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Exploration of the Behavioral, Electrophysiological, and Psychometric Effects of KTH Speech-Tracking Training in Noise in Normal Hearing Adults

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Looking at hearing loss through the WHO-ICD model for disability reveals that auditory interventions do not necessarily address all of the components of auditory disability. Auditory training has been proposed as a solution to address activity-level deficits. The purpose of this study was to examine structure- and activity-level changes as the result of auditory training for normal hearing individuals training in the presence of noise. Thirty adults with normal hearing were placed into three experimental groups: A group engaging in active auditory training in noise, a group listening to speech material in noise, and a control group that performed no activity in noise.

Measurements were taken of the rate and errors made for the auditory training. Performance measures on a word recognition task in noise (the QuickSIN), electrophysiological changes on an analysis of portions of the frequency following response (FFT), and self-reported measurements from the Speech and Spatial Qualities of Sound (SSQ), were all measured before and after to monitor changes as the result of training.

Results show significant improvement on the auditory training task in terms of both rate and number of errors made. ANOVA's reveal a significant effect of test condition on performance on the QuickSIN. There were mixed results in analyses of the differences in the electrophysiological measurements. There were no significant effects of training condition on answers to the SSQ.

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Overall results, similar to other auditory training studies, are mixed. There were significant results in both on- and off-task measures of performance the result of auditory training in noise, however structure-level changes were more mixed in results. Effects on self-reported changes were not measured. This research serves as a proof-of-concept for assessment of changes the result of auditory interventions. The next step is to examine disordered populations.

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Exploration of the Behavioral, Electrophysiological, and Psychometric Effects of KTH Speech-Tracking Training in Noise in Normal Hearing Adults

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Chapter I - INTRODUCTION

An Overview of Hearing Loss in Adults and Its Management.

Hearing loss is a condition impacting a significant portion of the population across the globe. According to the World Health Organization, in 2018, 466 million persons were living with some form of disabling hearing loss (WHO, 2018). In the United States, similar large numbers are cited, with 30.0 million persons over the age of 12 reporting some degree of hearing loss (Lin, Niparko, & Ferrucci, 2011). The Centers for Disease Control report that 15% of adults living in the United States report having some trouble hearing. This estimate places hearing loss on par with other well-known disorders like heart disease and difficulties with vision, which 9% of persons living in the United States report living with (Blackwell, Lucas, & Clark, 2014). The direct medical costs for the first year of treatment of hearing loss and lost productivity attributable to hearing loss was estimated to cost the United States 9.6 billion USD in 2002, and is estimated to cost 60.3 billion USD by the year 2030 (Stucky, Wolf, & Kuo, 2010). Hearing loss is a significant problem both in the United States and the world as a whole, with long lasting consequences not only at the personal level of the patient, but for society as well.

A model for health that is increasingly utilized to address both assessment and intervention of not only hearing disorders, but all health disorders, is the World Health Organization's International Classification of Functioning, Disability, and Health (often stylized as WHO-ICF) (WHO, 2002). Originally described in 1980 as the International Classification of Impairment, Disability, and Handicap (ICIDH), and revised in 2001, the WHO-ICF utilizes a bio-psycho-social approach to classify a disorder's limitations on a person that takes into account the person, their health condition, as well as environmental and personal factors that can either ameliorate or exacerbate perceptions of limitations. Consequences of disease are described as impacts of functioning and disability.

For any health condition, or disorder, the model focuses on the consequences of the disorder that the *person* experiences, namely limitations on body systems and structures, limitations on activities, and limitations on an individual's participation in society (WHO, 1980). Looking at hearing loss through the ICF- model breaks down the impact of hearing loss into limitations on those same domains (Meyer, Grenness, Scarinci, & Hickson, 2016). Limitations of the structural integrity of body systems of the person with hearing loss (e.g. cochlear nerve damage), limitations on activities of the person with hearing loss (e.g. difficulty hearing in noise), and limitations on the participation of a person with hearing loss in social roles and occupations (e.g. performing the duties of grandmother or dental hygienist) are all different ways that the health condition hearing loss could impact an individual.

In terms of hearing assessment, tests exist to measure the structure-, activity-, and participation-level limitations described by the ICF model. Many diagnostic hearing evaluations examine the structure-level of deficit of hearing loss. Behavioral assessments, such as the audiogram, or objective assessments, such as the threshold seeking Auditory Brainstem Response (ABR), or the Auditory Steady-State Response (ASSR) are all established methods of inferring structure-level function of the auditory system. ABR and ASSR measure electric responses of the auditory system in response to various frequencies and intensities of sounds (Huizing & Pollack, 1951; Picton, Dimitrijevic, Perez-Abalo, &Van Room, 2005; Starr & Achor, 1975). They do little to gauge a person's ability to understand a speaker's words. A similar limitation is found with the audiogram. The audiogram can provide a fairly accurate measure of an auditory system's ability to respond to various frequencies at various intensities, but it cannot reliably be used to gauge how much difficulty a person will have in listening in a noisy environment (Killion & Niquette, 2000). Structure-level assessments of auditory function will not necessarily accurately measure the activity level of auditory ability.

Attempts have been made to predict activity-level ability from structure-level ability, however. The Articulation Index, originally described as a method of quantifying intelligibility of speech through something like a telephone (French & Steinberg, 1947), has been used for decades as a method of extrapolating activity-level abilities, such as speech understanding, from the structure-level audibility measurements of an audiogram. Use of the Articulation Index for predicting speech intelligibility for all listeners, however, is limited, with variability from person to person, particularly in cases of severe hearing loss and advanced age (Amlani, Punch, & Ching, 2002). Amlani and colleagues also note the variability in correlation of the Articulation index to other activity-level measures of speech recognition based on the amount of context available in the word recognition task. The Articulation index correlates more strongly to monosyllabic word recognition than, for example, sentences.

In terms of auditory intervention, a similar division exists for addressing structure-level deficits vs. activity-level deficits. Hearing aids, at their core, are devices designed to restore audibility by providing an amplified signal to an impaired ear. While hearing aids are able to restore hearing sensation via prescriptive targets of gain varying according to frequency, they are unable to address decreased frequency resolution secondary to hearing loss beyond optimization of the signal to noise ratio (e.g. remote microphone usage, directional microphone usage) (Van Tasell, 1993). Hearing aids may not necessarily aid in listening in a noisy environment (Chung, 2004), because they cannot return the damaged structure to optimal levels of function.

The assessment of activity-level abilities associated with hearing loss has primarily been associated with word recognition testing. As the activity in question is "hearing speech," several tests have been designed to approximate a person's ability to receive and understand speech, whether it be speech in quiet or speech in noise. Word recognition tests, including the Northwestern University Auditory Test 6 (NU6) (Tillman & Carhartt, 1966), the Maryland Consonant-Vowel Nucleus Contrast test (CNC) (Causey, Hood, Hermanson & Bowling, 1984), and the Central Institute for the Deaf W-22 tests (Hirsh, Davis, Silverman, Reynolds, Eldert, & Benson, 1952), are in wide use to measure word recognition in quiet at a particular volume. To measure word recognition in noise, tests including the Quick Speech-in-Noise test (QuickSIN) (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004), the Bamford-Kowal-Bench Speech-in-Noise Test (BKB-SIN) (Bench, Kowal, & Bamford, 1979), AzBio Sentence Test (Spahr, Dorman, Litvak, Van Wie, Gifford, Loizou, Loiselle, Oakes, & Cook, 2012), and the Hearing in Noise Test (HINT) (Nilsson, Soli, and Sullivan, 1994) are used widely clinically. Each of these tests are designed to approximate the activity of hearing and understanding speech, whether it be in quiet or in noise, and can be used to highlight activity-level deficits in either people with hearing loss or people with normal levels of hearing.

The assessment of participation-level restrictions for people with hearing loss is an area largely dominated by self-reported measures. Whereas otoscopy, audiometry, and immittance testing are all designed to measure body structure and function, often times it is the case history and use of self-report measures that are used to elicit participation-level deficits (Meyer, Grenness, Scarinci, & Hickson, 2016). The reason for this is the inclusion of open-ended questions inquiring about a person's lifestyle, which are critical in the determining the needs and responsibilities for a person to participate at the community level. Several self-reported assessments have been used to measure participation-level restrictions secondary to hearing loss, including, the Client Oriented Scale of Improvement (COSI) (Dillon, James, & Ginis, 1997), the Hearing Handicap Inventory for the Elderly / Adults (HHIE/HHIA) (Ventry & Weinstein, 1982), and the Speech and Spatial Qualities of Sound Questionnaire (SSQ) (Gatehouse & Noble, 2004). These measures are clinically useful for highlighting participation-level deficits, but each have issues in terms of using them for research. For example, the COSI asks participants to elicit their own goals, which makes between-subject comparison difficult. The SSQ has 50 items, and it is difficult to glean clinically meaningful measurements from all of these items at once.

William Noble, in *Self-Assessment of Hearing and Related Functions* (1998), notes that measurement of participation-level restrictions (what at that time was termed hearing handicap, according to the WHO-ICIDH) is mired by a confounding between participation-level deficits and activity-level deficits (which, at that time, were termed disability-level deficits, according to the WHO-ICIDH). Noble notes that both the Hearing Measurement Scale, an item developed before the establishment of the WHO-ICIDH, and the HHIE, published after the establishment of the WHO-ICIDH, confound these deficits. In addition, he notes that the discussion of activity-level and participation-level deficits in other areas of the literature use the terms almost interchangeably (Noble, 1998).

In addition to a confounding of terms and definitions, the relationship between activity-level and participation-level deficits has been complicated by interactions *between* activity-level and participation-level deficits. Hallberg and Carlsson (1991) determined that the use of strategies to lessen activity-level deficits (then termed disability) actually increased negative self-perception and perception of others when it comes to hearing loss (Hallberg & Carlsson, 1991).

There is a difficulty accurately measuring participation- and activity-level deficits, because of their influence on each other.

Nevertheless, addressing activity- and participation-level limitations remain an important component to treating hearing loss. Meyer and colleagues (2016) applied the ICF model to hearing health care, noting that the core-sets of the ICF for hearing loss, the categories of activity- and participation-level limitations, have a large influence on aural rehabilitation outcomes for people with hearing loss (Meyer, et al., 2016). This has been echoed in literature examining factors of successful hearing aid use in older adults (Hickson & Meyer, 2014; Laplante-Lévesque, Knudsen, Preminger, Jones, Nielsen, Öberg, Lunner, Hickson, Naylor, & Kramer, 2012; Saunders, Frederick, Silverman, & Papesh, 2013). These metrics may be difficult to measure accurately, but if we are to successfully treat hearing loss, the treatment needs to not only address structure-level restrictions, but also activity-level and participation-level restrictions as well.

Current Foci of Aural Rehabilitation

Arthur Boothroyd provides a succinct definition for the scope of audiological interventions for hearing loss known as aural rehabilitation:

"The reduction of hearing-loss-induced deficits of function, activity, participation, and quality of life through sensory management, instruction, perceptual training, and counseling" (Boothroyd, 2007).

The current model of aural rehabilitation in health care appears to struggle with addressing these deficits. In the first place, for many adults, hearing loss goes untreated. Kochkin reported that adoption rates for hearing aids has remained below 25% for people living with hearing loss from 1984-2008 (Kochkin, 2007). Lin and colleagues (2011), report 76.6% of adults with a severe hearing loss and 40% of adults with a moderate hearing loss using a hearing aid, but only 3.4% of adults with a mild loss using a hearing aid to help with audibility (Lin, et al., 2011). It should also be noted that treatment for hearing loss is often restricted to the fitting of hearing aid technology and related hearing aid accessories (Gagné, 2000), with coverage of other facets of aural rehabilitation, such as communication and coping strategies, or auditory training, being covered only informally with patients (Prendergrast & Kelley, 2002). The end result is a treatment for hearing loss that strives to address structure-level limitations of an impaired auditory system, but that struggles with residual activity-level and participation-level deficits experienced by the person wearing hearing aids.

The use of amplification has been found to increase speech intelligibility in quiet for people with sensorineural hearing loss, but does not effectively improve intelligibility of speech in noisy environments, especially when that background noise is speech (Turner & Henry, 2002). Listening in noise consistently remains an area for improvement listed by users of amplification (Kochkin, 2000; 2007). There is a limitation present if hearing aids are commonly the only treatment for hearing loss. Combine this with the fact that the average person with hearing loss waits 7 years to pursue hearing aids (Kochkin, 2009), and we are faced with a situation that there is only one common treatment for hearing loss, and a societal delay for utilizing that treatment. Hearing loss is not being effectively treated for the disordered population.

