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Development of Psychoacoustic Screening Tests for Hearing Assessments

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Abstract

The evaluation of suprathreshold listening abilities in audiological assessment is often minimized despite the valuable insight it produces about auditory discrimination skills. These capabilities can be assessed from psychoacoustic tests. However, measuring these abilities requires a significant amount of time. Therefore, screening tests were developed for frequency discrimination, gap detection, and amplitude modulation tests to identify individuals for whom these skills are most likely to be useful. The purpose of this project was to determine the ability of this screening tool to predict good performers and determine who is likely to have reduced skills and require full threshold assessment. Thirty normal hearing adults were enrolled in the study. The psychoacoustic threshold and screening tests employed the same 3-alternative forced choice procedure. Threshold estimates were obtained and compared to the screening test results. Findings revealed that listeners with psychoacoustic thresholds that fell within normal limits also passed the screening test.

Keywords

Psychoacoustics, psychophysics, psychoacoustic screener, screening, temporal processing, temporal resolution, frequency discrimination, gap detection, amplitude modulation, thresholds, suprathreshold, three-alternative forced choice, adaptive

Summary for Lay Audience

The ability to encode acoustic signal features of sound at suprathreshold levels shapes our perception of auditory signals. Suprathreshold abilities to discriminate acoustic signal features of sounds are overlooked in hearing assessments. Audiological assessments rarely evaluate suprathreshold auditory processing abilities beyond speech discrimination measures. Yet the ability to discriminate acoustic signal features of sounds can be impaired in listeners with hearing difficulties. This inability is found in listeners with auditory processing disorders. Professional associations recommend the use of both speech and non-speech-based tests to evaluate discrimination abilities. However, the use of speech-based tests is commonly preferred over non-speech based test. Psychoacoustics is a branch of hearing sciences that measures the physical properties of sounds and the sensations they evoke. Psychoacoustics are non-speech based tests that can assess the suprathreshold abilities to detect and discriminate acoustic features of sounds. However, these psychoacoustic tests can be lengthy, difficult, and require rigorous attention to complete. Therefore, psychoacoustic screeners for frequency discrimination, gap detection, and amplitude modulation have been created to identify individuals with reduced auditory discrimination abilities. It is important to assess auditory discrimination abilities through non-speech based tests since they are not confounded by language factors. The psychoacoustic screeners adhere to strict methodology procedures and principles of psychoacoustics similar to their test versions. The goal of the study was to evaluate the utility of psychoacoustic screening in a normal adult population. Psychoacoustic tests yield threshold estimates of their discrimination abilities. These thresholds were compared to the accuracy of the screeners' ability to assess good performers on these psychoacoustic tests. Findings in the study revealed that listeners with psychoacoustic thresholds that were within normative limits passed all the screeners too. The study demonstrates the possibility of screening for good performers on psychoacoustic thresholds in a normal adult hearing population.

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Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

Auditory Processing Disorder	APD
American Academy of Audiology	AAA
American Speech Language and Hearing Association	ASHA
Amplitude Modulation 20 Hz	AM20
Amplitude Modulation 200 Hz	AM200
British Society of Audiology	BSA
Canadian Association of Speech-Language Pathologists and Audiologists	CASLPA
Decibel	dB
Distortion Product Otoacoustic Emission	DPOAE
Frequency Discrimination	FD
Gap Detection	GD
Hertz	Hz
Milliseconds	msec
Otoacoustic Emissions	OAE
Sound Pressure Level	SPL
Standard Deviation	SD
Modulation Depth	m
Tucker Davis Technologies	TDT
Win in Noise Test	WIN

Chapter 1

1 Introduction

To recognize and understand the sounds of our environment, the auditory system must be able to accurately process complex auditory signals. The perception of auditory signals is shaped by our ability to encode basic signal features of sounds at suprathreshold levels. To evaluate these perceptual abilities requires strict adherence to the principles of signal detection theory (Green & Swets,1996). However, these procedures seldom receive clinical attention or use. Instead, the use of speech-based tests is commonly preferred yet they are seldom standardized. Speech-based tests measure overall speech performance but do not elucidate the underlying acoustic feature discrimination skills upon which perception of the speech is based. Psychoacoustic tests are non-speech-based measures that can assess the ability to detect and discriminate the fine features of sounds at suprathreshold levels given the relationship between the physical properties of sounds and our perception of those sensations (Roesser et al., 2007).

1.1 Suprathreshold Discrimination Abilities

1.1.1 Suprathreshold Testing in Auditory Processing Disorders

It has been well established that restricting audiometric assessment to threshold level evaluation may not accurately capture the hearing difficulties experienced by some individuals (Fullgrabe, 2012, Jerger et al., 1990, Stach et al., 1990, and Tremblay et al., 2015). Yet audiological assessments seldom evaluate suprathreshold auditory processing beyond speech discrimination measures. The ability to discriminate fine differences in frequency or following rapidly changing stimuli envelopes or other features of sounds is often impaired in listeners with hearing difficulties, and sometimes even in the presence of normal audiometric thresholds. This inability is also found in listeners with auditory processing disorder (APD) (Jerger et al., 1990, Chermak and Musiek, 1997, Billiet and Bellis 2011, Hind et al., 2011, and Musiek et al., 2018). The American Speech and Hearing Association (ASHA) has defined APD as individuals with deficits in the neural processing of auditory information in the central auditory nervous system not due to higher order language or cognition (ASHA, 2005). These individuals often have reduced auditory performance, difficulty in auditory discrimination, sound localization, and comprehension of speech, especially in the presence of background noise. ASHA recommends a test battery of both behavioural and physiological tests, including speech and non-speech based tests, to diagnose difficulties in auditory discrimination skills. It is well known that APD can have comorbidity with other conditions such as speech and language disorders (Sharma et al, 2009), and so performance on speech tests may be confounded. For this reason, it has been suggested that the evaluation of suprathreshold discrimination abilities, especially with non-speech based tests, is beneficial in differentiating those with APD from other disorders (Moore, 2006 and Moore et al., 2011).

1.1.2 Limitations of Speech-based Testing

Speech-based testing is often limited to English and therefore lacks applicability in evaluating suprathreshold discrimination abilities in individuals with different linguistic backgrounds. English speech-based tests have seen more use over other alternatives due to their availability, longevity, research support, and compatibility with most clinicians' own first language (Ramkissoon & Khan, 2003). Although speech-based tests have been developed in other languages, their accuracy and standardization have not yet been established (Marinova-Todd et al., 2011). Speech-based test performance can be confounded by the listener's linguistic background and competency. Information about a listener's auditory discrimination skills can be measured without the confounds of language through non-speech based tests. Yet, only a few non-speech based tests are available for hearing assessments. Important information about the auditory system's ability to encode spectral and temporal features of sounds can be measured using non-speech based tests but they are overlooked despite their benefits. For these reasons, speech-based tests are not the only sufficient method to evaluate suprathreshold auditory processing discrimination abilities.

1.1.3 Professional Recommendations on Discrimination Tests

To assess behavioural auditory processing abilities, professional associations such as ASHA recommend the inclusion of auditory discrimination tests that evaluate the listeners' ability to differentiate sounds that differ in frequency, intensity, and/or temporal parameters (ASHA, 2005). Other professional associations, like the American Academy of Audiology (AAA), Canadian Association of Speech-Language Pathologists and Audiologists (CASLPA), and the British Society of Audiology (BSA), also recommend similar tests of discrimination, temporal processing, resolution, binaural, dichotic listening, and other processes to highlight the integrity of the central auditory nervous system (AAA, 2010; CASLPA, 2012; BSA, 2018). These types of behavioural test recommendations suggest the need for further suprathreshold testing of discrimination abilities using non-speech auditory stimuli, especially in APD assessments. Ludwig and colleagues (2014) support using non-speech based tests since nonverbal stimuli can allow differentiation of auditory processing abilities between APD and related disorders such as specific language impairments. However, despite the support and recommendations from professional associations to assess different types of auditory discrimination capabilities, the selection of these tests is not standardized and the tests themselves are rarely clinically accessible. Therefore, it is important to recognize and implement more available non-speech based tests to evaluate suprathreshold discrimination abilities.

1.1.4 Need for Non-speech Based Testing

The inability to perceive fine acoustic features of a signal relates to the improper processing of temporal and spectral aspects of incoming speech. Degraded processing of these acoustic elements of speech can reduce the accuracy and quality of the sound. Without the confounds of language, the ability to detect and discriminate between small and large differences in features of sounds using non-speech based tests can be helpful in identifying those with listening difficulties. Non-speech based auditory processing abilities such as temporal and spectral resolution have been regarded as important factors in understanding spoken languages (Brewer et al., 2016). Children with APD likely have difficulty when encoding the spectral and temporal features of signals, especially in the presence of speech in noisy environments (ASHA 2005, Allen & Allan 2011, Allen &

Allan 2014, and Musiek et al., 2017). These auditory processing skills measured by non-speech-based tests are crucial for understanding the perception of spoken language (Brewer et al., 2016 and BSA, 2018). However, research indicate that the use of speech-based test results alone fail to reveal deficits in children suspected of APD (Ludwig et al., 2014). Recognizing the variety of both speech and non-speech based tests is crucial to understand suprathreshold discrimination abilities. Yet, speech-based tests are more adequately available despite the recommendation to use both types of measurements (ASHA, 2005, and Moore, 2006).

