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Selective noise cancelling application for misophonia treatment

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Misophonia is a sensory disorder where specific stimuli, usually auditory, trigger the fight-flight-freeze response, causing extreme reactions, typically anger, panic, or anxiety. Research into treatment for misophonia is limited, primarily consisting of case studies applying common methods of therapy. However, research into similar disorders like tinnitus shows that there are many avenues of treatment that should be investigated, including audiological treatment. To apply audiological treatment to misophonia, selective noise cancelling must be used to control specific trigger sounds. In this research, a basic selective noise cancelling algorithm was developed using a convolutional neural network and was evaluated using a survey. Participants rated their reaction to trigger sounds, non-trigger sounds, and trigger sounds that had been selectively cancelled. The misophonic reactions to selectively cancelled sounds were significantly less than to trigger sounds. This shows that selective noise cancelling could be used to apply audiological treatments to misophonia.

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CHAPTER I

COMPREHENSIVE LITERATURE REVIEW OF TREATMENTS AVAILABILE FOR MISOPHONIA

1.1 Introduction

Misophonia is a disorder that has generally been characterized by decreased tolerance and extreme reactions to specific stimuli, normally specific sounds or their associated stimuli (Brout et al., 2018; Cavanna & Seri, 2015; Edelstein et al., 2013; Ferrer-Torres & Giménez-Llort, 2022; M. M. Jastreboff & Jastreboff, 2002; Potgieter et al., 2019; Yilmaz & Hocaoglu, 2021). The most common reported “trigger sounds” that cause these reactions include eating-related sounds such as chewing and crunching, repetitive sounds such as clicking, picking, and tapping, and other mouth and nose sounds like breathing, sniffing and coughing, drinking, and swallowing (Cecilione et al., 2022; Dover & McGuire, 2021; T. H. Dozier, 2015c; Karalis et al., 2022; Rosenthal et al., 2021; Schneider & Arch, 2017). In addition to auditory triggers, those with misophonia can also experience similar reactions to visual stimuli – jaw movement, repetitive motions, leg swinging, and hair twirling – that may or may not be related to auditory triggers (Cavanna & Seri, 2015; Edelstein et al., 2013; A. Schröder et al., 2013). The reactions to these triggers can range from disgust to rage to loss of control to severe anxiety and are generally directed toward the source of the trigger. In 2022, Swedo et al. employed the Delphi method to develop an official consensus definition for misophonia.

“Misophonia is a disorder of decreased tolerance to specific sounds or stimuli… that tend to evoke strong negative emotional, physiological, and behavioral responses that are not seen in most other people. Misophonic responses do not seem to be elicited by the loudness of auditory stimuli, but rather by the specific pattern or meaning to an individual... who may have difficulty distracting themselves from the stimulus and may experience suffering, distress, and/or impairment in social, occupational, and academic functioning.” (Swedo et al., 2022b)

Misophonia is often discussed in conjunction with similar auditory-based disorders like tinnitus and hyperacusis under the umbrella of decreased sound tolerance (Aazh et al., 2019; Henry et al., 2022; M. M. Jastreboff & Jastreboff, 2002; P. J. Jastreboff & Jastreboff, 2014; P. Jastreboff & Jastreboff, 2015; Meltzer & Herzfeld, 2014; Raj-Koziak et al., 2021). Chronic tinnitus is often defined as an auditory perception that has no physical acoustic source, leading to physiological problems such as discomfort, anxiety, or stress (Bhatt et al., 2017; Czornik et al., 2022; Stobik et al., 2005). Hyperacusis can be defined as the perception of everyday sounds as unusually or overwhelmingly loud or intense (Auerbach et al., 2014; Baguley, 2003), also defined as unusually high auditory gain (Henry, 2022). These disorders are different, but they share many similar characteristics, such as an abnormal sensitivity to auditory stimuli, unusual and extreme reactions to auditory stimuli, and drastic impact of the lives of people with these disorders.

Treatments for these other auditory disorders are well researched and draw tools from a variety of fields, including psychology, audiology, engineering, and physiology. Traditional therapies like cognitive behavioral therapy (CBT), acceptance and commitment therapy (ACT), and tinnitus retraining therapy (TRT) have been successfully used to reduce long term disability of both hyperacusis and tinnitus (Czornik et al., 2022; Fackrell et al., 2017; Henry, 2022; Holmes

& Padgham, 2011; Kalle et al., 2018; Zachriat & Kröner-Herwig, 2004). Clinicians and researchers have used auditory methods like hearing aids and sound masking with noise generators to reduce the short-term affect of these conditions and aid in long-term treatment plans (Fackrell et al., 2017; Henry, 2022; Holmes & Padgham, 2011; Kalle et al., 2018; Searchfield et al., 2017). Some investigation has also been made into pharmacological treatments (Czornik et al., 2022; Fackrell et al., 2017; Holmes & Padgham, 2011), surgery (Czornik et al., 2022; Fackrell et al., 2017; Searchfield et al., 2017), and alternative medicine such as acupuncture and ginkgo biloba (Holmes & Padgham, 2011). Researchers have demonstrated effectiveness when using multimodal approaches to treating disorders like hyperacusis and tinnitus, such as combining elements of CBT and more sound based therapies (Baguley & Hoare, 2018; F Cima et al., 2012; Nolan et al., 2020). More comprehensive reviews of the available and researched treatments for these disorders are available.

Research into misophonia is relatively new and the condition itself has not been officially classified as a psychological disorder (Ferrer-Torres & Giménez-Llort, 2022; M. M. Jastreboff & Jastreboff, 2002; Yilmaz & Hocaoglu, 2021). Research into treatments is experimental, focused primarily on a few select types of treatment, and generally tested in small samples or single case studies. The goal of this review is two-fold: first, to comprehensively determine the current state of research into treatments for misophonia; and second, to identify areas of future research into treatments for misophonia.

1.1.1 Contributions

- First comprehensive literature review focusing specifically on the researched treatments of misophonia
- Identified lack of standardized model for understanding mechanics of misophonia

- Identified need for randomized clinical trials to validate more methods of treatment than just CBT
- Identified need for more research into technological and alternative treatments for misophonia, building on the foundation of tinnitus research

1.2 Methods

The literature review was conducted according to the PRISMA 2020 statement guidelines for systematic reviews (Page et al., 2021). Two previous literature reviews of misophonia were used as guides in this process. The 2018 review by Potgieter et al. served as an example of the process. The 2022 review by Ferrer-Torres and Giménez-Llort, as the most recently published review on misophonia literature at the time, served as both an outline for the categorization of treatments and as a sanity check to ensure that the literature review was of sufficient scope. Eligibility criteria were established, the databases and search strategy for each source was defined, and the selection and collection processes were conducted according to the defined criteria. Finally, the information was collected and aggregated into categories based on treatment types.

1.2.1 Eligibility Criteria

Records were immediately excluded if they were not peer-reviewed, not in English, or did not make any mention of misophonia. After the initial exclusion, records were included in the final study if they mentioned a treatment for misophonia or mentioned technology in relation to misophonia. Literature reviews were included.

1.2.2 Sources and Searches

Searches included records up to December 2022 and were conducted using two databases: the EBSCO Discovery Service and PubMed. The same search terms were used for both databases and each search was filtered to only include records published after the year 2000. This year was chosen because 2001 is generally accepted as the year that the term misophonia was coined (Ferrer-Torres & Giménez-Llort, 2022; Yilmaz & Hocaoglu, 2021). Table 1.1 summarizes the searches performed.

Table 1.1 Searches performed for literature review.

Database	**Search Terms**	**Filters**	**Dates Searched**
EBSCO	misophonia AND treatment	2000 < YEAR < 2022	9/22, 12/22
PubMed	misophonia AND treatment	2000 < YEAR < 2022	1/23

1.2.3 Selection Process

The initial search was conducted by one researcher who utilized the exclusion criteria. Records were tracked using an Excel spreadsheet that collected basic information such as title, primary author, inclusion status, and some basic notes on content. After the initial search, the inclusion criteria were applied by one researcher and then validated by another researcher.

1.2.4 Data Collection Process

Two researchers reviewed the included records independently. Each researcher used an Excel sheet to track the title, author, year, and treatment type(s) of each record. The reviewers also captured a summary of the treatment(s) described in the record, the outcomes and effectiveness of the treatment(s), notes on particularly interesting sections or sentences, and any mention of technology in relation to the treatment of misophonia. After the individual review, the researchers discussed their conclusions and found that a consensus existed on the data extracted from the records. The records were then grouped into treatment categories, using the review by Ferrer-Torres and Giménez-Llort as a starting point for the categorization process.

1.3 Results

1.3.1 PRISMA

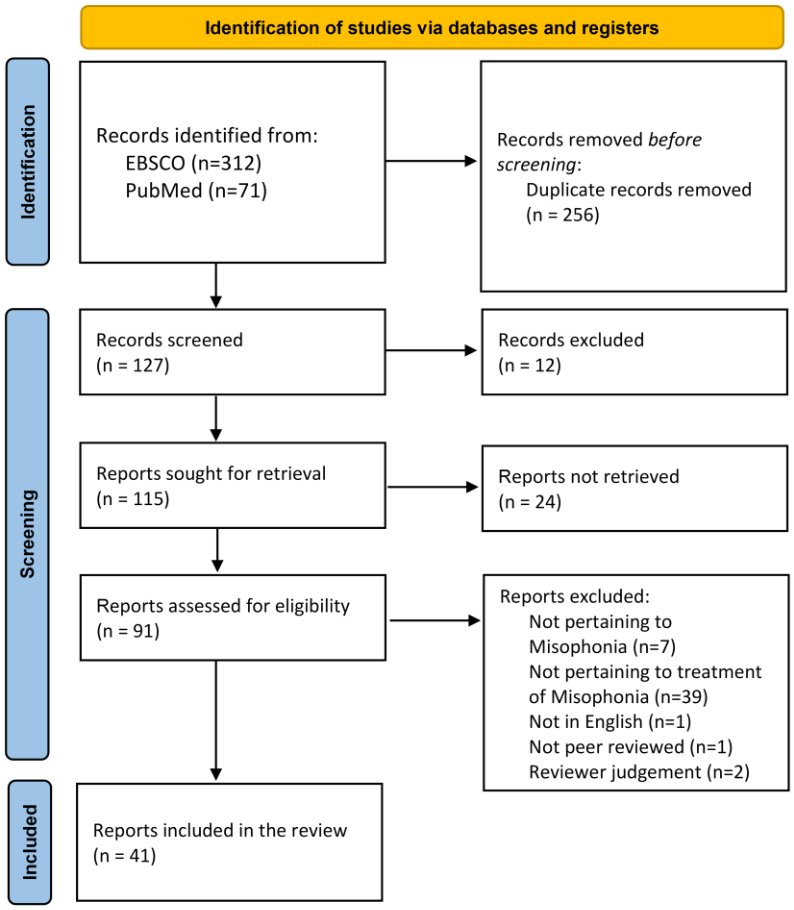

Figure 1.1 PRISMA tracking of report collection for literature review.

One paper by M. M. Jastreboff & Jastreboff (2017) was found that seemed to meet the inclusion criteria but was deemed by the reviewers to contain similar information to another by the same authors, so it was excluded from the results. Another paper contained the appropriate keywords and mentioned misophonia and technology but was primarily focused on an AI-based decision system for auditory disorders and was deemed to be irrelevant for the current review (Tarnowska et al., n.d.).

1.3.2 Table Summary

Table 1.2 lists every paper included in the review, broken into categories.

Table 1.2 Summary of all papers found in literature review.

