to create the sound, with minimal background and supplemental visual stimuli. The 21 sounds were each presented randomly in two blocks. Participants were instructed to watch and listen to each video and rate how acceptable the sound was to them using a slider-bar ranging from 0-10 and set at a center point of 5. They were asked to consider all qualities of the sound as they made their decision (Appendix A). Participants were allowed to watch the videos multiple times.

7. UNCOMFORTABLY LOUD

6. LOUD, BUT O.K.

5. COMFORTABLE, BUT SLIGHTLY LOUD

4. COMFORTABLE

3. COMFORTABLE, BUT SLIGHTLY SOFT

2. SOFT

1. VERY SOFT

Figure 1. Loudness contour anchors established by Cox et al. 1997.

Statistical Analyses

Statistical analyses were performed using IBM SPSS version 27.0.0.0 through Macintosh OS Catalina version 10.15.7. An a priori power analysis was performed for sample size estimation using G*Power (Faul et al., 2009). We hypothesized that individuals with higher ratings of personality traits associated with positive life outcomes would also have higher positive emotional reactivity and higher ratings of sound acceptability. Thus, a one-tailed analysis was used. With an alpha of 0.05 and power of 0.80, the projected sample size needed for a linear multiple regression analysis with seven predictors (five personality trait scores and two emotional reactivity scores) and an estimated effect size of Cohen's $d = 0.3$ was N=43.

RESULTS

Of 64 participants' survey data, 11 were removed prior to data analyses. Seven surveys were not completed (< 99% completion) and 4 had data consistent with having been created by a bot (e.g. completed in only a few minutes). This resulted in fifty-three valid completed surveys. Variables were computed and checked for normality and multicollinearity. The majority of the data were consistent with a normal distribution with one exception: the demographic variable race was significantly skewed, with 69.8% of the participants identifying as White/Caucasian. When this variable was placed in the regression model as a predictor, the results were unaffected, indicating that the race variable was not a confounder in the model. The data were found to have no multicollinearity based on a >2.5 variance inflation factor (Allison, 1999) within a multiple regression analysis.

Personality & Emotional Reactivity

The first aim of this study was to determine the relationship between measures of personality and emotional reactivity. Means and standard deviations of the responses to the questionnaires are provided in Table 3. From this table you can see that, on average, our participants rated themselves lower for extraverted, neurotic, and conscient traits, but higher for agreeable and open traits, with little variability overall. In general, our participants reported higher positive emotional reactivity than negative reactivity.

To evaluate associations between personality traits and emotional reactivity scatterplots were first inspected for nonlinear trends. None were noted, so a linear regression was used to statistically evaluate the data. Table 4 summarizes these correlations and demonstrates statistically significant positive associations between reports of positive general reactivity and extraversion (r=0.31, p=0.02), positive general reactivity and agreeableness (r=0.58, p<.001), and general negative reactivity and neuroticism (r=0.64, p<.001). A small but statistically significant negative association between agreeableness and general negative reactivity was observed (r=-0.31, p=0.02). Although the relationships between emotional reactivity and extraversion and neuroticism were expected, it was of interest to note the relationship between measures of agreeableness with measures of both positive and negative emotional reactivity for these participants.

Table 3. Personality and Emotional Reactivity: Responses to IMM and PERS-S

Factor	*M*	*SD*
Extravert	3.53	1.68
Openness	5.47	1.45
Neurotic	4.00	1.59
Conscient	4.44	1.52
Agreeable	5.42	1.11
Negative Reactivity	29.21	8.70
Positive Reactivity	35.49	6.46

Table 4. Relationship between Personality and Emotional Reactivity

	Emotional Reactivity	
Personality	Positive	Negative
Extravert	0.31*	-0.13
Openness	0.01	-0.03
Neurotic	0.01	0.64**
Conscient	-0.09	0.01
Agreeable	0.58**	-0.31*

*p<.05. **p<.001.

Sound Acceptability Ratings

During the survey, participants were asked to rate each everyday sound twice during the D-SAT. The first and second ratings were compared using paired *t*-tests, which showed no significant differences between trials for any of the sounds. This finding suggested that there were no significant learning effects. Thus, the two ratings were averaged for every sound for each participant. Scores were further combined so that each participant had a mean score for each of the nine loudness/duration sound categories. These ratings are summarized in Table 5. From this table it can be seen that in each duration category soft sounds were rated most acceptable (a higher number) and loud sounds were rated least acceptable. However, within each loudness category, a different duration was rated most acceptable. For soft sounds, as duration increased acceptability improved; for loud sounds, as duration increased acceptability decreased. For average sounds, episodic sounds (phone ringing and rattling paper) were rated most acceptable.

Table 5. Sound Acceptability Test Sound Category Average Ratings

	Duration					
	Transient		Episodic		Continuous	
Intensity	*M*	*SD*	*M*	*SD*	*M*	*SD*
Soft	7.44	1.71	8.15	1.55	8.22	1.46
Average	5.05	3.31	6.43	1.91	4.79	2.25
Loud	3.62	3.18	3.30	1.89	2.90	1.71

Associations between Personality, Emotional Reactivity, and Sound Acceptability

Table 6 summarizes the correlations between measures of personality, emotional reactivity, and ratings of sound acceptability. Very few acceptability ratings were correlated with measures of personality or emotional reactivity. However, agreeableness was positively related to acceptability ratings for transient and episodic loud sounds, and episodic average sounds, and general negative reactivity was negatively associated with acceptability ratings for transient loud sounds. Because agreeableness and general negative reactivity were both related to sound acceptability ratings for transient loud sounds we wanted to determine if they explained distinct aspects of the variance in these ratings. Thus, we included these variables into a stepwise regression as predictor variables for transient loud sound acceptability ratings. Table 7 summarizes these results. When only entering general negative reactivity, the model was able to account for some variance in transient loud sounds (ΔR^2=.106, $F(1,50)$=5.56, p=.02). Adding Agreeableness to the model did not explain any additional variance in acceptability ratings for transient loud sounds, suggesting that measures of these two attributes capture the same underlying characteristic that influences acceptability ratings for sounds with these acoustic parameters.

Table 6. Pearson Correlations Between Personality, Emotional Reactivity, and Sound Acceptability

		Personality Traits						Emotional Reactivity	
		Extraversion	Agreeable	Conscient	Neurotic	Openness		Negative	Positive
D-SAT Domain									
Transient	Soft	.09	.14	.08	.15	-.10		.12	.24
	Average	.15	.19	.22	-.05	.04		-.11	.19
	Loud	.08	.30*	.07	-.01	.12		-.31*	.24
Episodic	Soft	-.09	.19	-.05	-.01	-.09		.07	.19
	Average	.07	.37**	.19	.16	.08		-.08	.24
	Loud	-.03	.27*	.00	.06	.14		-.21	.25
Continuous	Soft	-.003	-.18	-.12	.05	-.20		.24	-.10
	Average	.18	.01	-.22	-.12	-.12		-.20	.01
	Loud	.12	.25	-.04	-.04	-.03		-.26	.17

*p<0.05. **p<.01.

Table 7. Regression Analyses with General Negative Reactivity and Agreeableness Predictors

	Loudness Duration Category				
	Transient Loud				
Step and predictor variable	B	SEB	β	*t*	*p*
Step 1					
Constant	5.50	.83		6.62	<.001
General Negativity	-.06	.03	-0.31	-2.36	.02
Step 2					
Constant	3.11	1.67		1.86	.07
General Negativity	-.05	.03	-.24	-1.77	.08
Agreeableness	.36	.22	.23	1.64	.11

DISCUSSION

When listeners make determinations about how acceptable a sound is, they undoubtedly reflect on acoustic characteristics like loudness and duration of the sound. For this experiment participants tended to rate soft, continuous sounds (e.g., a small fan blowing) as the most acceptable, and loud, continuous sounds (e.g., vacuum cleaner) as least acceptable. Yet, there is sufficient variability in sound ratings to suggest that other aspects of the sound or the listener might also impact how acceptable these sounds might be perceived. The first aim of this research was to evaluate the relationships between emotional reactivity, measures of personality, and everyday sound acceptability in young adults with typical hearing abilities. As anticipated, negative emotional reactivity was positively associated with neuroticism. Yet, surprisingly, of these two variables, only negative emotional reactivity was even weakly related to sound acceptability ratings. Participants who indicated greater negative emotional reactivity had a slight tendency to rate all average and loud sounds as less acceptable than those with less negative emotional reactivity. This trend was most notable for loud transient sounds. Although previous literature has strongly linked neuroticism and negative emotional reactivity together, only negative emotional reactivity is specifically related to a propensity to exhibit higher arousal when exposed to sensory stimuli (Costa & McCrae, 1980). Individuals higher in negative emotional reactivity may experience higher levels of arousal in response to nonspeech sounds and be more attentive not only to acoustic aspects of the sounds, but also to any negative thoughts and emotions that these sounds might evoke.

We also found that positive emotional reactivity was positively associated with agreeableness (r=.58, p<.001) and extraversion (r=.31, p=.02). This supports previous findings by Watson and Clark (1988) that positive affect and extroversion are positively correlated, however, previous research has not demonstrated similar relationships between agreeableness and positive emotional reactivity.

We anticipated that individuals higher in extraversion would report greater sound acceptability given the relationship between extraversion and sensation-seeking; however, measures of extraversion were not significantly associated with ratings of sound acceptability for any categories. The only personality trait that was related to sound acceptability ratings was agreeableness, and this was only true for average and loud sounds. Research has shown that people high in agreeableness are more likely to control negative emotions in conflict situations (Jensen-Campbell & Graziano, 2001). It is possible that these individuals were similarly able to control negative emotions or reactions in response to these auditory stimuli. The agreeableness personality trait is also strongly characterized by a desire to be cooperative and help others. It is possible that individuals higher in agreeableness might be more willing to tolerate sensory stimuli in daily listening or, alternatively, less likely to report strong negative reactions to these sounds even if they were experienced.

Together, these results suggest that personality traits and emotional reactivity are related and are at least partly involved in sound acceptability ratings. However, our findings differ from some previous research. For example, Shepherd et al. (2015) found that the introversion-extroversion dimension of personality was most related to sound sensitivity. Similarly, Moghadam et al. (2021) modeled the effect of personality traits on sound sensitivity, and found that extroversion and neuroticism were the most important for sound sensitivity. Sound sensitivity is generally thought of as a negative construct, with higher sensitivity relating to a lower tolerance of sounds. In contrast, sound acceptability is a more positive construct, with higher acceptability relating to a higher tolerance of sounds. It is possible that the construct of sound acceptability was differently interpreted and therefore driven by different factors than the construct of sound sensitivity. The regression analysis revealed that the personality trait agreeableness was highly correlated with positive reactivity. These two variables explained much of the same variance, and it is possible that personality traits did not really influence sound sensitivity for this group.

For the typical-hearing participants in this study, there was a general agreement that soft sounds were acceptable. It is possible that the limited age range and hearing abilities reduced the potential influences of emotionality or personality in the sound ratings. Those with hearing loss may accept these everyday sounds differently, as presbycusis and noise-induced hearing loss affect the frequency spread of the sounds. These types of hearing loss are at a larger risk for loudness recruitment, perceiving an abnormally large increase in loudness with only a slight increase in the sound's measured intensity (Baguley & McFerran, 2011). These everyday sounds were not amplified or processed by hearing aids for these individuals. It is likely that more variability would be seen if those rating these digital sounds were hearing aid users.

Some additional considerations about this sample and the methods used for this study include the fact that the original SAT was not designed to be presented digitally, and therefore limitations of recordings and loudspeakers may have influenced the results. Two sounds in the study—bike bell and rattling keys—were not able to be presented at the target volume due to digital peak clipping limitations. Presenting these two sounds at a softer intensity than intended may have influenced the acceptability of these sounds for some participants. Another factor that might have limited the results in this study are the loudspeakers the participants used. We were unable to test the frequency and intensity range capabilities of the speakers used by the participants. In attempt to account for the intensity level differences between speakers, we utilized a novel calibration and loudness adjustment method. Participants were instructed to not adjust the volume of their device or the on-screen videos at any time following the calibration procedure. While participants may not have heard the everyday sounds at the same intensity, which at least provided a perceptual normalization across testing conditions and participants. Additionally, we were unable to determine if any equalization parameters were adjusted. Therefore, we cannot account for any acoustic effects due to the participants' equipment or personal device settings.