1.2 Psychoacoustics in Audiology Assessments

Psychoacoustics is a branch of hearing science that measures the relationship between sounds and the perceptions they evoke. Psychoacoustic assessments involve measuring the listener's ability to detect and discriminate signal features of sounds at suprathreshold levels. Some studies use psychoacoustic test measures to examine the relationship between hearing impairment and speech perception (Rosen 1992, Bailey and Snowling, 2002) but such tests remain limited in research. Musiek and colleagues (2018) have emphasized that different psychoacoustic tests have documented value in defining deficits of the central auditory nervous system. However, assessments of suprathreshold discrimination abilities using non-speech based tests like psychoacoustics are often overlooked in the clinical population despite recent developments with their applicability. Psychoacoustic tests are typically administered using research grade equipment and are conducted strictly in laboratory settings. Clinicians largely lack accessibility to the equipment needed, expertise, and the programming required to include psychoacoustic testing in a clinical test battery. Recently, a portable/ mobile psychoacoustic test system has been developed and tested to help reduce the impractical cost and setup for research grade psychoacoustic equipment (Barket & Purdy, 2016; Soares et al., 2021). In their study, frequency discrimination, gap detection, amplitude modulation, and binaural masking level difference tests produced equivalent thresholds to the research grade system. This suggests that psychoacoustics is a feasible option for evaluating suprathreshold discrimination abilities that encode the rapidly changing, spectral, temporal, and binaural aspects of sound. Although these limitations are resolved, the challenge of time and duration to explore multiple aspects of temporal and spectral features of sounds in these tests has not been addressed. In general, psychoacoustic tests can be lengthy. The development of a screening test for discrimination skills would be a benefit in determining when further assessment is needed in the identifying those with poor discrimination abilities.

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Chapter 2

2 Psychoacoustics

2.1 Developing Psychoacoustic Screeners

The evaluation of suprathreshold discrimination abilities needs to be efficient and quick. Performances on psychoacoustic experiments have been known to be affected by various factors such as attentional levels, concentration and motivation of the listener and response criteria used for the task (Wightman et al., 1989). AAA states that behavioural central auditory tests, in terms of administration time and diagnostic power, can be accomplished within 45-60 minutes but confounds of fatigue, attention and motivation issues increase testing time (AAA, 2010). To develop a screening tool, researchers must adhere to strict procedural rules and signal control features. Few studies have incorporated a screening or training phase when measuring auditory discrimination abilities using psychoacoustic procedures (Abramson and Lloyd, 2016, Sanchez and Lam, 2007, and de Carvalho, 2021). Furthermore, currently only one study, by de Carvalho and colleagues (2021), has created a screening tool for auditory processing disorders called AudBility. Within their procedure, a gap screening test is included but it is more of a training tool than a screener since it does not follow psychoacoustic methodology or use standard deviation threshold cut-off ranges. Psychoacoustic screening is limited in the field and there is no proper direction in how it should be developed. Due to progression and advancements in resolving cost efficiency issues and setup of psychoacoustic tests in recent years, the development of a psychoacoustic screener is the next step for measuring auditory discrimination abilities.

At its core, we understand that the strength of nonspeech tasks is that it is not bounded by linguistic factors so we can examine the fundamental auditory elements of signal encoding processes in hearing. Although our suprathreshold abilities can change over time with significant practice and training, large differences in thresholds are still problematic as an indicator of poor auditory discrimination skills. It has been suggested that suprathreshold discrimination deficits continue to persist even if audibility and loudness perception are restored through compensation strategies (Kortlang et al., 2015). With many published discrimination thresholds on various psychoacoustic tests are available such that typical levels of performance can be used to determine and/or verify pass/fail criteria for screening tools. The creation of a psychoacoustic screening tool for specific discrimination abilities would reduce the impact of attention and decrease test time for the listener. It has been suggested that the development of a screening tool that can identify those that require further investigation into their signal encoding abilities would be a good way to adopt psychoacoustic tests into further clinical assessments (Allan, 2011).

2.2 Psychoacoustic Testing Methods and Principles

2.2.1 Thresholds in Psychoacoustics

In psychoacoustics, a listener's perceptual accuracy is described though a psychometric function (Shen, 2013). A psychometric function yields a threshold, an estimate of a predetermined percent correct performance on the psychometric function in a slope that describes the rate of change in performance of the listener as the signal is changed. Because normal hearing adults show limited variation in psychometric function slopes, a single point on the psychometric function (threshold) can be used to describe their performance (Allen and Wightman, 1994). Adult thresholds remain relatively similar on many discrimination tests (Jesteadt et al., 1977, Wightman et al., 1989, Freyman & Nelson, 1991, Shailer & Moore, 1983, and Shemesh, 2008).

Thresholds obtained using psychoacoustic measures highlight the auditory system's ability to encode basic signal features. Threshold values are the primary area of interest when understanding suprathreshold mechanisms of discrimination abilities during psychoacoustic measurements. Individuals may show elevated thresholds, which would indicate their limitations in processing and encoding large differences in signal features. Some children tend to show poorer or more variable thresholds with shallower psychometric functions (Allen & Wightman, 1995) while others can perform comparably to adults (Halliday et al., 2008).

2.2.2 Forced-choice Procedure in Psychoacoustics

Measuring an individual's response to sound using very well-controlled procedures and stimuli can potentially aid in the identification of listening difficulties undetected by the basic audiological evaluations. The procedures used to assess psychoacoustic performance use well defined stimuli and methodology (Green, 1966). Psychoacoustic assessment often uses forced-choice procedures in research settings. Forced-choice procedures have well defined trials that consist of multiple listening intervals. A listener performing the task is instructed to select which of the intervals contained the signal that was different from the rest. Even if the listener is unsure of the target, they must respond in each trial for the test to continue. By requiring a response in each trial, the performance estimate is bias free. Bias can be reflected in the listener who is either very liberal or very conservative in their response to a given trial. In a forced choice procedure, the listener must make a choice in each trial regardless of their degree of certainty. In most forced choice psychoacoustic tests, threshold is taken at the signal level that produces a 70.7% correct performance (Leek, 2001). The number of alternatives determines the level of chance against which performance is evaluated. A 2AFC procedure places chance performance at 50% while a 3AFC procedure has a chance level of 33%. This methodology and its techniques are simple, robust, efficient and reliable procedures (Levitt,1971).

2.2.3 Adaptive Rules in Psychoacoustics

An important part of psychoacoustic testing is how stimulus values change from trial to trial. Signal values in each trial may be fixed (differences of various magnitudes may be tested in a predetermined order) or vary as a function of the listener's performance in previous trials. Stimulus differences are adaptive. The adaptive rules allow for greater efficiency in testing. Signal values are concentrated in the range of just detectable differences. More signals around the threshold estimate makes the estimates more reliable. The rules by which stimulus values change determine the estimated percent correct and also determine which percent correct level is being tracked. For example, a task in which signal values are increased after every incorrect response and decreased after every correct response (a 1- down, 1- up tracking rule) focuses the majority of trials around the expected 50% correct threshold value. By comparison, a rule that uses a 2-down-1-up adaptive tracking rule results in a tracking of the 70.7% correct level (Levitt, 1971).

Adaptive methods of measurement have been developed with the goal of preserving accuracy and reliability, while maximizing efficiency and minimizing subject and experimenter time to completion (Leek, 2001). Adaptative procedures have the advantage of placing more trials around the desired percent correct level taken to indicate threshold (Roesser et al., 2007). Starting values in adaptive procedures are set high to ensure that the listener understands what to listen for before the stimulus values are gradually reduced until the listener cannot detect which interval contains the different sound (Leek, 2001). When the direction change fluctuates between getting smaller or larger, a reversal is said to have occurred. Trials are stopped after a fixed number of trials have been completed or a predetermined number of reversals is obtained. Threshold will be calculated by averaging the signal values at which the reversals occur.

2.2.4 Percentage Correct in Psychoacoustics

The significance of the percent correct level tracked varies with the number of alternatives (Shelton and Scarrow, 1984). Variations in the number of options in each trial determine levels of chance against which performance is evaluated. A two-alternative forced choice versus a four-alternative forced choice places chance performance at 50% and 25%, respectively. The number of alternatives varies the significance of percent correct performance. A fixed percent correct level in a 4 alternative versus a 2 alternative forced choice procedure indicates a better performance level, as it is farther away from chance (Shelton and Scarrow, 1984). A psychometric function illustrates the changes in performance (detection or discrimination) that occur with changes in stimulus values (Roesser et al., 2007). In an adaptive, forced choice procedure, threshold is estimated by measuring stimulus levels expected to produce a desired performance level on that function. The entire psychometric function is not mapped. Performance is measured with trials having intervals with and without signals, resulting in an estimation of both hit and false alarm rates. As a result, an individual's performance can range from chance to the maximum value that may or may not be associated with 100% of the correct levels presented. Bias is eliminated by the trial design. Modifying the adaptive rules produces estimates of different performance levels. For these reasons, the rigorous methodology in psychoacoustics produces thresholds that are efficient and reflective of one's ability to encode basic signal features.