Category	Authors	Title	Summary of Category
Acceptance and Commitment Therapy (ACT)	(Petersen & Twohig, 2022)	Acceptance and Commitment Therapy for a Child with Misophonia: A Case Study	Third-wave behavioral therapy treatments applied to specific patients with Misophonia with measurable success
	(Schneider & Arch, 2017)	Case Study: A Novel Application of Mindfulness- and Acceptance-Based Components to Treat Misophonia	
	(Schneider & Arch, 2015)	Letter to the editor: Potential treatment targets for misophonia	
Dozier Method (Counterconditioning)	(T. Dozier, 2022)	Case Study of Relaxation and Counterconditioning Therapy for Misophonia: A Conditioned Aversive Reflex Disorder	Counterconditioning to treat the initial physical reflex of Misophonia according to Tom Dozier's five-phase model of Misophonia
	(T. H. Dozier, 2015a)	Counterconditioning Treatment for Misophonia	
	(T. H. Dozier, 2015b)	Etiology, Composition, Development and Maintenance of Misophonia: A Conditioned Aversive Reflex Disorder	
	(T. H. Dozier & Mitchell, 2022)	Novel Five-Phase Model for Understanding the Nature of Misophonia and Providing Treatment	
	(T. H. Dozier, 2015c)	Treating the Initial Physical Reflex of Misophonia with the Neural Repatterning Technique: A Counterconditioning Procedure	
	(Noziglia et al., 2019)	MisophoniAPP Person-Centric Gamified Therapy for Smarter Treatment of Misophonia	
Pharmaceutical	(Webb & Keane, 2022)	MDMA for the Treatment of Misophonia, a Proposal	Experimental treatments for Misophonia using drugs approved for other disorders
	(Pan et al., 2022)	Treatment of Misophonia with Risperidone in a Patient with Autism Spectrum Disorder	
Cognitive Behavioral Therapy (CBT)	(Bernstein et al., 2013)	A brief course of cognitive behavioral therapy for the treatment of misophonia: A case example	Traditional behavioral therapy treatments applied to patients with misophonia in specific case studies and wider controlled studies with varied measurable success
	(Aazh et al., 2019)	Cognitive Behavioral Therapy For Alleviating The Distress Caused By Tinnitus, Hyperacusis And Misophonia: Current Perspectives	
	(I. J. Jager et al., 2021)	Cognitive behavioral therapy for misophonia: A randomized clinical trial	
	(A. E. Schröder et al., 2017)	Cognitive behavioral therapy is effective in misophonia: An open trial	
	(McGuire et al., 2015)	Cognitive-Behavioral Therapy for 2 Youths With Misophonia	
	(Muller et al., 2018)	Cognitive-Behavioral Therapy for an Adolescent Female Presenting With Misophonia: A Case Example	
	(Dover & McGuire, 2021)	Family-Based Cognitive Behavioral Therapy for Youth With Misophonia: A Case Report	
	(Reid et al., 2016)	Intensive cognitive-behavioral therapy for comorbid misophonic and obsessive-compulsive symptoms: A systematic case study	

Table 1.2 (continued)

Category	Authors	Title	Summary of Category
Cognitive Behavioral Therapy (CBT) continued	(Henry et al., 2022)	Sound Tolerance Conditions (Hyperacusis, Misophonia, Noise Sensitivity, and Phonophobia): Definitions and Clinical Management	Traditional behavioral therapy treatments applied to patients with misophonia in specific case studies and wider controlled studies with varied measurable success
	(I. Jager et al., 2022)	Synopsis and Qualitative Evaluation of a Treatment Protocol to Guide Systemic Group-Cognitive Behavioral Therapy for Misophonia	
	(Altinöz et al., 2018)	The effectiveness of Cognitive Behavioral Psychotherapy in Misophonia: A Case Report	
	(Roushani & Mehrabizadeh Honarmand, 2021)	The Effectiveness of Cognitive-behavioral Therapy on Anger in Female Students with Misophonia: A Single-Case Study	
	(Lewin et al., 2021)	Transdiagnostic cognitive behavioral therapy for misophonia in youth: Methods for a clinical trial and four pilot cases	
	(Cecilione et al., 2022)	Treating Adolescent Misophonia With Cognitive Behavioral Therapy: Considerations for Including Exposure	
	(Karalis et al., 2022)	Treatment challenges for Misophonia with comorbid mood and anxiety disorders, a case report	
	(Bruxner, 2016)	Mastication rage': a review of misophonia - an under-recognized symptom of psychiatric relevance?	
Literature Reviews	(Yilmaz & Hocaoglu, 2021)	Misophonia: A Review	Literature reviews or review studies concerning Misophonia and containing specific sections on Misophonia treatments
	(Potgieter et al., 2019)	Misophonia: A scoping review of research	
	(Ferrer-Torres & Giménez-Llort, 2022)	Misophonia: A Systematic Review of Current and Future Trends in This Emerging Clinical Field	
	(Cavanna & Seri, 2015)	Misophonia: current perspectives	
	(Meltzer & Herzfeld, 2014)	Tinnitus, Hyperacusis, and Misophonia Toolbox	
	(Smith et al., 2022)	Perceptions of various treatment approaches for adults and children with misophonia	
	(Claiborn et al., 2020)	Self-Identified Misophonia Phenomenology, Impact, and Clinical Correlates	
	(Frank, n.d.)	Therapist-rated Engagement and Compliance as Proxies for Treatment Success: A Bayesian Mediation Analysis of Exposure and Stress Management for Adults with Misophonia	
Miscellaneous	(Haq et al., 2021)	Behavioral Treatment of Problem Behavior for an Adult with Autism Spectrum Disorder and Misophonia.	Behavioral therapy
	(Cowan et al., 2022)	Misophonia: A psychological model and proposed treatment	Original model and approach
	(I. Jager et al., 2021)	EMDR therapy for misophonia: a pilot study of case series	Eye Movement Desensitization and Reprocessing (EMDR)
	(Frank & Mckay, 2018)	The Suitability of an Inhibitory Learning Approach in Exposure When Habituation Fails: A Clinical Application to Misophonia	Exposure Therapy
	(P. J. Jastreboff & Jastreboff, 2014)	Treatments for decreased sound tolerance (hyperacusis and misophonia)	Tinnitus Retraining Therapy (TRT)

1.4 Discussion

The literature reviews provided context for each of the different treatments and verified that the authors did not overlook any critical papers regarding treatment alternatives for misophonia (Cavanna & Seri, 2015; Claiborn et al., 2020; Ferrer-Torres & Giménez-Llort, 2022; Meltzer & Herzfeld, 2014; Potgieter et al., 2019; Smith et al., 2022; Yilmaz & Hocaoglu, 2021). Most of the literature reviews focused their attention on the etiology and proposed models for the onset and functioning of misophonia (Cavanna & Seri, 2015; Claiborn et al., 2020; Ferrer-Torres & Giménez-Llort, 2022; Potgieter et al., 2019; Yilmaz & Hocaoglu, 2021). Meltzer and Herzfeld (2014) developed a toolbox of potential treatments designed specifically for audiologists; this toolbox focused on tinnitus but could be applied to hyperacusis and misophonia. Most importantly, Smith et al. (2022) investigated the perception of individuals with misophonia towards various treatments, including medication, lifestyle modifications, relaxation techniques, psychological treatment, audiologic treatments, and neuromodulation. Smith's study provided a framework for understanding what the current categories of treatment were for this current research.

1.4.1 Cognitive Behavioral Therapy

Cognitive Behavioral Therapy (CBT) is one of the most studied behavior therapies to date. CBT focuses on negative mental patterns that lead to emotional distress and undesired behaviors (Hofmann et al., 2012). CBT is also the most researched treatment for Misophonia and the only treatment to have clinical trials performed. In general, the case studies and trials using CBT have proven effective in reducing misophonic symptoms (Ferrer-Torres & Giménez-Llort, 2022; Potgieter et al., 2019; Yilmaz & Hocaoglu, 2021) and papers discussing possible treatments often primarily focus on CBT (Aazh et al., 2019; Bruxner, 2016; Henry et al., 2022; Karalis et al., 2022).

Some of the first instances of CBT in Misophonia treatment were early case studies (Altinöz et al., 2018; Bernstein et al., 2013; Cecilione et al., 2022; Dover & McGuire, 2021; I. Jager et al., 2022; Lewin et al., 2021; McGuire et al., 2015; Muller et al., 2018; Reid et al., 2016). In each of these case studies, a patient visited a clinician with misophonic symptoms, sometimes comorbid with OCD-like symptoms or other disorders. The authors conducted a series of CBT sessions with the patient, focusing on the mindset behind the reactions to triggers and the cognitive processes that were related to the negative emotions. In a few cases, the authors also attempted exposure and response prevention (ERP), which only showed success in combination with CBT treatment (Cecilione et al., 2022; Dover & McGuire, 2021; Reid et al., 2016; Roushani & Mehrabizadeh Honarmand, 2021). Specifically worth noting is a comment made by Cecilione et al.: exposures must be performed in combination with the correct atmosphere, support, and relaxation and mental processes to be effective. In each case study, the authors measured the severity of the patient's Misophonia, normally using AMISOS and complementary scales. From the measurements, they saw a decrease in the severity of Misophonia, ranging from somewhat improved to almost complete reduction. At the end of each case study, as is common, the authors noted the necessity for more controlled trials to validate the effectiveness of this treatment. I. Jager et al. (2022) do describe a treatment protocol for group CBT to treat Misophonia. However, they were only able to test the protocol on a single individual, with results similar to the other case studies. Lewin et al. (2021) also give an outline for potential treatment protocols, with some success in phase 1 pilot trials.

In addition to the case studies, three trials were found that used CBT to treat misophonia. In 2017, A. E. Schröder et al. (2017) published the first true study of CBT treatment for patients with misophonia, pulling from patients referred to the University of Amsterdam's Academic Medical Center (AMC). While the study had some limitations and was not a randomized controlled trial (RCT), it still showed that CBT was effective in treating the symptoms of misophonia for around half of the patients. In 2021, the AMC published the first RCT using CBT to treat misophonia. Using a highly controlled treatment protocol, a control group on a treatment waiting list, and multiple measures including a 1-year follow-up, the authors showed a clinical improvement in almost three quarters of the treated patients. Also in 2021, Roushani & Mehrabizadeh Honarmand (2021) used CBT on three randomly selected female students at Shahid Chamran University in Iran. The authors specifically focused on the effect of treatment on anger as a symptom. The study showed substantial improvement in two students and small improvement in a third student using the Novaco Anger Scale. To varying degrees, these three trials confirm the conclusions of the published case studies; CBT is helpful in reducing the impacts of misophonia.

1.4.2 Acceptance and Commitment Therapy

Acceptance and commitment therapy (ACT) is part of the third wave of behavior therapy treatments and focuses more on the individual's relationship to psychological events while applying an understanding of the mechanics of the events and their context (Hayes et al., 2006). ACT targets six core processes to allow the individual to build a healthier relationship with themselves and their circumstances: acceptance, cognitive defusion, contact with the present, self as context, values, and committed action (a more detailed description of ACT can be found in

Hayes et al. (2006)). Two reports found in the literature review discussed case studies using ACT in patient treatment.

Petersen and Twohig (2022) applied ACT with principles from dialectical behavior therapy (DBT) to the treatment of the misophonia of a 12-year-old female (pseudonym “Kelly” in the report). In the treatment, Kelly attended sixteen weekly, 50-minute sessions, each focusing on aspects of her experience and introducing ACT principles to be applied in her daily life. The first sessions focused on basic education and mindfulness; the treatment then moved to engaging in more understanding with the condition and separating Kelly from her misophonia without suppressing or denying it; the final sessions introduced specific activities to engage with herself and others with compassion and empathy. The authors used the Amsterdam Misophonia Scale (AMISOS) (A. Schröder et al., 2013) to provide a baseline score for Kelly’s misophonia and measure improvement over time. Kelly’s AMISOS scores decreased over the treatment period. This, along with testaments from the patient and her mother, suggests that ACT was successful in reducing the symptoms of misophonia and increasing the ability to tolerate the condition. This study was the first use of ACT to treat misophonia in a child and therefore while it is useful in showing the value of ACT in a case study, it does not provide a systematic or controlled experiment for this treatment. The authors also note that controlled exposure was not used but could have shown positive results. In addition, they suggest that while earplugs or headphones can have harmful audiological effects and lead to avoidance behavior, they can also be useful in specific situations. Finally, the authors stress that research concerning treatment and diagnosis of misophonia is limited and so any treatment must be presented with full transparency.

Schneider and Arch (2017) used ACT to treat a 17-year-old male, pseudonym “Michael”. In the treatment, Michael attended 10 50-minute sessions following a similar procedure as the previous study, including basic mindfulness and education, internal connection and sympathy, and engagement with his surroundings. The authors again used the AMISOS scale, and Michael's responses show a decrease over the sessions and into the 6-month follow-up. It is worth nothing that Michael reported subthreshold symptoms of obsessive-compulsive disorder (OCD), which shares with misophonia unwanted thoughts and compulsive behaviors and is a common candidate for ACT use. The authors specifically state that because misophonia is not well studied they did not apply a strict curriculum for ACT or DBT but pulled principles from both treatments based on the situation. The authors also experimented with physical relaxation in response to triggers, which has been studied in multiple case reports (T. Dozier, 2022; T. H. Dozier, 2015b, 2015c).

Both these case studies provide evidence for the effectiveness of ACT and DBT in the treatment of misophonia. The focus on accepting situations, separating from the symptoms without suppressing them, and more active engagement with the symptoms and situations gave the patients tools to actively address their misophonia and triggering situations instead of defaulting to the inflexible routine of anger or anxiety in response to trigger sounds. A larger, controlled, and systematic study is needed to validate the effectiveness of ACT in treating misophonia. Schneider and Arch (2015) suggest that because misophonia involves emotional responses that are harder to habituate through exposure, these methods of acceptance and engagement with misophonia may be particularly effective.

1.4.3 Counterconditioning and Neural Repatterning Technique

The counterconditioning technique, often also referred to as the neural repatterning technique (NRT) by papers, is built on the five-phase model of Misophonia developed by Dozier and Mitchell (2022). The five-phase model theorizes that Misophonia contains a Pavlovian-conditioned physical reflex response to triggers, which then causes the intense emotional reactions characteristic of Misophonia (T. H. Dozier, 2015b). There are other phases to this model of Misophonia, but the physical reflex is the primary concern of the counterconditioning treatment.

In Dozier's method of counterconditioning, the patient is exposed to a mild form of a known trigger, which will cause the physical reflex. At the same time, the patient is exposed to a counterconditioning stimulus, often music, which should elicit a positive response. This combination allows the patient to focus on relaxing their physical reflex without experiencing the emotional response to the trigger. Over time, the physical reflex can be controlled and reduced, which reduces the emotional response and the rest of the phases in the five-phase model. (T. H. Dozier, 2015b).