Due to the remote nature of the study, there are also some limitations related to participant understanding and ability to follow instructions. Specifically, it is unknown if participants accurately calibrated the volume on their devices, were in an adequately quiet environment, or kept the volume at a consistent level as instructed. Turner et al. (2021) evaluated the capabilities of participants to complete the categorical loudness scaling procedure in a remote data collection format. Their results indicate that participants are able to appropriately limit ambient noise in their environment and that reliability for within-run remote measurements were similar to in-lab results (Turner et al., 2021). Similarly, recent research in our laboratory confirmed that young adult participants with typical hearing abilities were able to reliably adjust volumes to match loudness categories using these stimuli, even when the categories were randomized and not presented in an ascending manner (Vaden & Johnson, 2022). If participants adjusted their device volume during the study, we are unable to account for it.

It should be noted that these participants in this study self-reported greater emotional reactivity than the normative values reported in Preece et al. (2018) in both directions (i.e., greater positive and greater negative reactivity), and the variability for negative reactivity was larger for this participant group overall. Preece et al. reported x=33.2 and sd=6.88 for positive reactivity and *x*= 26.54 and *sd*=8.14 for negative reactivity. Comparing the magnitude of the difference between these two samples, our participants self-reported more positive reactivity (*d*=0.34) with less variability and more negative reactivity (*d*=0.32) with more variability than those from Preece et al. (2018). These effect sizes are small but notable, and likely represent demographic differences in the samples. Additionally, our participants reported higher scores on prosocial personality traits. It is possible that the participants in this study volunteered and completed the survey because they were inherently more prosocial and agreeable than the general population. This supports previous findings that those who volunteer for research tend to have higher agreeableness (Lönnqvist et al., 2007). It is also possible that these participants self-reported more agreeableness due to a response bias to be more socially desirable (Cox et al., 2007). While we did not evaluate social desirability in this study, previous researchers have concluded that social desirability does not invalidate personality measures (McCrae & Costa, 1983; Pauls & Stemmler, 2003). With these thoughts in mind, the generalizability of these findings may be limited to young adults with typical hearing that have similar perceptions of their personality traits and emotional reactivity. Extending the population sample to include individuals of diverse age, background, and affect/personality type would enhance the generalizability of these findings. Additionally, future research should compare these results to those obtained for individuals with hearing loss, with and without amplification, to provide meaningful insight into the impact of sound acceptability on audiologic outcomes.

CONCLUSION

This study highlighted the close relationships between some personality traits and emotional reactivity and demonstrated that aspects of these traits impact perceived sound acceptability. For these young adults with typical hearing abilities, sound acceptability ratings were driven by different combinations of loudness and duration of the sound and further influenced by emotional reactivity. While this study focused on young adults with typical hearing abilities, the results suggest that evaluating emotional reactivity could help in identifying those who might have reduced sound acceptability. While the current study does not provide insights as to how clinicians may improve sound acceptability, it does provide a potential profile for patients who may be more/less likely to experience low sound acceptability. These findings provide a rationale for further investigation of the impact of these variables on amplified sound acceptability for hearing aid users.

Chapter 3

ACOUSTIC-PERCEPTUAL DIMENSIONS UNDERLYING REAL-WORLD SOUND ACCEPTABILITY JUDGMENTS BY YOUNG ADULTS WITH TYPICAL HEARING

There is great variability in people's tolerances to sound (R. A. Bentler & Cooley, 2001), and diagnosis of decreased sound tolerance relies on a person's self-report (Henry et al., 2022). However, decreased sound tolerance is ill-defined and may refer to a variety of issues such as hyperacusis, misophonia, phonophobia, or sound sensitivity (Henry et al., 2022). Sound sensitivity generally refers to "the physiological and psychological state of a person that increases their reactivity to sound" (Shepherd et al., 2019). However, the definition of sound sensitivity varies within the literature (Anderson, 1971; Henry et al., 2022; Job, 1999; Miedema & Vos, 2003) and those with sound sensitivity are often found report more negativity in general (Jastreboff & Jastreboff, n.d.; Miedema & Vos, 2003). To explore individual perceptions in a more holistic way, the concept of acceptability was considered. Acceptability does not have a straightforward definition, as it encompasses several constructs (Sekhon et al., 2017). For instance, sound acceptability has been defined as a person's overall impression of a sound, including considerations of the sound's aversiveness, annoyance, pleasantness, loudness, perceived quality, and the person's emotional reactions to the sound (Huber & Johnson, accepted; Johnson, 2012). This holistic construct can be impacted by the intensity and duration of a sound (Johnson, 2012). In fact, human listeners exploit several auditory features when perceiving and categorizing sounds, including pitch, duration, loudness, and timbre (Susini et al., 2011). For example, a study by Allen and Bond (1997) evaluated sound comparisons of stimuli including pure tones, harmonic complexes, and bands of noise. Using a visual analog scale, similarity ratings between pairwise tokens showed that brief auditory stimuli were grouped together by the periodicity of the sound and number of spectral peaks. Within these perceptual groupings, stimuli were further ordered by their spectral content. Critically, participants were not given guidance about the factors they should use to make their judgments. This suggests listeners' form perceptual similarities between complex sounds implicitly, by comparing their underlying spectral features. Similarly, Aldrich, Hellier, and Edworthy (2009) observed that young adults with typical hearing grouped everyday sounds along three dimensions: duration, intensity, and pitch. While duration, intensity, and pitch may be the primary factors governing sound similarity judgments, other factors can influence perceptual responses, including the age of the listener or whether they use amplification devices. For example, Keidser et al. (2010) found that hearing aid users reacted differently to laboratory-generated sounds than to everyday real-world sounds, reporting more discomfort with the former stimuli. Similarly, a study by Hernandez et al. (2006) found that for new hearing aid users, even soft sounds may be adverse for some listeners. This suggests that loudness is a highly salient (though presumably not exclusive) acoustic facet that listeners consider when making judgments about sound discomfort.

In addition to these external acoustic-perceptual factors, internal state and traits of the listener also influence the perceived qualities of sound. Emotionality is an internal factor that is related to sound acceptance. Huber and Johnson (accepted) found that lower negative emotional reactivity was indicative of higher sound acceptability in young adults with typical hearing. Previous literature exploring sound sensitivity found that the personality traits extroversion and neuroticism were related to reports of sound sensitivity (Moghadam et al., 2021; Shepherd et al., 2015). Greater sound sensitivity has also been found to relate to greater levels of anxiety (Milenković & Paunović, 2015; Stephens, 1970) and greater amounts of life stress (Nivison & Endresen, 1993; Shepherd et al., 2015). Apart from these internal states and traits that may influence sound sensitivity, a person's previous experience with particular sounds can also impact their perceptions in multiple domains, including their perceptions of acceptability (Sekhon et al., 2017) and ability to recognize speech in the presence of those sounds (Brown & Bidelman, 2022).

Despite understanding acoustic-perceptual dimensions that listeners often utilize when attempting to categorize sounds into groups it is still unknown if similar acoustical perceptual dimensions are used when judging the acceptability of sound. The majority of previous research on sound acceptability has used Likert-type ratings of different sounds. This technique does not uncover the underlying acoustic-perceptual features that listeners actually use to make those judgements. However, newer application of some analysis methods have been used to explore such issues. For example, multi-dimensional scaling (MDS) analysis is a multivariate, exploratory data analysis technique that can be used in uncovering the perceptual dimensions that drive listeners' similarity/dissimilarity ratings (Borg and Groenen, 2005). MDS is a data-reduction technique aiming to reveal similarities among variables and representing these similarities spatially. This study used a multi-dimensional scaling procedure to categorize factors that listeners consider when making sound acceptability judgements. Additionally, individual states and traits of an individual have not been evaluated in relation to their impact on underlying judgments of sound acceptability. Therefore, this study also evaluated how participants' individual traits impact the way they make judgments about sounds' acceptability. We hypothesized that we would be able to see participants' perceptions of loudness, duration, and pitch through multi-dimensional scaling spatial plots, and that we would see influences of age, personality, and emotional reactivity in participant decisions.

MATERIALS AND METHODS

Participants

Data collection was completed for this side study using the same participants from the previous study by Huber & Johnson (accepted). Participants were recruited via social media and word of mouth. A link to the online survey and tasks was e-mailed to those interested. Sixty-four participants enrolled in the study. However, data from 11 listeners were excluded from analyses due to incomplete responses (N=7), missing data from non-completion (N=2), or random answering (N=2). Data from the remaining 53 participants (39 female) were analyzed. Each self-reported their hearing abilities as having no greater than mild hearing problems. Their ages ranged from 18-30 years old (*M*=22.36 years, *SD*=2.89). Other demographic characteristics, including gender, race, ethnicity, education level, and neighborhood noise levels are described in Table 8. Participants gave written informed consent in accordance with a protocol approved by the University of Memphis Institutional Review Board (FY2021-24). They were compensated with a $10 Amazon gift card for their time and effort.

Table 8. Demographics of the Sample

Demographics	*n*
Gender	
Female	39
Male	14
Race	
White or Caucasian	37
Black or African American	10
Asian	3
Pacific Islander	2
Other	1
Ethnicity	
Non-Hispanic	47
Hispanic or Other	6
Education	
Less than high school diploma or GED	1
High school diploma or GED	3
Some college	12
Associate degree	8
Bachelor’s Degree	27
Master’s Degree	2

Materials

International Mini-Markers

The International Mini-Markers (IMM) responses were used to determine the magnitude of personality traits (agreeableness, extraversion, neuroticism, conscientiousness, and openness) per participant. The IMM was developed as a brief version of the Big Five personality trait set (Thompson, 2008), and has been used previously in audiology literature (Benfield et al., 2014; Cox et al., 1999, 2005; Franklin et al., 2013; Miedema & Vos, 2003). The IMM uses 40 descriptor words presented to participants with instructions to "describe yourself as accurately as possible. Describe yourself as you see yourself at the present time, not as you wish to be in the future." Participants were given a scale to rate each trait from 1 (extremely inaccurate) to 9 (extremely accurate), with 5 being a neutral center point. Some items were reversed items to counterbalance between negatively and positively keyed items. Ratings for items were summed for each of the five personality traits.

Perth Emotional Reactivity Scale

The Perth Emotional Reactivity Scale Short form (PERS-S) was used to evaluate participants' emotional reactivity. The PERS-S is a validated scale designed to measure aspects of how a person typically reacts to experiencing emotional events with 18 questions divided evenly among domains (Preece et al., 2018). Emotional Reactivity can be measured as a general positive and general negative overall value, or with subscales evaluating activation, duration, and intensity in the positive and negative direction. We chose to sum the responses for general negative reactivity and general positive reactivity scales for this study, as demonstrated in Preece et al. (2018) and Hurriyati et al. (2020). Higher scores indicate higher levels of reactivity in the domain.

D-SAT

A modified version of the Sound Acceptability Test (SAT; Johnson, 2012), the Digital SAT (D-SAT) was used to quantify participants' acceptability of everyday sounds. The test includes audiovisual presentations of 21 everyday real-world sounds at nine different combinations of duration and intensity (Table 9). For this study, new stimuli were recorded from the SAT at average seated participant head-height (approximately 1 meter from the floor) and at distances of 25-35" to retain as much of the in-person presentation experience of the original SAT as possible. Each of the 21 sounds was presented randomly in two blocks, resulting in 42 total presentations. Participants were asked to rate the acceptability of the sound from 0-"not-at-all-acceptable" to 10-"very much acceptable." They were allowed to watch and listen as many times as they wanted for each sound.