2.3 Screening Psychoacoustic Thresholds

2.3.1 Types of Psychoacoustic Evaluations

Psychoacoustics can be used to evaluate many aspects of auditory function, including temporal processing: temporal ordering/sequencing, temporal integration/summation, temporal masking and temporal resolution and many other domains. For example temporal resolution has been traditionally measured using gap detection (Shailer & Moore, 1983, and Shemesh, 2008). Poor thresholds and scores within psychoacoustics can contribute to poor auditory performance, detection, and perception of sound signals. Psychoacoustic tests to measure temporal deficits and explain perceptual challenges have been seen more researched in APD compared to other assessments of hearing disorders (Musiek, Baran, and Pinheiro, 1990, and Musiek et al., 2005). Although psychoacoustic tests are seldom used in clinics, research involving their use suggests there are limitations to the suprathreshold abilities. Research has established individual differences in sensory processing, as demonstrated clearly in genuinely poor performers on psychoacoustics tests for example, in frequency discrimination (Moore et al., 2008). Montgomery et al. (2005) suggest that individuals may exhibit multiple auditory deficits, including both temporal and spectral mechanisms, in classic psychoacoustic tasks. Poor suprathreshold abilities exist, but measuring these abilities takes precise focus, time and effort using psychoacoustic procedures.

2.3.2 Screening for Frequency Discrimination

In evaluating suprathreshold performance it is necessary to decide which acoustic features will be tested. Commonly evaluated is frequency discrimination. Which measures the minimal, detectable differences between two frequencies that the listener can perceive (Amitay et al., 2005). The smallest difference that can be discriminable at a predetermined level is known as the differential threshold. The frequency discrimination psychoacoustic test measures how well a listener can discriminate between sounds of different frequencies. This ability relates to our perceptual ability to understand meaningful changes. Adult listeners can perceive generally 1 – 2% of the frequency discrimination changes being tested, but their thresholds can increase as frequency increases beyond 1000 Hz (Yost, 2007) and/or if signal level increases as well (Sek and Moore, 1995). Individuals tested at midfrequency sounds, such as 1000 Hz, can discriminate differences as little as 2-3 Hz (Roeser et al., 2007). Frequency discrimination thresholds have been reported to show poor thresholds in children and those with auditory processing disorders (Moore et al., 2008, and Hill et al., 2005). Despite frequency discrimination being a well-known task in research settings, there are currently no published screeners that follow its psychoacoustic parameters.

2.3.3 Screening for Gap and Amplitude Modulation

Important temporal information within a signal's envelope relates to a listener's ability to perceive rapid changes in auditory signals (Conte et al., 2017). Sounds are always rapidly changing and requires the auditory system to perceive information as quickly as possible. Two common psychoacoustic measurements that examines temporal resolution are gap detection (Musiek et al., 2005) and amplitude modulation detection (Viemeister, 1979) tests. Gap detection assess the listener's ability to detect small gaps within a sound stimulus. Understanding brief silent periods between sounds is related to the identification of voicing, the parsing of syllables and the determination of word boundaries (Eggermont and Wang, 2010). Normative gap detection thresholds have been reported to range approximately between 2 to 20 milliseconds (McCroskey and Keith, 1996).

Alternatively, the amplitude modulation test examines the listener's sensitivity to a modulated noise by measuring the temporal modulation transfer function. Signal amplitudes are modulated, in a manner similar to the envelope fluctuation of speech stimuli. The thresholds are measured in modulation depth from 0 to 1 where 0 indicates no modulation and 1 indicates full modulation. Higher modulation frequencies require larger modulation depths to be detected than do slower modulations (Viemeister 1979, Hall and Grose, 1994, and Peter et al., 2014). Reductions in the perception modulation was seen in children with APD who showed poorer modulation thresholds at both 20 and 200 Hz compared to typically developing children and adults (Ly, 2019). The ability to extract temporal envelope cues are essential for understanding speech in both quiet and noisy backgrounds. Although both tests prove as important measures of temporal resolution abilities, there are also currently no published screeners that assess it.

2.3.4 Reason and Considerations for the Development of Psychoacoustic Screening Tools

The purpose for any possible future psychoacoustic screening tool is to identify individuals for poor or reduced suprathreshold abilities. Reduced spectral and temporal encoding in suprathreshold mechanisms are associated with different hearing disorders in some individuals (Zeng et al., 1999, Zeng et al., 2004, Allen & Allan, 2014, Allan 2011, Summers et al., 2013, and Rance, 2015). The introduction of a screening tool that adheres to strict psychoacoustic procedures would assist those that require further investigation into their signal encoding abilities. Practice items with large signal differences are important when measuring suprathreshold abilities in order to familiarize the listener with what to listen for (Musiek, 1994, and Musiek et al., 1990). A psychoacoustic screening tool would benefit from incorporating large signal differences in its design.

Screening levels must be carefully chosen. Expected performance levels have been reported throughout literature and can be used to set known threshold limits of possible perceptual deficits that are 2 standard deviations from the average reported population norm. Other studies and protocols involving psychoacoustics report setting 2 SD on their tests as a deficit or impaired ranged criteria (Kishon-Rabin et al., 2009, and Włodarczyk et al., 2019). Auditory processing disorder assessments also use a 2 SD criteria for their temporal processing deficit criteria for behavioural measurements (ASHA, 2005) and would benefit the most from such proposed screening tools. A psychoacoustic screener designed around their 2 SD thresholds would benefit assessments involving psychoacoustics. Measuring suprathreshold abilities takes precise focus, time, and effort. A psychoacoustic screening test that could quickly identify performance would only further advocate psychoacoustic measurements into clinical relevancy.

2.4 Purpose of Study

The purpose of this study was to develop and evaluate the utility of psychoacoustic screening tools that could suggest when further assessment is required. Psychoacoustic screeners have been developed for each of the following psychoacoustic tests: frequency discrimination, gap detection and amplitude modulation. The study screened for good performers on psychoacoustic thresholds in a normal adult population. The accuracy and duration of completion of the screeners was compared with their obtained test thresholds. It was hypothesized that listeners with psychoacoustic thresholds that fell within normal limits would pass their respective screeners.

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Chapter 3

3 Methods

3.1 Participants

Thirty adults (age range: 18 - 25 years, mean: 22.71 years, SD: ±1.60 years) were enrolled in the study. All participants reported no hearing or listening difficulties and had no history of family hearing loss or learning difficulties. Participants were graduate and undergraduate students enrolled at Western University. All participants were screened for normal hearing using pure tone audiometry (≤ 20 dB HL at octave intervals from 250 to 4000 Hz), distortion product otoacoustic emissions (present DPOAE responses), and tympanometry (type A responses) in both ears. Acoustic reflex thresholds were obtained in response to 1000 Hz tones (80-100 dB) and broadband noise at 1000 Hz (65-90 dB) activators in both left and right ears (Parra et al., 2005). Participants were also administered the Word in Noise test (WIN) to assess suprathreshold hearing by measuring each listener's ability to understand words in the presence of background multi-talker babble in both ears (Wilson, 2003). In this task, the multi-talker babble background noise remained constant while the level of the speech was reduced from 24 to 0 dB SNR in 4 dB steps. All participants had WIN scores within normal ranges (>23 words correct) (Wilson et al., 2003).

This study was conducted in the Child Hearing Research Laboratory (CHRL) of the National Centre for Audiology (NCA) at Western University. The study was approved by the Human Research Ethics Review Board of Western University. All consent forms were signed and obtained prior to the assessment. Participants were compensated and thanked for their participation in the study. The NCA's Infection Prevention and Control (IPAC) protocol for COVID-19 was followed for each participant session to ensure safe conditions for research.

3.2 Stimuli, Task and Procedure

All psychoacoustic screeners and test signals were generated from the Tucker Davis Technologies (TDT) system 3 RP2 real time signal processor 2.1 and were presented at 65 dB SPL. Signals were presented and controlled by a Dell Dimension 8100 desktop computer located outside the sound isolation booth. All test stimuli were presented only in the right ear via Etyomotic ER-3A insert earphones. Responses were obtained on an Elo Touch system 15" CRT Touch monitor Model 1525C located inside the sound isolation booth. All psychoacoustic screeners followed the same generated signal parameters as their respective psychoacoustic test versions.

A two-down-one up three alternative forced-choice (3AFC) procedure (Levitt, 1971) was used for frequency discrimination, gap detection, amplitude modulation tests. The 3AFC is recommended as it is the most efficient procedure for psychophysics and has less within-subject variability (Shelton and Scarrow, 1984). The order of screeners and tests were randomized and counterbalanced. For each psychoacoustic test, participants were instructed to follow a series of three of the same graphic image that appeared on the computer-based touch pad. They selected their preferred type of graphic (balloons, flowers, or sharks) before the test was administered. Each graphic image underwent a change in animation or colour to signal a sound presentation. The target (different) signal was presented in only one of the three intervals. The participant's task was to select the graphic that was presented with the target signal. Only the right ear was tested and all measurements were carried out in the sound booth. The last four reversal points were used to estimate thresholds. Each participant completed a minimum of two blocks (30 items each), and the average of the two blocks was used as their threshold estimate.