Dozier's first paper on this counterconditioning technique (T. H. Dozier, 2015b) contains short descriptions of case studies supporting his theory. There are also three published case studies showing the results of the counterconditioning technique on specific patients.

The first case study was performed in 2015 on a 21-year-old female (pseudonym Miley) (T. H. Dozier, 2015c). At the time of the study, no clinically validated assessments had been developed for Misophonia, so the author used multiple available assessments: the Misophonia Assessment Questionnaire (MAQ) and the Misophonia Coping Responses surveys developed by audiologist Marsha Johnson, the Misophonia Physical Sensation scale and Misophonia Trigger Severity scale developed by audiologist Natan Bauman, and the Misophonia Activation Scale from misophonia-UK.org and the Misophonia Emotional Response survey from the author. At the beginning of the study, Miley reported her symptoms as extreme and scored high on the assessments used. Over the course of approximately a month, Miley used progressive muscle relaxation (PMR) techniques twice a day and NRT treatments between 3 to 6 times a week. Miley's score on the MAQ before and after treatment shows significant decline in the severity of her reactions to the triggers that had been treated using NRT. Follow-ups 6 and 12 months after treatment showed that her response to the treated triggers remained low, but the response to non-treated triggers remained or grew stronger. The author notes that the NRT treatment did not eliminate the trigger response, but merely lessened it; he therefore suggests that NRT could be used in conjunction with other therapies like CBT to better treat a patient. In the discussion section, the author mentions another patient who used white noise and open ear headphones to reduce her responses to triggers based on the MAQ, showing the same results with simple white noise that the complex counterconditioning treatment showed. This reinforces that while the treatment in this case worked, the measurements used are not validated.

The second case study in 2015 focused on a 48-year-old female (pseudonym Sarah), whose most extreme triggers were caused by her husband. Again, the self-reported MAQ was the primary assessment tool to measure success of treatment. Over the course of 18 weeks, fourteen virtual counterconditioning sessions were held virtually to treat four selected triggers (three auditory triggers and one visual trigger). The three auditory triggers were successfully lowered according to MAQ scores after 2 sessions per trigger. The visual trigger took longer to treat, but after 8 sessions the patient and therapist mutually agreed to terminate treatment, as the response to the visual trigger had been sufficiently reduced. Sarah's MAQ scores after treatment and in a 4-month and 10-month follow-up show a reduction in the responses to the specific triggers. However, just as the previous case study, the effect on non-treated triggers is not known. In addition, the visual trigger and one of the audio triggers were caused by the same action, but the response to the visual trigger took longer to treat and did not reduce when the response to the audio trigger was reduced. This again shows that counterconditioning is primarily effective on individual triggers and does not provide an overall treatment for Misophonia. The author notes that while the assessment scores provide empirical support for this treatment, they do not prove generalized effectiveness; in addition, the response severity could also have been produced by avoiding triggering situations and implementing other coping techniques that occurred in tandem to counterconditioning treatment.

The final case study was published in 2022 and covers the treatment of a 47-year-old female (pseudonym Olivia), diagnosed with bipolar II and self-reporting Misophonia (T. Dozier, 2022). Her Misophonia and other conditions were extreme enough to lead to consistent withdrawal and avoidance, spending about 95% of her time alone. The MAQ was used throughout the course of treatment to measure progress, and the AMISOS was used prior to treatment and concluding treatment to provide a validated measure of treatment success. Over 13 weeks, the counterconditioning treatment was taught and applied, beginning by identifying physical reflexes to triggers, then using PMR to relax the reflex with recorded triggers in combination with positive stimuli. Based on the AMISOS score taken in the first session, after the last session, and a year after treatment, the severity of Olivia's Misophonia was reduced by over 80%. This case study provides further support for counterconditioning in the context of the five-phase model of Misophonia, but because the theory and treatment are experimental and unvalidated, no conclusion data can be drawn.

In addition to these case studies, another published paper makes significant mention of the counterconditioning technique and specifically NRT. Noziglia et al. (2019) developed a gamified version of the Trigger Tamer app developed by Dozier. The Trigger Tamer app allows the patient to self-administer NRT by playing positive sounds while introducing user-selected triggers at low volume and frequency. Noziglia et al. sought to improve on this app by introducing in-game rewards to encourage continued use and using a game system to create a more meaningful context for the treatment. This paper, like many others, also mentions the common use of noise cancelling headphones and noise masking as a way of reducing the impact of triggers, but specifically points out that this technique does not have any long-term positive impact on the severity of the patient's Misophonia.

The counterconditioning treatment, based on the five-phase model of Misophonia, has been shown to successfully reduce the severity of specific triggers in case studies, using both unvalidated and validated measures. Dozier does note that this treatment has only shown effectiveness on the specific triggers being treated and might be best used in combination with other treatments such as CBT. In addition, no clinical study or even group study has been performed, so the broad effectiveness of this treatment is unknown.

1.4.4 Pharmaceutical Treatments

There is a dearth of research on the effects of pharmaceutical treatments on Misophonia and its symptoms. Two reports were identified in the literature review that mention the use of specific pharmaceuticals in the treatment of Misophonia. The reports are either hypothetical or case studies, suggesting a theoretical precedent for pharmaceutical treatments (Karalis et al., 2022). However, further research is needed into this area of treatment, specifically beginning with the pharmaceutical treatments that have been studied for tinnitus and hyperacusis, as mentioned in the introduction.

Webb & Keane (2022) proposed a hypothetical treatment plan for Misophonia using MDMA, generally known as ecstasy. They drew comparisons between the symptoms of Misophonia and other conditions that have been treated with MDMA, including post-traumatic stress disorder (PTSD). The authors suggest that MDMA could reduce the perception of strong negative stimuli, reduce the autonomic hyperarousal that occurs with PTSD and therefore potentially Misophonia, increase cognitive flexibility, and improve close relationships with individuals who are often the source of severe triggers. These effects have been proven in separate studies treating PTSD and other disorders, but no studies have been performed to validate these effects on Misophonia. The authors suggest using the treatment protocol used in the Multidisciplinary Association for Psychedelic Studies Phase 3 studies for PTSD treatment with MDMA. Although no published study has used this treatment yet, the noted similarities between PTSD and Misophonia could point to the potential effectiveness of MDMA in the future.

Pan et al. (2022) reported on the effects of risperidone treatment on the Misophonia of a patient presenting with autism spectrum disorder (ASD), intellectual disability, generalized anxiety disorder, and schizoaffective disorder. The authors note that risperidone has been researched as a potential treatment for hyperacusis, which shares similarities with Misophonia as discussed in the introduction. The patient scored a 31 out of 40 on the AMISOS-revised (AMISOS-R) scale upon admission; after a few days of risperidone dosage, the patient’s AMISOS-R score dropped to a 5. A follow-up 2 months after the treatment began showed that the patient’s Misophonia remained improved. The cause of the effectiveness of risperidone on the Misophonia is unknown, particularly when other drugs failed. More research is required to understand the biological causes of Misophonia and how risperidone impacts those causes.

1.4.5 Miscellaneous Treatments

Reports that were not similar to any other reports or did not fit into the categories outlined in the literature reviews were collected into a miscellaneous category. Each of the reports is briefly described below.

The first miscellaneous report used conventional behavioral treatment on a patient with misophonia and autism spectrum disorder (ASD). The authors used behavioral therapy instead of CBT because of the lack of strong verbal communicative skills in the patient that are necessary for the application of CBT. Using an ABA-based treatment showed success in reducing the sound-based problem behaviors in the patient. The authors do note that their research is difficult to generalize, a common problem in treatment of individuals with ASD.

Cowan et al. (2022) introduced a model for misophonia building on the Pavlovian conditioning theory developed by M. M. Jastreboff & Jastreboff (2002). The authors point out that the Jastreboff model does not account for the initial unconditioned response that leads to anger as a conditioned response to specific sounds. In response, the authors suggest that rigidity toward a specific sound made by a specific person could start the cycle of increased awareness to sounds, distress from sounds, and expanding triggers in new situations. Based on this model, they introduce a theoretical treatment framework termed experiential acceptance and stimulus engagement (EASE). A vignette of a patient with misophonia is introduced and the treatment plan is applied to the case, focusing on ending toxic hope, reducing avoidance of sounds, and actively dealing properly with triggering situations. This model is theoretical, and the treatment is unvalidated.

Eye movement desensitization and reprocessing (EMDR) was used by I. Jager et al. (2021) in a small study to treat misophonia using specific traumatic experiences. When evaluated using the AMISOS-R scale, all but one of the seven patients showed improvement, and two patients demonstrated a full response rate according to the CGI-Improvement scale. The study has many limitations, including bias, lack of a control, a small sample size, and lack of a follow-up to determine long-term effects. However, the study showed that EMDR is worth investigating, especially as an alternative treatment when CBT is not available.

Frank & Mckay (2018) introduced an idea of applying inhibitory learning to exposure therapy when treating misophonia. They suggest that applying inhibitory learning to interrupt the usual pattern of trigger and response can lead to better results when traditional exposure therapy does not achieve the desired result in session. Exposure therapy is traditionally viewed negatively by those who have misophonia, but the individual results of the treatments applied by the authors seem to show incremental improvement in the condition of the patients.

Finally, P. J. Jastreboff & Jastreboff (2014) summarize tinnitus retraining therapy (TRT) and the use of sound generators to mask trigger noises. They primarily discuss TRT in relation to hyperacusis, but also show how a similar treatment can be used to both lessen the short-term effects of trigger noises with sound masking and reduce long-term misophonic responses with a form of exposure therapy.

1.5 Conclusions

The primary goals of this paper were to identify the current research into treatments for misophonia and pinpoint any areas that could be investigated in the future based on research from tinnitus, hyperacusis, and other auditory-related disorders. The bulk of research into the treatments of misophonia is focused on psychiatric treatments and therapies. This makes sense because most of the current research is being performed by clinicians who are treating patients, and so they use the fully validated tools currently at their disposal. Experimentally, many of these therapies have shown success in treating misophonia. However, because of the nature of the current research, most reports are case studies or small studies and do not provide strong conclusive evidence for any particular treatment. There is no standard model for understanding how misophonia functions, and there are no standard treatments or protocols available currently.

Additionally, because the primary research focus is on psychiatric treatments, other methods of treatment for disorders like tinnitus and hyperacusis that have proven effective independently or in conjunction with psychiatric treatments have not been investigated for misophonia, as shown in Figure 1.2.

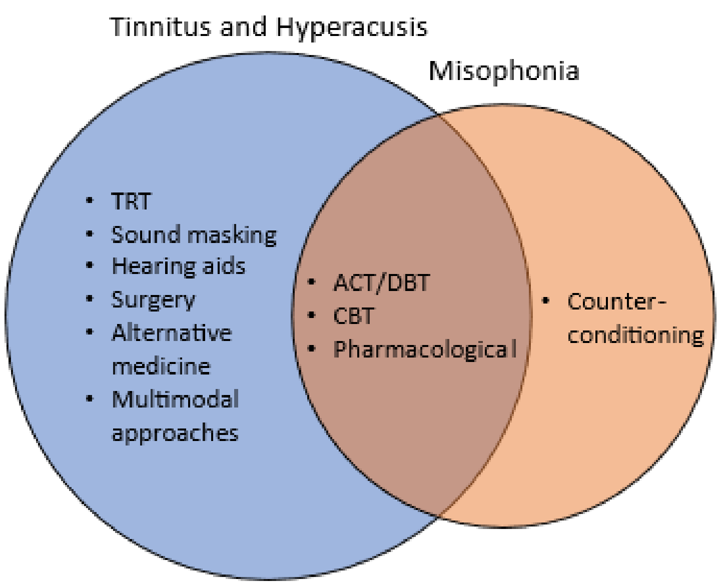

Figure 1.2 Treatments sorted by applications with multiple studies.

Alternative medicines like acupuncture have been used by those suffering from misophonia, but no research has been done to validate the effectiveness of these methods. More importantly, audiological methods such as noise masking technology or noise canceling technology are commonly used by people with misophonia, but little research has been done into the pros and cons of these technologies, especially in conjunction with psychiatric methods, as is often applied in TRT for tinnitus or hyperacusis.

1.6 Future Research

More research is needed to investigate the generalizability of many of the psychiatric treatments covered in this paper. CBT is the only treatment that has been validated through an RCT, and other treatments show promise based on the case studies and reports.

Alternative methods of treatment such as medication and alternative medicine would also benefit from further research. These treatments have not been researched effectively for misophonia but have shown strong results for other auditory disorders.

Finally, more research is needed for the use of technology and audiological tools to treat misophonia, especially in conjunction with psychiatric treatments. This is a common and validated style of holistic treatment for tinnitus and other disorders but has not been researched effectively for misophonia treatment.