Table 9. SAT Sounds by Intensity and Duration Categories. *Sounds used for the D-SAT are indicated by **

		Duration		
		Transient (≤1 sec)	Episodic (1-5 sec)	Continuous (≥5 sec)
Intensity	Soft (<55 dB SPL)	Clicking Pen* Keyboard Typing	Shuffling Cards Cutting Paper*	Electric Fan Pen Scribble*
	Average (55-75 dB SPL)	Pen Tapping* Door Bang	Phone Ring Rattling Paper*	Hair Dryer* Coffee Grinder
	Loud (>75 dB SPL)	Dishes* Hammer Desk Bell	Silverware Rattling Keys Bike Bell*	Vacuum* Drill Marbles

Absolute and relative sound acceptability judgments

The perceptual judgments tasks comprised 45 sound files developed as a variation of the D-SAT. The D-SAT asks participants to consider all aspects of an everyday sound as they watch and listen to a video of an everyday sound being created, such as dishes clanging against each other or a vacuum cleaner running. The 27 nonspeech sounds for this task were selected to represent 9 categories that varied in duration (<1s – 10s) and intensity (45-78 dB SPL). Participants then rated the acceptability of each sound on a Likert scale from 1-Not at all Acceptable to 10-Very much Acceptable.

For the sound comparison task, one exemplar sound was selected from each of the 9 categories. We then extracted 1 sec excerpts from each exemplar to create shorter tokens necessary for rapid perceptual similarity ratings. These tokens were then paired with every other to create 45 unique pairs of sounds (with 1s intervening silence). To reduce the length of the test and possible fatigue, sounds were compared in one order (A to B) but not in the reverse (B to A). Intensity levels of the D-SAT sounds were initially measured in relation to the calibration passage, presented at 67 dB SPL. Although this ensured relative loudness similarities between devices, it did not guarantee that all sounds were presented at the same intensity levels. Details about the development of the D-SAT can be found in Huber and Johnson (accepted).

Survey Procedure

The online survey was developed using umSurvey Qualtrics XM^{OS} survey software (*umSurvey*, 2020). If a participant did not meet the inclusion criteria of being 18-30 years old or reporting no greater than mild hearing problems, the survey was terminated. All questions required a response to proceed.

Participants answered demographic questions, completed personality and emotionality questionnaires, completed the D-SAT (full-length sounds), and then completed the sound acceptability comparison task.

Given that tasks were virtual, exact stimuli presentation levels were unknown. In an attempt to normalize the differences in presentation levels for sounds of different intensities, participants listened to a speech passage intended to be presented at an “average” or “comfortable” level. They were asked to adjust a volume slider on the embedded YouTube video to maximum and then adjust the volume of their device until it was comfortable, as indicated by a self-reported “4 - Comfortable” using the Cox Loudness Contour Anchors (Cox et al., 1997; Figure 1). They were allowed to play the video as many times as necessary until they felt they had successfully set the volume of their device to “4-comfortable.” Participants were then presented with the 45 sound comparison files. They were instructed to play each file and rate the similarity of the acceptability of the two sounds on a scale from “0-I prefer one over the other” to “100-Same acceptability/No difference.” Because acceptability is a complex concept, a detailed description (provided in Appendix A) was presented prior to the D-SAT. Instructions for the comparison task were to play the sound file then indicate how similar the acceptability of the two sounds were to each other using the slider bar provided. Detailed instructions can be found in Appendix B. Participants were allowed to play the audio files multiple times before making their ratings.

Analysis

Conducted here on listeners’ pairwise sound similarity ratings, MDS maps the *perceptual* distances between tokens into a common Euclidean space, where distances between perceptual objects quantify the magnitude of similarity /dissimilarity in sound judgments. The resulting visual plot spaces points to represent their perceptual similarity to each other, akin to distances between cities on a map. Points in MDS space that are close together are perceptually more similar to one other, whereas points further apart are perceived less similar (Wickelmaier, 2003). MDS results in a smaller set of underlying latent factors (i.e., the orthogonal axis in the MDS map) that reflect the underlying and independent “dimensions” underlying listeners’ perceptual responses. Perceptual ratings are abstract, and it is often unclear what acoustic sound features listeners actually exploit in making acceptability judgments. Thus, interpreting the MDS dimension allowed us to identify and characterize the degree to which listeners weight different acoustic features in making acceptability judgments for everyday sounds. Standard scree plot and stress measures (representing the goodness of fit) were used to determine the number of dimensions in the final MDS solution. Similarity scores were used for the analysis.

Statistical Analysis

Statistical analyses were performed using IBM SPSS version 27.0.0.0 through Macintosh OS Catalina version 10.15.7. We used the multi-dimensional scaling (MDS) module PROXSCAL v.1.0 (Leiden SPSS Group, n.d.) to evaluate similarity of acceptability ratings between each everyday sound stimulus, and ALSCAL for evaluation of individual differences in participants' MDS maps.

RESULTS

Listeners compared the 9 sounds against every other sound, resulting in 45 sound similarity comparisons. The grand average sound dissimilarity matrix, reflecting differences in acceptability judgments between tokens is shown in Table 10. Smaller values indicate an overall closer similarity of acceptability for a given sound pair. MDS applied to this dissimilarity data yielded a two-dimensional solution based on a scree plot with Normalized Stress=0.09 and Dispersion Accounted For=.91 (Kruskal, 1964; Wickelmaier, 2003). The final coordinates of the sounds' similarity of acceptability ratings for these two MDS dimensions are shown in Table 11 and visualized in Figure 2.

Table 10. Similarity matrix of sound acceptability ratings input to MDS

Sounds	Pen Click	Cutting Paper	Pen Scribble	Pen Tapping	Rattling Paper	Hair Dryer	Dishes	Bike Bell	Vacuum
Pen Click	0								
Cutting Paper	.99	0							
Pen Scribble	.71	.48	0						
Pen Tapping	.69	.51	.66	0					
Rattling Paper	.38	.61	.44	.38	0				
Hair Dryer	1.29	.60	.58	1.06	.99	0			
Dishes	.62	1.28	.82	1.19	.82	1.29	0		
Bike Bell	1.06	1.32	.85	1.44	1.09	1.08	.54	0	
Vacuum	1.39	1.18	.85	1.51	1.25	.71	1.06	.59	0

Table 11. Final MDS Dimension Coordinates

	Dimension	
	1	2
Pen Click	-.33	.53
Cutting Paper	-.41	-.45
Pen Scribble	-.05	-.12
Pen Tapping	-.71	-.04
Rattling Paper	-.39	.16
Hair Dryer	.16	-.66
Dishes	.28	.63
Bike Bell	.69	.27
Vacuum	.77	-.31

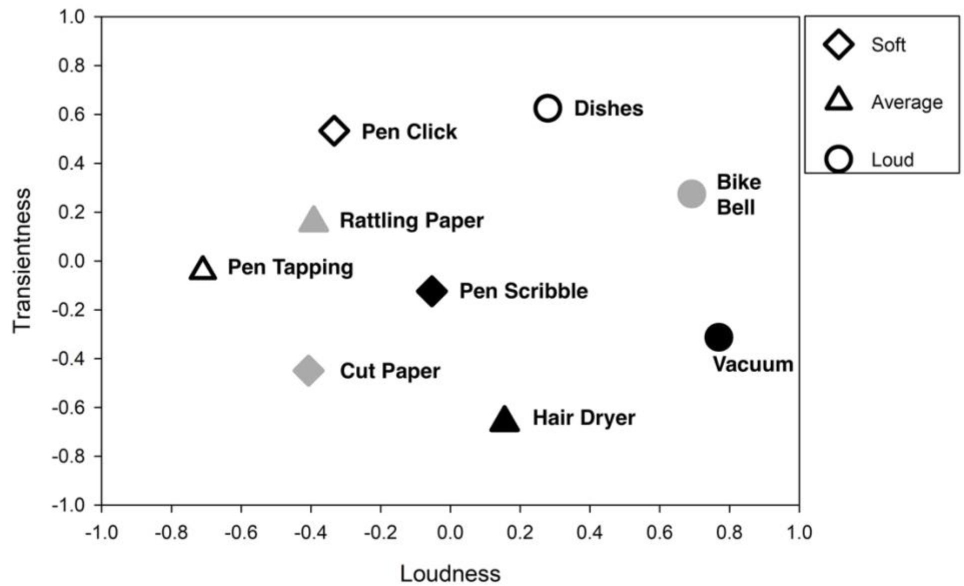

Figure 2: MDS spatial plot of sound acceptability ratings. Icon color indicates SAT sound duration: white ≤1s, gray 1-5s, black >5s.

Data in an MDS space can often be describe in different facet diagrams, depending on how the data cluster along a particular dimension (i.e., facet; Borg & Groenen, 2005). Generally, there are three types of facet diagrams: axial, modular, and polar. An axial diagram generally shows grouping of items into sub-sections along a dimension, appearing as vertical regions along the x-axis. A modular diagram groups items into somewhat concentric bands, and a polar plot divides the dimension into sections with a similar starting point, with the data clustering in a pie-like configuration. In this study, the dimension #1 clearly showed an axial configuration between the loud sounds and the soft and average sounds (Figure 2). This confirms that participants consider loudness when judging sound acceptability. Dimension #2 did not have any clearly defined features, although a somewhat modular configuration of sound transientness was seen (Figure 2). This suggests that participants also consider the transientness of the sound when judging sound acceptability. However, the data were not as separable along this dimension, suggesting that transientness, or temporal attack, might be less important when making acceptability ratings compared to loudness.

The grand average MDS space identified two primary dimensions underlying listeners' sound acceptability ratings according to the loudness and duration of those naturalistic sounds. While these group-level data are informative in uncovering which perceptual features are important for acceptability, they do not reveal how *individual* listeners differentially weigh these perceptual attributes when forming their individual judgments. To address this question, we assessed individual ALSCAL MDS solutions along with participants' demographic and other measurable traits to evaluate whether participants with different attributes placed more/less importance on loudness and duration when judging acceptability. For this analysis, ALSCAL projects each participant's data onto a common space, showing how they weight the importance of each dimension identified in the MDS solution (Figure 3). Again, for dimension #1, there was a clear axial configuration, with participants in our sample clustered into two subgroups.

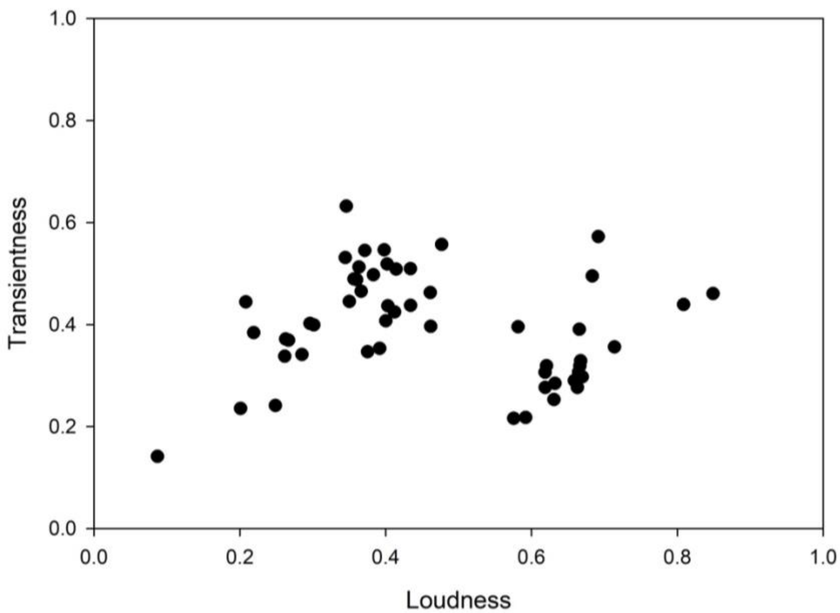

Figure 3: ALSCAL visualization of the individual participants' weights for dimension 1 and dimension 2

Follow up analysis of the demographic data with *t*-tests did not reveal obvious differences that might account for separation of the two groups. However, a reanalysis of the acceptability ratings for the full-length D-SAT sounds probed earlier in the survey revealed differences between these groups in how they rated acceptability of soft sounds ($t(51)=-3.12$, $p<0.01$). In general, participants with lower similarity ratings on dimension #1 (interpreted as "loudness") tended to have a smaller overall range of acceptability ratings for the full-length sounds. For dimension #2 (interpreted as "transientness"), there were no clearly defined participant groups. Therefore, to assess factors which drive participants' use of transientness, we divided the sample based on subjects with the lowest and highest weights along dimension #2. Cutoffs for the groups were <0.3 (n=11) and >0.5 (n=10) on this dimension. Demographic data were compared with *t*-tests for these two groups to explore if these characteristics might explain group differences along this perceptual dimension. We found participants differed in terms of positive emotional reactivity ($t(19)=2.32$, $p=0.03$), age ($t(19)=-2.96$, $p=0.01$), and how they rated episodic full-length sounds ($t(19)=2.24$, $p=0.04$). Those who placed less weight on transientness generally had more positive emotional reactivity, were younger, and rated full-length episodic sounds as more acceptable. Across participants, as acceptability for full-length soft sounds increased, the dimension score increased as well ($r^2=.12$).