In addition, people with hearing loss prioritize interventions that address activity- and participation-level deficits (Granberg, Dahlström, Möller, Kähäri, & Danermark, 2014), and so, it is important for any aural rehabilitation program to include auditory interventions that have a significant effect on those activity- and participation-level domains, not only the structure-level deficits experienced by a patient.

In a published survey of practicing audiologists, Clark and colleagues (2017), highlighted areas of audiological practice that are often overlooked. According to the survey results, for example, less than half of responding audiologists always include communication partners in the treatment plan for someone with hearing loss. Only 42% of respondents report always providing augmentative communication strategies. Only 19% of respondents always instruct on the optimization of speech signals. Only 15% of respondents reported providing formal auditory training, with half of those responding only doing so rarely for their patients (Clark, Huff, & Earl, 2017). All of these aspects of aural rehabilitation are geared towards addressing activity-level restrictions for people living with hearing loss. If the only a minority of audiologists are providing these services, then there is a lack of therapeutic services for people with hearing loss addressing their activity-level deficits.

Auditory Training

Boothroyd has repeatedly made an argument for perceptual speech training as a means to address activity-level restrictions that result from auditory disorders (Boothroyd 2007; 2010). He argues that structure-level restrictions can be treated via sensory aids, such as amplification, that counseling can be used to address participation-level deficits, and that auditory training can be used to address any activity-level deficits related to listening (Boothroyd, 2007).

Auditory training has a long history in aural rehabilitation. Mark Ross describes the use of intensive auditory training in combination with the use of amplification and counseling as far back as 1952, in what he describes as “audiological Camelot” (Ross, 1997).

Auditory training can be broadly split into two categories: analytic and synthetic (Erber, 1996). Analytic auditory training takes a bottom-up approach, and is primarily focused with detection and discrimination of specific sounds, with the hope that the enhanced ability to detect and discriminate sounds will aid in identification and comprehension of a message. Synthetic training, in contrast, focuses on meaning, syntax, and context of a message to aid in understanding. With synthetic training, a listener utilizes contextual cues and inference to aid with sentence and phrase-level material. It should be noted that even the most synthetic training paradigms include analytic components when the listener is required to give an exact response and rely on the non-contextual cues as well (Blamey, Dooley, Alcántera, Gerin, & Seligman, 1993). Both forms of auditory training focus on the important point that success in auditory training needs to be able to generalize to real world situations, and not just at the specific task they were engaging with for auditory training. Many investigators conducting experiments with auditory training use untrained measures of speech intelligibility to determine if improvements achieved in auditory training are generalizing to other listening situations.

There are many examples in auditory literature across the decades exploring the effectiveness of both analytic (Bode & Oyer, 1970; Fu & Galvin, 2007; Saunders, Smiths, Chisolm, Frederick, McArdle, & Wilson, 2016; Tye-Murray, 1990; Walden, Erdman, Montgomery, Schwartz, & Prosek, 1981) and synthetic (Bernstein, Bakke, Mazeyski, Blake-Rahter, Preseley, Hume, Plant, & Levitt, 2012; Gagné, Dinon, & Parsons, 1991; Montgomery, Walden, Schwartz, & Prosek, 1984) forms of auditory training. Reviews of auditory training programs highlight both outcomes with significant changes attributed to auditory training and the drawbacks of both types of auditory training programs. One review of 13 computer based auditory training programs noted mixed results between studies, significant but small improvements as a result of training, and a lack of commonality between outcome measures used (Henshaw & Ferguson, 2013). An earlier review of both synthetic and analytic auditory training programs by Sweetow and Palmer (2005) also noted the issues elucidated by Henshaw and Ferguson:

> Despite the large number of articles that have been published related to auditory training, only a handful meet the rigorous scientific criteria set forth to qualify as evidence based in this paper, and even these have methodological flaws that make it difficult to reach a compelling conclusion related to auditory training. (p. 502)

Both articles acquiesce that hearing-impaired individuals do appear to improve their communication skills following auditory training. Participants across myriad studies included in the reviews improved on both trained stimuli (including phonemes, monosyllabic words, nonsense words, and localization tasks), but also untrained stimuli (including word recognition tests in quiet and in noise). Some studies also found significant improvement on self-reported scores of hearing handicap (Kricos, et al., 1992; Kricos & Holmes, 1996). Many studies included in the reviews noted inconsistent measurements of compliance with auditory training, inconsistencies in terms of follow-up assessment for participants, were not blinded studies, or involved small subject samples. The reviews conclude by calling for more high-level evidence studies of auditory training with carefully selected, standardized outcome measures able to gauge clinically significant changes as a result of auditory training.

Speech Tracking Training

Speech Tracking Training is a synthetic method of auditory training originally described by Carol De Fillipo and Brian Scott in 1978. In the process of what would ultimately be termed Continuous Discourse Tracking, or CDT, a talker reads prepared text, one line at a time, to a trainee or “receiver.” The receiver must report back verbatim the prepared text. Provided the repetition of the utterance is correct, the talker proceeds to the next line of text. If the utterance is not correct, a pre-determined repair strategy is used until the utterance is correct, at which point the talker proceeds to the next line of prepared text (De Filippo & Scott, 1978). Several measurements are taken of this process, which are termed on-task measures of performance, including the tracking rate (in words per minute - wpm), the ceiling rate (the fastest rate achieved during a tracking session; again, measured in wpm), the number of lines of text successfully tracked during a session of training, and the number of errors made. CDT was proposed as a method of clinician-directed auditory training and a method of communication training. It uses connected speech, rather than the presentation of singular words or sounds combined with face-to-face interaction, in order to measure reception and comprehension of a more whole message. The utility of CDT lies in the task being both a method of auditory training and also a measure of benefit of that training. If measurements of speech tracking training improve, trainees are more able to efficiently receive and comprehend messages from a trainer.

CDT utilizes five ideas that Wolfle outlined in his chapter in *The Handbook on Experimental Psychology* (Wolfle, in Stevens, 1951). Wolfe postulated that successful training programs should include the following:

1. Training should be realistic and mirror the thing that training wishes to improve.
2. Training must involve active engagement instead of passive reception.
3. Training should be varied and not static in its substance.
4. Training must have consistent measure of progress taken to demonstrate improvement.
5. There must be feedback in the moment to keep up patient motivation.

These concepts have been noted by Sweetow and Palmer (2005) as important concepts to integrate into an auditory training regimen. CDT strives to mirror face-to-face turn-taking conversation in its procedure (De Filippo & Scott, 1978). It utilizes customizable stimulus text that can be used to keep a listener actively entertained while they are training (Bernstein, et al., 2012; Dempsey, Levitt, Josephson, & Porrazzo, 1992; Gnosspelius & Spens, 1992). The material does not repeat, which keeps it varied. The procedure measures progress as training proceeds, which can be used to demonstrate improvement (Plant, Bernstein, & Levitt, 2015), which can be shown to the listener to keep up patient motivation if need be (Gnosspelius & Spens, 1992). Kraus and White-Schwoch (2015), argue that auditory training needs to incorporate listening with attention, memory, and built-in feedback and rewarding systems (Kraus & White-Schwoch, 2015). Connected discourse tracking involves all of these features, and is a candidate for a successful auditory training method.

In addition to studies demonstrating benefit as a result of connected discourse speech tracking (Bernstein, et al., 2012; Plant, et al., 2015), the procedure has also attracted some criticism. Owens & Raggio (1987), in the development of their own UCSF Speech Tracking Procedure, note the significant impact that linguistic complexity and paragraph structure can have on the tracking process, specifically that narrative passages are easier to track compared with descriptive passages (Owens & Raggio, 1987). Tye-Murray and Tyler (1988) published a critique of CDT as a whole, where they pointed out that too much variability is present in the entire procedure. Listener-variability can affect tracking results, depending on the language level of the listener, depending on the repair strategy chosen by the listener in the event of a tracking error, or even depending on the confidence level of the listener. Talker-variability can affect tracking results, with the trainer being able to affect results by changing the clarity or speed of their speech, the volume of their speech, or by combining pointed facial expressions or enunciations with presentation of the stimulus (Tye-Murray & Tyler, 1988). Sparks and colleagues (1978) corroborate this claim, noting that listener performance on CDT decreases initially whenever a listener engages in CDT with a novel talker (Sparks, Kuhl, Edmonds, & Gray, 1978). Finally, stimulus variability can affect the tracking performance of CDT, with more linguistically complex sentence material being more difficult to track than linguistically simple material.

In response to these criticisms and as a result of the technological developments at the end of the twentieth century, several adaptations of CDT have been developed to reduce these variabilities in the process. Each of these adaptations shares two commonalities in their development:

1. They chose to use computers to automate the tracking process to some degree, so that measurements of tracking did not need to interrupt the tracking process itself, and
2. They sought to control to some degree talker-, text-, and listener-variability in the CDT process.

Gagné and colleagues (1991) examined a connected discourse training program developed by Pichora-Fuller and Benguerel known as the Computer-aided Speechreading

Training program (CAST), finding significant performance improvements of subjects in post-test assessments (Gagné, Dinon, & Parsons, 1991). CAST used sentences presented via videocassette tape providing an audiovisual message, which the participant was instructed to type back on a keyboard. Correction strategies in the case of an error were either a repetition of the entire sentence clip, or a display of the word with the incorrect part of the sentence highlighted in text. The procedure was far more analytic than synthetic, as it prioritized bottom-up processing of individualized sounds within an utterance, rather than reliance on linguistic context. CAST was designed to control the text-level and receiver-level variabilities inherent to CDT. The source material was limited in linguistic complexity so as to focus and analyze individual visemes instead of sentences, and listeners were limited to keying in what they heard as a specific repair strategy, in the event of a tracking error. Pichora-Fuller and Benguerel (1991) noted that automatization of the tracking procedure allowed for calculations that would otherwise have taken too long to calculate by hand, but also that the interactional component of discourse tracking was eliminated by the CAST procedure of typing what was heard instead of repeating it aloud (Pichora-Fuller & Benguerel, 1991).

Dempsey and colleagues described a computerized form of speech tracking known as Computer-Assisted interactive Tracking Simulation (CATS) (Dempsey, Levitt, Josephson, & Porrazo, 1992). The CATS system used a laserdisc video player to play audiovisual recordings of short stories. The stories were bisected into short videos, one for each line of the story. Trainees were instructed to repeat back the prerecorded utterances, and were graded by an observer to determine whether, similar to traditional speech tracking, the source material should be repeated or if the source material would be allowed to progress to the next line. An advantage of the CATS system is that it sought to control for the variability inherent to the highly synthetic nature of speech tracking training. Text material was standardized between subjects, and talker variability was mitigated by every trainee receiving the same recordings of a talker for each presentation. A disadvantage noted by the authors is that CATS was limited at the time by its technology. The time required to change between video tracks of the laserdisc cumulatively added over a minute to the tracking time required for a participant to complete a story, compared with the same story tracked in the traditional manner.

In Sweden, at the Royal Institute of Technology (Kungliga Tekniska Högskolan, or KTH), Gnosspelius and Spens (1992) developed a computerized form of CDT that more closely adhered to the original procedure described by De Fillipo and Scott in 1978. KTH Speech Tracking Training involves a talker and listener sitting opposite each other at a table. The talker reads a line from the target source material, and the listener repeats the line verbatim. One specific repair strategy is used: if an error (called a 'block') occurs, the line is repeated from the word where the error occurred. If the error persists a pre-determined number of times (2 times is the default in the software), the word is displayed on a screen for the listener to read, who then is able to repeat the target line with visual support. Upon successful tracking of a stimulus line, the talker then proceeds to the next line in the stimulus material.

KTH speech tracking preserved the intent of CDT, to provide a face-to-face interaction between talker and listener, while simultaneously controlling for some of the listener- and text-variability inherent to the CDT process. The listener is limited to one form of correction strategy in the case of errors, and the text lines tracked in a session are limited to a few words per line. In addition, computer automation allows for calculation and measuring of variables like tracking rate, total number of errors made, and ceiling rate, without the talker-trainer needing to pause the tracking session to note these measurements.