CHAPTER II

SELECTIVE NOISE CANCELLING APPLICATION FOR MISOPHONIA TREATMENT

2.1 Introduction to Misophonia and Problem Statement

2.1.1 Definition of Misophonia

Misophonia is an sensory disorder where specific stimuli, usually auditory, trigger the fight-flight-freeze (F3) response, causing extreme reactions in the sufferer, usually in the form of anger, panic, or anxiety, as can be seen in Figure 2.1. An official definition can be found in Swedo et al. (2022):

“Misophonia is a disorder of decreased tolerance to specific sounds or stimuli… that tend to evoke strong negative emotional, physiological, and behavioral responses that are not seen in most other people. Misophonic responses do not seem to be elicited by the loudness of auditory stimuli, but rather by the specific pattern or meaning to an individual... who may have difficulty distracting themselves from the stimulus and may experience suffering, distress, and/or impairment in social, occupational, and academic functioning.” (Swedo et al., 2022b)

Figure 2.1 Simplified visualization of the mechanics of Misophonia.

The specific point of the definition is that the strong negative reactions occur in the presence of *specific* stimuli; that is, a stranger on the street eating noisily may not have the same effect as a close family member eating in the same manner. The most common specific stimuli, or “triggers”, include eating-related sounds such as chewing and crunching, repetitive sounds such as clicking, picking, and tapping, and other mouth and nose sounds like breathing, sniffing and coughing, drinking, and swallowing (Cecilione et al., 2022; Dover & McGuire, 2021; T. H. Dozier, 2015c; Karalis et al., 2022; Rosenthal et al., 2021; Schneider & Arch, 2017). Other non-auditory triggers can be developed as well, such as jaw movement, leg swinging, and repetitive motions that may or may not be linked to auditory triggers (Cavanna & Seri, 2015; Edelstein et al., 2013; A. Schröder et al., 2013).

Anecdotal reports show that the strong negative emotional, physiological, and behavioral responses often include outbursts of anger, extreme panic attacks, self-isolation, and in some cases self-harm behaviors. Those suffering from misophonia express feelings of intense, uncontrollable rage which can then lead to guilt, especially if the anger is directed towards a loved one. Others mention panic attacks so severe that radical self-isolation seems to be the only response. Most people with misophonia have identified significant detriment to their relationships, work lives, and mental and emotional health.

2.1.2 Current State of Research

As the date of the official definition suggests, research into this condition is limited and recent. Estimates of the pervasiveness of misophonia suggest that somewhere around 5% or 6% of the population suffers from misophonia severe enough to inhibit their daily lives (Jakubovski et al., 2022; X. Zhou et al., 2017). This is similar to the prevalence of tinnitus, a well-researched auditory disorder with somewhere between 5% and 10% of the population showing tinnitus symptoms that affect their daily lives. Misophonia is more prevalent than commonly known disorders like OCD (Adam et al., 2012; Mohammadi et al., 2004; Sasson et al., 1997). However, despite the prevalence of misophonia, the research conducted specifically concerning the treatment of misophonia consists primarily of psychiatric case studies (Cavanna & Seri, 2015; Ferrer-Torres & Giménez-Llort, 2022; Potgieter et al., 2019; Yilmaz & Hocaoglu, 2021), with a few large studies using cognitive behavioral therapy (CBT) (I. J. Jager et al., 2021; Roushani & Mehrabizadeh Honarmand, 2021; A. E. Schröder et al., 2017). This dearth of research into treatments for misophonia is unacceptable given the prevalence of the condition.

The initial research into misophonia compared it to other sensory conditions, specifically tinnitus and hyperacusis (Aazh et al., 2019; Henry et al., 2022; M. M. Jastreboff & Jastreboff, 2002; P. J. Jastreboff & Jastreboff, 2014; P. Jastreboff & Jastreboff, 2015; Meltzer & Herzfeld, 2014; Raj-Koziak et al., 2021). Both these conditions have decades of research into possible treatments, ranging from psychiatric to pharmacological to physical sound masking and hearing aids to alternative medicines and surgeries (Auerbach et al., 2014; Baguley, 2003; Baguley & Hoare, 2018; Bhatt et al., 2017; Czornik et al., 2022; F Cima et al., 2012; Fackrell et al., 2017; Henry, 2022; Holmes & Padgham, 2011; Kalle et al., 2018; Michiels et al., 2016; Nolan et al., 2020; Searchfield et al., 2017; Stobik et al., 2005; Zachriat & Kröner-Herwig, 2004). Because the symptoms and triggers for these conditions are similar to misophonia, Jastreboff and Jastreboff (2014) suggest that tinnitus retraining therapy (TRT) could be applied to hyperacusis, misophonia, and similar conditions with decreased sound tolerance. From their example, future research into misophonia could be concentrated on these already validated methods of treatment to evaluate their effectiveness with misophonia treatment.

Specifically, many anecdotal reports show that people with misophonia often use noise cancelling technology to remove triggers from their environment (Frank & Mckay, 2018; Noziglia et al., 2019; Petersen & Twohig, 2022; Smith et al., 2022), but most clinicians warn that this coping mechanism actually increases sensitivity to triggers and does not help in long-term reduction of misophonic symptoms (Cecilione et al., 2022; Noziglia et al., 2019; Schneider & Arch, 2017). The Jastreboffs and others suggest that using noise cancelling or masking in a structured manner with psychiatric treatments could be beneficial for misophonia as it is for tinnitus and hyperacusis (Bernstein et al., 2013; T. H. Dozier, 2015a; Ferrer-Torres & Giménez-Llort, 2022; I. Jager et al., 2022; P. J. Jastreboff & Jastreboff, 2014; Petersen & Twohig, 2022; Smith et al., 2022). In this type of treatment (hereafter termed audiological treatment), specifically designed noise cancelling or masking is used to slowly introduce sounds to the patient with therapy sessions, with full control over the sounds in the hands of the clinician or patient. The objective is to give the patient the tools to manage the sounds in a controlled environment, so as they experience sounds in an uncontrolled environment, they are able to cope properly. Figure 2.2 shows how the applications for this type of treatment with tinnitus and hyperacusis can reveal a potential application for misophonia.

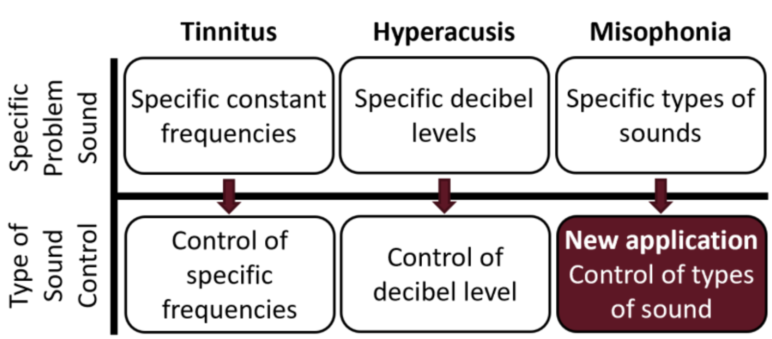

Figure 2.2 Potential application of audiological treatment for misophonia using specific control of types of sounds.

Tinnitus treatment uses generated white noise at specific frequencies to control the characteristic ringing in the ears. Hyperacusis treatment uses noise cancelling or noise masking with adjustable volumes to control the loudness of sounds. Because misophonia deals with specific types of sounds (as seen in the definition and examples), the type of noise cancelling or masking needed for misophonia treatment is selective noise cancelling, where the volume of specific noises can be controlled. This will allow control over when trigger sounds are experienced and how extreme they are, which will give clinicians the opportunity to teach proper coping mechanisms to patients in a controlled environment and allow patients to practice those coping mechanisms with control over their environments.

2.1.3 Problem Statement

The aim of this research is to investigate the potential of using selective noise cancelling in a similar setting to the audiological treatments mentioned above. The hypothesis is that audio clips with trigger sounds cancelled using selective noise cancelling will elicit a lower misophonic response from a person with misophonia than a trigger sound without selective noise cancelling. Validating this hypothesis will allow for further investigation into using selective noise cancelling with forms of audiological treatment for a more holistic approach to misophonia treatment.

2.1.4 Contributions

- Developed convolutional neural network capable of identifying trigger sounds in audio
- Validated the potential of using selective noise cancelling to apply a form of tinnitus retraining therapy to misophonia

2.2 Background Literature Reviews

2.2.1 Outline of Background

There are two critical factors to answering the primary research question. The first is developing a prototype of selective noise cancelling to be used on misophonia trigger sounds, and the second is a method of evaluating the selective noise cancelling to validate the hypothesis. Section 2.2 gives background on how selective noise cancelling can be designed using neural networks, and Section 2.2.3 identifies a framework for validating the selective noise cancelling in a human study.

2.2.2 Selective Noise Cancelling Design

Traditional active noise cancelling, when simplified, has two steps: receive a sound input, then cancel the sound, either by reducing the decibel level to zero or playing an inverse sound to counteract the sound waves. Selective noise cancelling as discussed in the previous chapter has an added step in the middle: before a sound is cancelled, it must be classified to determine whether it should be cancelled or not. Figure 2.3 demonstrates this added step; sound classification is the only necessary development to create the selective noise cancelling proposed in this paper from the active noise cancelling processes that already exist.

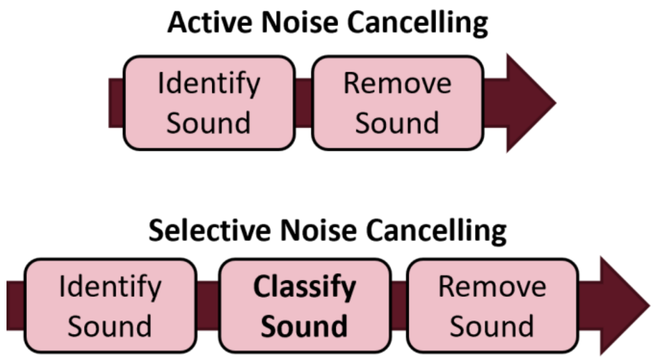

Figure 2.3 Traditional active noise cancelling process compared to the selective noise cancelling process proposed in this paper.

Sound recognition is a popular application for artificial neural networks, a type of deep learning. Specifically, many papers have investigated using convolutional neural networks (CNN) for sound recognition. CNNs expand on the traditional neural network architecture with back-propagation training by including convolutional layers. A convolutional layer uses a kernel or filter to extract features from the input, usually an image. The kernel is generally small, often $3x3x1$ or $5x5x1$, and iterates over the entire image, essentially compressing the image while retaining critical features. shows a visual example of a kernel in action.

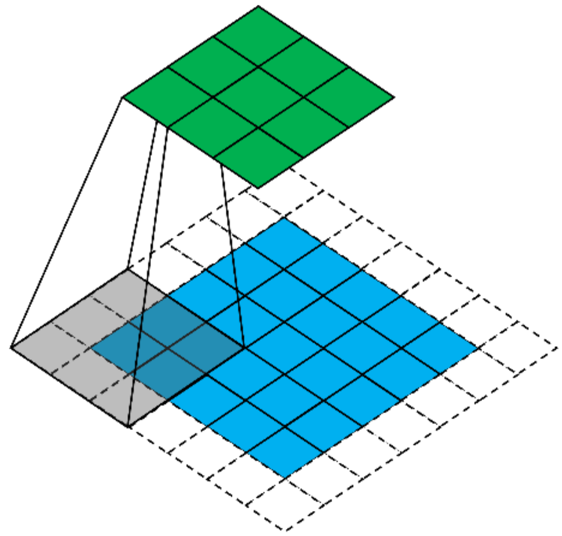

Figure 2.4 Visualization of a kernel reducing a 5x5x1 image into a 3x3x1 image using a 3x3x1 kernel.

(Saha, 2018)

Because kernels can break down an image into specific features, using multiple convolutional layers with different kernels allows the network to decompose the images into small features that can be interpreted and used to make classifications or decisions. Figure 2.5 shows an example of this process at different stages, starting with full input images of faces and going into specific lines (or feature maps) that can be used to classify the image.

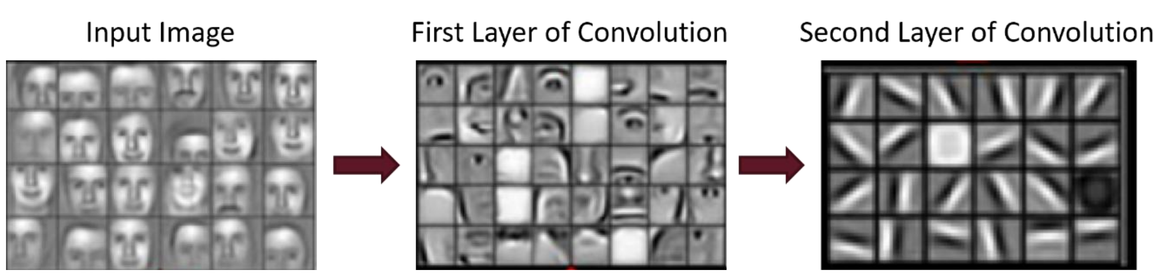

Figure 2.5 Examples of images being decomposed into small features that can be interpreted by the neural network.

Adapted from Siegel et al. (2016)

The feature map outputs of these convolutional layers can be combined with a traditional fully connected neural network to create a complex architecture capable of using the extracted features to classify images or even identify multiple objects within a single image. Figure 2.6 shows such a network with the specific application of handwritten letter recognition.