DISCUSSION

We evaluated factors that impact judgments about sound acceptability for young, typical hearers. Multidimensional scaling of listeners' perceptual responses to naturalistic sounds were used to uncover which perceptual dimensions listeners rely on when making sound acceptability judgments, and how much weight different types of listeners place on these dimensions. Examination of MDS results highlighted two underlying features driving listeners' acceptability judgments. Loudness loaded onto the first dimension indicating that this was the most salient acoustic-perceptual attribute driving acceptability judgments. This is consistent with previous research (Aldrich et al., 2009) Transientness loaded onto the second dimension. This finding agrees with those of Allen and Bond (1997) who showed participants categorized sound using acoustic factors such as periodicity and spectral peaks.

In this study, we used two listening tasks to measure absolute and relative sound acceptability judgments to evaluate what acoustical perceptions listeners used to rate the similarity of the acceptability of the everyday sounds. The first was the D-SAT, where sound tokens were presented for their full-length, ranging from 6-10 secs. The second listening task featured sound comparisons, where listeners judged how similar pairs of these sounds were in terms of their acceptability. Comparing the two listening tasks, the full-length D-SAT presentations and the sound comparison presentations, the sounds only differed by the duration of the sound. When looking at the similarity of acceptability of the sound pairs in the second listening task, those who rated lower on loudness tended to have a smaller range of acceptability of full-length sounds overall. Interestingly, participants who placed lower importance on loudness rated full-length soft sounds differently than those who weighted higher on that dimension. Specifically, those who placed less importance on loudness had lower acceptability of full-length soft sounds. Across participants, as acceptability for full-length soft sounds increased, the dimension score increased as well. This suggests loudness and duration interact for sound acceptability ratings. Previous research supports this idea; longer sound durations were found to be more annoying and less acceptable than shorter durations at soft, average, and loud intensities (Hernandez et al., 2006; Johnson, 2012). These findings are important, because oftentimes loud sounds are considered when evaluating a patient's comfort with amplification. However, for some hearing aid users, sounds with longer durations at various intensities can be adverse. Such effects could be due to altered neural adaption secondary to hearing loss. Indeed, emerging evidence suggests that in addition to more obvious changes in threshold sensitivity, the normal reduction (adaptation) in response to sustained stimuli is compromised with hearing loss, especially for loud sounds. With amplification, the aim is to restore the accessibility to these softer sounds. Clinically, the ongoing process of acclimatization to amplification should include sound acceptability evaluations at soft, average, and loud levels.

Notably, we found that additional factors unrelated to acoustics influenced sound acceptability ratings. Comparisons between demographic and MDS perceptual data showed that listeners with lower positive emotional reactivity placed higher weight on transientness and had a slightly smaller range of acceptability ratings than listeners who did not weigh this dimension as heavily for their perceptual response. Our study did not evaluate participants' level of fatigue or presence of anxiety or depression; however, previous studies show that higher negative reactivity and lower positive reactivity are correlated with depression and anxiety (Preece et al., 2018). Depression and anxiety also relate to a higher degree of sound sensitivity (Milenković & Paunović, 2015), suggesting that these people are likely to report less sound acceptability. This suggests that understanding the emotionality of patients may aid in predicting how they will adjust to amplified sounds. Those with more negative emotional reactivity, depression, and/or anxiety may need a longer acclimatization period, counseling about adjusting to amplification, or increased access to auditory rehabilitation. Additionally, adjustments to compression ratios and/or attack/release times of hearing aids may increase the acceptability of amplified everyday sounds; however, future research is needed to confirm this suggestion.

Additionally, we found that age may have impacted judgments comparing sounds' acceptability on transientness. This supports the findings of Allen & Bond (1997) who showed that the age of a listener impacts the categorization of sounds. While it is interesting that those who are older may focus more on the transientness of sound when judging acceptability, the age range of our participants makes it difficult to generalize these conclusions. However, this finding does suggest that future studies with a larger and more age diverse sample are warranted.

Some considerations when attempting to interpret or generalize these findings include that this study was presented via an online survey due to the COVID-19 pandemic. It is possible that the participants adjusted the volume of their devices during the survey. Additionally, while the stimuli were randomized within the full-sound portion and the comparison portion, all participants heard the full sounds before hearing the sound comparisons. This may have influenced results by allowing participants to reflect on the full sounds when hearing the sound clips in the sound comparison task. Finally, the sound comparison task was at the end of the survey for all participants, and we cannot account for the effects of fatigue on the responses.

Our findings in young listeners may not generalize to older adults and it is possible that those with hearing loss judge sounds differently than those with typical hearing. Beyond sensory deprivation and decreased neural responsivity in auditory processing, hearing loss can increase the body’s stress response (Kurioka et al., 2021). It is possible that over time, this increase in stress relates to anxiety and/or depression, shifting the way an individual judges sounds. Future research should compare sound acceptability for a wider range of hearing abilities as well as a larger age group. It may also be of interest to simulate these everyday sounds as amplified sounds to a group of typical hearers and compare their acceptability to those with hearing loss utilizing hearing aids. Identifying how sounds are grouped by those with hearing loss may help in developing programming strategies to increase amplification acclimatization.

CONCLUSION

This study evaluated acoustic-perceptual features that young adults with typical hearing use to judge sound acceptability. We found that loudness and transientness of sound were primarily used when making these judgments of everyday sounds. Additionally, we found that those who are younger or have lower positive emotionality reported a smaller range of acceptability ratings. This suggests that age and emotionality influence how an individual judges sound acceptability, and clinicians may consider evaluating emotionality when a patient reports adverse outcomes with amplified sounds. However, our findings may not generalize to the older adult population or to those with hearing loss, and these suggestions should be considered carefully.

Chapter 4

THE RELATIONSHIP OF DICHOTIC LISTENING ABILITIES AND SOUND SENSITIVITY FOR OLDER ADULTS

Currently, the most prevalent treatment for hearing loss is amplification; however, it has been estimated that less than 25% of those that could benefit from amplification use it (*Use of Hearing Aids by Adults with Hearing Loss*, 2014). Some individuals choose not to seek amplification because of a denial of their hearing loss, the perceived efficacy and value of hearing aids, or the stigma of hearing aids, among other reasons (Kochkin, 2007). Others might choose to try hearing aids, but discontinue using them for various reasons, including loudness issues, poor benefit in noisy situations, and issues with feedback (McCormack & Fortnum, 2013). Even for those that choose to wear hearing aids, approximately 80% report loudness discomfort from amplified sound (Keidser et al., 2010). It is a common audiologic clinical practice to limit the maximum output of a hearing aid to manage discomfort from loud amplified sounds. Typically, this is accomplished by limiting the maximum outputs across frequencies according to the sound levels that the average adult reports as uncomfortable. These are known as average loudness discomfort levels (LDLs). However, actual measured LDLs have been shown to vary substantially between individuals, even when their hearing sensitivities are the same (R. A. Bentler & Cooley, 2001; Sherlock & Formby, 2017). Therefore, measuring LDLs for each individual is recommended (Cox et al., 1997). However, even when using measured LDLs for fitting hearing aids, hearing aid users continue to report loudness discomfort issues in their daily life. These patient reports suggest that measured LDLs are not directly related to real-world ratings of loudness discomfort (Filion & Margolis, 1992; Lindley et al., 2001) and more loudness discomfort was reported for laboratory sounds than sounds experienced in daily life (Keidser et al., 2010). It has been hypothesized that these differences in sound ratings may be a reflection of an individual's experience, emotional reactivity, or personal preference, as well as the non-realistic acoustic characteristics of recorded sounds played in a contrived laboratory setting (Keidser et al., 2010). Additionally, Hernandez et al. (2006) noted that while many participants wearing hearing aids rate loud sounds as annoying, others also rate some soft sounds as annoying (Hernandez et al., 2006), indicating loudness may only be one aspect of sound annoyance. Issues with amplified sound, like unwanted background noise and poor sound quality, are the top factor for unmet expectations with amplification (McCormack & Fortnum, 2013; Picou, 2020).

These adverse effects of hearing aids continue to be reported despite digital sound processing features developed with an aim to provide improved comfort with amplified sound. Notably, a variety of digital noise reduction (DNR) features have been developed to reduce annoyance and discomfort from a variety of sounds. The earliest versions of DNR aimed to reduce the amplification of loud continuous sounds. Generally, these strategies have been seen to reduce noise annoyance and increase satisfaction for hearing aid wearers (R. Bentler et al., 2008; Brons et al., 2013, 2014; Palmer et al., 2006). Newer types of DNR seek to adapt to different types of noises, targeting unwanted sounds such as wind (Chung, 2018), transient sounds like slamming doors (Chung, 2018; Liu et al., 2012), hearing aid whistling (T. A. Ricketts & Hornsby, 2005), and noise in reverberant spaces (Picou & Ricketts, 2019). Each of these features has been demonstrated to be efficacious in specific listening situations (Chung, 2018; Chung & Zeng, 2009; Liu et al., 2012; Picou & Ricketts, 2019; T. Ricketts et al., 2008). One method for quantifying sound acceptance is measuring acceptable noise levels (ANLs; Nabelek et al., 2006). ANL is the difference between the most comfortable listening level of speech and the loudest background noise that is acceptable, and is not dependent on age, hearing acuity, or gender

(Franklin et al., 2013; Nabelek et al., 2006; Rogers et al., 2003). Lower ANLs suggest a listener accepts higher levels of background noise. Successful hearing aid users have been found to have lower ANLs (Nabelek et al., 2006), and using DNR was found to reduce acceptable noise levels (ANLs) of hearing aid users significantly (Mueller et al., 2006).

However, it is possible that sound factors other than loudness are related to poor outcomes with amplification. For example, Keidser et al. (2010) had hearing-aid wearers rate loud, real-world sounds in the laboratory. Their participants rated all the sounds as uncomfortably loud. They also reported that they disliked some sounds in general, and that they had previous negative experiences with some of the other sounds. Therefore, Keidser et al. (2010) hypothesized that hearing aid wearers are not able to separate loudness discomfort from other negative aspects of sound (Keidser et al., 2010). This suggests that hearing aid users may consider factors other than loudness when judging the comfort of sound. Although most hearing aid users are able to acclimate to the settings of their hearing aids, some do not, even after eight weeks of use (Lindley et al., 2001), suggesting some users are more sensitive to amplified sound than others. However, when hearing aid users report adverse outcomes with sound, their sound tolerances are rarely evaluated.