Participants also completed each psychoacoustic screener either before or after administering their respective full test versions. A 3AFC procedure was also employed for the screeners. Participants were instructed that the procedure for the screeners was the same as that for their respective tests. The same graphics (balloons, flowers, or sharks) used on the screeners were applied to their respective tests. On the computer-based touch pad, three of the same graphic images appeared, changing in animation or colour to indicate a signal presentation. Of the three graphic images generated, the target signal was presented in only one of the three intervals. The participant's task was to discriminate and select the target graphic that presented the target signal. Only the right ear was tested on the screeners and all measurements were carried out in the same sound booth. A minimal correct selection on three out of the last four items was used as the pass/fail criterion for the screener. Participants were always given a scheduled break after half of the psychoacoustic screeners and tests were completed. Additional breaks upon request were given to ensure fatigue or inattention would not affect performance. Thresholds on each test were compared to the 2 SD score of the screeners.

3.2.1 Frequency Discrimination Threshold Measurements

For the frequency discrimination test, the generated standard signal was 1000 Hz and the target stimuli varied adaptively. The starting level of the target signal was set at 1200 Hz. The upper limit of the target stimulus frequency was set at 3500 Hz while the lower limit frequency was set at 1000 Hz. The duration of the stimuli was 500 ms, and listening intervals were separated by a 400 ms inter-stimuli interval. A listener responding with two consecutive correct choices resulted in a reduction of the target frequency by a factor of 0.7143. A listener's incorrect responses resulted in an increase of the target frequency by a factor of 1.4.

3.2.2 Gap Detection Threshold Measurements

Gap detection test signals used a narrowband noise (400 Hz bandwidth) centered at 1000 Hz. Throughout each trial, one target had the silent gap interval centered within the noise while the other two did not. A continuous Gaussian noise centered at 1000 Hz with a bandwidth of 400 Hz was presented to avoid the spectral splatter that may arise from the gap in the target signal (Allan 2011). The duration of each signal was 400 ms and signals were separated by a 400 ms inter-stimulus interval. The initial starting gap length was 40 ms and was varied adaptively with each response. The initial gap step size was set at 15 ms. A listener's incorrect responses resulted in a change of the gap size by a factor of 0.5. The final gap step size for the last item in this task was set at 0.25 ms.

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3.2.3 Amplitude Modulation Threshold Measurements

Amplitude modulation (20 Hz and 200 Hz) generated a narrowband noise (1000 Hz ‘s bandwidth) signal centered at 700 Hz. The duration of the signal and masker was set at 575 ms with an inter-stimulus interval of 400 ms. Modulation depth (m) was adjusted between 0 to 1, where 0 represents 0% modulation and 1 signifies 100% modulation depth. The amplitude modulation frequency (20 Hz or 200 Hz) had the modulation depth, m, adaptively adjusted throughout the diagnostic test. The initial modulation depth (m) was set at 0.75 and was decreased by a factor of 0.5 after the first two reversal points. This factor was further decreased to 0.25 after the first four reversal points were obtained. The average thresholds, m, were converted to dB using a 20* log (m).

3.2.4 Psychoacoustic Screeners Signal Measurements

Each psychoacoustic screener used the same generated signals as was used in the full threshold assessment versions. Instead of 30 items, each included a minimum of seven items (refer to table 1) presented in a non-adaptive procedure. The initial trials began with an easily discriminated value to introduce listener to the difference to introduce listener to the task. The last four trials were presented at a difference level that were similar to 2 SD values from the published data, specifically for frequency discrimination (Jesteadt et al., 1977, Wightman et al., 1989, Freyman & Nelson, 1991), gap detection (Shailer & Moore, 1983, Shemesh, 2008), and amplitude modulation (Viemeister, 1979, Ly, 2019). Achieving a threshold from the test versions that exceeds these 2 SD values is suggestive of difficulties in signal encoding abilities and clinically would suggest the need for full testing. (refer to table 1). The 1 up 2 down rule tracks the 70.7% correct level (Levitt, 1970). To achieve the closest value of this percentage correct level at known cut-off value limits, participants who achieved a minimum of 75% correct on the last 4 items passed the screener. A percentage score less than 75% would have resulted in a fail on the screeners.

Psychoacoustic Screening Design Stimulus Features and Levels							
Screener	**Item 1**	**Item 2**	**Item 3**	**Item 4**	**Item 5**	**Item 6**	**Item 7**
FD	1400 Hz	1200 Hz	1050 Hz	1017 Hz	1017 Hz	1017 Hz	1017 Hz
Gap	50 ms	35 ms	20 ms	9 ms	9 ms	9 ms	9 ms
AM20	1 m	0.7 m	0.4 m	0.15 m	0.15 m	0.15 m	0.15 m
AM200	1 m	0.7 m	0.4 m	0.24 m	0.24 m	0.24 m	0.24 m

Table 1. Psychoacoustic screening stimuli across each of the 4 tests. Each screener's last 4 stimuli were set at 2 SD deviation from their respective population estimate. Stimuli units are represented as Hertz (Hz), milliseconds (ms), and modulation depth (m).

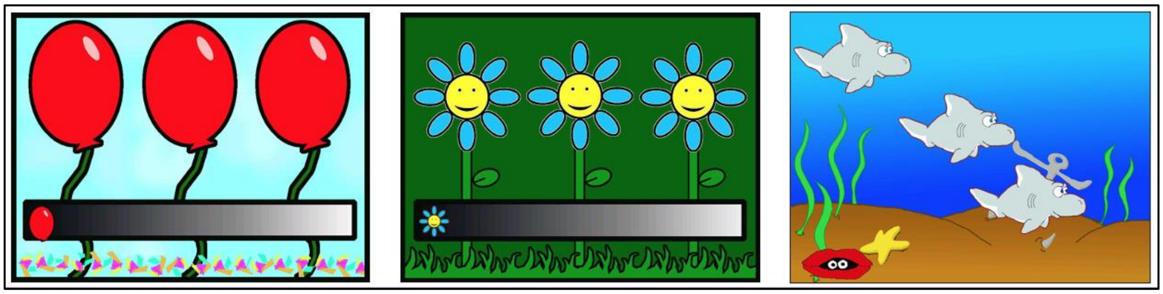

Figure 1. Screenshot of 3 psychoacoustic tests with different animations that the listener may select from. This is an example of different graphic images in the test using the 3AFC method. Listeners must select among the three stimuli to identify the target stimuli in order for the next trial to begin. A correct selection would prompt a short animation sequence. All psychoacoustic screeners and their respective threshold test versions used the same animation and procedures.

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Chapter 4

4 Results

4.1 Hearing Thresholds and Oto-acoustic Emissions

Adult hearing thresholds consistently indicated that all participants had normal peripheral hearing abilities. A repeated measure analysis of variance (RMANOVA) was carried out on hearing thresholds, with frequency (250, 500, 1000, 2000, 4000, and 8000 Hz) as a within subjects factor and ear (right/left) as a between subjects factor. There were no significant differences in hearing thresholds between ears [$F(1, 29) = 3.309$, $p = 0.079$] and no significant interaction between ear and test frequency [F, $(5, 145) = 1.164$, $p = 0.330$]. There were significant differences in hearing thresholds between frequencies [$F(5,145) = 13.026$, $p < 0.001$].

A RMANOVA was also performed on distortion product oto-acoustic emissions (DPOAE) with test frequencies (500, 1000, 1500, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000 and 10000 Hz) as a within subjects factor and ear (right/left) as a between subjects factor. There were no significant difference in DPOAE amplitude between ears [$F(1, 58) = 0.051$, $p = 0.822$] and there was no significant interaction between ear and test frequency [$F(11, 271.084) = 1.001$, $p = 0.444$]. The results suggest that all participants had normal hearing sensitivity as required for entry into the study.

4.2 Psychoacoustic Threshold Estimates

All 30 adults completed two 30 trial blocks of frequency discrimination, gap detection and amplitude modulation (at 2 modulation rates). Table 2 shows threshold estimates for each psychoacoustic test. Thresholds were calculated for each block. Threshold estimates were averaged across the 2 repetitions to produce a single estimated threshold. A paired samples t-test was administered to determine the differences between blocks used for thresholds estimates.

Psychoacoustic Tests Results				
	FD (Hz)	**GD (msec)**	**AM20 (m)**	**AM200 (m)**
Mean	1007.541	6.495	0.101	0.171
SD	3.881	1.333	0.018	0.033
Mean +1 SD	1011.352	7.828	0.119	0.267
Mean + 2 SD	1017.974	10.494	0.155	0.27
SE	0.709	0.243	0.003	0.006

Table 2. Descriptive results for Frequency discrimination at 1000 Hz (FD), Gap detection in noise (GD), and Amplitude modulation at 20 Hz (AM20) and 200 Hz (AM200) tests. Thresholds were given in hertz (Hz), milliseconds (msec), and modulation depth (m), respectively. Mean thresholds were obtained by averaging two blocks of each test trial.

4.2.1 Frequency Discrimination Test

Frequency discrimination thresholds were compared for block 1 and block 2. A Shapiro-Wilk test was performed and showed that neither block 1 ($W = 0.92$, $p = 0.031$) nor block 2 ($W = 0.88$, $p = 0.004$) were normally distributed. Based on this outcome, a non-parametric test was used. The Wilcoxon’s signed rank test showed that block 1 thresholds (Mdn = 1007.347) were higher when compared to block 2 (Mdn= 1004.57), $z = 3.87$, $p < 0.001$. Figure 2 shows adult frequency discrimination 1000 Hz thresholds obtained by young adults plotted as a function of the listener’s age. The dashed line represents two standard deviations. These findings are consistent with previously published data (Jesteadt et al., 1977, Wightman et al., 1989, and Freyman & Nelson, 1991).