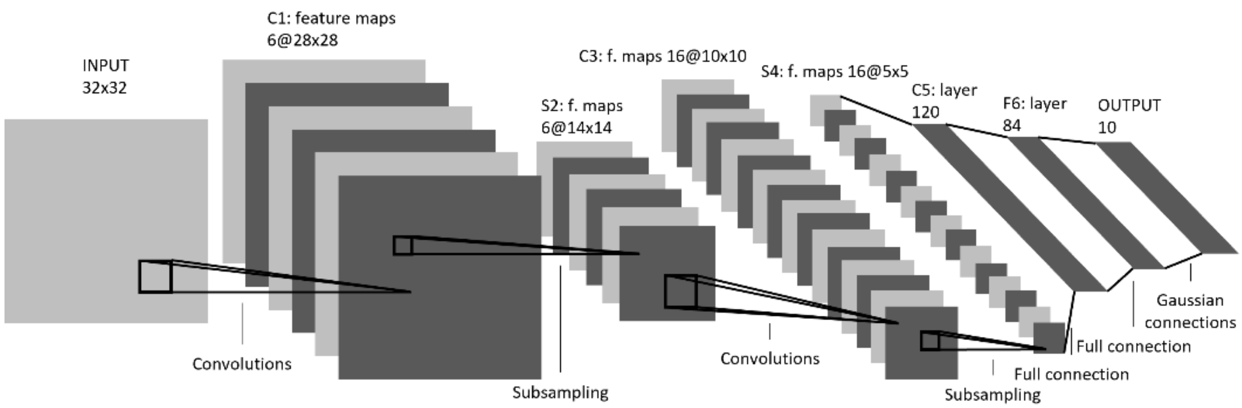

Figure 2.6 Example of a CNN architecture for handwriting recognition.
(Lecun et al., 1998)

CNNs are very capable for image recognition; however, the application of this research is sound recognition. The typical technique for sound recognition is to convert the audio into an image using spectrograms (Anuntachai & Pavaranchanakul, 2020; B et al., 2020; Huaysrijan & Pongpinigpinyo, 2021; Jin et al., 2022; Lee & Kim, 2020; Mkrtchian & Furletov, 2022; Yuh & Kang, 2021; Zhang et al., 2021). A spectrogram displays frequency on the y-axis, time on the x-axis, and volume (usually in decibels) with the color of the pixels in the image, as shown in Figure 2.7. This allows the CNN to view a small window of sound as an image and classify it based on the extracted features from the convolutional layers.

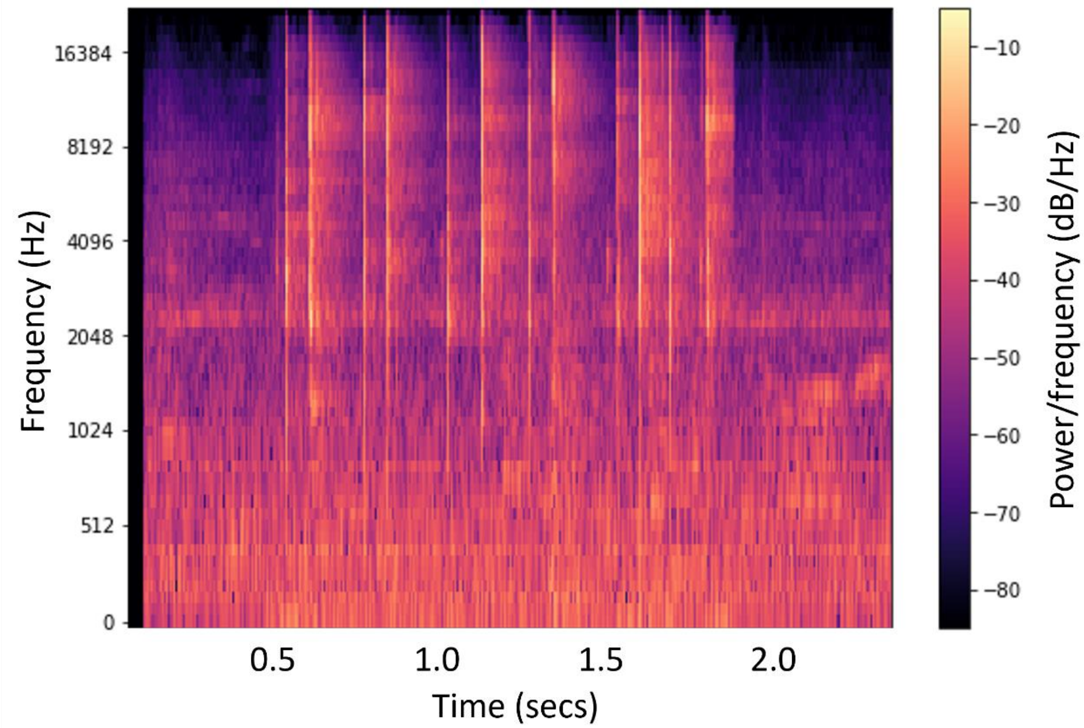

Figure 2.7 A generated spectrogram of a pen clicking.

Different types of model architectures building on or deviating from the traditional CNN architecture have been investigated. Recurrent neural networks (RNNs) that factor in the sequence of data have also been used because they allow for contextual interpretation of the clips that are used to generate the spectrograms (Chatterjee et al., 2020; Singh et al., 2021; Xia et al., 2020; T. Zhou et al., 2021). Pre-existing neural networks like AlexNet have been used with success (B et al., 2020). Some newer research has investigated using multiple networks in tandem with spectrograms and waveforms for stronger classification (Dong et al., 2020; C. Y. Wang et al., 2020; M. Wang et al., 2020). While more complex networks such as the examples above show high accuracy with sound recognition, the basic CNN architectures used as benchmarks in these papers are accurate enough to provide a minimum viable product for quick prototyping and experimentation.

Most papers used a dataset of clean individual sounds for training and testing. However, one paper in particular experimented with using clean sounds for training but introducing background noise in the testing dataset to simulate varying noise conditions (C. Y. Wang et al., 2020). Because of the specific application of selective noise cancelling, that process was used in designing the methods for this research.

2.2.3 Human Validation of Sound-Related Research

To find a prior basis for this study, studies were identified that used human participants to rate sounds on some objective scale. Four papers were found that provided examples of similar research (Bailes & Dean, 2009; Bolton et al., 2020; Valentin et al., 2022; Young et al., 2017).

Two of the studies dealt with emotional responses or valence. Young et al. (2017) used the emotional responses of participants to validate the emotional aspects of the Oxford Vocal Sounds database and find differences in how genders perceive emotion through audio. Bailes & Dean (2009) asked participants to rate music clips on valence and arousal in a two-dimensional scale to measure how sound structure affected the reaction of the participant.

The other two studies dealt with recognizing sounds. Valentin et al. (2022) evaluated the similarly of a recreated airplane cabin mock-up to the sounds of a real airplane cabin by asking participants to rate sounds on a similarity Likert scale. Bolton et al. (2020) showed that emergency alarm sounds could be masked by their primary harmonics by asking participants to compare an alarm sound to a test sound that had the alarm sound injected into it on certain tests.

The common format of these studies is a participant listening to a sound out of a pre-selected and randomized bank of sounds and giving some subjective rating to the sound. The delivery differs from study to study and the goal of the research changes, but the basic framework remains the same. Specifically, the self-administered nature of the examples provided the groundwork for designing this study.

2.3 Methods of Study

2.3.1 Neural Network Design

Because a basic CNN architecture is capable of providing a strong baseline and rapid prototyping, the network used in this experiment is a basic CNN architecture. This particular architecture was chosen out of four basic architectures because it showed usable results in early testing, is quick to train, and easy to explain. Table 2.1 and Figure 2.8 outline the architecture, which uses two convolutional layers and two standard dense layers.

Table 2.1 Proposed CNN architecture description.

Layer (type)	**Output Shape**	**Activation Function**	**Param #**
Input	(none, 64, 87, 1)	N/A	0
Conv2D	(none, 60, 83, 32)	ReLU	832
MaxPooling2D	(none, 30, 41, 32)	N/A	0
Conv2D	(none, 29, 40, 64)	ReLU	8256
MaxPooling2D	(none, 14, 20, 64)	N/A	0
Dropout(0.3)	(none, 14, 20, 64)	N/A	0
Flatten	(none, 17920)	N/A	0
Dense	(none, 50)	ReLU	896050
Dense	(none, 2)	Softmax	102

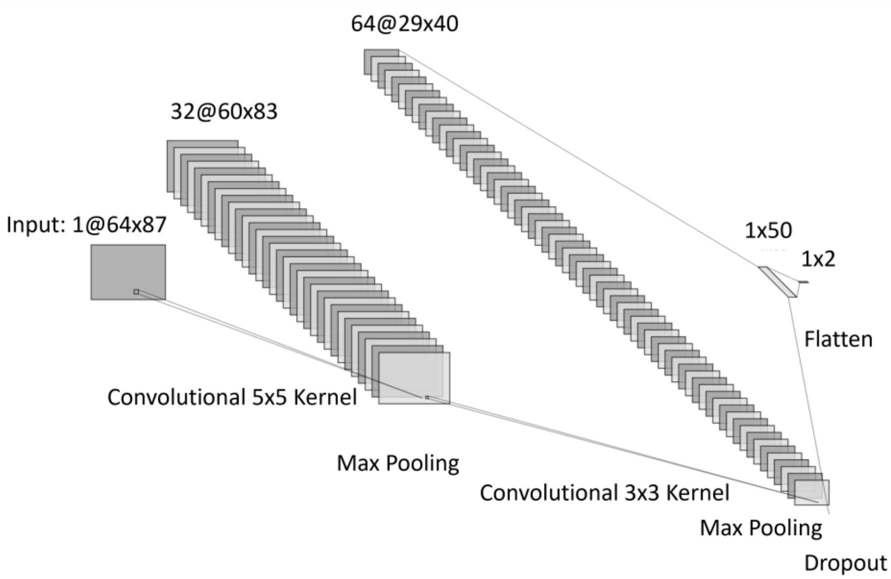

Figure 2.8 Proposed CNN architecture for selective noise cancelling.

The input for the network is a spectrogram, as shown in Section 2.2.1. Each spectrogram is 64x87x1 and is generated from a 0.125 second audio clip using a Gaussian window with a mean of 512 samples and a standard deviation of 85 samples.

The architecture had a binary output of "trigger sound/no trigger sound" because differentiating between trigger sounds is unnecessary at this time. Future work could investigate a multi-output network to classify specific trigger sounds simultaneously.

2.3.2 Sound Preparation

Once the neural network was designed, the sounds to be used for training and the experiment were selected. Based on the anecdotal reports in case studies and a survey performed by Claiborn et al. (2020), four types of trigger sounds were selected from the top three categories of trigger sounds by percentage of people triggered: chewing sounds and crunching sounds were selected from the most common category of mouth sounds, sniffing was selected from breathing sounds, and pen clicking was selected from mechanical sounds. This was done to ensure the highest likelihood of participants experiencing reactions to at least one of the sounds. Table 2.2 shows the categories of sounds from Claiborn et al.

Table 2.2 Ranking of categories of trigger sounds in terms of commonality.

Trigger sound	**Percent (N = 1,061)**
Mouth sounds, such as chewing, crunching food, lip smacking, slurping, tongue clicking, or throat clearing	96.5%
Breathing sounds, such as gasping, wheezing, sniffing, or other loud, mouth sounds	83.3%
Mechanical sounds made by hand, such as keyboard clicking, pen clicking, pencil tapping, crinkling paper, or nail clipping	67.3%
Foot sounds, such as tapping, stomping, shuffling, or squeaking shoes	59.5%
Hand sounds, such as finger snapping, tapping, or rubbing	58.7%
Speech sounds, such as consonant sounds (s, k, p, etc.) or mispronunciation of words	46.0%
Mechanical sounds without people involved, such as clock ticking, copy machine noise, or phone ringing	38.3%
Joint sounds, such as knuckle cracking	36.9%
Other sounds	27.6%

(Claiborn et al., 2020)

Then, “neutral” or “control” sounds were selected that are regularly encountered and would likely not cause a misophonic reaction in the participants (not mentioned in the Claiborn study or anecdotes). Ambient sounds of neighborhoods, streets, and nature were selected as a category that occurs in every day life and should not be cancelled out; talking with no mouth sounds was selected as another category that should not be cancelled out; and finally music was selected because it is often used to calm down or mask trigger sounds and so is likely not a trigger itself.

The ‘cancelled’ sounds, or the sounds that have been run through selective noise cancelling, were then created. The first step in the process was to develop a dataset for training.

Trigger sounds from the four categories and control sounds from the three categories were sliced into 0.25 second increments to match the input of the neural network. The dataset was then split into training and validation data with an 80/20 split. The testing dataset was created by using new control sounds and trigger sounds mixed with ambient noise, as noted in C. Y. Wang et al. (2020) to simulate real noise conditions. The training and testing datasets were augmented using random white noise and volume augments. After the network was trained, the trigger sounds were sent through the network to detect and cancel out the triggering portion of the sound clip. Figure 2.9 outlines this process. Table 2.3 shows the number of sounds in each category to be used for the study.