Research on sound sensitivity among adults with hearing difficulties is limited. Sound sensitivity has been defined as a pervasive and negative attitude towards sound in general (Anderson, 1971) and a judgmental, evaluative tendency towards the perception of emotional features of sound at suprathreshold levels (Heinonen-Guzejev et al., 2011). Yet the primary predictors of sound sensitivity have not been established. Sound sensitivity has been attributed to a person's internal physiological, psychological, or lifestyle-related states which may increase their amount of reactivity to noise in general (Job, 1999). Some researchers have postulated that personality may be a driving force behind sound sensitivity. For example, Shepherd et al. (2015) found a tendency for noise-sensitive females to have higher conscientiousness, lower extroversion, lower openness, and higher neuroticism, while noise-sensitive males demonstrate higher conscientiousness, lower extroversion, and higher agreeableness traits (Shepherd et al., 2015). Similarly, other researchers found that typical-hearing young adults with lower openness and higher conscientiousness are less willing to accept background noise (Franklin et al., 2013), and those with higher agreeableness have a higher acceptance of loud sounds (Huber & Johnson, 2021). Other researchers have evaluated internal states as predictive factors for sound sensitivity. Regardless of personality traits, those with heightened anxiety (Milenković & Paunović, 2015; Stephens, 1970) and more general life stress (Nivison & Endresen, 1993; Shepherd et al., 2015) tended to have more sound sensitivity. Also, those with heightened anxiety and stress demonstrated higher negative emotional reactivity (Becerra et al., 2017; Preece et al., 2018). Emotional reactivity characterizes an emotional response in terms of activation, intensity, and duration. Huber & Johnson (2021) explored the relationship between emotional reactivity and sound sensitivity in typically hearing young adults. They found that those with higher negative emotional reactivity are less likely to accept loud, transient sounds (Huber & Johnson, 2021).

Clinically there is no clear diagnostic criteria for what constitutes sound sensitivity (Henry et al., 2022). Additionally, it is difficult to assess real-world sound tolerances. Various sound sensitivity questionnaires have been developed and validated (Sherlock & Formby, 2017; Zimmer & Ellermeier, 1999); however, researchers have found that retrospective questionnaires are influenced by recall bias and limited by semantic memory (Holube et al., 2020; Wu et al., 2020). Semantic memory is not connected to a specific event, but rather centered on a person's beliefs or attitudes about the type of situation. In contrast, episodic memory is a set of previous personal experiences occurring at a time or place (Wu et al., 2020). The longer-term semantic memories spanning weeks or months may result in different answers than the shorter-term episodic memories of just hours or days. In general, semantic memories explain a person's general beliefs or how they remember an experience while episodic memories give details about the actual experience. It has been suggested that in-situ responses to self-assessment measures related to semantic memory may reduce response bias and provide more accurate info about real-world experiences (Punch et al., 1994; Wu et al., 2020).

One way to provide an in-situ evaluation of sound tolerance would include bringing the real-world into the clinic by presenting everyday sounds in a controlled environment. Johnson et al. (2012) evaluated sound tolerance in this manner, and asked participants to consider the "acceptability" of the everyday sounds. They defined sound acceptability as encompassing more than a reaction to loudness; rather, it included factors such as annoyance, aversiveness, and pleasantness when evaluating sound tolerance (Johnson, 2012). This definition has some similarities to previous definitions of sound sensitivity in that it includes a person's attitude toward a sound. The issue of sound sensitivity may be important to understanding why some of those with hearing loss do not adopt hearing aids or adapt well to amplified sound; however, the prevalence of sound sensitivity remains unclear.

Several researchers have attempted to evaluate the prevalence of sound sensitivity. Each developed their own questionnaires with a varying number of items to evaluate sound sensitivity. Some focused primarily on the person's beliefs about being sound sensitive while others focused on the person's reactions about particular sounds or sound groups. In contrast to using questionnaires, Jastreboff and Jastreboff (2016) estimated sound sensitivity prevalence based off the clinically observed prevalence of tinnitus and hyperacusis patients. Results of these studies estimate sound sensitivity prevalence in the general population to range from 3.5% (Jastreboff & Jastreboff, 2016) to 35% (Cash, 2015), with other estimates in-between (Andersson et al., 2002; Fabijanska et al., 1999; Zelaya, 2014). The variance in questionnaire design and content may explain this wide range of estimated prevalence of sound sensitivity in the general population. The prevalence of sound sensitivity specifically in the older adult population (>65 year of age) has yet to be established.

In addition to sound sensitivity, older adults have other sound processing issues. When older adults self-report hearing disabilities, they typically note poor speech perception in noisy environments (Shahidipour et al., 2021). The primary reason for reduced speech perception is hearing acuity (Humes et al., 1994), though some older adults perform worse than expected for their hearing acuity. This may be related to a decrease in attention (Dubno et al., 1995) or working memory (Hoover et al., 2017). Attention and working memory are both part of executive functioning which has been seen to decline with age (Fischer et al., 2017; Gates et al., 2010). Although executive function is not specifically considered to be an auditory function (Hoover et al., 2017), its decline negatively impacts auditory processing (Fischer et al., 2017; Gates et al., 2010). This is because the auditory processing of speech places a higher burden on executive function processes, especially in the presence of background noise (Tun et al., 2012). In a difficult listening environment, attention is strained to focus on one speaker while verbal working memory is taxed to hold on to the message long enough to understand (Tun et al., 2012). If a listener has poor or declining executive function, these tasks will be much more difficult. Additionally, if the listener has hearing loss, the message may not be clear to begin with, adding even more difficulty to the task.

Another factor researchers have found to impact understanding speech in noise is dichotic listening abilities (Hugdahl, 2011). Listeners typically listen binaurally, using both ears, in their daily life. The auditory processes for binaural listening can be divided into two distinct types: binaural separation and binaural integration. Binaural separation is the process by which a person can focus on one stimulus while tuning out another. For example, binaural separation is useful when there are competing talkers and the listener is only interested in one talker. They can focus on the one talker and filter competing talkers. In contrast, binaural integration is the process by which a person hears different stimuli in each ear and can understand the full meaning of both stimuli. For example, a person may hear one sentence in their right ear and a different sentence in their left ear. Using binaural integration, they can understand both sentences in their entirety.

To repeat different signals presented to each ear, a listener must produce separate perceptions of the input from each side. The neural signal from input to each ear ascends through many nuclei in the ascending auditory system where acoustic features from the separate signals interact. Binaural signals are first integrated at the brainstem (Repp, 1977). where coincident timing and matching spectral components of the signals are likely to perceptually fuse and ascend through the auditory pathway as a single input. Some acoustic portions of the two signals may be excited or suppressed through mechanisms that provide information regarding location and lateralization of the two signals. Preserved signals ascend both contralaterally and ipsilaterally, but the contralateral pathway is larger and more heavily myelinated (Kimura, 1961). Input to the right ear is processed initially in the left hemisphere and input to the left ear is processed initially in the right hemisphere and from there, neural signals cross through the corpus callosum to activate the ipsilateral hemisphere on each side (Kimura, 1961).

Confirmation that a majority of normal individuals processe language in their left hemisphere was noted by evidence (Geschwind and Levitsky, 1968). that two-thirds of post-mortem brains had larger planum temporale in the left hemisphere, while others' were larger for the right hemisphere or equal in size for both hemispheres. (Geschwind and Levitsky (1968) This finding supports the idea that some individuals may have a left-hemisphere dominance while others have a right-hemisphere dominance or no dominant hemisphere at all. Kimura noted that adults produced a right-ear advantage when asked to identify quadruple pairs of dichotic digits, adding further support of left-hemisphere (contralateral to right ear) dominance for language. (Kimura, 1961). Dichotic listening patterns in children show similar patterns with a majority demonstrating a right-ear advantage and others showing either a left-ear advantage or no ear advantage (Moncrieff, 2011).

In a binaural separation task, listeners are asked to focus on and repeat only the information presented to either the left or right ear (Hiscock and Kinsbourne, 1999). This suggests that attention influences dichotic listening to increase performance in each ear can but the difference between the two ears is not likely to change significantly. This attentional effect seems to develop in childhood (Moncrieff, 2011). Attention is regulated by gamma-amniobutyric acid (GABA).

Gamma-amniobutyric acid (GABA) is an inhibitory neurotransmitter that is important for regulating attention and executive function. GABA levels increase through adolescence, plateau in early adulthood, and gradually decrease through adulthood and aging (Porges et al., 2021). GABA has been found to decrease with aging. Recently, GABA was found to partially mediate the relationship between age and results for a speech in noise test (Dobri and Ross, 2021). A reduction in GABA affects attentional resources and executive function. It is possible that a reduction in speech understanding is related to a reduction in attention due to reduced GABA levels. Takio et al. (2009) saw a reduction in older adult dichotic listening outcomes, specifically in conditions that required selective attention. Older adults have been found to be unable to overcome a right ear advantage, even when focusing attention on left ear stimuli (Gootjes et al., 2007; Takio et al., 2009).

Clinically, binaural listening abilities are assessed with dichotic listening tests. These tests present a different stimulus to each ear simultaneously. The clinician instructs the patient whether to focus on one ear (evaluating binaural separation) or both ears (evaluating binaural integration). When evaluating binaural integration in the clinic, the left ear often has poorer performance than the right ear. This difference in performance is known as the right ear advantage (REA). Researchers have demonstrated that older adults perform worse on binaural integration tasks than other age groups (Gallun, 2021; Roup et al., 2006; Takio et al., 2009; Wilson & Jaffe, 1996), with a more distinct right-ear advantage (Noffsinger et al., 1996; Roup et al., 2006; Wilson & Jaffe, 1996), suggesting a negative effect of aging on this aspect of the auditory system.

Individuals with poor executive function also tend to have poor dichotic listening abilities (Bouma & Gootjes, 2011; Fischer et al., 2017; Takio et al., 2009). Specifically, attention has been seen to modulate ear advantage. For example, if the clinician directs the patient to focus on their left ear, the left ear will tend to have a higher score than when they are not instructed to focus on a specific ear (Bouma & Gootjes, 2011). Takio et al. (2009) compared younger and older adults' ability to shift their attention from one ear to the other when directed. They found that older adults were unable to focus their attention to overcome the right-ear advantage while young adults were able to focus their attention, suggesting the older adults' attention process in their executive functioning had declined (Takio et al., 2009). Similarly, Bouma and Gootjes (2011) compared three age groups of older adults and saw a decline in dichotic digits scores as age increased, especially for the unattended ear in a directed listening task. This research further supports that executive function declines with age and impacts dichotic listening abilities.

Poor executive function also has been found to relate to depressive disorder (Hoffman et al., 2017) and anxiety disorders (Ramírez et al., 2015). These relationships have been found through measurements of heart rate variability, which reflects the status of an individual's autonomic nervous system in different environments. Those with depression and anxiety have been found to have lower heart rate variability during executive function tasks than controls (Hoffmann et al., 2017; Ramírez et al., 2015), indicating greater stress in those conditions. Similarly, Shepherd et al. (2016) found that participants with noise sensitivity had reduced heart rate variability during listening tasks than those without noise sensitivity (Shepherd et al., 2016). It has also been noted that those with a higher propensity towards depression and anxiety are more likely to have noise sensitivity (Jüris, Ekselius, et al., 2013; Milenković & Paunović, 2015; Stephens, 1970).

There seem to be several notable relationships among factors involved in sound sensitivity and dichotic listening abilities. Lower executive function is related to higher depression and higher anxiety (Hoffmann et al., 2017; Ramírez et al., 2015), as well as lower dichotic listening abilities . Those with higher propensities towards depression and anxiety tend to have greater sound sensitivity (Jüris, Ekselius, et al., 2013; Milenković & Paunović, 2015; Stephens, 1970) and self-report more hearing disability (Kim et al., 2017; Tremblay et al., 2015). Greater self-reported hearing disability also correlates with greater sound sensitivity. Poorer dichotic listening abilities have been seen in those with clinical depression (Bruder et al., 2001, 2004).