The use of KTH speech tracking has been primarily limited to cochlear implant aural rehabilitation in the literature. Tobey and colleagues examined the effect of pharmacological intervention on speech tracking in cochlear implant recipients, and found that both groups, engaging in speech-tracking training, experienced improvements in tracking rate over an eight week period of 24 total training hours (Tobey, Devous, Buckley, Overson, Harris, Ringe, & Martinez-Verhoff, 2005). Bernstein and colleagues (2012) examined both KTH speech tracking and traditional CDT in cochlear implant users and found significant improvements in tracking rate and sentence recognition tasks after an eight-week period of approximately 3 total training hours for both methods of speech tracking training (Bernstein, et al., 2012). Plant and colleagues (2015) describe a case study of a cochlear implant user who experienced a significant increase in words correctly tracked over a nine-month period with approximately 70 total training hours Each of these studies notes the importance of clinician directed auditory training as part of an aural rehabilitation program and of its power to help patients maximize the use of their impaired listening.

What remains, according to recommendations from reviews for auditory training programs in the literature (Sweetow and Palmer, 2005; Henshaw & Ferguson, 2013), is the generation of high-level evidence examining the effectiveness of KTH auditory training. Specifically, Henshaw and Ferguson (2013) prescribe a study that is randomized, blinded, with a sample size dictated by a power calculation, with the possible inclusion of an ‘active’ control group performing a task similar to the training group, with no expected improvement in performance, in order to guard against placebo effects (Henshaw & Ferguson, 2013).

Measuring Effectiveness of Auditory Training

What constitutes improvement as a result of auditory training? Multiple answers can be used to address this question. At a minimum, persons engaging in auditory training should be expected to improve at the training task itself (Dubno, 2013; Barcroft, Spehar, Tye-Murray, & Sommers, 2016). These measurements, referred to in this paper as on-task measures of improvement, should serve as the baseline, but not the only, measure of success of auditory training. In order to determine if auditory training is effective, it should be measured whether treatment effects of auditory training generalize beyond the treatment itself (Sweetow & Palmer, 2005), as the ultimate goal of auditory training should be an improvement of auditory ability, not just ability to hear the specific stimuli used in auditory training.

In addition to the importance of measuring both on- and off-task measures of auditory ability as a result of auditory training, Boothroyd (2007), points out the importance of targeting outcome measures to specifically measure not only structure- and activity-level changes, but also participation-level changes and, by extension, quality of life, as these are likely equally important when it comes to the ideas of the impacts of communication in every-day life (Boothroyd, 2007).

The Use of the Frequency-following Response to Gauge Training-related Auditory Changes

Several studies have utilized electrophysiological measurements correlating to structure-level changes in the auditory system as a means of measuring impact of auditory training. Electrophysiological measurements of the brain's response to sound can be used to determine if the central auditory system is improving its ability to encode speech signals. Human participants engaging in perceptual speech training have shown structure-level changes of the auditory system in response to this training on electrophysiological measurements such as the mismatch negativity (MMN) (Tremblay, Kraus, & McGee, 1998), and the frequency-following response (FFR) (Carcagno & Plack, 2011; Russo, Nicol, Zecker, Hayes, & Kraus, 2005; Song, Skoe, Wong, & Kraus, 2008). The FFR is a particularly interesting evoked potential because of its power to represent the central auditory nervous system's ability to represent temporal information of sounds, whether they be pure tones (Liu, Palmer, & Wallace, 2005), tonal components of speech (Song, et al., 2008), or whole syllables (Skoe & Kraus, 2010). It is an electrophysiological representation of the brain's ability to process particular sounds, and can be used to measure structure-level changes to the auditory system.

The FFR is also useful because the stimulus used to evoke the potential can be presented both in quiet and noise, and the waveform's degradation can be measured, accordingly, as was done by Russo and colleagues in 2004 (Russo, Nicol, Musacchia, & Kraus, 2004). The introduction of competing noise alongside a stimulus can degrade the fidelity of the FFR, as they demonstrated when they compared the FFR of a /da/ syllable in quiet and presented along-side gaussian white noise. The authors conclude that the FFR could be used to assess benefit of auditory training as evidenced by an increase in the magnitude of the fundamental frequency and its harmonics in the presence of noise, in their case as it pertains to children with brainstem-encoding deficits. The same concept, however, could apply to auditory training for people normal hearing or hearing loss: an improvement in magnitude of the response of the FFR, particularly that of a degraded FFR obtained in the presence of noise, is an indicator of improvement of the central auditory system's ability to encode the signal, reflecting a structure-level change as a result of auditory training.

To this end, Song and colleagues used the FFR elicited in quiet and noise to examine the effect of speech in noise based computerized auditory training for normal hearing listeners (Song, Skoe, Banai, & Kraus 2012). They found significant improvements of the FFR amplitudes corresponding to the fundamental frequency and second harmonic after 10 hours of training for stimuli elicited in the presence of noise, concluding that that this is evidence of auditory training improving the auditory system's ability to process speech sounds in the presence of noise. Song and colleagues also compared these results with behavioral assessments of speech-in-noise, namely the QuickSIN and HINT tests. This is particularly important because it involves the evaluation of auditory training via a structure-level assessment (the FFR in the presence of noise), but also activity-level assessments (speech-in-noise tests), in order to provide a more holistic view of changes as a result of auditory training. Song and colleagues did not only find significant results in their structure-level assessments, but in their activity-level assessments as well.

Statement of Purpose

Auditory training is a component of aural rehabilitation suggested to address activity-level deficits arising from hearing loss, in conjunction with amplification to address structure-level deficits, and counseling to address participation-level deficits. There is, however, a paucity of high-level evidence examining the effectiveness of auditory training as a whole, and specifically clinician-directed auditory training. In addition, outcome measurements of audiological intervention often focus on one domain of the ICF, but struggle to examine multiple levels of possible deficit in order to measure impact of audiological function. The purpose of this research study was to determine if KTH Speech Tracking Training in the presence of noise was able to improve structure-level measurements as well as activity-level measurements of auditory function in a randomized research design, with a sample size dictated by power calculation, so as to make an effort to best adhere to “high-level” quality of evidence needed for evaluations of auditory training. Average rate of speech tracking and number of errors made during a training session were selected as measurements of on-task performance. Analyses of specific portions of the FFR in response to a /da/ stimulus in the presence of noise were selected as off-task structure-level measures of auditory system change, the QuickSIN test was selected as an off-task activity-level measure of auditory system change, and questions from the SSQ were used as a self-reported activity-level measure of auditory system change.

Research Questions

For normal hearing listeners who engage in training with KTH speech tracking training in the presence of noise:

1) Are there on-task changes as a result of training corresponding with activity-level deficits?
    a. It is hypothesized that auditory training in the presence of noise will have a positive significant effect upon on-task measurements of that auditory training.
2) Are there off-task structure-level changes as a result of training, measurable via electrophysiological measures?
    a. It is hypothesized that auditory training in the presence of noise will have a significant effect on structure-level assessments.
3) Are there off-task activity-level behavioral changes as a result of auditory training, measureable by behavioral word-recognition tests?
    a. It is hypothesized that auditory training in the presence of noise will have a significant effect on off-task activity-level behavioral measures.
4) Are there off-task activity level self-report changes as a result of auditory training?
    a. It is hypothesized that auditory training in the presence of noise will have a significant effect on off-task activity level self-report measures

Chapter II - METHOD

This study was a quantitative research design targeted to assess both on- and off-task benefit secondary to KTH speech tracking training in the presence of noise. The University of Connecticut Storrs Institutional Review Board (IRB) approved all study procedures.

Participants

Thirty normal hearing adults between the ages of 18 and 33 were recruited from the University of Connecticut and surrounding communities for this study. An a-priori power analysis indicated that for a mixed analysis of variance, with a large effect size of .6, a sample size of 30 participants, with 10 participants in each group, would result in a power level of .8 and an alpha of .05. An effect size of .6 was determined by similar effect sizes measured from comparable auditory training studies in the literature (Song et al., 2012), and from 156 meta-analyses of treatment effect size (Lipsey & Wilson, 1993).

The average age of the participants was 20.5 years of age, with a standard deviation of 2.5 years. 23 of the participants in this study were female, 7 were male. Krizman and colleagues note differences in the FFR in bilingual persons (Krizman, Marian, Shook, Skoe, & Kraus, 2012). To that end, participants were all native mono-lingual English speakers, and in order to qualify for the study, they were required to not have significant foreign language experience prior to middle-school defined as formal education or presence of a second language in the home. Group membership was matched for sex, to ensure roughly even distribution of genders across groups, but otherwise participants were randomly assigned into one of three groups for purposes of this experiment. Each participant underwent a series of qualifying tests to ensure that they met the criteria for participation.

Participants in this study were compensated via extra-credit if they were recruited from an undergraduate course. If the qualifying procedures revealed that a participant did not fit the criteria for participation, they were not enrolled in the study, and received a smaller amount of extra credit for their time if they were recruited from a participating undergraduate course.

Qualifying Phase

The initial battery of auditory assessment included otoscopy, pure-tone audiometry, speech reception thresholds (SRT), word recognition testing in noise, and the Dichotic Digits Test (Musiek, 1983). All qualifying testing was performed in a double-walled sound-treated booth.

Otoscopy

Otoscopy was used to screen for outer ear issues of the ear canal and tympanic membranes. Individuals without a healthy appearing tympanic membrane or occluding cerumen in either ear canal were not included in this study. No participants screened presented with issues of unhealthy appearing tympanic membranes or occluding cerumen.

Audiometry

Participants in this recruited sample all had normal hearing levels, as measured using a Grayson Stadler, Inc. (GSI) 61 Audiometer and ER-3A insert earphone transducers. Pure-tone air-conduction thresholds were measured from 250-8000 Hz bilaterally, utilizing a modified

Hughson-Westlake method procedure (Carhart & Jerger, 1959). Normal hearing thresholds are defined in this study as being measured less than or equal to 25 dB HL (American Speech Language Hearing Association, 2017), and all participants had thresholds at or better than this level in both ears. Figure 2.1 shows the average pure-tone thresholds for participants in this study. Two participants screened did not meet the inclusionary criteria of normal hearing levels for this study.

Speech Recognition Threshold (SRT)

A speech recognition threshold was obtained for each participant in both ears. Spondee words were presented via monitored-live-voice using a descending and bracketing procedure to obtain the SRT (American Speech Language Hearing Association, 1988). The speech recognition threshold for each ear was defined as the lowest level at which participants were able

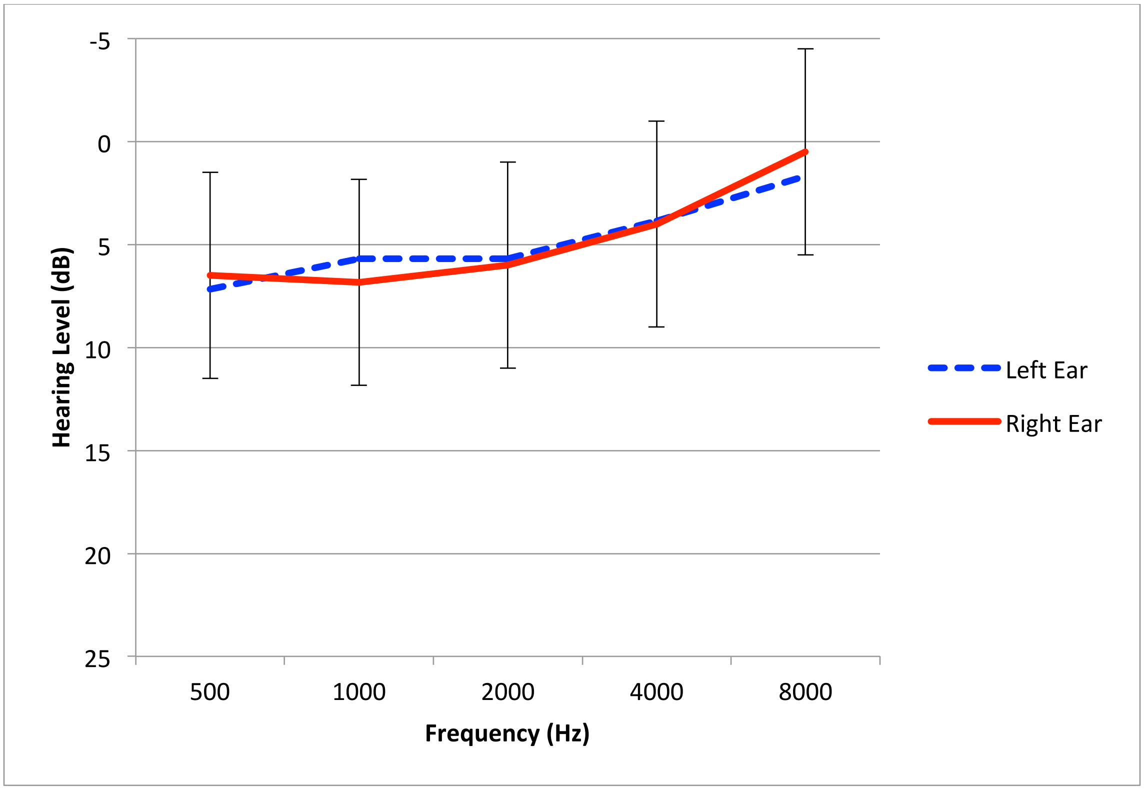

Figure 1. Mean pure tone thresholds for each ear for all participants (n = 30). Brackets at each frequency indicate one standard deviation.

to correctly repeat the target word 50% of the time. For inclusion in this study, thresholds were required to demonstrate good agreement (≤10 dB difference) with the three-frequency pure-tone average of 500, 1000, and 2000 Hz in each ear. No participants were excluded from this study based on speech recognition threshold testing.