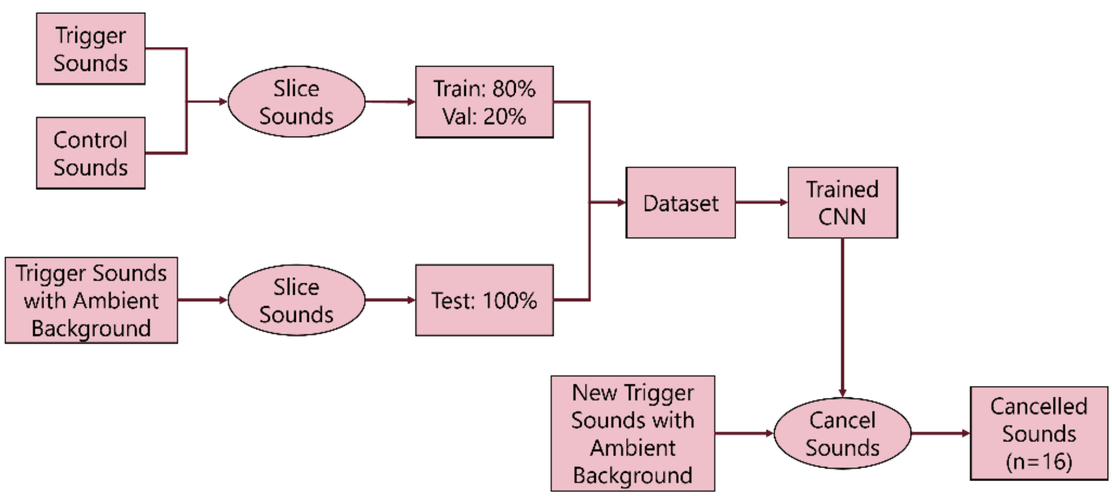

Figure 2.9 Process of creating cancelled sounds for study.

Table 2.3 Number of sounds for study

Category of Sound	Number of Samples for Study
Trigger Sound	16
Control Sound	16
Cancelled Sound	16

2.3.3 Recruitment

Participants for the study were selected from the population of people with misophonia, either self-diagnosed or with an official diagnosis. The misophonia community on Reddit (www.reddit.com/r/misophonia) was selected as the single largest population of people with misophonia that allows recruitment for approved research. At the time of the study, there were over 65,000 members in the community. Participants were recruited with a post containing a basic description of the research and a link to the Qualtrics survey. In addition, participants were recruited through a mailing list with over 800 members who were willing to participate in online surveys related to misophonia. A power analysis was conducted using an effect size of 0.55 and a power of 0.8 taken from the example of Bolton et al. (2020), showing that 16 participants were needed.

2.3.4 Survey

The Qualtrics survey contained three sections. The first section of the survey consisted of a demographic questionnaire. This questionnaire contained basic demographic questions of age, gender, age of onset of misophonia, and if the participant was currently receiving treatment for misophonia, whether therapy, audiological aid, pharmacological aid, or some other form of treatment. Participants were asked to rate their misophonia on the Misophonia Activation Scale (T. Dozier, 2016).

The second section consisted of 48 randomly shuffled questions. Each question contained one of the 48 sounds, either a trigger sound, control sound, or cancelled sound, and a slider. On the slider, the left-most side was labeled as "no misophonic reaction to sound" and the right-most side was labeled as "extreme misophonic reaction to sound," where "misophonic reaction" was defined as the reaction the participant generally has to their specific triggers. This slider captured data on a scale from 1 to 100, which was not visible to respondents. At each question, participants were instructed to listen to the sound and rate their reaction to it. After each question, participants were asked if they wanted to continue to the next question, to give time for recuperation if a trigger was particularly extreme. At any point, participants were able to opt out from the survey with no ramifications. After the control sounds with talking was a question asking what the last word spoken in the audio clip was. This was to determine if the participant was actually responding to the questions, allowing for easier data cleaning. Figure 2.10 shows an example of a question with the data cleaning questions.

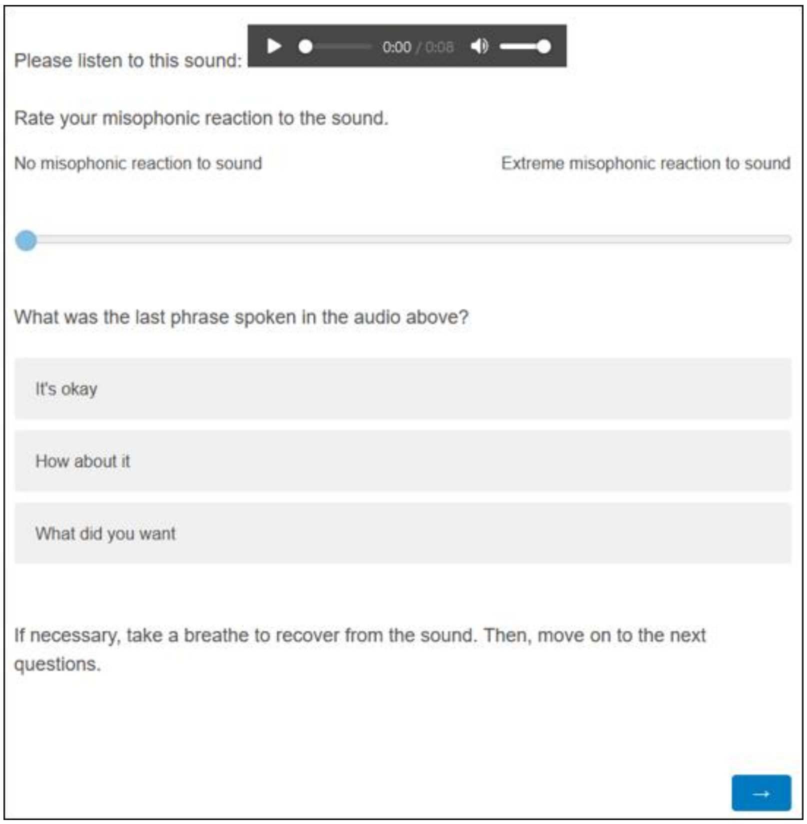

Figure 2.10 Example of a question in the first portion of the Qualtrics survey.

In the third section of the survey, participants were asked to rate on a Likert scale how often they were triggered by the specific sounds that occurred in the survey, including the control sounds. These questions were used for further data cleaning.

2.3.5 Data Analysis

The dependent variable for this study is reaction rating, measured as an integer value on a scale of 1 to 100, where 1 is the lowest possible reaction to a sound and 100 is the most severe reaction possible to a sound. The independent variable is sound category, which has three values: control, trigger, and cancelled. The hypothesis is that the reaction rating for cancelled sounds will be significantly lower than the reaction rating for trigger sounds. This will indicate that selective noise cancelling significantly lowers misophonic reactions to trigger sounds. Additionally, the reaction rating for control sounds should be significantly lower than the reaction rating of the trigger sounds. This will indicate that the experimental methods were valid, in that trigger sounds elicited a higher reaction than non-trigger sounds as is expected for participants with misophonia.

The hypothesis is defined in the following equations:

$$reaction_{cancelled} < reaction_{trigger} \tag{2.1}$$

$$reaction_{control} < reaction_{trigger} \tag{2.2}$$

IBM SPSS software (v. 29) was used for data analysis. The first step in the data analysis process was to clean the data. Incomplete responses and responses that failed the validation checks in the survey were removed. Responses for specific types of trigger sounds were removed if the participant responded that they never were triggered by that sound. Responses for specific types of ambient sound were removed if the participant said they were triggered most of the time or always by that type of ambient sound. Then, summary descriptive statistics of the reaction ratings were calculated for each sound category.

The hypotheses were then tested using a repeated measures (RM) ANOVA test with α=0.05. The ANOVA test was chosen because the data generally follows a normal distribution, the distributions have similar variance, and the data between participants is independent. The sounds in each category (trigger, control, cancelled) were averaged for each participant, creating three measures that could be used in the RM ANOVA. After the initial repeated measures ANOVA test of the hypotheses, the data was aggregated by type of sound (e.g., chewing, ambient crowd noise, cancelled pen click) for each participant using an average. This more detailed aggregation was used to test more detailed effective RM ANOVA tests for each type of sound. Finally, further exploratory analyses were conducted to explore the influence of demographic factors on reaction ratings.

The overall effectiveness of the technology was calculated using a unitless metric for improved understanding. The responses for the first survey section were converted into values per participant using the following equations:

$$Control\ Similarity\ (CS) = |mean_{cancelled} - mean_{control}| \tag{2.3}$$

$$Trigger\ Similarity\ (TS) = |mean_{cancelled} - mean_{trigger}| \tag{2.4}$$

$$Effectiveness = \frac{CS}{TS} \tag{2.5}$$

An effectiveness score less than 1.0 means that the reaction to cancelled sounds is more similar to control sounds than trigger sounds, meaning that the technology is effective. An effectiveness score greater than 1.0 means that the reaction to cancelled sounds is closer to the reaction to trigger sounds, meaning the technology is not effective. If $TS = 0$, then the

Effectiveness score is marked as “null.” Effectiveness was calculated for each participant, as well as the overall system.

2.4 Results

2.4.1 Participants

The survey was open for 17 days and 113 participants entered responses into the survey. Seven responses were removed because they failed the data validation checks, and 17 responses were removed because they were incomplete. The remaining valid responses were cleaned according to the processes in Section 2.3.5. Eight participants rated one or more of the control sounds as triggers, and 17 participants rated one or more of the trigger sounds as a control sound; these responses were removed from the data. After the initial data validation and cleaning, there were 89 valid responses to the survey.

Participants were predominately female (63 female, 19 male, 5 non-binary / third gender, 2 prefer not to say) and between 18 and 77 years old (39.2 ± 15.5). The average age of onset was 12.7 ± 8.8 years old, and the average length of time having misophonia at the point the survey was taken was 26.5 ± 15.9 years. Out of the 89 participants, 36 selected that they were currently receiving or had received treatment (therapy = 24, counseling = 14, audiological treatment = 8, pharmacological treatment = 7, other = 10); Table 2.4. The self-rating on the Misophonia Activation Scale revealed that almost all of the participants had a misophonia rating of at least 4 (6.4 ± 1.9). Figure 2.11 shows the misophonia severity, age of onset, and age of the participants. A few participants reported the age of onset as below 5; these responses were not removed because there is support for infants and toddlers exhibiting misophonic symptoms (Sanchez & Silva, 2018; Siepsiak et al., 2023).

Table 2.4 Combinations of treatments received by participants.

Treatments	N	%
All	**29**	**33%**
Therapy	11	15%
Therapy and Other Treatments	13	12%
Counseling	14	16%
Audiological	8	9%
Pharmacological	7	8%
Other	10	11%

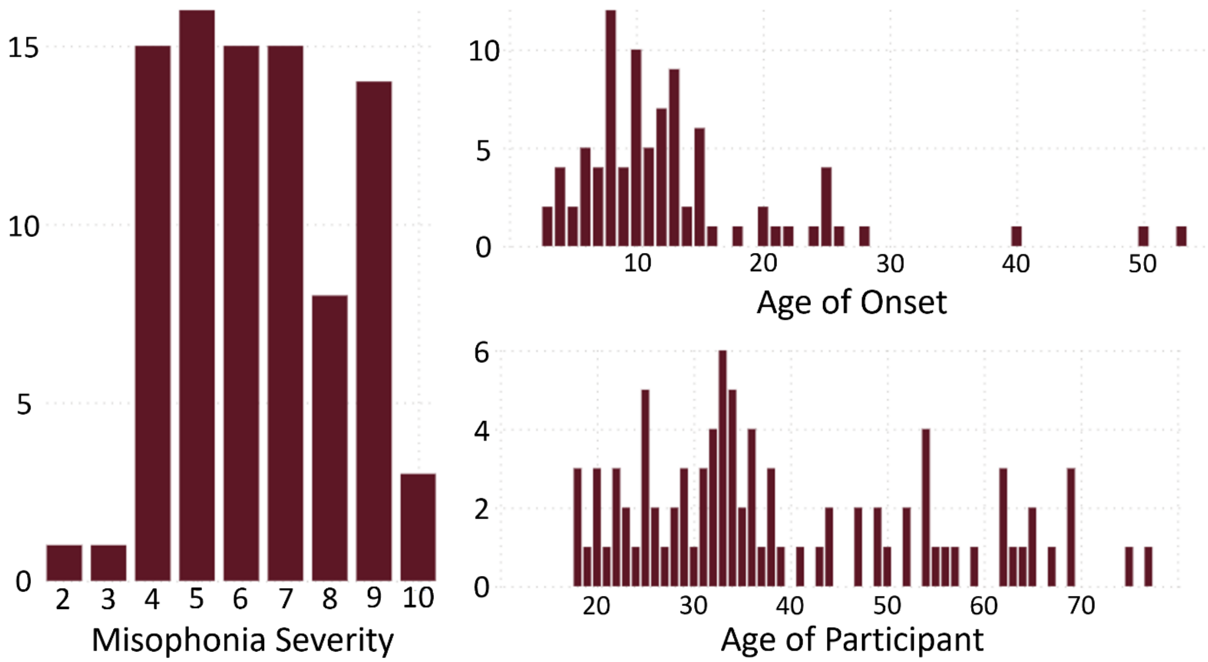

Figure 2.11 Visualizations of misophonia severity, age of onset, and age of participant.