However, despite the known relationships among these factors, the relationship between dichotic listening and sound sensitivity has yet to be studied. If these processes share an underlying etiology, there could be potential for remediation of sound sensitivity through established audiological training techniques. Children, adolescents, and older adults diagnosed with various auditory processing disorders have been seen to improve dichotic listening abilities after auditory training (Dubno, 2013; D. Moncrieff et al., 2017). Therefore, it is possible that auditory training to strengthen dichotic listening skills may also help resolve sound sensitivities.

To address this gap in the literature, the goal of this project was to evaluate the relationship between dichotic listening abilities and sound sensitivity in older adults. Based on previous literature indicating the relationships of executive function to sound sensitivity and dichotic listening (Bouma & Gootjes, 2011; Fischer et al., 2017; Hoffmann et al., 2017; Ramírez et al., 2015; Takio et al., 2009), it was hypothesized that those with poor dichotic listening would report more sound sensitivity than those with normal dichotic listening abilities. This cross sectional exploratory study compared the dichotic listening abilities of those with self-reported sound sensitivity to those without self-reported sound sensitivity to determine this relationship.

A second aim was to estimate the prevalence of sound sensitivity in older adults in the United States by evaluating a cross section of older adults with a validated sound tolerance questionnaire (Cash, 2015). Based on an average of previous prevalence findings of other age groups and geographical regions, it was hypothesized that between 15-20% of older adults in the United States have sound sensitivity. Since sound sensitivities can result in poor outcomes with hearing aids, understanding the prevalence of sound sensitivity in the older adult population will provide evidence for or against the need for developing a sound sensitivity clinical assessment protocol. This protocol may help clinicians identify those patients who are most likely to have sound sensitivities and therefore need different hearing aid fitting strategies or auditory training to help adapt to amplified sound.

MATERIALS AND METHODS

Participants

Data collection was completed remotely. Participants were recruited via e-mail, social media, and word-of-mouth. A total of 704 surveys were started; however, only 158 surveys were completed. Of those 158 completed surveys, 118 were found to have incorrect attention question responses and/or random answering. Data from the remaining 40 participants (18 male) were analyzed. Participants ranged in age from 65-79 years old (M=69.95 years, SD=4.04). Other demographic characteristics, including gender, race, ethnicity, education level, and self-reported hearing ability are described in Table 12. With an alpha of 0.05 and power of 0.80, the projected sample size needed for a Type III F-Test in Multiple Regression analysis with 3 test predictors, 3 full predictors, and an estimated 0.3 correlation is 115 participants (*SAS*, 2016). With 40 participants, this model resulted in 32.1% power. Participants gave informed consent in accordance with a protocol by the University of Memphis Institutional Review Board (FY2022-349). They were compensated $5 for their time and effort.

Table 12. Characteristics of the Sample

Characteristic	*n*
Gender	
Female	18
Male	22
Race	
White or Caucasian	30
Black or African American	6
Pacific Islander	2
Native American / Alaskan Native	1
Other	1
Ethnicity	
Non-Hispanic	30
Hispanic or Other	9
Other	1
Education	
Less than high school diploma or GED	1
High school diploma or GED	4
Some college	4
Vocational certification	2
Associate degree	4
Bachelor's Degree	12
Master's Degree	6
Doctoral Degree	7
Self-Reported Hearing Ability	
No Hearing Loss	14
Mild Problems	12
Moderate to Severe Problems	5
Diagnosed with Hearing Loss	9

Materials

Dichotic Listening Test

The Randomized Dichotic Digits Test (RDDT) was developed to assess binaural integration. It is available on the VA CD Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0 (Department of Veterans Affairs, 1998). It has 54 presentations of 1-, 2-, or 3-digit pairs that the listener is instructed to repeat. The digit pairs are spoken with a male voice, and they comprise only the single-syllable digits 1 through 10, with the two-syllable digit 7 being omitted. The order is randomized so the listener does not know how many digits will be presented each time. For the free-recall version of the test, it does not matter the order the listener repeats the digit pairs back. For this study, an online version of this test was created to allow for remote testing. In this version, the listener typed the digits that they heard instead of saying them aloud, with no response time limit. The next stimulus played when the participant submitted their response for the current stimulus. Participants were scored based on how many digits they correctly identified for each ear in the two-digit condition (Strouse & Wilson, 1999). Percentage correct scores for each ear (D. W. Moncrieff & Wilson, 2009; Strouse & Wilson, 1999), the difference between the two ears' scores (D. W. Moncrieff & Wilson, 2009; Strouse & Wilson, 1999), and the sum of the two ears' scores (Fischer et al., 2017) were all computed.

Questionnaires

Sound sensitivity. The Decreased Sound Tolerance (DST) Scale was developed for Cash (2015) by a panel of research experts in decreased sound tolerance to evaluate self-reported symptoms of misophonia, hyperacusis, or general noise sensitivity. The DST Scale asks individuals to rate their level of discomfort on a 4-point Likert scale in response to range of human-produced and environmental sounds. The sound descriptions include human-produced sounds such as chewing, breathing, and clicking; common sounds such as a truck driving by, background television, or an audience applauding; and general sounds such as nails on a chalkboard, ambulance sirens, or flatulence sounds. Participants were scored based on a count of the number of items they responded with a 3 or 4 (DST-Count method). Higher scores suggest higher sound sensitivity.

Personality. The International Mini-Markers (IMM) responses are used to determine the magnitude of each of five personality traits: agreeableness, extraversion, neuroticism, conscientiousness, and openness. The IMM was developed as a brief version of the Big Five personality trait set (Thompson, 2008), and has been used previously in noise sensitivity literature (Benfield et al., 2014; Cox et al., 1999; Franklin et al., 2013). Thompson (2008) validated the IMM against Saucier's Mini Markers (Saucier, 1994) and found good inter-scale correlations, indicating its validity as an independent measure (Thompson, 2008). The IMM presents 40 descriptor words to participants with instructions to "describe yourself as accurately as possible. Describe yourself as you see yourself at the present time, not as you wish to be in the future." Participants were given a scale to rate each trait from 1 (extremely inaccurate) to 9 (extremely accurate), with 5 being a neutral center point. Some items were reversed items. A score for each of the five traits was calculated by adding together the response values of the items related to that trait.

Emotional Reactivity. The Perth Emotional Reactivity Scale (PERS) was developed to evaluate individuals' emotional reactivity. The PERS is a validated scale designed to measure aspects of how a person typically reacts to experiencing emotional events with 30 questions divided evenly among domains (Preece et al., 2018). Emotional Reactivity can be measured as a general positive and general negative overall value. A final score was calculated by summing the individual's responses in the positive and negative domain as recommended by Preece et al. (2018) and Hurriyati et al. (2020). Higher scores indicate higher levels of reactivity in the domain.

Anxiety & Depression. The Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) is a self-assessment questionnaire that evaluates states of anxiety and depression. The HADS questionnaire has fourteen items, equally divided for depression and anxiety subscales. Each item is scored from 0 to 3, with three being the highest anxiety or depression level. A total subscale score of 8 or more points out of a possible 21 indicates considerable symptoms of anxiety or depression. For this study, a cumulative score was computed by adding the total scores for depression and anxiety to provide a global measure of psychological distress (Roberts et al., 2001; Singer et al., 2009).

Cognitive Assessment

To screen for any cognitive impairments, scores across several tests were totaled to assess for general cognitive ability. The tests included a digit span task (DS Task), card sorting task, a word memory task, and self-report cognitive questions.

Digit Span Task. The digit span task was modeled from the digit span task used by Orsini et al. (1987). A set of spoken digits was presented to the participant at the rate of one digit per second. The participant was then given the opportunity to type the digits into a text box. The participants were able to somewhat control the pace of the test by controlling when they entered their response; however, once they submitted their response, the next stimuli set began automatically. Digit sets were presented in pairs, such that the participant had two chances at a set length. If one or both sets in the pair were correct, the next set pair would be one digit longer in length. If both sets were incorrect, the test concluded. While there are several variations of digit span tasks, older adults are known to have a higher performance on forward digit span tasks (where the individual repeats back the digits presented in the same order) than other variations (Taub, 1972), possibly due to this version requiring less cognitive load than other variations (Nagaraj, 2020).

Card Sorting Task. The card sorting task was modeled from the Delis–Kaplan Executive Functioning System (D-KEFS) Sorting Task (Delis et al., 2012). The six cards presented to the participants could be sorted into eight groups of two, with five sorts being primarily perceptual or nonverbal (i.e., circle vs square shaped cards) and the remaining three sorts being primarily verbal (i.e., transportation vs nature words). The participants were asked to sort the six cards into two groups, then type a description of how they sorted the groups. Participants were allotted four minutes to complete as many sorts and descriptions as possible. Scores were calculated by two conditions based on the D-KEFS scoring system (Delis et al., 2012). First, the number of correct sorts was determined, and a point was given when cards were sorted into unique and correct groups. If groups were repeated, incorrect, or missing, no points were rewarded. Secondly, the corresponding descriptions were scored. For descriptions that accurately described a group, two points was awarded. For descriptions that partially described a group, one point was awarded. For descriptions that did not describe the group or were blank, no points were awarded. The maximum score for accurate descriptions was four.

Word Recall Task. The word recall task was modeled from the Memory Impairment Screener (MIS) section of the Cognitive Assessment Toolkit (*Cognitive Assessment Toolkit*, n.d.). The word recall task comprised four words provided visually to the participant with instruction to not write them down in any way, but to remember them for later in the test. After the digit span task and the card sorting task, they were asked to recall the four words and type them into a text box. For each correctly recalled word, a point was rewarded.

Self-Report Cognitive Questions. Self-report cognitive questions were modeled from the Informant Interview section of the Cognitive Assessment Toolkit (*Cognitive Assessment Toolkit*, n.d.). Participants were presented with questions such as “Do you have more trouble remembering recent events than you used to?” Each multiple-choice question had answer choices of “Yes,” “No,” “Not Sure,” and some additionally had “N/A.” If participants responded with “yes” or “not sure,” a text box appeared with a prompt to have them provide more details. For these six questions, a response of "yes" was given two points, "not sure" was given one point, and "no" or "N/A" was given no points.

To compute the final cognitive score, scores from the digit span task, card sorting task, and word recall task were added. Because items from the self-reported cognitive questions indicated cognitive decline, the reversed scores from this section were subtracted from the previous total.

Survey Procedure

Participants received a link to the study developed using umSurvey Qualtrics XM^{OS} survey software (*UmSurvey*, 2020). It included demographic questions, IMM, PERS, the DST Scale, HADS, the cognitive assessments, and the Digital RDDT. If they did not meet the criteria of being a minimum of 65 years old, the survey ended immediately. All shown questions required a response, excepting any unanswered questions when the allotted time ended during the card sorting task. An identifying code was provided at the end of the survey to submit as proof of identity to receive compensation.

For the DS Task and RDDT, some set-up was required. A calibration procedure asked the participants to listen to a calibration speech passage and adjust their volume to comfortable, indicated by a self-report of "4-comfortable" using the Loudness Contour Anchors (Cox et al., 1997). Then participants were asked to listen to three short audio clips and respond to which ear they hear it in to ensure the audio is set-up for two channels. If they answered incorrectly, an error message appeared with options to fix the error and continue or to resume the survey later. After set-up was complete, participants were instructed to not adjust the volume of their device for the remainder of the survey. The DS task started with two practice trials of 3-digits to ensure they understood the task instructions. Later in the survey, the RDDT was presented. After each set of the 54 digit-pairs played, a text box with a written prompt appeared, already selected and ready for text entry. The prompt was "Type the numbers that you heard." Then the participant selected the "next" button to hear the next item.

Analysis

Statistical analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) Version 27. Descriptives were reviewed for distributions of the data. There was one variable that was not normally distributed: the ear difference dichotic listening score. However, this variable has been found to not normalize with arcsine transformations (Moncrieff et al., 2017). Due to the non-normal distribution of the ear difference score, nonparametric regression analyses were initially performed to evaluate the relationship between dichotic listening and sound sensitivity. Other initial analyses included cross tabulation for sensitivity and specificity of the DST-Count method for identifying sound sensitive individuals and nonparametric correlation analyses between various variables.