Word Recognition in Noise

The ability to recognize words in the presence of noise was screened for by use of a QuickSIN word list (QuickSIN; Etymotic Research, 2001). The word list is comprised of 6 sentences presented at 70 dB HL, via ER-3A insert earphones, amongst an increasing level of 4-talker babble. Participants were instructed to repeat back as much of each sentence that they were able to, and were invited to guess if they were unsure of a part of the sentence. The QuickSIN test gives a measurement of hearing ability in the presence of noise classified as "signal-to-noise-ratio (SNR) loss," a number between 25.5 and -4.5 dB SNR Loss. This value is calculated as the difference between 25.5 and total number of key words correctly repeated in any one list. Individuals with a severe degree of SNR loss, defined by the QuickSIN manual as a SNR loss of >15 dB, did not meet the inclusion criteria for this study. *A priori*, it was decided to include individuals who exhibited scores of the Quick-SIN indicating a mild to moderate SNR loss (3-15 dB) in order to possibly capture participants who could present with normal hearing levels, but have difficulties with hearing in the presence of noise. In spite of this decision, no participant during the QuickSIN screening measured an SNR loss of 3 dB or greater. List one of the QuickSIN was used as the word recognition in noise screening test for every participant. A copy of the instructions and QuickSIN word list utilized can be found in Appendix A.

Dichotic Digits Test

The Dichotic Digits Test (DDT) (Musiek, 1983; Musiek, Gollegly, Kibbe, & Verkest-Lenz, 1991) was administered to screen for integrity of the central auditory system. The Dichotic Digits Test is a test sensitive to lesions in the central auditory system consistent with central auditory dysfunction. It was selected because while other tests in the screening battery look at the outer, middle, and inner ears, a quick assessment of the auditory function of the brainstem and cerebrum can rule out participants who have issues. The DDT also would be valuable in future studies should this project be adapted to hearing loss populations, as the test is relatively resistant to cochlear hearing loss (Musiek, et al., 1991). The test consists of spoken digits from 1-10, with the exception of seven, which differs from the other nine digits in syllable length. Two pairs of digits are presented binaurally, and the participant is asked to repeat all four numbers back in any order, and encouraged to guess if they're unsure of any of the numbers. 80 numbers are presented in total, and the number of correct numbers repeated is converted to a percentage score. The Dichotic Digits Test was administered via ER-3A insert earphones at 50 dB SL in reference to the obtained speech recognition threshold in each ear. Individuals with a score of less than 90% on the Dichotic Digits Test did not meet the inclusion criteria for this study. No participants screened were screened out of this study as a result of the dichotic digits test. A copy of the instructions for the Dichotic Digits test can be found in Appendix B.

Click-Evoked ABR

A click-evoked auditory brainstem response test was also administered to screen for auditory integrity of the auditory nerve and auditory brainstem. The click-evoked auditory brainstem response test can be used to measure integrity of the central auditory system (Starr & Achor, 1975).

Participants were seated in a chair in an electromagnetically shielded double-walled sound-treated booth, and a vertical montage of three Ag-AgCl electrodes was placed on the participants head (Cz – active, Fpz – ground, A2 – reference) (Homan, Herman, & Purdy, 1987). Electrical impedances were measured to be less than 5 kiliohms per contact, and impedances were no more than 2 kiliohms between electrodes.

An average waveform based on 2000 trials of a click stimulus, presented monaurally at 31.1 Hz at 80.3 dB sound pressure level (SPL) via an ER-3A insert earphone , was obtained for each participant. The latencies for waves I, III, and V were identified by one rater. Individuals with wave latencies outside of the latency normative value +/- one standard deviation did not meet the inclusionary criteria for this study. Waveform latencies for inclusionary criteria and standard deviations can be found in Table 1.

Table 1: Waveform latencies for ABR inclusionary criteria (from ICS Chartr EP 200 user manual).

Waveform	Mean Latency	Standard Deviation
I	1.54 ms	0.11 ms
III	3.69 ms	0.10 ms
V	5.54 ms	0.19 ms

Experimental Phase

The experiment consisted of 10 condition and assessment sessions in total administered to participants randomly assigned to three groups: a group engaging in speech tracking in the presence of noise (labeled the training group), a group engaged in passive listening to an audiobook in the presence of noise (labeled the listening group), and a group that engaged in no noise based activity at all (labeled the control group). The inclusion of a passive listening group was based out of a desire to better separate training gains achieved by actively training in noise, rather than passive exposure to speech in the presence of noise. The first session was a pre-condition assessment visit in which the participants completed behavioral, self-report, and electrophysiological measures designed to serve as a baseline for the experiment. Eight condition visits followed, in which participants completed activities that depended on the experimental condition to which they were randomly assigned. Finally, the tenth visit was a second assessment session in which participants completed the same assessment measures post-condition visits as they did in their pre-condition visit. A breakdown of visits is visible in table 2.

Pre-condition Assessment

Enrolled participants in this study completed three different measures designed to measure off-task changes as a result of training or listening in noise at the beginning and end of enrollment in this study. The QuickSIN test was used as an objective measure of speech recognition in noise, the SSQ survey was used as a self-assessment of listening ability in noisy situations, and an FFR in response to a /da/ stimulus in quiet and noise was obtained, to examine neuroplastic coding of a signal in quiet and in noise.

Table 2: Breakdown of participant visits by type.

Visit	Type
1	Pre-condition Assessment Visit
2	Condition Visit 1
3	Condition Visit 2
4	Condition Visit 3
5	Condition Visit 4
6	Condition Visit 5
7	Condition Visit 6
8	Condition Visit 7
9	Condition Visit 8
10	Post-condition Assessment Visit

QuickSIN

The QuickSIN test (Etymotic Research, 2001) was chosen as a behavioral measure to objectively assess the activity-level performance; specifically, listening in noise. The QuickSIN consists of 12 standard equivalent lists to measure SNR loss, a measurement of hearing ability in noise (Niquette et al., 2001). The QuickSIN has precedence in the literature as an outcome measure for both hearing impaired participants (Walden and Walden, 2005), and normal hearing participants (Song, Skoe, Banai, & Kraus, 2012).

Each list of the QuickSIN consists of 6 sentences, presented at 6 different signal to noise (SNR) ratios, ranging from +25 to 0 dB, in 5 dB decrements, with one sentence presented at each SNR. On the QuickSIN, the presentation level of the target sentence remains the same, with the competing 4-talker babble varying between sentences.

Participants were instructed to repeat back as much of the sentence as possible, and key words in each sentence were graded as correct or incorrect. Again, SNR Loss is calculated as the difference between 25.5 and total number of key words correctly repeated in one list. The QuickSIN tests were administered under ER-3A insert earphones at 70 dB HL (Killion, et al., 2004).

The QuickSIN is designed primarily as a quick estimate of SNR loss, and the authors of the test note that the administration of one QuickSIN list yields a measurement within 1.8 dB of the true measurement of SNR loss at the 80% confidence level (Killion, et al., 2004). To increase accuracy of SNR Loss measure as an activity-level performance, 4 QuickSIN tests were administered and averaged together as the pre-condition SNR Loss measurement, providing a measurement of SNR loss within 1.4 dB of the true measurement of SNR loss at the 95% confidence level (Killion, et al., 2004). As all participants were screened for listening ability in noise with list one, the first QuickSIN list was not used in either the pre-condition assessment visit or the post-condition assessment visit. The four QuickSIN lists used for the pre-condition assessment visit and the four QuickSIN lists used for the post-condition assessment visit were randomly selected and ordered for each participant from the 11 remaining available QuickSIN lists. No QuickSIN list was repeated between pre-condition and post-condition assessment visits.

The Speech and Spatial Qualities of Hearing Scale (SSQ)

The Speech, Spatial, and Qualities of Hearing Scale (SSQ), a survey that consists of 50 visual assessment scales, was chosen as a self-reported activity-level measure of listening ability in difficult listening situations. The SSQ is a clinical tool used to measure hearing disability across several domains (Gatehouse & Noble, 2004). The test asks questions about listening to speech in a variety of difficult listening situations (collectively known as 'speech' domain questions), questions about listening to speech in a variety of directional, distance, and movement situations (collectively grouped as the 'spatial' domain questions), and questions about the quality of hearing, paying special attention to the naturalness and clarity of speech (collectively known as the 'quality' domain questions).

The SSQ was administered via paper-and-pencil format. The response scale was a 10-centimeter visual analog scale, numbered from 0-10, with millimeter indentations. Responses were recorded to the nearest 10^{th} of a point value, based on proximity of the marked X to the closest millimeter demarcation of the visual analog scale.

In looking at the 50-item SSQ questionnaire, steps were taken to maximize sensitivity of the instrument to activity-level deficits for normal hearing listeners, while minimizing issues of too many statistical analyses. Studies utilizing the SSQ often tend to use grand averages of the Speech, Spatial, or Quality domains of the SSQ items (Banh, Singh, & Pinchora-Fuller, 2012), or to break them into one of several different sub-domains (Gatehouse & Akeroyd, 2006). Complicating the issue of how to analyze answers to the SSQ is the fact that many individual items in the SSQ may not be particularly variable for normal hearing individuals.

Two studies of note have attempted to perform individual analyses of items from the SSQ in order to determine which questions are the most variable in normal hearing listeners, and by extension, which can be the most sensitive to detecting the success of interventions of aural rehabilitation. Agus and colleagues (2009), analyzed the responses from over 3000 responses to a mailed SSQ assessment to both respondents who identify as having normal hearing and respondents who identify as having hearing difficulties, and found that 5 questions, united by themes of listening to two targets, and listening amongst the presence of babble, that were the most variable in respondents (Agus, Akeroyd, Noble, & Bhullar, 2009). Demeester and colleagues (2012) attempted to further quantify the sensitivity of the SSQ to detecting difficulties of listening in noise, an activity-level deficit, by analyzing the lowest scoring items from the SSQ from a sample of normal hearing young adults, normal hearing older adults, and hearing impaired adults. Their findings led to the development of the SSQ-5, a short form of the full questionnaire made up 5 items from the SSQ that most highly correlate with difficulties of listening in noise. They found this combination of questions from the SSQ has a 95.6% probability of correctly categorizing speech recognition abilities in noise (Demeester, Tobsakal, Hendricx, Fransen, Van Laer, Van Camp, Guy, Van de Heyning, & Van Wieringen, 2012). From the individual analyses calculated by Demeester and colleagues on young normal hearing respondents, the five lowest scoring items on the SSQ for that particular demographic were chosen as measurements of self-reported disability or handicap, as they are the least likely to experience a ceiling effect in normal-hearing listeners.

The Frequency Following Response (FFR)

The Frequency Following Response (FFR), an electrophysiological measure, was chosen as an objective structural-level measure. FFR was analyzed over specific temporal portions of a /da/ stimulus in quiet and in the presence of noise.

For the FFR recording, participants were seated in a chair in a double-walled sound-treated booth. A vertical montage of three Ag-AgCl electrodes was placed on the participant's head (Cz - active, Fpz - ground, A2 - reference) (Homan, et al., 1987). These three sites were scrubbed with Nuprep® Skin Prep Gel, and electrodes attached by way of Ten20® Conductive Paste. Once electrodes were attached, participants were instructed to sit quietly and relax their body, while they listened to sounds transmitted via ER-3A insert earphones. Electrical impedances were measured to be less than 5 kiliohms per contact, and impedances were no more than 2 kiliohms between electrodes.