2.4.2 Data Analysis

2.4.2.1 Summary Statistics

The summary statistics for the reaction ratings for each type of sound were calculated and placed in Table 2.5. The scale for the reaction ratings is from 1 to 100, where 1 is the lowest reaction to a sound and 100 is the most extreme reaction to the sound.

Table 2.5 Summary statistics for the participant responses to each sound used in the study.

Category	Sound	N	Median	Mean	Standard Deviation
Trigger	Chew	344	84	74.2	29.1
	Crunch	339	78	71.6	29.4
	Pen Click	284	39	41.3	31.2
	Sniff	337	50	52.5	33.8
Control	Ambient Crowd Noise	327	5	15.6	21.1
	Music	352	1	5.4	11.6
	Outdoor Ambience	334	1	4.3	9.5
	Talking	343	3	10.7	17.6
Cancelled	Cancelled Chew	342	3	10.9	18.7
	Cancelled Crunch	333	2	9.5	16.9
	Cancelled Pen Click	279	2	9.0	15.1
	Cancelled Sniff	326	2	8.0	13.2

2.4.2.2 Initial ANOVA Analysis

The initial RM ANOVA test was run with the three aggregated categories of sounds: trigger, control, and cancelled. Mauchly's test of sphericity showed that the data violated the assumption of sphericity, so the Greenhouse-Geisser adjusted measure was used. There was a statistically significant effect of the category of sound on the reaction rating by the participant ($F_{1.3,114.3} = 497.7$, $p < 0.001$). Figure 2.12 visually displays the marginal means of the three categories of sounds.

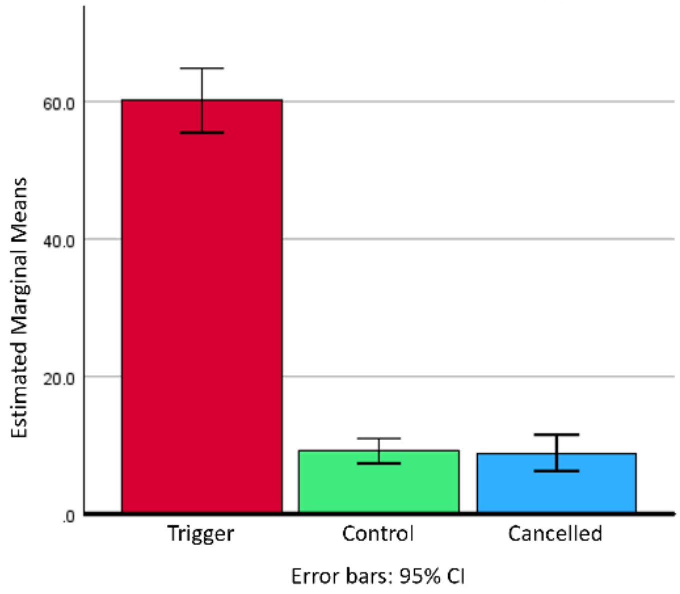

Figure 2.12 Estimated marginal means of the three categories of sounds.

A post hoc pairwise comparison using least significant difference (LSD) showed a significant difference between the trigger sounds and control sounds ($p < 0.001$) and between the trigger sounds and cancelled sounds ($p < 0.001$). However, the difference between the control sounds and cancelled sounds was not statistically significant ($p = 0.785$). Table 2.6 shows the full results of the pairwise comparison.

Table 2.6 Pairwise comparison results of the three categories of sounds. Significant differences have been highlighted.

Categories		**Mean Difference**	**Standard Error**	**Significance**	**95% Confidence**	
					Lower Bound	**Upper Bound**
Trigger	Control	50.973	2.142	< **0.001**	46.716	55.230
	Cancelled	51.238	2.229	< **0.001**	46.808	55.668
Control	Trigger	-50.973	2.142	< **0.001**	-55.230	-46.716
	Cancelled	0.265	0.969	**0.785**	-1.660	2.190
Cancelled	Trigger	-51.238	2.229	< **0.001**	-55.668	-46.808
	Control	-0.265	0.969	**0.785**	-2.190	1.660

2.4.2.3 Detailed ANOVA Analysis

A more detailed ANOVA analysis was used to measure the differences between specific trigger sounds and their corresponding cancelled sounds. Mauchly's test of sphericity showed that the data violated the assumption of sphericity, so the Greenhouse-Geisser adjusted measure was used. There was a statistically significant effect of the type of sound on the reaction rating by the participant ($F_{3.4,236.9} = 213.8$, $p < 0.001$). Figure 2.13 shows the marginal means of the eight types of sounds.

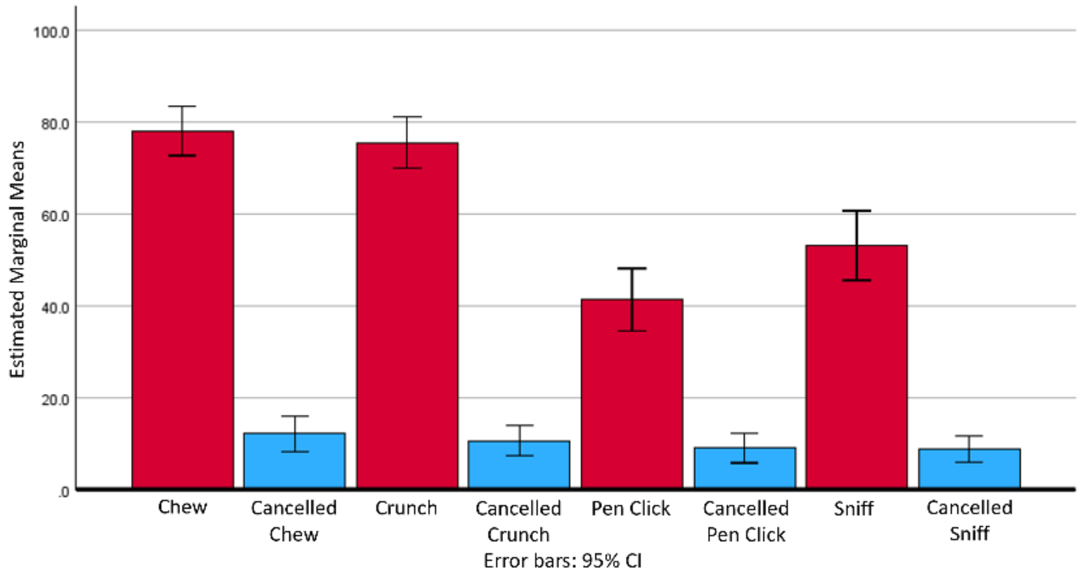

Figure 2.13 Estimated marginal means of the eight types of sounds measured in the detailed RM ANOVA.

A post hoc pairwise comparison using LSD showed a statistically significant decrease in the reaction rating between each trigger sound and the corresponding cancelled sound (e.g., chew and cancelled chew) ($p < 0.001$ for each set of sounds). Table 2.7 shows the full pairwise comparison.

Table 2.7 Pairwise comparison results of the eight types of sounds. Significant differences have been highlighted.

Categories		Mean Difference	Standard Error	Significance	95% Confidence	
					Lower Bound	Upper Bound
Chew	Cancelled Chew	65.943	2.856	**< 0.001**	60.245	71.641
	Crunch	2.491	1.986	**0.214**	-1.470	6.453
	Cancelled Crunch	67.416	2.873	**< 0.001**	61.683	73.148
	Pen Click	36.697	3.282	**< 0.001**	30.149	43.245
	Cancelled Pen Click	69.057	2.834	**< 0.001**	63.403	74.711
	Sniff	24.921	3.996	**< 0.001**	16.949	32.893
	Cancelled Sniff	69.211	2.747	**< 0.001**	63.731	74.692
Cancelled Chew	Chew	-65.943	2.856	**< 0.001**	-71.641	-60.245
	Crunch	-63.451	2.952	**< 0.001**	-69.340	-57.563
	Cancelled Crunch	1.473	1.040	**0.161**	-0.601	3.547
	Pen Click	-29.246	3.364	**< 0.001**	-35.956	-22.535
	Cancelled Pen Click	3.114	1.062	**0.005**	0.996	5.233
	Sniff	-41.021	3.880	**< 0.001**	-48.761	-33.281
	Cancelled Sniff	3.269	1.077	**0.003**	1.121	5.416
Crunch	Chew	-2.491	1.986	**0.214**	-6.453	1.470
	Cancelled Chew	63.451	2.952	**< 0.001**	57.563	69.340
	Cancelled Crunch	64.924	3.036	**< 0.001**	58.867	70.981
	Pen Click	34.206	3.359	**< 0.001**	27.504	40.907
	Cancelled Pen Click	66.566	2.866	**< 0.001**	60.848	72.283
	Sniff	22.430	4.044	**< 0.001**	14.363	30.497
	Cancelled Sniff	66.720	2.883	**< 0.001**	60.968	72.472
Cancelled Crunch	Chew	-67.416	2.873	**< 0.001**	-73.148	-61.683
	Cancelled Chew	-1.473	1.040	**0.161**	-3.547	0.601
	Crunch	-64.924	3.036	**< 0.001**	-70.981	-58.867
	Pen Click	-30.719	3.115	**< 0.001**	-36.932	-24.505
	Cancelled Pen Click	1.641	0.612	**0.009**	0.420	2.863
	Sniff	-42.494	3.602	**< 0.001**	-49.680	-35.308
	Cancelled Sniff	1.796	0.628	**0.006**	0.543	3.048
Pen Click	Chew	-36.697	3.282	**< 0.001**	-43.245	-30.149
	Cancelled Chew	29.246	3.364	**< 0.001**	22.535	35.956
	Crunch	-34.206	3.359	**< 0.001**	-40.907	-27.504
	Cancelled Crunch	30.719	3.115	**< 0.001**	24.505	36.932
	Cancelled Pen Click	32.360	3.146	**< 0.001**	26.084	38.636
	Sniff	-11.776	3.719	**0.002**	-19.194	-4.357
	Cancelled Sniff	32.514	3.040	**< 0.001**	26.449	38.579

Table 2.7 (continued)

Categories		Mean Difference	Standard Error	Significance	95% Confidence	
					Lower Bound	Upper Bound
Cancelled Pen Click	Chew	-69.057	2.834	**< 0.001**	-74.711	-63.403
	Cancelled Chew	-3.114	1.062	**0.005**	-5.233	-0.996
	Crunch	-66.566	2.866	**< 0.001**	-72.283	-60.848
	Cancelled Crunch	-1.641	0.612	**0.009**	-2.863	-0.420
	Pen Click	-32.360	3.146	**< 0.001**	-38.636	-26.084
	Sniff	-44.136	3.621	**< 0.001**	-51.359	-36.912
	Cancelled Sniff	0.154	0.595	**0.796**	-1.032	1.341
Sniff	Chew	-24.921	3.996	**< 0.001**	-32.893	-16.949
	Cancelled Chew	41.021	3.880	**< 0.001**	33.281	48.761
	Crunch	-22.430	4.044	**< 0.001**	-30.497	-14.363
	Cancelled Crunch	42.494	3.602	**< 0.001**	35.308	49.680
	Pen Click	11.776	3.719	**0.002**	4.357	19.194
	Cancelled Pen Click	44.136	3.621	**< 0.001**	36.912	51.359
	Cancelled Sniff	44.290	3.569	**< 0.001**	37.170	51.410
Cancelled Sniff	Chew	-69.211	2.747	**< 0.001**	-74.692	-63.731
	Cancelled Chew	-3.269	1.077	**0.003**	-5.416	-1.121
	Crunch	-66.720	2.883	**< 0.001**	-72.472	-60.968
	Cancelled Crunch	-1.796	0.628	**0.006**	-3.048	-0.543
	Pen Click	-32.514	3.040	**< 0.001**	-38.579	-26.449
	Cancelled Pen Click	-0.154	0.595	**0.796**	-1.341	1.032
	Sniff	-44.290	3.569	**< 0.001**	-51.410	-37.170

2.4.2.4 Exploratory Analyses

To use ANOVA analyses with the demographic data, the values for age, age of onset of misophonia, and the length of time having misophonia were aggregated into buckets, in addition to the time of day in which the survey was taken. Following the assumptions of normality and equal variance, the buckets were designed to capture a generally normal distribution for each set of data. Table 2.8 shows the divisions of the buckets for each set of data.

Table 2.8 Definitions of buckets used for aggregating demographic data.

Data	Division Definition	Bucket Number
Age	18 - 19	1
	20 - 29	2
	30 - 39	3
	40 - 49	4
	50 - 59	5
	60 - 69	6
	70 - 79	7
	80 +	8
Age of Onset	0 - 4*	1
	5 - 9	2
	10 - 14	3
	15 - 24	4
	25 +	5
Length of Time Having Misophonia	0 - 9	1
	10 - 19	2
	20 - 29	3
	30 - 49	4
	50 +	5

*Note that there is evidence for children under the age of five to exhibit misophonic symptoms. (Sanchez & Silva, 2018; Siepsiak et al., 2023)

Gender, severity of misophonia, age, age of onset, and length of time having misophonia were all tested individually as between-subjects factors for the basic ANOVA with the three aggregated categories of sound and for the detailed ANOVA with the eight aggregated types of sound. The time the survey was taken was also tested. As shown in Table 2.9, none of the tests resulted in a significant effect of the demographics on the reaction rating. In addition, linear regression tests on the continuous variables did not result in significant correlations.