Several regression models allow for testing complex relationships among variables. An add-on package PROCESS developed by Alex Hayes (2022) was used for moderation and mediation analyses. This package was used to test the impact of anxiety/depression on the relationship between dichotic listening and sound sensitivity. Three models were completed. In each model, dichotic listening was included as the independent variable (X) and sound sensitivity as computed by the DST score was included as the outcome variable (Y). In the first model, dichotic listening was represented with the right-ear score; in the second model, it was represented with the ear-difference score; in the third it was represented with the total DL score. The mediating effects of anxiety/depression between dichotic listening (X) and sound sensitivity (Y) were explored in each model. Mediation analyses test if the relationship between two variables (X and Y) can be explained by their relationship with a third variable (M). Potential mediators should be associated with both X and Y. Direct (X→Y) and indirect (X→M→Y) pathways were examined using the mediation model (model 4) and bias-corrected bootstrapping.

RESULTS

Prevalence

At this time, there are not enough participants to evaluate prevalence of sound sensitivity in the older adult population. Data collection is ongoing. In our current sample, 32.5% of participants were categorized as sound sensitive based on the DST-Count method. This is higher than the expected 15-20% prevalence.

Participant Factors

Results of the questionnaires can be viewed in Table 13. In general, our participants rated themselves highest for personality traits of agreeableness (M=4.0, SD=.75), conscientiousness (M=3.52, SD=.64), and openness (M=3.44, SD=.74). Our participants also self-reported more positivity (M=54.3, SD=9.96) than negativity (M=42.08, SD=11.62). Generally, our participants were not depressed (M=5.28, SD=3.4) or anxious (M=7.53, SD=3.46).

Table 13. Internal Traits of the Sample

Characteristic	*M*	*SD*
Personality		
Neuroticism	2.80	.62
Agreeableness	4.00	.75
Conscientiousness	3.52	.64
Openness	3.43	.74
Extraversion	2.96	.78
Emotional Reactivity		
General Positive	54.30	9.96
General Negative	42.08	11.62
Anxiety/Depression		
Anxiety	7.53	3.46
Depression	5.28	3.40
Anxiety/Depression Total	12.43	6.59
Cognitive Assessment		
Digit Span Task	3.5	3.12
Card Sorting Task	8.4	6.40
Word Recall Task	2.73	1.43
Self-Report Cognition Questions	3.78	2.80
Cognitive Total	10.85	8.39

Cognition

Results of the cognitive assessment can be seen in Table 13. Our participants performed lower than expected on the forward digit span task (*M*=3.5, *SD*=3.12). Additionally, our participants did not perform well on the card-sorting task (*M*=8.4, *SD*=6.4). For the word recall task, participants recalled 0 to 4 of the 4 words provided (*M*=2.73, *SD*=1.43). Typically, recalling half the words or fewer is considered an indicator of possible cognitive impairment (*Cognitive Assessment Toolkit*, n.d.), and a score on the standard assessment of one or less has been found to predict who may develop Alzheimer's disease within the following year (Modrego & Gazulla, 2013). For the self-report cognition questions, most of our participants self-reported few cognitive issues (*M*=3.78, *SD*=2.8). The cognitive total ranged from -7 to 31 (M=10.85, SD=8.39).

Sound Sensitivity

The DST Scale has a single question for self-reporting sound sensitivity and the presence of tinnitus. Within our participants, 18 self-reported being sound sensitive. However, when using the DST-Count method, only 13 participants were categorized as sound sensitive. The DST-Count method had a 55.6% sensitivity and 86.4% specificity of categorizing those who self-reported sound sensitivity correctly within our participants. More of our participants reported tinnitus (n=23). However, tinnitus was not found to be related to sound sensitivity in this sample (*b*=-1.58, *p*=.60). Additionally, self-reported hearing ability was not related to sound sensitivity (H(1)=2.76, *p*=.10).

Dichotic Listening

Dichotic listening ability was evaluated in three ways: the score for the dominant ear based on two-digit presentations (dominant-ear DL score), the difference score of the non-dominant ear from the dominant ear for the two-digit presentations (ear difference DL score), and the total score for the two-digit presentations (total-DL score). Higher scores for the right-ear DL score indicates more correct answers for that ear. Lower scores for the ear difference DL score indicates more similarity between the two ears. Our participants' right ear DL scores ranged from 6% to 100% (M=65.58%, SD=25.73%) and their ear difference DL scores ranged from 0% to 44% (M=10.88%, SD=10.38%). This suggests that there was a wide range of right-ear ability. Additionally, some participants were able to perform similarly from both ears while others had a distinct difference between ears. The total DL score ranged from 7% to 98.5% (M=63.7%, SD=23.73). Self-reported hearing ability was not found to related to dichotic listening by right-ear DL score (H(1)=.36, *p*=.55), ear difference DL score (H(1)=.40, *p*=.53), or total DL score (H(1)=.01, *p*=.92).

Dichotic Listening, Sound Sensitivity, and Anxiety/Depression

To initially explore relationships between dichotic listening, sound sensitivity, and anxiety/depression, non-parametric correlation analyses were performed. Dichotic listening and sound sensitivity approached significance by the dominant-ear DL score (*r*=-.28, *p*=.08), were related by the total DL score (*r*=-.31, *p*=.05), and approached significance with the ear difference DL score (*r*=-.28, *p*=.08). Dichotic listening was also related to anxiety/depression by the dominant-ear DL score (*r*=-0.47, *p*=.002), the total DL score (*r*=-.47, *p*=.002), and by the ear difference DL score (*r*=-.46, *p*=.003). Sound sensitivity was related to anxiety/depression (*r*=.48, *p*=.002). Based on these results, individuals with lower right ear DL scores had more sound sensitivity and were more likely to self-report higher anxiety/depression, and those with higher anxiety/depression had higher sound sensitivity.

Figure 4 displays the diagram of the model used for testing the mediating effect of anxiety/depression. In the model, dichotic listening as measured by the dominant-ear DL score was included as the independent variable (X), sound sensitivity as measured by the DST-Count was included as the dependent variable (Y), and anxiety/depression as measured by the HADS was included as the tested mediator (M). Anxiety/depression was associated with dominant-ear DL score (*b*=-12.44, 95% CI [-19.81, -5.08], *t*=-3.42, *p*=.002) and with sound sensitivity (*b*=.67, 95% CI [0.22, 1.12], *t*=2.99, *p*=.05). Since guidelines for mediation indicate that the variable under exploration must be associated with both X and Y (Kraemer et al., 2008), anxiety/depression met the guidelines and was interpreted further as a possible mediator in this model. The direct effect of dominant-ear DL score to sound sensitivity was not found to be significant (*b*=-3.60, 95% CI [-15.23, 8.03], *t*=-.63, *p*=.53); however, the indirect effect between these variables was found to be significant, indicating that anxiety/depression fully mediated the relationship between dichotic listening and sound sensitivity (b=-8.34, 95% CI [-16.24, -2.07]).

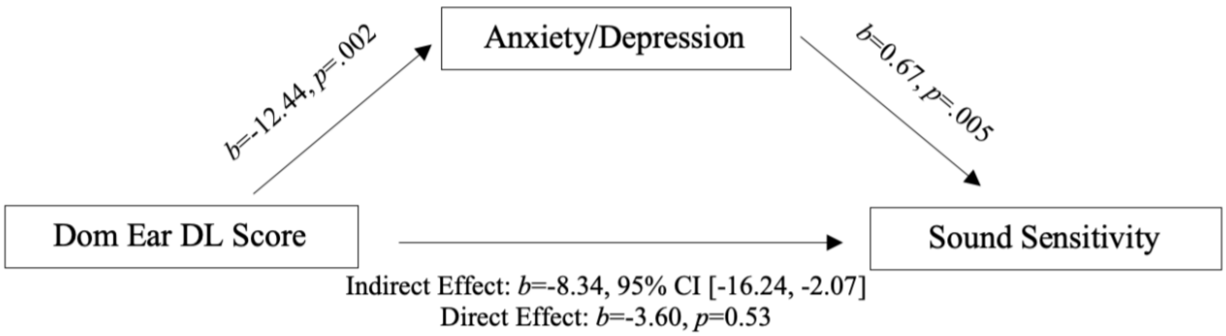

Figure 4: The mediation model with X=Dominant-Ear DL Score and the effect of each pathway.

A second model was analyzed with the ear difference DL score as the independent variable (X; Figure 5). In this model, anxiety/depression was associated with sound sensitivity (*b*=.72, 95% CI [-.2802, 1.16], *t*=3.31, *p*=.002), but not ear difference DL score (*b*=-18.71, 95% CI [-47.07, 9.65], *t*=-1.34, *p*=.19). Since anxiety/depression did not meet guidelines for mediation analysis, no further analyses were performed.

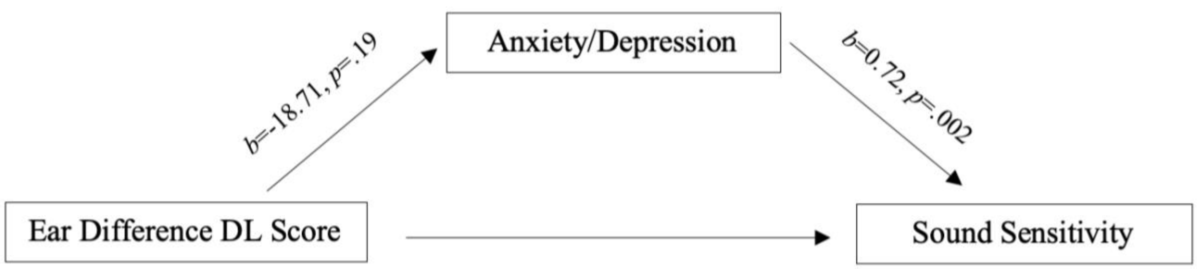

Figure 5: The mediation model with X=Ear Difference DL Score and the effect of each pathway.

A third model was analyzed with the total DL score as the independent variable (X; Figure 6). In this model, anxiety/depression was associated with the total DL score (*b*=-12.73, 95% CI [-20.85, -4.62], *t*=3.18, *p*=.003) and with sound sensitivity (*b*=.68, 95% CI [.2306, 1.12], *t*=3.07, *p*=.004). We interpreted this model further and found that the direct effect of total DL score to sound sensitivity was not found to be significant (*b*=-3.71, 95% CI [-16.11, 8.69], *t*=-.61, *p*=.55); however, the indirect effect between these variables was found to be significant, indicating that anxiety/depression fully mediated the relationship between dichotic listening ability and sound sensitivity (b=-8.62, 95% CI [-16.44, -1.93]).

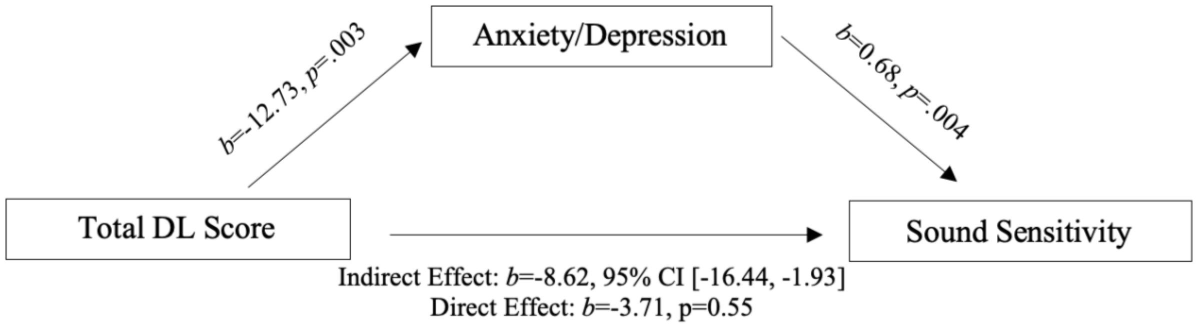

Figure 6: The mediation model with X=Total DL Score and the effect of each pathway.