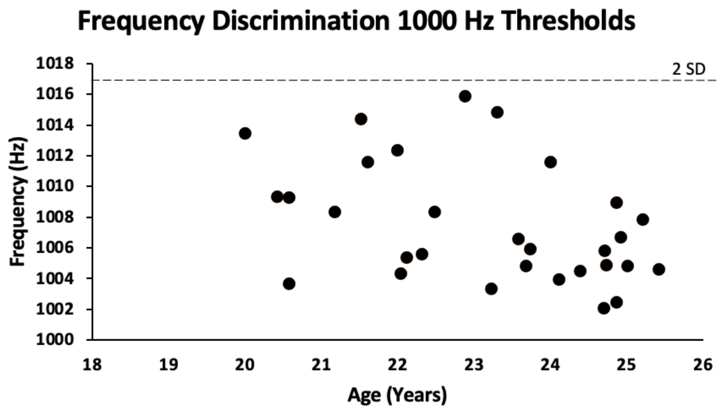


Figure 2. Frequency discrimination 1000 Hz thresholds obtained by young adults are shown as a function of the listener's age. The dash line represents normative adult values using a two standard deviation criterion similar to the screener version. Thresholds below the dash line are considered within normative range.

4.2.2 Gap Detection Test

Gap detection thresholds were compared for block 1 and block 2. A Shapiro-Wilk test was performed and did not show evidence of non-normality in either block 1 (W = 0.947, p = 0.142) or block 2 (W = 0.95, p = 0.296). On average, threshold estimates for block one (M = 6.623, SD = 1.617) were higher than those estimated from block 2 (M = 6.366, SD = 1.848) but this difference, 0.257, was not statistically significant, t(29) = 0.633, p = 0.532. The distribution of the gap detection test results suggests no deviation from normality. Figure 3 show adult gap detection thresholds obtained by young adults as a function of the listener's age. The dashed line represents two standard deviations poorer than the mean. These findings are consistent with previously published data (Shinn et al., 2009, Majak et al., 2015, Shailer & Moore, 1983, Musiek et al., 2005, and Shemesh, 2008).

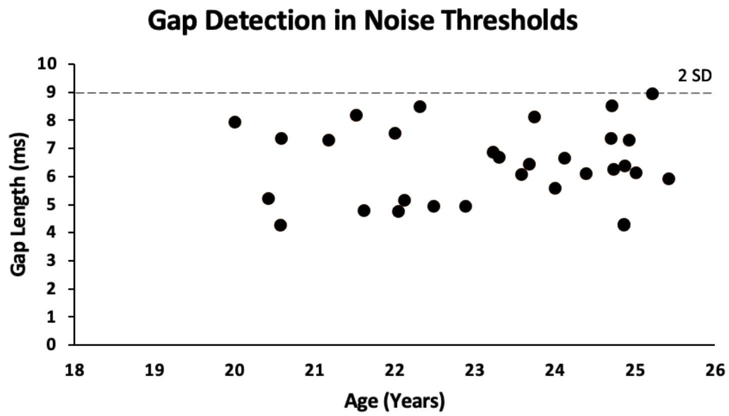
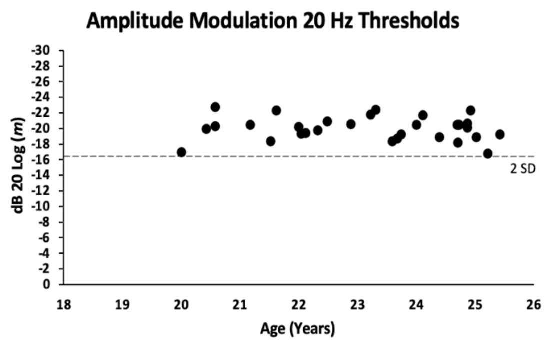


Figure 3. Gap detection in noise thresholds obtained by young adults are shown as a function of the listener's age. The dash line represents normative adult values using a two standard deviation criterion similar to the screener version. Thresholds below the dash line are considered within normative range.

4.2.3 Amplitude Modulation Test

Amplitude modulation thresholds at 20 Hz and 200 Hz were compared for block 1 and block 2. A Shapiro-Wilk test was performed and did not showed evidence of non-normality in either block 1 (W = 0.97, p = 0.535) or block 2 (W = 0.97, p = 0.466) on 20 Hz and block 1 (W = 0.98, p = 0.913) or block 2 (W = 0.98, p = 0.706) on 200 Hz. On average, threshold estimates at 20 Hz for block 1 (M = -20.153, SD = 2.159) was similar compared to block 2 (M = -20.248, SD = 2.457). The average difference, 0.095, was not statistically significant, t(29) = 0.150, p = 0.882. Threshold estimates at 200 Hz for block 1 (M = -15.371, SD = 2.718 were higher than those estimated in block 2 (M = -16.043, SD = 2.010). This difference, 0.672, was not statistically significant, t(29) = 1.207, p = 0.237. Figures 4 and 5 shows amplitude modulation thresholds obtained shown as a function of the listener's age. The dashed line represents two standard deviations. These findings are consistent with previously published data (Viemeister, 1979, Ly, 2019, and Soares et al., 2021).



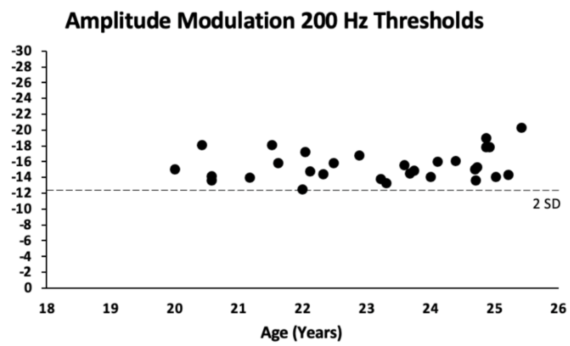


Figure 4 and Figure 5. Amplitude modulation 20 Hz and 200 Hz thresholds are shown as a function of listener's age. Modulation depth thresholds were converted to dB from the equation 20*log10 (m) function. The dashed line represents two standard deviations.

4.3 Psychoacoustic Screener Results

All thirty adults completed and passed each respective psychoacoustic screeners FD, GD, AM20 and AM200, as expected. Table 3 displays the number of individuals completing each psychoacoustic test and their obtained passed percentage on the screeners. Table 4 displays the total number of listeners and the accuracy of their screening through sensitivity/specificity table. Figure 6 shows total adult performance achieved across each of the four psychoacoustic screening tasks. Figure 7 represents the average total percentage on the final 2 SD screening levels.

Psychoacoustic Screeners 2 SD Criterion Levels				
Percentage Correct Scored	**FD (2 SD)**	**GD (2 SD)**	**AM20 (2 SD)**	**AM200 (2 SD)**
100%	25	22	19	25
75%	5	8	11	5
50%	-	-	-	-
25%	-	-	-	-

0%	-	-	-	-

Table 3. Total amount of listener's percentage correct on the psychoacoustic screeners. A 2 SD criterion was used as the screener's cut-off threshold. Individuals must obtain a percentage correct value of 75% on the last four items of the screener to pass.

	Failed Screener (FD, GD, AM20, AM200)	Passed Screener (FD, GD, AM20, AM200)
Poor Psychoacoustic Threshold (≥ 2 SD)	TBD (TP)	TBD (FP)
Good Psychoacoustic Threshold (≤ 2 SD)	0 (FN)	120 (TN)

Table 4. Sensitivity/Specificity table results for all psychoacoustic screeners (TP = true positive, FP = false positive, FN = false negative, TN = true negative, and TBD = to be decided). Individuals all passed each respective screeners and obtained good psychoacoustic thresholds that were within 2 SD of the normative cutoff.

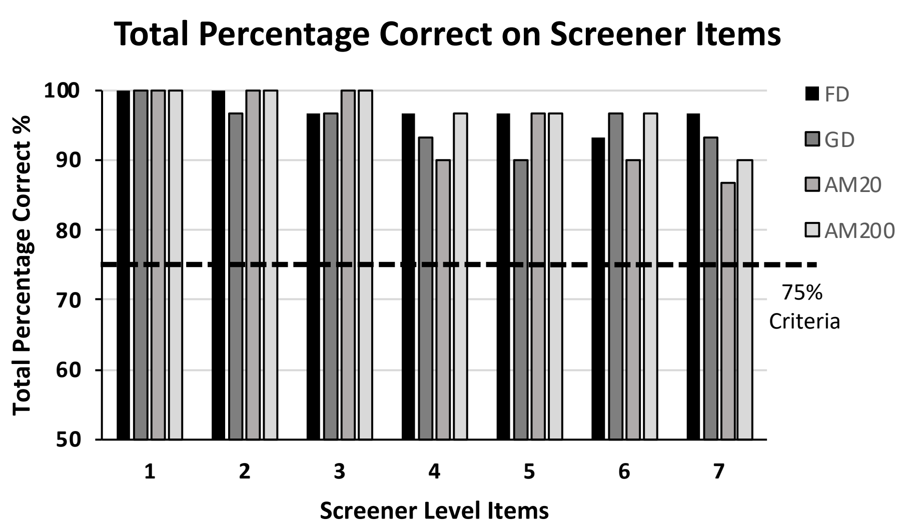


Figure 6. Average percentage correct achieved on each screener level.