Table 2.9 Within-subjects effects of each set of demographic data on the eight types of sound.

Demographic Data	Type III Sum of Squares	df	Mean Square	F	Significance	Partial Eta Squared
Gender	10253.554	10.390	986.846	1.697	**0.079**	0.072
Misophonia Severity	15590.593	26.316	592.447	0.932	**0.565**	0.109
Age	9670.059	19.809	488.158	0.761	**0.757**	0.068
Age of Onset	11353.479	13.560	837.259	1.400	**0.157**	0.079
Duration of Misophonia	11065.929	13.579	814.925	1.361	**0.176**	0.077
Start Time of Survey	5912.899	6.785	871.520	1.443	**0.191**	0.041

2.4.2.5 Effectiveness Score

The effectiveness score of the technology for each participant was calculated using the equations in Section 2.3.5. The mean effectiveness score was 0.3 ± 0.16 and a median of 0.05.

2.5 Discussion

2.5.1 Hypothesis Validation

The hypothesis as defined in Equations 2.1 and 2.2 says that selective noise cancelling is effective for controlling the misophonic reactions to trigger sounds, which would allow for further investigation into using selective noise cancelling for more holistic treatments of misophonia (Bernstein et al., 2013; T. H. Dozier, 2015a; Ferrer-Torres & Giménez-Llort, 2022; I. Jager et al., 2022; P. J. Jastreboff & Jastreboff, 2014; Petersen & Twohig, 2022; Smith et al., 2022). The results in Figure 2.12 and Table 2.6 show that in the data collected, trigger sounds are rated significantly higher (eliciting a more extreme reaction) than control sounds, which validates the measure being used in the study (Swedo et al., 2022).

In addition, the results in Figure 2.12 and Table 2.6 show that trigger sounds that have been modified using selective noise cancelling elicit a significantly lower misophonia response than trigger sounds that have not been selectively noise cancelled. This means that selective noise cancelling is effective for lowering the misophonic reaction to trigger sounds; or in other words, removing the trigger sound with selective noise cancelling removes the reaction to the sound, as the Jastreboffs and others have suggested.

2.5.2 Further Analyses

2.5.2.1 Data Cleaning and Processing

As expected, some participants responded that sounds classified as trigger sounds in the study did not trigger them and that some control sounds did trigger them. This is because triggers are unique for each individual and cannot be fully generalized for a population of this size. The reactions from those specific participants for those sounds were removed. This removal of data did not affect the outcome of the study because for each sound there were still more responses than the required amount.

Further investigation into the reaction rating data revealed outliers, both extremely low responses for trigger sounds and extremely high responses for control and cancelled sounds. Figure 2.14a visually shows the amount of outliers for each category, where the width of the violin plot indicates the number of data points at that reaction rating. Figure 2.14b shows the actual responses of an individual participant as an example; the first trigger sound has three responses that are high, as expected, and then a fourth response that is close to zero but not zero. The most likely explanation for these outliers is that triggers are highly unique and often people with misophonia will be triggered by specific instances of a type of sound and not other instances; to reference the definition of misophonia, it is the specific pattern of sound that is triggering (Swedo et al., 2022). These outliers were not removed because there is no evidence that they are incorrect inputs and the definition of misophonia supports the presence of them. Even with the outliers, the ANOVA analyses showed a statistically significant difference.

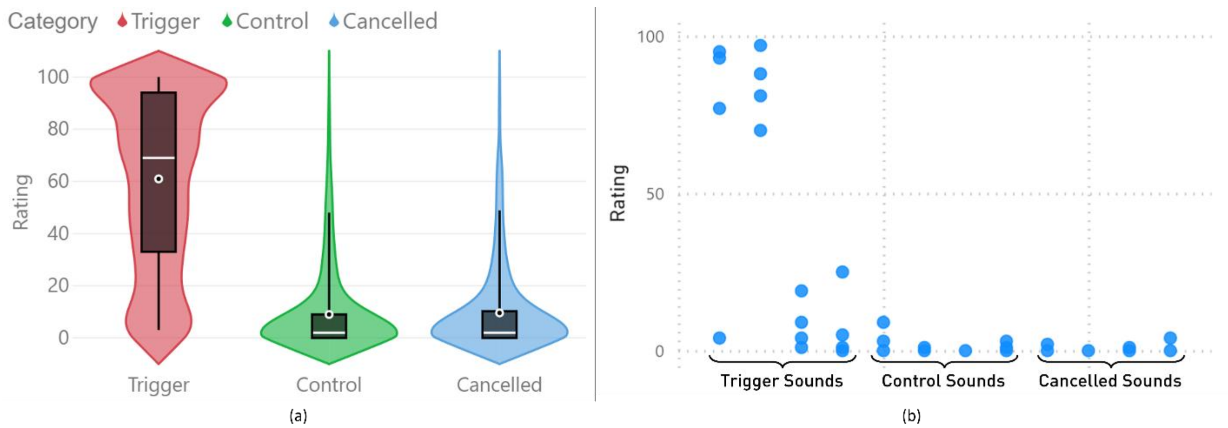

Figure 2.14 (a) Violin plot of the reaction ratings grouped by the three categories of sounds and (b) Scatter plot of the responses of a single participant.

2.5.2.2 Impact of Types of Sounds

In this study, four types of trigger sounds were used to increase the likelihood that every participant would be triggered by at least one sound. Further exploration in Section 2.4.2.3 demonstrated that, while selective noise cancelling significantly lowered the reactions to all trigger sounds tested, chewing and crunching were more affected than pen clicking and sniffing. This is primarily because pen clicking and sniffing are less common or less severe triggers than chewing and crunching (Claiborn et al., 2020; Swedo et al., 2022).

2.5.2.3 Impact of Demographics

None of the demographics had a significant effect on the results, showing that selective noise cancelling is effective regardless of variables like age, severity of misophonia, and gender.

Other large-scale studies, while focused on CBT treatments rather than audiological methods, have similarly not shown significant differences based on most demographics (I. J. Jager et al., 2021; A. E. Schröder et al., 2017). However, other research has suggested that females report higher severity of misophonic symptoms than males (Concepcion et al., 2020; Savard et al., 2022; Siepsiak et al., 2020), and the data does appear to show that the female participants generally had more severe reactions to all sounds than male participants, as shown in Figure 2.15. This difference, if valid, could have an impact on the perceived effectiveness of the selective noise cancelling or the desire to use selective noise cancelling in treatment. Therefore, further research should be done to confirm or refine the findings of this study as related to gender differences.

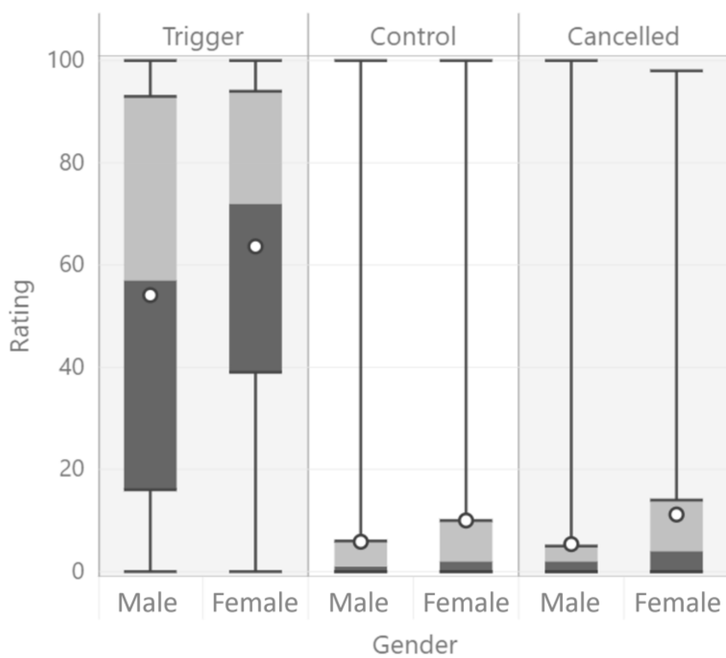

Figure 2.15 Differences in reaction ratings between male and female respondents.

2.5.3 Limitations

One of the major limitations of the study is that the environment in which the survey was taken was uncontrolled. A preliminary question asking if the participant was in a quiet room with earbuds was used in an attempt to mitigate this issue. However, differences in types of earbuds or headphones, volume of the device, environmental sound, and other factors could have introduced confounding factors that affected the results, especially with the demographic findings.

In addition, while the captured demographics showed no significant effect on the results, other demographics that were not captured, like nationality, could affect the results of the study.

Another limitation was the recruitment process. Most larger studies screen participants who have comorbid disorders (I. J. Jager et al., 2021; A. E. Schröder et al., 2017), while the screening in this study was limited to requiring the participant to be over 18 and be self-diagnosed or professionally diagnosed with misophonia. This was done to ensure the number of data points necessary to draw conclusions but could have introduced confounding factors in the participants.

The survey was unmonitored and self-administered by the participants; participants could have provided incorrect answers, rushed over parts of the survey, or changed environments halfway through, especially since the survey required voluntary exposure to trigger sounds. While attention validation questions were used and incomplete responses were removed, the unmonitored nature of the survey introduces the possibility of incomplete or inaccurate data.

In addition, the survey allowed the participant to interpret the reaction rating scale, meaning that different participants could have different reaction rating values but the same reaction, or vice versa. This should have minimal impact on the analyses in this paper because participants were compared against their own answers, but there is a possibility that the outcomes were influenced by this relativity.

Finally, the results of the study are necessarily limited because only four types of trigger sounds and four instances of each trigger sound were tested. The effectiveness of selective noise cancelling on the misophonic reaction to other types of trigger sounds, especially less common or less severe trigger sounds, remains an unknown.

2.5.4 Future Research

Because of these limitations, more research should be performed with more controlled environments, stricter screening, and a broader range of trigger sounds. This will strengthen the conclusions drawn from this first step in the research. Experts in misophonia treatment, especially those who have performed large studies, could be consulted on how to improve the testing process and environment to reduce the limitations of this study. Additional measures, such as physiological metrics or brain scans, could also be used to measure the severity of the misophonic reaction to sounds more accurately.

This survey design could also be applied in other ways. It could be used as a more verifiable method of identifying people with misophonia, as opposed to a questionnaire where the patient must recall their perceptions of their reactions to sounds. Ideally the patient would be removed entirely from the process of diagnosing misophonia, but using this survey would still get closer to the actual reactions of the patient as opposed to their perceptions. Alternatively, the survey could be used to investigate and assess potential treatments in an A-B style study where the participant takes the survey before and after applying treatment and the effects of the treatment can be measured more empirically than a self-reporting questionnaire.

In addition, the neural network design could be refined. More testing should be performed with the parameters of spectrogram generation, dataset creation, and length of audio clips. Experimentation with fuzzy logic to allow users to customize the aggressiveness of the network would further validate the intended use case. Further investigation into the more complex architectures detailed in Section 2.2.1 is also needed.

Finally, development and testing of a near real-time algorithm would allow for more testing in the intended environment. This research was conducted using an offline algorithm that analyzed and selectively cancelled sounds prior to the participant listening to them. Because of the design of the selective noise cancelling, real-time performance is impossible with current technology; however, near real-time performance could likely be achieved with a latency of less than a quarter second. This could potentially be applied in treatment settings and everyday use. For instance, one of the main difficulties with current treatment of misophonia is a patient anticipating a trigger sound and therefore experiencing the trigger whether they can actually hear it or not. Using a near real-time version of selective noise cancelling could allow a clinician to expose the patient to a video of someone performing a trigger and use the selective noise cancelling to remove the trigger sounds, allowing the patient to reduce their anticipatory reactions over time. Another application could be for video or audio streaming, where the output can be lagged slightly to match the latency of the selective noise cancelling system.

2.6 Conclusions

The current research into misophonia treatment is limited and primarily comprised of case studies and proposed treatments applying therapy techniques often used for anxiety and behavioral disorders. However, research into treatments for similar sensory disorders such as tinnitus and hyperacusis shows that a holistic approach, utilizing audiological treatments and alternative methods in addition to therapy, is more effective. The purpose of this research was to investigate the feasibility of using selective noise cancelling to control and reduce the misophonic reactions to trigger noises as a first step in applying audiological treatments to misophonia.

A basic prototype of selective noise cancelling was designed and applied to four types of trigger sounds. The effectiveness of the selective noise cancelling was evaluated in an online survey with 89 participants. The participants self-rated their reactions to the cancelled trigger sounds, un-cancelled trigger sounds, and non-trigger sounds to function as a control group.

The results showed that trigger sounds that had been selectively noise cancelled elicited a significantly lower misophonic reaction than trigger sounds that were not selectively cancelled. This means that selective noise cancelling can be applied to triggers to control misophonic reactions, allowing clinicians and patients to apply the audiological methods of treatment that are already validated for tinnitus and hyperacusis.

Future research should investigate the effectiveness of selective noise cancelling on more types of trigger sounds in a more controlled environment, as well as more robust and real-time designs for the selective noise cancelling.

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