DISCUSSION

The DST-Count method was used as a possible way to quantify an individual's level of sound sensitivity to classify them as sound sensitive or not sound sensitive. We estimated how sensitive and specific the DST-Count method is for identifying those as sound sensitive compared to a single item question about sound sensitivity. The DST-Count was 55.6% sensitive and 86.4% specific to estimating the presence of self-reported sound sensitivity. Therefore, the DST count is a useful tool for ruling out sound sensitivity, though it may not detect all individuals that feel they are sound sensitive. It is likely that the single-item question was poorly interpreted, or that individuals were not accurate at self-identifying as sound sensitive. For example, someone that strongly dislikes the sound of someone chewing may describe themselves as sound sensitive where the DST-Count method would not identify them as sound sensitive based on this one item.

Our participants' self-reported hearing ability was not related to sound sensitivity. This contrasts some previous research which found that self-reported hearing loss was related to sound sensitivity while hearing acuity was not (Heinonen-Guzejev et al., 2011). Together, this suggests that sound sensitivity cannot be predicted from an audiogram or by self-report hearing handicap, and that clinicians may need to probe further to understand a patient's sensitivity to sound and amplified sound. It is possible that a larger sample size would give more insight into this relationship. As expected, participants' self-reported hearing loss was related to their dichotic listening ability for right ear scores and total dichotic listening scores (Fischer et al., 2017). This suggests that individuals likely consider the effects of their dichotic listening ability, such as difficulty when there are multiple talkers, when reporting their hearing ability. Since hearing acuity differs from self-reported hearing loss, clinicians should consider evaluating dichotic listening ability when a patient reports more hearing difficulties in daily life than expected for audiometric test results.

Our participants' self-reported emotional reactivity was generally higher for positive reactivity than for negative reactivity. Compared to the emotional reactivity reported in Preece et al. (2018), our participants were slightly less negative and slightly more positive than the norms. Additionally, our participants reported high agreeableness, which has been found to correlate with positive emotional reactivity (Huber & Johnson, accepted). Previous researchers have noted that individuals who volunteer to participate in a research study tend to be more agreeable (Lönnqvist et al., 2007). While social desirability may influence individuals, previous researchers have concluded that personality measures are not invalidated by social desirability (McCrae & Costa, 1983; Pauls & Stemmler, 2003). Considering this, the generalizability of these findings may be limited to those that have similar perceptions of their emotional reactivity and personality traits within a similar age range and with similar hearing acuity.

In our study, anxiety/depression fully mediated the relationship between dichotic listening and sound sensitivity. This suggests that hearing issues related to dichotic processing results in anxiety and depression, which, in turn, is associated with sound sensitivity. Overall dichotic listening ability has been found to improve in the pediatric population with Auditory

Rehabilitation for Interaural Asymmetry (ARIA; Moncrieff et al., 2017), and is being applied to the adult population. If dichotic listening ability can be improved with rehabilitation strategies, it may also improve self-reported anxiety and depression. This in turn may reduce sound sensitivity in this population. This suggests that when a patient reports sound sensitivity or continues to have adverse outcomes with amplified sounds, clinicians might evaluate the individual's dichotic listening ability. Those with poorer dichotic listening ability are more likely to self-report higher anxiety/depression and experience sound sensitivity issues. Future research may focus on rehabilitation strategies for poor dichotic listening ability, with a focus on measuring anxiety/depression pre- and post-rehabilitation to further understand the relationship between dichotic listening and anxiety/depression. Researchers should consider measurements of sound sensitivity pre- and post-rehabilitation to understand the impact of dichotic listening auditory rehabilitation on sound sensitivity. Additionally, reduced anxiety and depression would likely lead to improved overall quality of life. While this research did not evaluate quality of life, future research would benefit from including a quality of life measure.

Limitations

Participants self-selected to be part of this study. Some individuals may have chosen to not participate due to a requirement to use a computer, internet, and headphones. During recruitment, many individuals noted not having access to headphones or earbuds to use during the study. The small sample size may have decreased the overall effects seen in the mediation model. For instance, some variables we hypothesized would be covariates (personality traits of agreeableness and neuroticism) were not significant in the model. However, while a larger sample size may provide more insight into how these individual characteristics may further impact the model, it is still notable that this small sample size was able to demonstrate a significant relationship between dichotic listening, anxiety/depression, and sound sensitivity.

There were some reports of sounds not playing consistently during the survey. This may explain some of the incomplete surveys. Additionally, some users did not know what to do if their computer was set to play sounds binaurally instead of as a 2-channel set-up, which resulted in their ending the survey incomplete.

CONCLUSION

This study evaluated the complex relationship between dichotic listening and sound sensitivity in older adults. We found that anxiety/depression fully mediated this relationship and was a key factor to understanding the relationship between dichotic listening and sound sensitivity. Additionally, we noted that, in our sample, self-reported hearing ability was not related to sound sensitivity. For patients who report sound sensitivity or continuing adverse effects with amplified sounds, clinicians should consider how auditory processing abilities and resulting anxiety/depression might be contributing to patient outcomes. Affective counseling and treatments for auditory processing could provide more meaningful real-world benefits than simple adjustments to hearing aid sound processing characteristics.

Chapter 5

GENERAL CONCLUSION

Amplification is a common treatment for hearing loss, though many individuals have adverse outcomes with amplified sounds. While strategies have been developed to mitigate issues of loudness, transient sounds, background noise, and more, some individuals continue to have adverse outcomes with hearing aids. It is possible that these individuals have underlying sound sensitivities; however, there is limited research on sound sensitivity's relationship with individual traits, emotionality, and other listening abilities. This research series aimed to evaluate these gaps and provide clinical recommendations based on the results.

First, the relationships between personality traits, emotional reactivity, and sound acceptability were evaluated. It was found that for the typical-hearing individuals in the study, those reporting higher neuroticism and a greater degree of negative emotional reactivity were more likely to have lower sound acceptability. Then we evaluated the acoustical-perceptual factors that individuals consider when evaluating sound acceptability. For the typical-hearing individuals in this study, factors of loudness and transientness were most salient when making judgments about sound acceptability. Interestingly, those who were younger or had lower positive emotional reactivity had a smaller range of acceptability overall. Finally, the relationship between dichotic listening and sound sensitivity was explored. The results of this research revealed that anxiety and depression mediate the relationship between dichotic listening and sound sensitivity. Those that have lower dichotic listening ability tend to have higher anxiety and depression, and those individuals tend to have more sound sensitivity.

This research demonstrates that sound sensitivity is multifaceted and can be influenced by factors such as personality, emotional reactivity, anxiety/depression, and dichotic listening ability. Clinicians may consider personal factors such as these when counseling about and fitting amplification devices. While those with higher agreeableness or positive reactivity are more likely to accept amplified sounds, those with higher neuroticism or higher negative reactivity may need longer acclimatization periods to accept amplified sounds.

Clinicians should be aware that self-reported hearing ability and measured hearing acuity are not directly related to sound sensitivity. Therefore, traditional measures of hearing ability cannot predict sound sensitivity. Additionally, individuals seem to have poor reporting ability when asked a single-item question about the presence of sound sensitivity. Due to this, clinicians should consider using a questionnaire such as the Decreased Sound Tolerance Scale with multiple items, which improves the validity for evaluating sound sensitivities.

While self-reported hearing ability is not related to sound sensitivity, those who self-report more hearing difficulties tend to have lower dichotic listening abilities. These individuals are more likely to report difficulty in listening environments with more background noise or multiple talkers, such as restaurants. This may lead these individuals to be more anxious during social interactions or to avoid social interaction, which may lead to depression. Those that have higher anxiety and depression are more likely to have sound sensitivity than others. Therefore, for those that continue to report adverse outcomes with amplified sound, an evaluation for poor dichotic listening, measures of anxiety and depression, and measures of sound sensitivity should be considered.

Auditory rehabilitation has been found to improve dichotic listening ability. Considering the known outcomes of poor dichotic listening, an improvement in dichotic listening ability may lead to increased social interaction and general quality of life. Therefore, it is possible that auditory rehabilitation for dichotic listening will also improve self-reported anxiety/depression.

Improvements in these areas may also show reduced sound sensitivity; however, this is outside of the scope of this research. Future research evaluating the effectiveness of dichotic listening auditory rehabilitation on self-reported anxiety/depression and sound sensitivity in the older adult population is supported by results in the current research.

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APPENDIX A
SOUND ACCEPTABILITY CONCEPT

Sound Acceptability

Acceptability is more than just deciding if the sound is "too loud" or "too soft." It includes loudness, but also many other qualities of each sound. Here's an example of what we mean: When you are given an apple, you decide how acceptable it is based on several things, like color, texture, size, smell, tartness, and sweetness. The types of apples you like might be different than the types of apples I like. Sometimes, the apple is bad and would be "very unacceptable" to you. You would not eat it. Sometimes, the apple meets all of your preferences and would be "very much acceptable" for you. Sometimes it falls somewhere in the middle.

We want you to think about how acceptable these sounds are in a similar way, considering all of the qualities of each sound to decide how acceptable it is to you.

APPENDIX B
SOUND COMPARISON INSTRUCTIONS

Now you will hear a pair of sounds. You may prefer one sound over the other, or you may feel they have equal acceptability. It may feel that you prefer one slightly over the other. Use the scale provided to rate each pair of sounds in terms of how *similar they are in acceptability.* You may listen to the pair as many times as you feel necessary to decide.

Note the marker will begin at "50" and must be selected to be considered a response, even if your response is "50."

APPENDIX C
IRB APPROVAL: PRO-FY2021-24

Institutional Review Board
Division of Research and Innovation
Office of Research Compliance
University of Memphis
315 Admin Bldg
Memphis, TN 38152-3370

August 24, 2020

PI Name: Rachel Huber
Co-Investigators:
Advisor and/or Co-PI: Jani Johnson
Submission Type: Initial
Title: Exploring the relationship between sound acceptability, emotional reactivity, and personality
IRB ID**:** #PRO-FY2021-24
Exempt Approval: August 24, 2020

The University of Memphis Institutional Review Board, FWA00006815, has reviewed your submission in accordance with all applicable statuses and regulations as well as ethical principles.

Approval of this project is given with the following obligations:

1. When the project is finished a completion submission is required
2. Any changes to the approved protocol requires board approval prior to implementation
3. When necessary submit an incident/adverse events for board review
4. Human subjects training is required every 2 years and is to be kept current at citiprogram.org.

For any additional questions or concerns please contact us at irb@memphis.edu or 901.678.2705

Thank you,
James P. Whelan, Ph.D.
Institutional Review Board Chair
The University of Memphis.

APPENDIX D
IRB APPROVAL: PRO-FY2022-349

Institutional Review Board
Division of Research and Innovation
Office of Research Compliance
University of Memphis
315 Admin Bldg
Memphis, TN 38152-3370

April 28, 2022

PI Name: Rachel Huber
Co-Investigators:
Advisor and/or Co-PI: Jani Johnson
Submission Type: Initial
Title: The Relationship of Dichotic Listening Abilities and Sound Sensitivity for Older Adults
IRB ID: #PRO-FY2022-349
Exempt Approval: April 27, 2022

The University of Memphis Institutional Review Board, FWA00006815, has reviewed your submission in accordance with all applicable statuses and regulations as well as ethical principles.

Approval of this project is given with the following obligations:

1. When the project is finished a completion submission is required
2. Any changes to the approved protocol requires board approval prior to implementation
3. When necessary submit an incident/adverse events for board review
4. Human subjects training is required every 2 years and is to be kept current at citiprogram.org.

For any additional questions or concerns please contact us at irb@memphis.edu or 901.678.2705

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James P. Whelan, Ph.D.
Institutional Review Board Chair
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