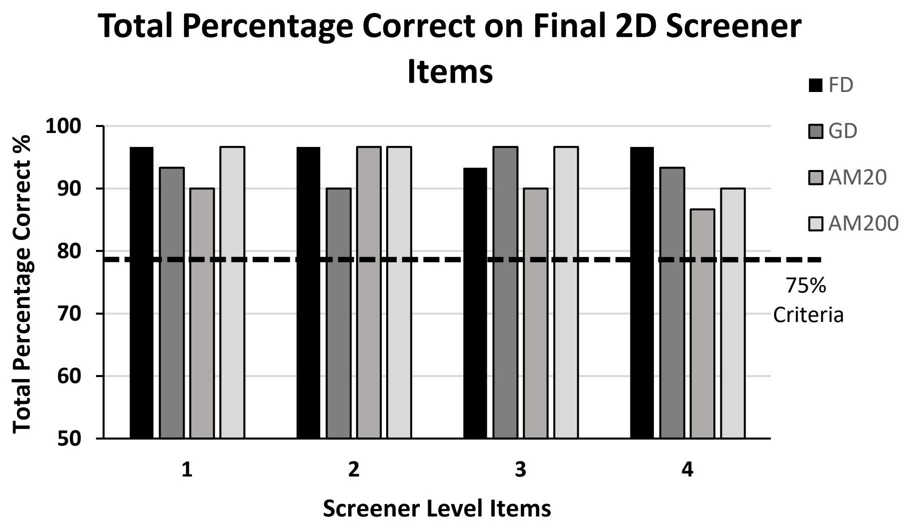


Figure 7. Average percentage correct achieved on final 2 SD screener levels. These levels are used as the pass/fail criterion for the screening test.

4.4 Correlation Between % Correct on Screeners and Test Thresholds

Figure 8, 9, 10 and 11 illustrates the correlation between % correct on the screeners and their respective test's thresholds (FD, GD, AM20 and AM200). Percentage correct (right and left ears). The correlation between the screener % percentage correct and thresholds were examined using the Pearson correlation coefficient. Adults showed a significant correlation between % correct on screener and thresholds for FD [r (30) = -0.398, p = 0.038], GD [r (30) = -0.361, p = 0.050] and AM20 [r (30) = -0.29, p = 0.12]. There was an insignificant correlation between % correct on screener and thresholds for AM200 [r (30) = -0.034, p = 0.857] respectively.

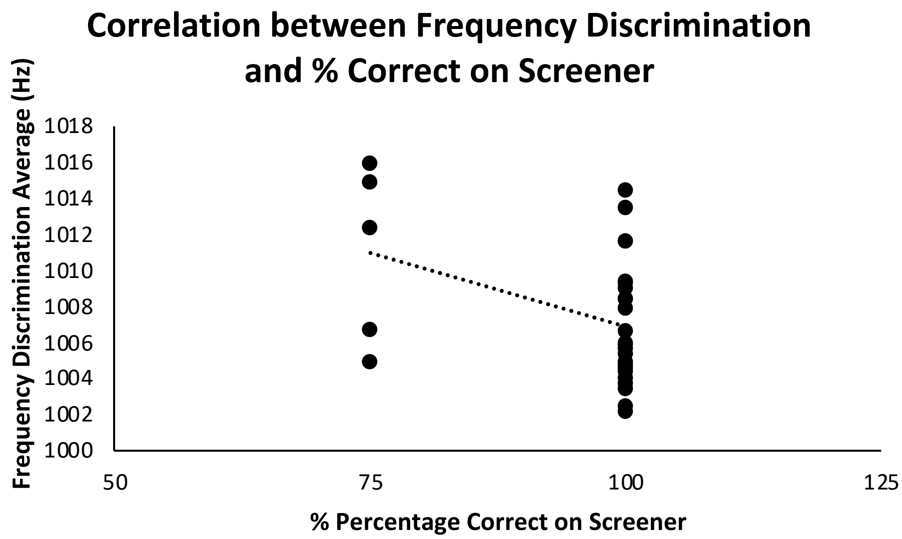


Figure 8. Correlation between % correct on screener and frequency discrimination thresholds. X-axis denotes the % correct on screener items and y-axis represents average FD thresholds.

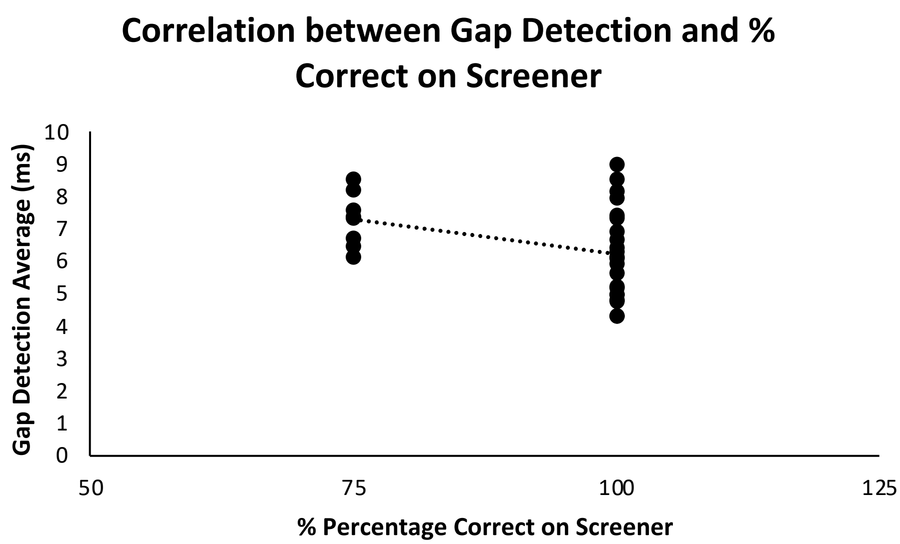


Figure 9. Correlation between % correct on screener and gap detection thresholds. X-axis denotes the % correct on screener items and y-axis represents average GD thresholds.

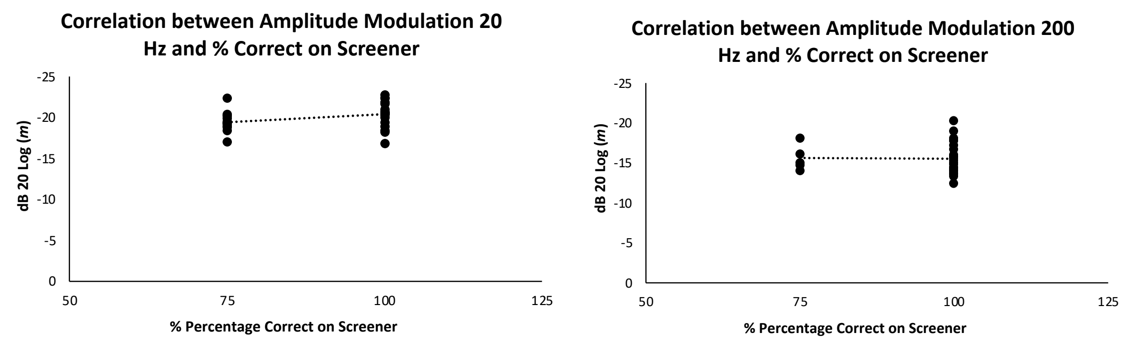


Figure 10 and 11. Correlation between % correct on screener and amplitude modulation 20 and 200 Hz respectively. X-axis denotes the % correct on screener items and y-axis represents average AM thresholds converted into dB 20 log (m).

4.5 Duration of Psychoacoustic Tests vs Screeners

Time taken to complete each psychoacoustic threshold estimate and screeners was recorded throughout the study. Figure 12 shows the total amount of time in seconds to complete one psychoacoustic task. Adults' performance shows that on average these screeners can be completed under a minute with the difference between each screeners being 1-2 seconds from each other. In comparison to their respective tests, screeners reduced the time of psychoacoustic tests significantly by roughly 3/4 the time. Average psychoacoustic screener times for FD, GD, AM20 and AM20 were 54.46, 52.79, 53.04, and 52.95 seconds respectively. Average psychoacoustic test times for 1 block were 4.15, 3.98, 4.06, and 4.02 minutes respectively.