The stimulus used was a six-formant /da/ previously described by Song and colleagues (Song, Nicol, & Kraus, 2011):

> "/da/ is a six-formant syllable synthesized at a 20 kHz sampling rate using a Klatt synthesizer (Klatt, 1980). The duration was 170 ms with voicing (100 Hz fundamental frequency) onset at 10 ms. Formant transition duration was 50 ms and comprised a linearly rising F1 (400–720 Hz), linearly falling F2 and F3 (1700–1240 and 2580–2500 Hz, respectively) and flat F4 (3300 Hz), F5 (3750 Hz) and F6 (4900 Hz). After the transition period, these formant frequencies remained constant at 720, 1240, 2500, 3300,

> 3750, and 4900 Hz for the remainder of the syllable. The stop burst consisted of 10 ms of initial frication centered at frequencies around F4 and F5.” (p.2270-2271)

Per previous administrations of this stimulus in obtaining an FFR measurement, the /da/ syllable was presented at 80.3 dB SPL at a rate of 4.35 Hz in alternating polarities (Song, et al., 2011; Song, et al., 2012) via an ER-3A insert earphone placed in the right ear for both the quiet and noise condition. Responses of alternating polarity were used to minimize stimulus artifact and the cochlear microphonic (Gorga, Abbas, & Worthington, 1985). In the noise condition, 4-talker babble from the QuickSIN was also presented monaurally via ER-3A insert earphone at 74.3 dB SPL, or at +6 dB signal-to-noise ratio. This 4-talker babble is available as a 56 second track on the QuickSIN disc, and was edited to loop for 19 minutes without a break in order to provide continuous 4-talker babble for the duration of each FFR measurement. Presentation of the noise condition and the quiet condition were randomized for both the pre-condition assessment and the post-condition assessments.

In both the quiet and noise conditions, 4000 sweeps of the ABR in response of the /da/ stimulus were collected using the SmartEP System (Intelligent Hearing Systems, Inc.) in continuous mode at a sampling rate of 20 kHz. Continuous recordings were filtered, artifacts (defined as sweeps more or less than 23 μV) were rejected, and averaged offline. Responses were band-pass filtered from 50 to 2000 Hz (12 dB/octave) to isolate brainstem activity (Skoe & Kraus, 2010). Waveforms were averaged with a time window spanning 40 ms prior to the onset of stimulus and 16.5 ms after the offset of the stimulus and then baseline corrected over the prestimulus interval (-40 ms to 0ms, where 0ms is the stimulus onset). The final average response used consisted of 4000 artifact free responses.

The FFR was divided into 2 distinct regions for analysis. The region corresponding to the transition portion of the /da/ syllable, 20-60ms, reflects electrical activity in the auditory system corresponding to the /da/ syllable transitioning from a stop consonant to a vowel. The region corresponding to the steady state portion of the /da/ syllable, 60-180ms, reflects neural encoding of the vowel portion of the stimulus. Song and colleagues (2012) argue that the analysis of the formant transition portion of the stimulus should be separated from the steady-state portion of the stimulus because transient noise affects the transition portion of the stimulus more so than the steady-state stimulus (Song, et al. 2012). Within each region, amplitudes of fundamental frequency (F0 – 100 Hz) and second harmonic (H2 – 200 Hz), components of the FFR that correlate to pitch-related cues of the presented stimulus. Comparisons of these FFR amplitudes in quiet and in noise were measured as an objective structure-level assessment of how the auditory system processes sound in noise, and of changes that resulted to those amplitudes within the three experimental groups of this dissertation.

Condition Visits

Condition 1 – Training Group

Participants in the training group returned for eight visits of auditory training in the presence of noise. For each visit, participants were seated in a sound treated booth across a table from a trainer. Trainer and participant were approximately one meter apart from each other. The trainer was a 29-year-old male with a Midwestern American English accent. The trainer proceeded to read tracking material, line by line, from a laptop computer screen, using an opaque acoustic hoop to ensure that presentation utilized the auditory communication modality only.

During speech tracking, the trainer reads a line of the training material to the listener, and the listener repeats back what they heard exactly. In the case that the repetition is correct, the trainer moves on to the next line of the training material. If the repetition is incorrect, the line of text is repeated from the point in the line that a mistake was made (mistakes in KTH speech tracking are known as 'blocks'). If a participant is still blocking on a word after two repetitions of the word, the blocked word is presented visually on a computer screen, attached to the laptop and facing the participant, located approximately 0.5 meters from the participant. Each training visit, participants engaged in five 9-minute tracking sessions per visit, with breaks taken between training as requested by either the trainer or the participant.

The material used for tracking was the novel *The Wonderful Wizard of Oz* (Baum, 1900). The Wizard of Oz was chosen because of its familiar and popular story, its accessible reading and vocabulary level, and due to the fact that it exists in the public domain. Previous tracking studies made efforts to utilize materials at approximately the 4^{th} to 6^{th} grade reading level

(Bernstein, 2012). *The Wonderful Wizard of Oz* has a Flesch-Kincaid reading level of 5.9 (Flesch, 1948), which is on par with this metric. The novel was broken up into 6320 individual lines of text to be used as speech tracking material. There were an average of nine words tracked per line, and material is broken up by lines *a priori* to ensure that all listeners receive the same text in the same way.

Participants engaged in speech tracking training in the presence of noise for this study. Once seated, two computer loudspeakers, located approximately .5 meters from the participant, and at 45° and 315° azimuth presented looped 4-talker babble taken from the QuickSIN test. An Equivalent Continuous Sound Level (Leq) of 60 dBA, approximately the level conversational of speech one meter from a talker, was obtained of the 4-talker babble over 60 seconds using a Brüel & Kjær 2250-L sound level meter at the approximate head level of the participant, and the trainer utilized a microphone and VU meter to ensure that presentation level of the training material peaked at 66 dBA, ensuring speech tracking training that occurred at a signal-to-noise ratio of approximately +6 dB.

KTH speech tracking software records several variables during training, some of which were used to measure on-task changes as a result of training. For participants in this study, tracking rate and the number of blocks in a nine-minute training session were used to measure the progress of auditory training in noise.

Condition 2 – Listening Group

Participants in the listening group engaged in eight 50-minute visits of listening to a recorded recitation of a book in the presence of background noise. Participants in this condition were seated in a sound treated booth and listened to recordings of a talker located approximately one meter away at zero degrees azimuth. The voice providing recorded recitation of the story was the same talker who facilitated KTH speech tracking training for participants in the training condition: a 28-year-old male talker with a neutral Midwestern accent. Computer loudspeakers located approximately .5 meters away, at 45° and 315° azimuth, presented competing noise.

The recorded stimulus that the listening group listened to were recordings of *The Wonderful Wizard of Oz* (Baum, 1900) and its sequel, *The Marvelous Land of Oz* (Baum, 1904). The Wizard of Oz was also chosen as the training material for the listening group to keep the training material the same between the training and listening groups, but also for the same reasons it was chosen as the training group stimulus: it is a familiar and entertaining story for listeners presented at an accessible language level, using a stimulus that exists in the public domain, free from licensing issues. An equivalent continuous sound level (Leq) of 66 dBA was obtained of the recorded stimulus over 60 seconds using a Brüel and Kjær 2550-L sound level meter at the approximate head level of the participant, to ensure a presentation level of 66 dB of the stimulus.

The competing noise stimulus used was 4-talker babble taken from the QuickSIN test. Four-talker babble from the 12 QuickSIN lists was looped and presented at 60 dB, also verified in the same manner with a Brüel and Kjær 2250-L sound level meter, to ensure a SNR of +6 dB.

Condition 3 – Control Group

Participants in the control group engaged in eight visits of quiet study or reading. Participants were invited to bring their own reading or study materials, or utilize provided magazines or books, provided they did so in ambient noise of the laboratory. This activity was designed to equate time spent in the study across experimental groups, and was not expected to influence outcome measures.

Post-condition assessment

After the final condition visit, participants returned for one final assessment visit. In the post-condition assessment visit, participants completed the same three measures that they completed in the pre-assessment visit in the same prescribed manner. Four QuickSIN word lists were administered, the SSQ was re-administered, and an ABR in response to the /da/ syllable in quiet, and in the presence of noise were obtained from each participant at this visit.

Chapter III – RESULTS

Question 1: Measures of on-task performance

Are there on-task changes as a result of training corresponding with activity-level deficits?

In order to determine if on-task training-related changes in speech tracking performance occurred at a statistically significant level, average tracking rate and average block rate were compared across visit for participants enrolled in the training group. Average tracking rate as a function of training session (the 40 sessions across eight visits) can be seen in Figure 3, and a condensed version of average tracking rate as a function of training visit (the eight training visits) can be seen in Figure 2. Average block rate as a function of training session can be seen in Figure 5, and average block-rate as a function of training visit can be seen in Figure 4.

A repeated measures analysis of variance (RMANOVA) with training session (8: Visits 1-8) as dependent variable and average tracking rate (in words per minute) as the within-subject factor in question showed a significant main effect of session with Huynh-Feldt correction ($F_{2.35,21.6} = 63.512$, $P < .001$) on tracking rate. Specific statistical measures of this RMANOVA can be seen in Table 3. This analysis demonstrated that there was an effect of training session on the rate at which participants in the training group were able to perform the training activity: Participants got faster as they trained more.

Similarly, an RMANOVA was also performed on the average block rate, or error rate , with training session (8: Visits 1-8) as dependent variable and average block rate (number of blocks in a session) as the within-subject factor. This yielded a significant main effect of session with Huynh-Feldt correction ($F_{6.17,55.57} = 36.849$, $P <.001$) on block rate. Specific statistical measures of this RMANOVA can be seen in Table 6. This analysis showed, similarly, that there was an effect of training session on block-rate, the number of mistakes made during training. As participants progressed through the auditory training activity, they made significantly fewer blocks.

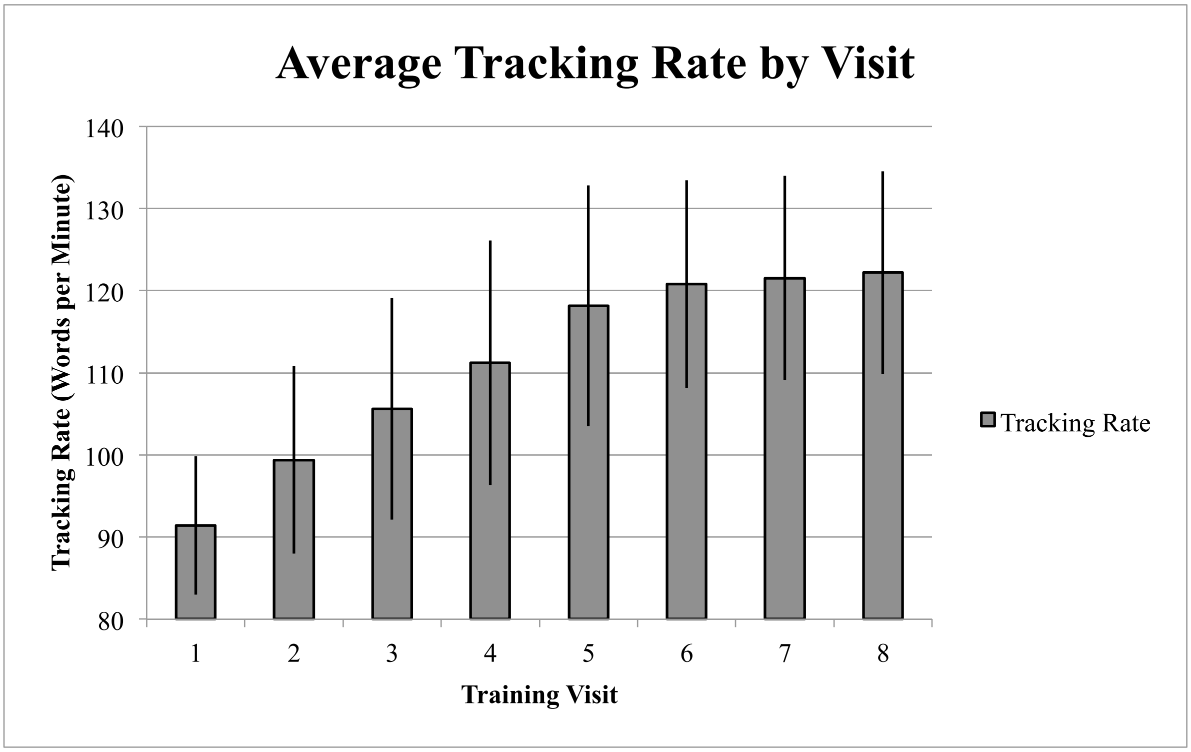

Figure 2: Graph of average tracking rate across eight visits. Each visit involves 5 nine-minute sessions of KTH Speech Tracking Training. Error bars represent +/- 1 standard deviation. Results indicate a significant effect of training visit on overall tracking rate, as determined by a repeated measures analysis of variance with tracking rate as the dependent variable ($F_{2.35,21.6} = 63.512$, $P < .001$)