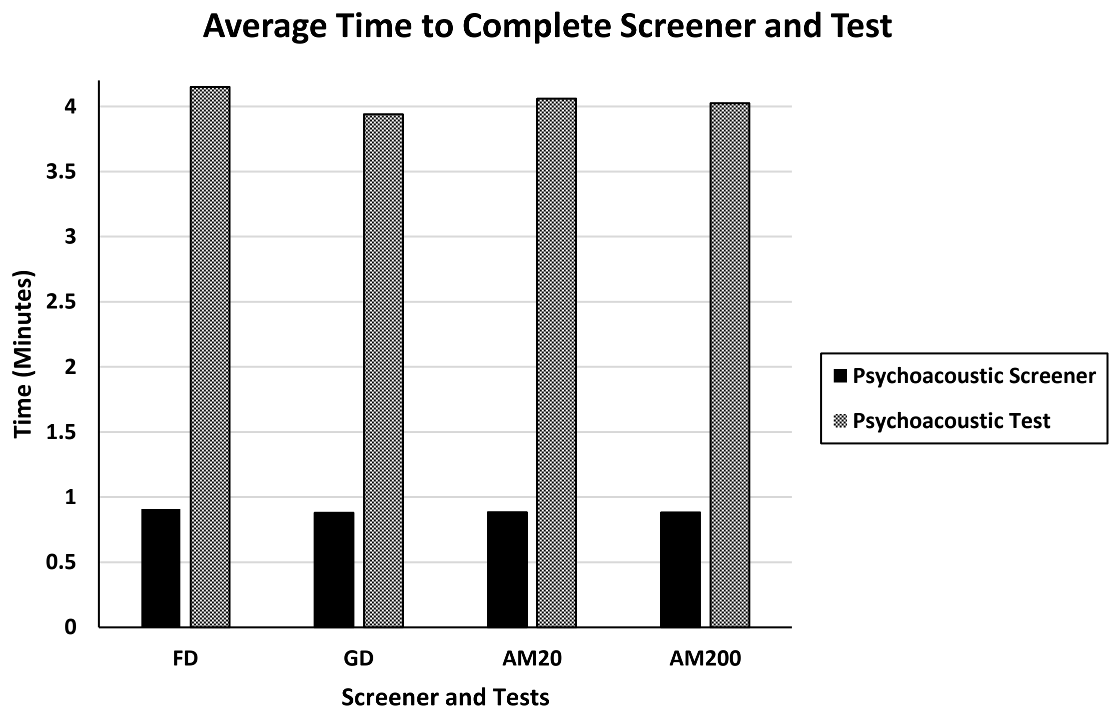


Figure 12. Average time of completion for each screener and test. Solid filled bars represents screener time and pattern filled bars represents test time.

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Chapter 5

5 Discussion

Psychoacoustic screening tools were developed to identify good performers and determine when full threshold assessment is required in a normal adult population. There were no significant differences in hearing thresholds and oto-acoustic emissions within all listeners, indicating that all listeners had normal peripheral auditory function. A three-alternative forced choice procedure was used to determine thresholds and conduct a screening for frequency discrimination (FD), gap detection in noise (GD), and amplitude modulation (AM20, AM200) tests and screeners.

For each listener, two blocks of 30 items were administered for each psychoacoustic test. The average of the two blocks were taken as the threshold estimate. Screeners were administered only once, before or after each of their psychoacoustic test measurements. Each screener took less than 1 minute to complete compared to their respective psychoacoustic tests, which averaged between 3-4 minutes per block (see figure 12). All individuals passed each psychoacoustic screener with percentage correct scores of either 75% or 100% (see table 3 and 4). Psychoacoustic thresholds were consistent with their respective tests and were within 2 SD of the screener's cut-off threshold criterion.

5.1 Frequency Discrimination 1000 Hz

Frequency discrimination thresholds at 1000 Hz were comparable to the reported literature (Jesteadt et al., 1977, Wightman et al., 1989, Freyman & Nelson, 1991, amd Soares et al., 2021). Some adult participants achieved frequency discrimination thresholds that were observed to be around 1-2% of the target frequency, and expected (Yost, 2007, and Roeser et al., 2007). In this study, slight variation of these obtained thresholds occurred across the frequency range and are often observed in the performance of children and adults not familiar with the task (Moore et al., 2008). Mid-frequencies between 400-2000 Hz demonstrate less influence on thresholds and therefore frequency discrimination at 1000 Hz thresholds were selected for the most optimal sensitivity for this range.

Frequency discrimination screener 2 SD thresholds were set at 1017 Hz and all participants fell within this 2 SD range. Exceeding this value would suggest they experienced difficulties in their ability to discriminate between sounds at different frequencies. Although, it is generally unclear how fine frequency discrimination capacities in normal subjects (e.g., discrimination of 2-4-Hz differences from 1000-Hz tones) could be related to the discrimination and recognition of complex stimuli such as speech (Freyman & Nelson, 1991), and further investigation into this relationship is needed. The assessment of suprathreshold abilities using frequency discrimination for individuals with hearing disorders such as APD, auditory neuropathy, and sensorineural hearing loss could provide insight into possible factors influencing difficulty with auditory processing.

5.2 Gap Detection in Noise

Gap detection thresholds fell within the approximate range of 2 – 20 ms, consistent with what is reported in the published literature (McCroskey & Keith, 1996). Thresholds obtained were consistent with reported literature (Shinn et al., 2009, Majak et al., 2015, Shailer & Moore, 1983, Musiek et al., 2005, and Shemesh, 2008). Adult listeners within the study were able to detect gaps of, on average, 4 ms, consistent with other reports of thresholds as small as 3-6 ms of (Majek et al., 2015, Musiek et al., 2005, Hoover et al. 2015, and Lister et al., 2011). Gap detection is the most frequently used and recommended method for investigating temporal resolution abilities. Measuring temporal resolution is believed to be linked to the understanding of acoustically degraded speech, which makes it a valuable test measurement. Gap detection thresholds of 4-8 ms are necessary for discriminating between different groups of listeners with normal and impaired temporal abilities (Lister et al., 2011).

Gap detection screener 2 SD thresholds were set at 9 ms and all participants fell within this 2 SD range. Exceeding this value would suggest difficulties in the ability to detect and resolve brief silent intervals of sounds. Some studies using gap detection also reported using a 2 standard deviation cut-off criterion (Shinn et al., 2009 and Majak et al., 2015) which corresponds closely to our set normative cut-off criterion. Individuals above the age of 12 years old are expected to be able to achieve thresholds that are within that value. Gap detection is an important temporal resolution measurement that has been used extensively.

5.3 Amplitude Modulation 20 Hz and 200 Hz

Amplitude modulation thresholds were better at 20 Hz compared to 200 Hz, consistent with previous findings and characterization of the human auditory system as a low pass filter. Thresholds obtained showed similar findings that have been reported in previous studies (Viemeister, 1979, Ly, 2019, and Soares et al., 2021). Amplitude modulation 20 Hz was always administered first and therefore the 200 Hz condition may have already been recognizable as the modulation signal; however, faster modulation rates are difficult to perceive overall. Amplitude modulation processing becomes inefficient at higher frequency rates due to the nature of our auditory system.

AM20 and AM200 screeners were set at modulation depths of 0.15 m and 0.24 m, respectively. Converting these values to dB through the equation of 20*log10 (m) function yields -16.48 dB and -12.40 dB. The ability to extract temporal envelope information is important for recognizing speech (Lorenzi, 2008). Exceeding these values would suggest difficulties in perceiving the following rapidly changing temporal acoustical features that are processed, including the envelope information and prosody cues. For the purpose of the screeners, AM20 was always administered first before the 200 Hz condition. Fast modulation encoding is difficult to process and was therefore administered before the faster rate modulation versions to aid in the understanding and comparing of the modulation task for each participant.

5.4 Psychoacoustic Screeners FD, GD, AM20 and AM200

The results indicated in tables 3 and 4 show that listeners with psychoacoustic thresholds that were within normative limits successfully passed each psychoacoustic screener. No further assessment or testing would be required from those who passed the screeners. Participants did not fall below 75%, which was expected given the adaptive two-down-one up procedure used, which gave a close percentage correct value of 70.7%. We set the pass criterion based on this percentage correct value to more closely resemble this value for the full psychoacoustic adaptive test (Levitt, 1971). Individuals must have achieved a minimum of three out of four on the last trial levels of the screeners set at their respective test's 2 SD thresholds. Results also showed that their psychoacoustic tests thresholds were comparable and were all within 2 SD of the screener's cut-off threshold limits for these tests. This indicates that everyone had adequate performance in their ability to perceive some of the most basic features of sound processing.

The psychoacoustic screeners were designed to have the minimal number of items possible by which to identify those with potentially poor suprathreshold mechanisms and thus requiring further assessment, as quickly as possible. The psychoacoustic screeners used 7 items where the first 3 items had large differences in their target signals so each participant knew what to listen for. The last four items, the actual screening trials, were set at 2 SD below average threshold for that group (i.e adults). The psychoacoustic screeners used 75% correct level as cut-off range as it tracked closely to the 70.7% correct level estimated during the full threshold estimates. Our study showed that, at least in this population of adult listeners, this assumption was met.

To evaluate suprathreshold mechanisms, psychoacoustics' well defined stimuli and psychometric principles were applied in the parameters of the screeners. ASHA recommends the criterion of 2 SD below the mean on auditory processing tests (ASHA, 2005). While some studies using psychoacoustics report also using a 2 standard deviation cut-off criterion (Shinn et al., 2009, and Majak et al., 2015). Few studies have created any sort of screener tool using psychoacoustic procedures and methods (Abramson and Lloyd, 2016, Sanchez & Lam, 2007, and de Carvalho, 2021). Of the ones that did, they did not use any 2 SD criterion that is recommended to distinguish poor from good encoding abilities.

We strongly believe that the use of non-speech based tests should be incorporated into more assessments to avoid any influences on overall thresholds among listeners from diverse backgrounds and languages (Dawes & Bishop, 2008). Screening tools and methods were not meant to be diagnostic but rather able to identify individuals at risk for reduced discrimination abilities. Inconsistent thresholds on psychoacoustic measurements are troublesome for the tester and evaluation of suprathreshold abilities. Psychophysical methods have always had the advantage of known stimuli but their disadvantage is that the stimuli may not represent the sounds represented in the listener's daily life, which makes the test more difficult (Flamme, 2001).

5.5 The Need for Psychoacoustic Screening Tools

Reduced spectral and temporal encoding at suprathreshold levels have been associated with different hearing disorders. Individuals who can only encode large differences in the signal features may be suggestive of an impaired auditory processing system (Kidd, 2002). Poor thresholds on these psychoacoustic tests are representative of impaired spectral and temporal mechanisms, resulting in a difficulty to discriminate between large differences in signal features of sound. Therefore, there is a need for a screening tool that can quickly suggest whether the individual requires further investigation into their psychoacoustic thresholds and poor acoustic discrimination abilities. Psychoacoustic tests are lengthy, often described as difficult, and require rigorous attention to complete. This study's newly developed screeners can be administered and completed more quickly than the full psychoacoustic test measurement, in 3/4 the time and items presented, while also being able to evaluate whether the listener can detect and discriminate signal differences that are 2 SD from the normative limits. Although the screeners were evaluated among normal hearing individuals, the utility of the screeners suggests they are accurate at screening those with thresholds that are within 2 SD of normative limits. The results of our study suggest the possibility and usefulness of screeners that have been developed by following strict psychoacoustic principles, procedures and known threshold cut-offs.

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6 Conclusion and Future Directions

Adult's suprathreshold auditory processing abilities were screened and compared to full threshold estimations. Frequency discrimination, gap detection, and amplitude modulation tests were administered with their respective screeners. Normal hearing listeners with psychoacoustic thresholds that fell within normal limits passed all psychoacoustic screening tests.

The study has demonstrated that it is possible to screen for good performers on psychoacoustic thresholds in a normal adult hearing population. All listeners had psychoacoustic estimated thresholds that were within 2 SD of normative cut-off limits. This demonstrates auditory discrimination abilities in the suprathreshold mechanisms that encode rapid changes, spectral, and temporal aspects of sounds can be screened in a properly functioning auditory system. All participants were able to recognize small differences within the signal parameters of each psychoacoustic measurement which suggests good signal encoding. An auditory system that is poor in discriminating and encoding acoustic signal features of sounds may lead to inaccurate representation and interpretations of the meaning of signals at higher processing levels. Suprathreshold abilities remain overlooked in clinical hearing assessments yet non-speech based tests such as the psychoacoustic skills assessed in this paper continue to provide important information on auditory discrimination capabilities. Screening individuals for auditory discrimination abilities assists in identifying those requiring further assessment of suprathreshold mechanisms. The psychoacoustic screeners can be quickly implemented and administered into any assessment of suprathreshold abilities involving the use of frequency discrimination, gap detection and amplitude modulation psychoacoustic tests.

Given the findings of this research project, there is a need to further investigate the accuracy and design of these psychoacoustic screening tests. The current study was conducted during the COVID-19 pandemic. This prevented the study from further assessing other factors and restricted the ability to investigate different populations. Although the study was limited to normal adult hearing population, the results of the study was necessary to establish findings for normative screening for good performers.

Future direction for the screeners should prioritize investigating different populations with known reduced auditory discrimination abilities and suprathreshold mechanisms such as children with auditory processing disorders. By studying individuals with reduced discrimination capabilities and thresholds, the full utility of the screener can be established.

Developing screeners for psychoacoustic measurements is a step closer to adopting these procedures into a clinical setting. The adaptative force choice method for our psychoacoustic screeners and measurements continue to show benefits as an effective method for accessing suprathreshold abilities in discrimination and encoding. Effort should be made to further develop the screeners and demonstrate the importance of investigating suprathreshold discrimination abilities as a part of hearing assessments.

Appendices

Appendix A: Approval for Research Involving Human Participants

Western Research

Research Ethics

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Prudence Allen
File Number:102932
Review Level: Delegated
Approved Local Adult Participants:0
Approved Local Minor Participants:480
Protocol Title: Auditory function and acoustic signal encoding in school-aged children
Department & Institution: Health Sciences\Communication Sciences & Disorders,Western University
Sponsor:
Ethics Approval Date: March 28, 2013 **Expiry Date:**December 30, 2014
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Letter of Information	102932 Letter of Information	
Assent	102932 Assent letter	

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the University of Western Ontario Updated Approval Request Form.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Ethics Officer to Contact for Further Information

This is an official document. Please retain the original in your files.

Date: 31 January 2022

To: Prudence Allen

Project ID: 102932

Study Title: Auditory function and acoustic signal encoding in school-aged children

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Date Approval Issued: 31/Jan/2022 13:12

REB Approval Expiry Date: 24/Jan/2023

***Ethics Approval Lapse:** January 25 - January 31, 2022*

Dear Prudence Allen,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

The Office of Human Research Ethics

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B: Letter of Information and Consent

Western
Health Sciences

Letter of Information and Consent

Study: Auditory function and acoustic signal encoding in school-aged children.

Principal Investigator: Prudence Allen, Ph.D.
Research Associates: Chris Allan, Ph.D.
Udit Saxena, M.Sc.

Place of testing: Child Hearing Research Laboratory
National Centre for audiology, Elborn College

Dear Potential Participant,

The pronouns "you" and "your" should be read as referring to the participant rather than the parent/guardian/next-of-kin who is signing the consent form for the participant.

Normal hearing and good auditory processing (listening) abilities are necessary for children to experience success in school. Recent studies have shown that some children experiencing school failure have Auditory Processing Disorders. Auditory processing disorders have also been found in children that experience difficulty learning to read and/or have delays in their speech development. You are being invited to participate in a study of hearing and listening being conducted by Western's Child Hearing Research Laboratory. This study is investigating the usefulness of various listening tests, such as the ability to distinguish a change in pitch, loudness or quality of a sound. The performance of normal or typically developing children will be compared to adults and children with auditory processing disorders.

Participants Initials ________

The objective of this project is to investigate hearing and listening abilities in children so that assessment tools can be developed for early and accurate identification of children with listening problems. In this study we plan to compare the performance of typically developing children with that of adults, and children with known Auditory Processing Disorders. For both groups of children, participants between the ages of 4 to 17 years old will be included in this study.

Ear and hearing measurements

If you agree to participate, you will sit comfortably with the researchers in a quiet room, listening to different sounds while wearing earphones. The listening tasks are completed by listening to sounds while watching a regular size computer screen or handheld computer screen. You will be presented with child-friendly computer graphics and with each graphic appearance on the screen you will hear a sound. You will be asked to identify which graphic on the computer screen best corresponds to what was just heard. The responses will be recorded by the computer.

We will also be making some measurements of your ears. During these tests you will wear earplugs and you will hear a variety of different sounds. Some of the sounds will be loud but they are not harmful. You can relax during these tests because you are not required to do anything other than remain still. Each test, individually, only takes a few minutes to complete but in total there is about 1.5 hours of testing to be completed.

The test session will be arranged at your convenience.

To help promote attention and focus on the task, breaks will be taken at regular intervals and whenever necessary or requested. Most children complete the testing in one session but testing can occur over more than one session if that is more convenient for you.

Participants Initials ________

Study risks

This study will involve no known risk to you. The sounds you will be hearing are usually as loud as conversational speech and will never be so loud as to be uncomfortable or damaging. You will experience little or no discomfort during this study. At times long term use of earphones can become uncomfortable however all attempts will be made to avoid this kind of discomfort. Rest breaks will be provided at regular intervals as well as upon request to prevent fatigue or distraction due to hunger or thirst.

Privacy and confidentiality

The information gathered during this study will remain confidential at all times. Information collected at the program on the computers will be password protected to ensure it remains confidential at all times. No individual listener will be identified in any analysis or publication, however, if it is determined that you may have hearing problems that require further attention you will be notified. During the study, a 4 character unique ID code will be used to reference each participant, rather than their full names. ID codes and corresponding full names of participants will be kept in a journal and locked in a cabinet at Western. Only the local research team may have access to the cabinet. The Representatives of the University of Western Ontario Health Sciences Research Ethics Board may contact you or require access to your study-related records to monitor the conduct of the research. The data and personal information will be kept as it is being collected and analyzed. Once the project is completed, all information containing participants' names and ID codes, including backup DVD's and paper documents, will be deleted and overwritten or destroyed by shredding. Upon publication, groupdata will be reported. If individual data is reported, references will be made to the age group only.

Participants Initials ________

Auditory function and acoustic signal encoding in school-aged children

CONSENT FORM

I have read the accompanying Letter of Information. The nature of the study has been explained to me and I agree to participate in this study.

All questions have been answered to my satisfaction.

Date: ____

Name: ______________________________________

Signature: ____________________________________

Did you experience any reading or learning difficulties while attending school? ☐ YES ☐ NO

Name of person obtaining informed consent: ____________________________

Signature of person obtaining informed consent: __________________________

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Curriculum Vitae

Name:	Minh Vu Duong
Post-secondary Education and Degrees:	The University of Western Ontario London, Ontario, Canada 2015-2020 B.A.
	The University of Western Ontario London, Ontario, Canada 2020-2022 MSc.
Honours and Awards:	Graduate Honors Roll 2020-2022
Related Work Experience	Graduate Teaching Assistant The University of Western Ontario 2020-2022
	Graduate Research Assistant The University of Western Ontario 2020-2022

Publications:

Soares, J. C., Veeranna, S. A., Parsa, V., Allan, C., Ly, W., Duong, M., Folkeard, P., Moodie, S., & Allen, P. (2021). Verification of a Mobile Psychoacoustic Test System. *Audiology Research, 11*(4), 673–690. https://doi.org/10.3390/audiolres11040061