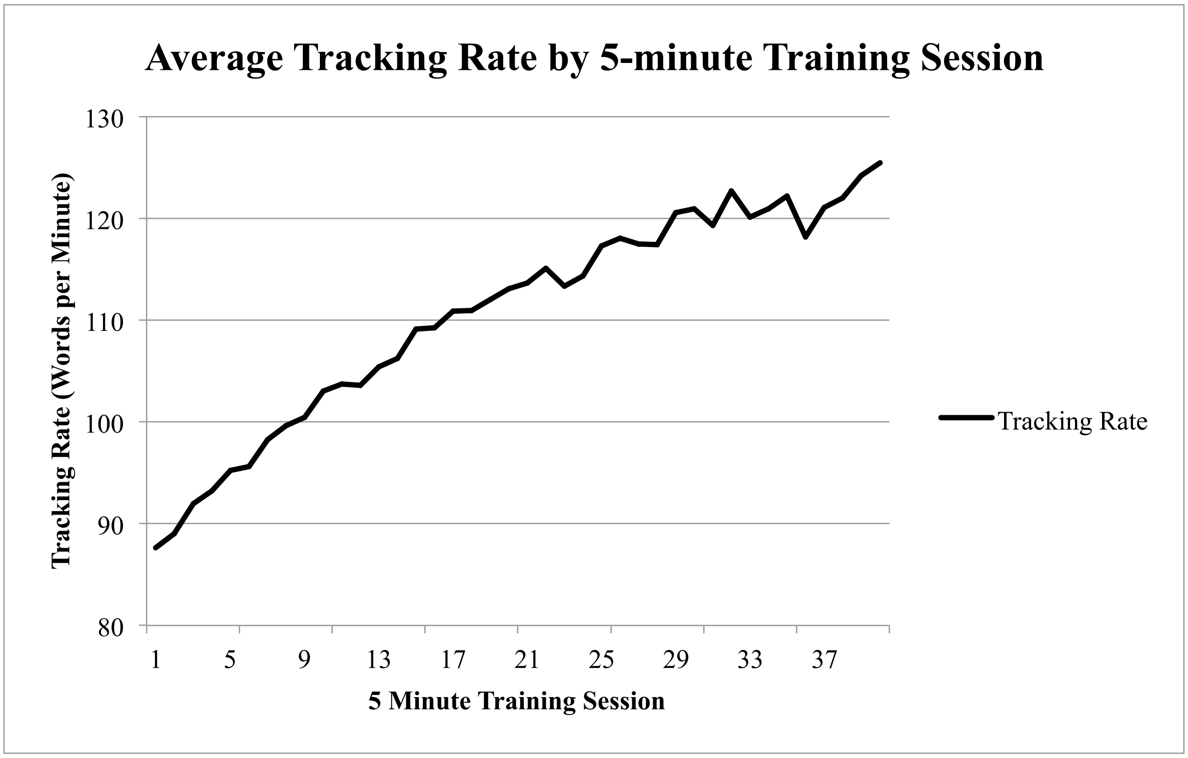

Figure 3: Graph of average tracking rate across all 40 five-minute training sessions. Each tick on the bottom axis is representative of a single visit, totaling up to eight visits per participant in the training condition.

Table 3: Within-Subjects Effects table for RMANOVA with Huynh-Feldt correction examining the effect of training visit on tracking rate. There was a significant effect of training visit on tracking rate ($F_{2.35,21.6} = 63.512$, $P < .001$).

Tests of Within-Subjects Effects for Tracking Rate

Measure: Tracking Rate

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Tracking-Rate	Sphericity Assumed	9301.431	7	1328.776	63.512	.000	.876
	Huynh-Feldt	9301.431	2.352	3954.974	63.512	.000	.876
	Lower-bound	9301.431	1.000	9301.431	63.512	.000	.876
Error(Tracking-Rate)	Sphericity Assumed	1318.058	63	20.922			
	Huynh-Feldt	1318.058	21.166	62.271			
	Lower-bound	1318.058	9.000	146.451			

Table 4. Pairwise comparisons for average sessions for tracking rate for visits 5-8. There are no significant differences between visits 5-8, whereas there are significant differences between this measure and visit 4.

Pairwise Comparisons

Measure: Tracking Rate

(I) Visit	(J) Visit	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
5	4	6.922*	.513	.000	4.679	9.164
	6	-2.635	1.30	1.00	-8.320	3.050
	7	-3.361	1.56	1.00	-10.188	3.465
	8	-4.019	1.36	.455	-9.981	1.943
6	4	9.557*	1.503	.004	2.980	16.133
	5	2.635	1.300	1.00	-3.050	8.320
	7	-.726	.559	1.00	-3.173	1.720
	8	-1.384	.704	1.00	-4.461	-1.694
7	4	10.283*	1.714	.006	2.787	17.779
	5	3.361	1.561	1.00	-3.465	10.188
	6	.726	.559	1.00	-1.720	3.173
	8	-.658	.481	1.00	-2.760	1.445
8	4	10.940*	1.495	.001	4.400	17.481
	5	4.019	1.363	.455	-1.943	9.981
	6	1.384	.704	1.00	-1.694	4.461
	7	.658	.481	1.00	-1.445	2.760

Based on the estimated marginal means

*. The mean difference is significant at the .05 level

b. Adjustment for multiple comparisons: Bonferroni

Table 5. Pairwise comparisons for average sessions for block rate for visits 4-8. There are no significant differences between visits 4-8.

Pairwise Comparisons

Measure: Block Rate

(I) Visit	(J) Visit	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
4	5	.380	.549	1.00	-2.023	2.783
	6	1.440	.580	.977	-1.098	3.978
	7	1.420	.494	.513	-.741	3.581
	8	1.580	.513	.369	-.666	3.826
5	4	-.380	.549	1.00	-2.783	2.023
	6	1.060	.437	1.00	-.853	2.973
	7	1.040	.449	1.00	-.924	3.004
	8	1.200	.456	.765	-.795	3.195
6	4	-1.440	.580	.977	-3.978	1.098
	5	-1.060	.437	1.00	-2.973	.853
	7	-.020	.261	1.00	-1.160	1.120
	8	.140	.313	1.00	-1.228	1.508
7	4	-1.420	.494	.513	-3.581	.741
	5	-1.040	.449	1.00	-3.004	.924
	6	.020	.261	1.00	-1.120	1.160
	8	.160	.173	1.00	-.598	.918
8	4	-1.580	.513	.369	-3.826	.666
	5	-1.200	.456	.765	-3.195	.795
	6	-1.40	.313	1.00	-1.508	1.228
	7	-1.60	.173	1.00	-.918	.598

Based on the estimated marginal means

*. The mean difference is significant at the .05 level

b. Adjustment for multiple comparisons: Bonferroni

Table 6: Within-Subjects Effects table for RMANOVA with Huynh-Feldt correction examining the effect of training visit on block rate. There was a significant effect of training visit on block rate ($F_{6.17,55.57} = 36.849$, $P < .001$).

Tests of Within-Subjects Effects for Block Rate							
Measure: Block Rate							
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Training Visit	Sphericity Assumed	251.214	7	35.888	36.849	.000	.804
	Huynh-Feldt	251.214	6.174	40.668	36.849	.000	.804
	Lower-bound	251.214	1.000	251.214	36.849	.000	.804
Error(BlockRate)	Sphericity Assumed	61.356	63	.974			
	Huynh-Feldt	61.356	55.567	1.104			
	Lower-bound	61.356	9.000	6.817			

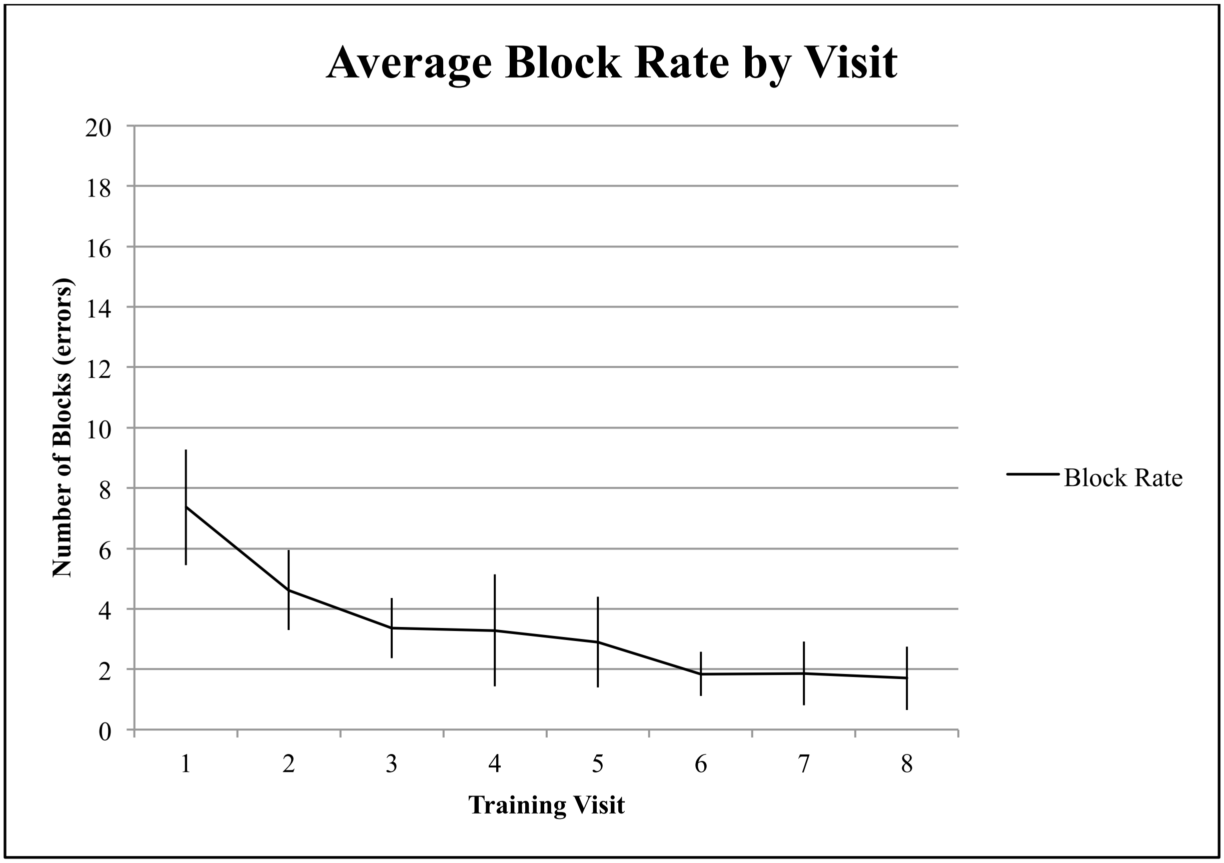

Figure 4: Graph of average block rate across eight visits. Each visit involves 5 five-minute sessions of KTH Speech Tracking Training. Error bars represent +/- 1 standard deviation. Results indicate a significant effect of training visit on average block rate, as determined by a repeated measures analysis of variance with block rate as the dependent variable ($F_{6.17,55.57}$ = 36.849, P <.001).

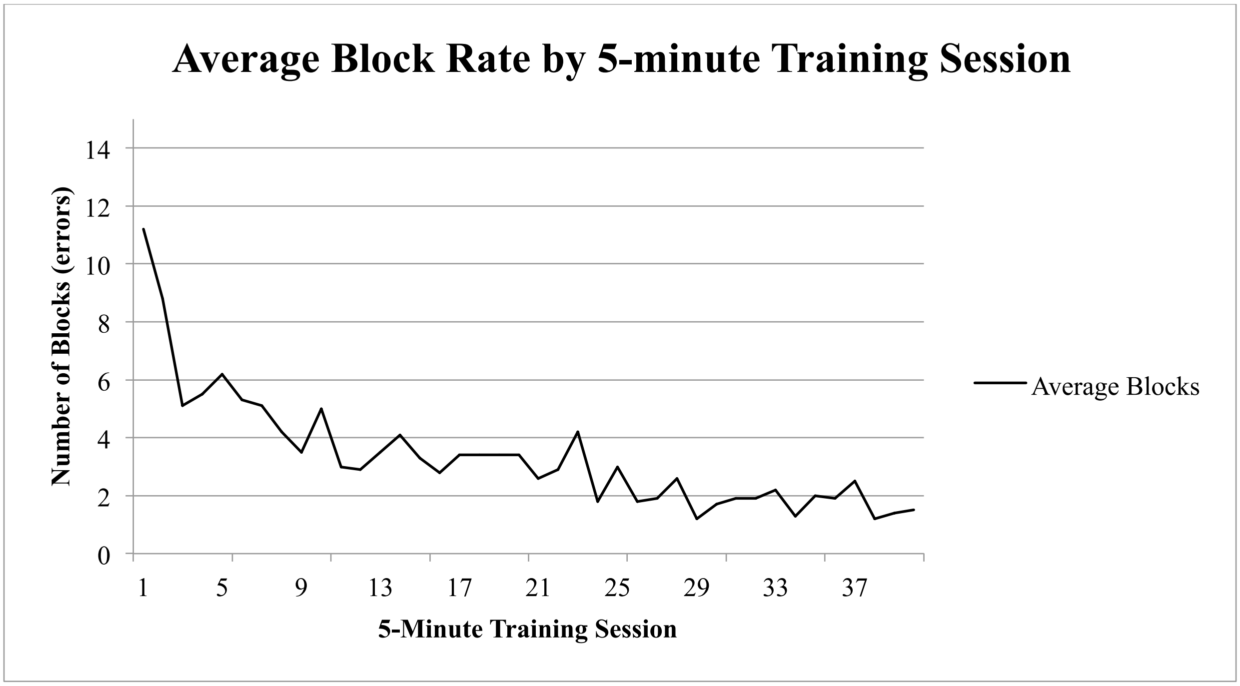

Figure 5: Graph of average block rate across all 40 five-minute training sessions. Each tick on the bottom axis is representative of a single visit, totaling up to eight visits per participant in the training condition.

Question 2: Electrophysiological Measures of Off-task Performance

Are there off-task structure-level changes as a result of training, measurable via electrophysiological measures?

Four separate analyses were performed to examine the effects of condition on electrophysiological evoked potentials in response to speech in the presence of noise. Evoked potentials were grouped into two separate portions of the /da/ stimulus: potentials evoked relative to the transition portion of the stimulus (from 20-60ms), and potentials evoked relative to the steady-state portion of the stimulus (from 60-180ms). For each of these groups, two analyses of covariance were performed, looking at measurements of the FFR corresponding to the fundamental frequency and the second harmonic of a /da/ stimulus before and after the condition visits. Each of these ANCOVA analyses took the post-stimulus measurement as dependent variable and the pre-stimulus baseline as co-variate, with condition being a fixed factor. Grand average spectra of the evoked response for the transition portion of the /da/ stimulis for the control, listening, and training groups can be seen in figures 7, 8, and 9, respectively. Grand average spectra of the evoked response for the steady state portion of the /da/ stimulus for the control, listening, and training groups can be seen in figures 11, 12, and 13, respectively.

Examining amplitudes evoked from the transition portion of the /da/ stimulus, there was no effect of condition on post-assessment fundamental frequency or second harmonic related amplitudes. Likewise, for amplitudes evoked from the steady-state portion of the /da/ stimulus, there was no effect of condition post-assessment on the fundamental frequency related amplitude. However, there was a significant effect of condition on amplitude the second harmonic of the steady state portion of the /da/ stimulus ($F_{2,26} = 4.24$, $p < .025$). Amplitudes for the fundamental frequency and second harmonic of both the transition and steady state portions of the /da/ stimulus in noise are visible in Figure 10.

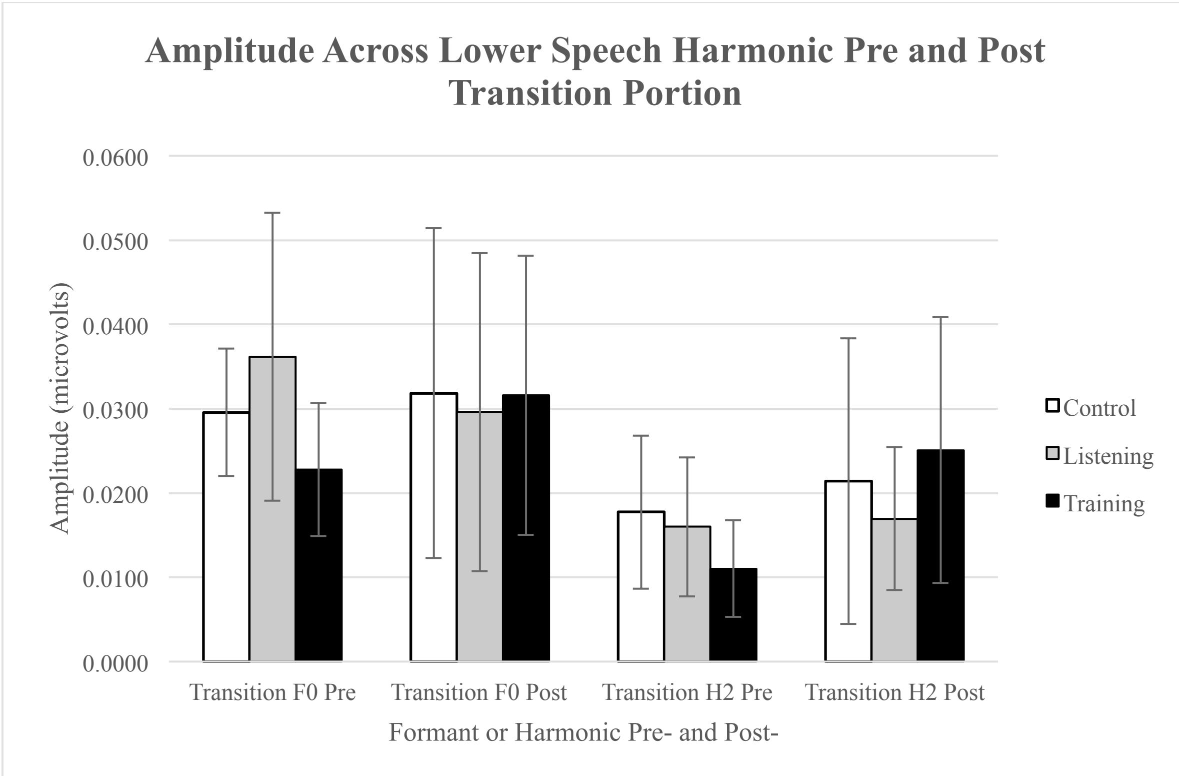

Figure 6: Average pre-condition and post-condition evoked potentials corresponding to the fundamental frequency and second harmonic of the transition portion of the /da/ stimulus presented in noise. Error bars represent one standard deviation of the mean.

Amplitude of the FFR as a Function of Frequency & Amplitude of the FFR as a Function of Time for the Transition Portion of the /da/ Syllable in the Presence of Noise (Control Condition)

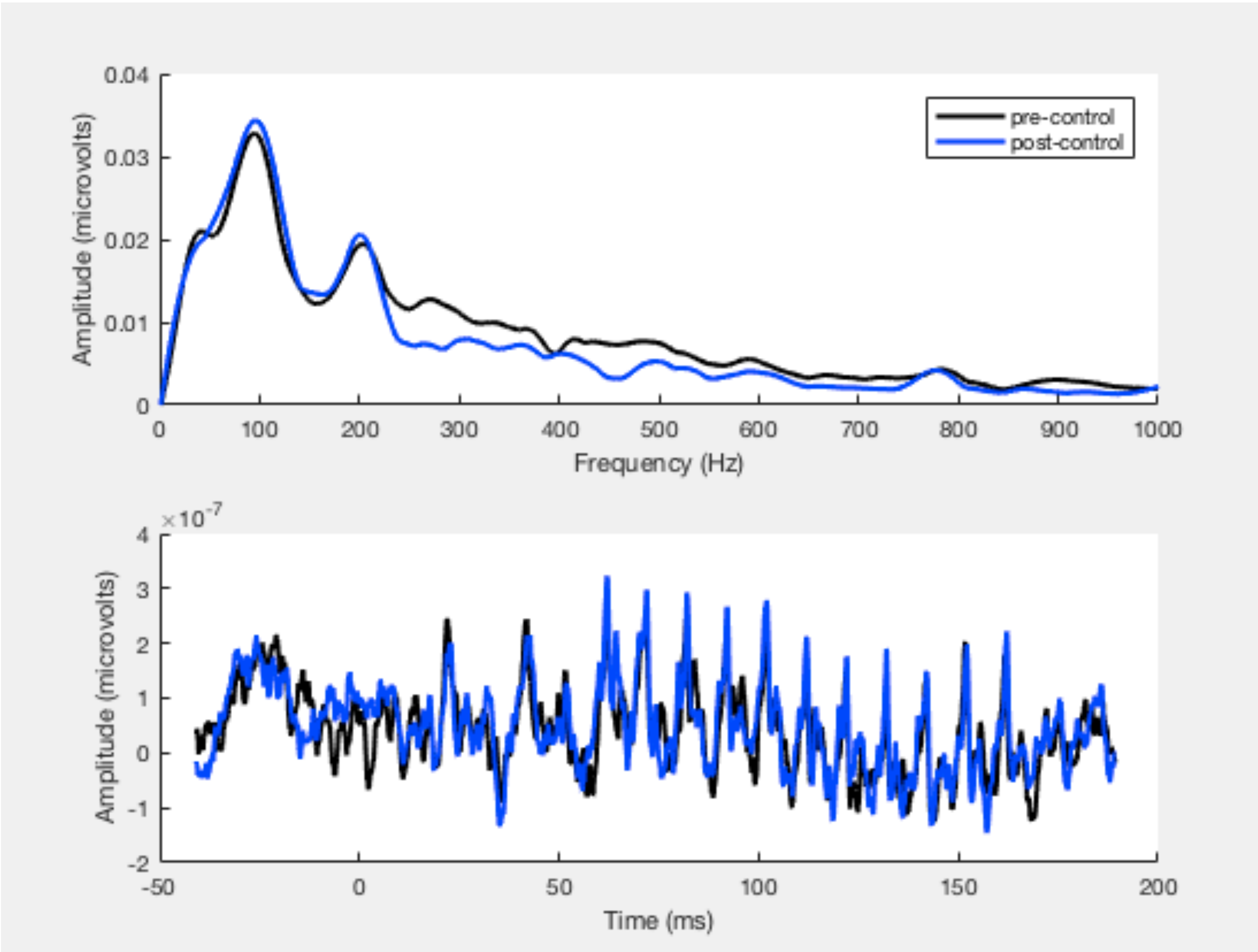

Figure 7: Grand average spectra of the fundamental (100 Hz) and harmonics (200-1000 Hz) calculated evoked responses to the transition portion of a /da/ syllable in the presence of noise for the control condition. There exist no statistically significant differences between conditions for both the fundamental frequency and the second harmonic of the transition portion of the /da/ syllable.

Amplitude of the FFR as a Function of Frequency & Amplitude of the FFR as a Function of Time for the Transition Portion of the /da/ Syllable in the Presence of Noise (Listening Condition)

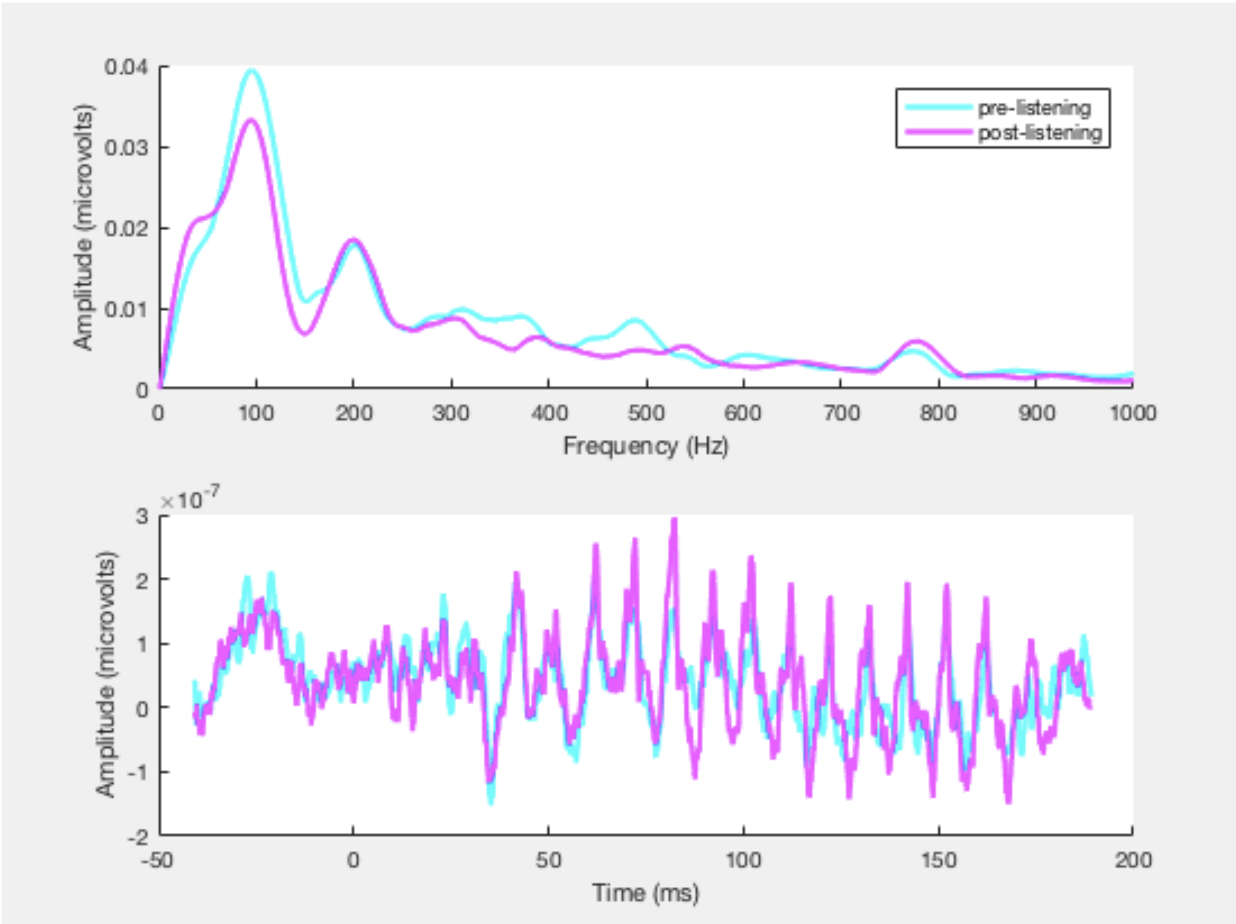

Figure 8: Grand average spectra of the fundamental (100 Hz) and harmonics (200-1000 Hz) calculated evoked responses to the transition portion of a /da/ syllable in the presence of noise for the listening condition. There exist no statistically significant differences between conditions for both the fundamental frequency and the second harmonic of the transition portion of the /da/ syllable.

Amplitude of the FFR as a Function of Frequency & Amplitude of the FFR as a Function of Time for the Transition Portion of the /da/ Syllable in the Presence of Noise (Training Condition)

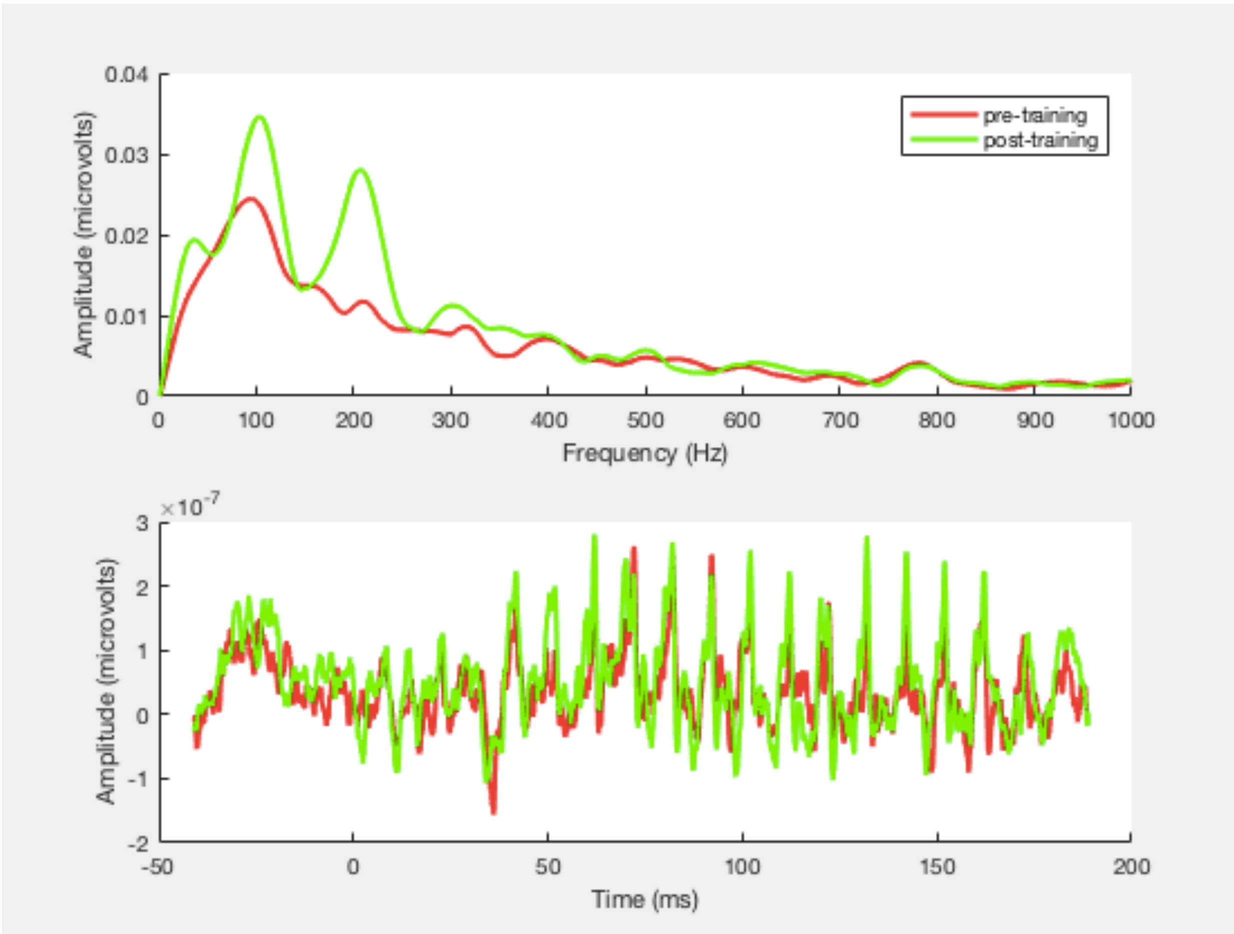

Figure 9: Grand average spectra of the fundamental (100 Hz) and harmonics (200-1000 Hz) calculated evoked responses to the transition portion of a /da/ syllable in the presence of noise for the training condition. There exist no statistically significant differences between conditions for both the fundamental frequency and the second harmonic of the transition portion of the /da/ syllable.

Table 7: Between-Subject Effect tests for the post-assessment fundamental frequency and second harmonic of the transition portion of the /da/ stimulus. There is no significant effect of condition on post-assessment evoked potentials relating either to the fundamental frequency or second harmonic of the transition portion of the /da/ stimulus.

Tests of Between-Subjects Effects

Dependent Variable: Transition F0 Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.001[a]	3	.000	.896	.457
Intercept	.001	1	.001	3.412	.076
Transition F0 Pre	.001	1	.001	2.591	.120
Condition	.000	2	.000	.452	.641
Error	.008	26	.000		
Total	.038	30			
Corrected Total	.009	29			

a. R Squared = .094 (Adjusted R Squared = -.011)

Tests of Between-Subjects Effects

Dependent Variable: Transition H2 Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	3	.000	.603	.619
Intercept	.002	1	.002	9.923	.004
Transition H2 Pre	4.679E-5	1	4.679E-5	.224	.640
Condition	.000	2	.000	.894	.421
Error	.005	26	.000		
Total	.019	30			
Corrected Total	.006	29			

a. R Squared = .065 (Adjusted R Squared = -.043)

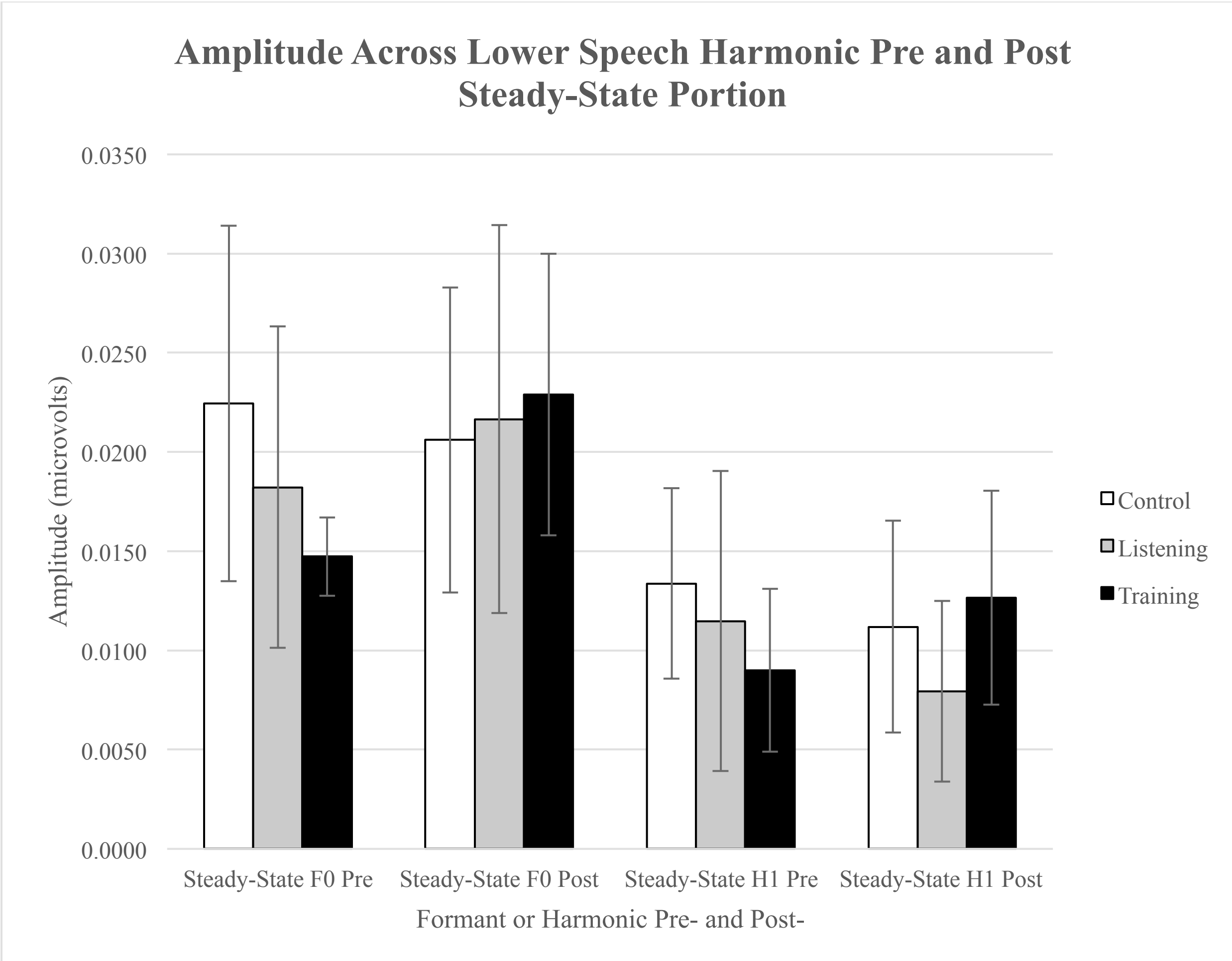

Figure 10: Average pre-condition and post-condition evoked potentials corresponding to the fundamental frequency and second harmonic of the steady-state portion of the /da/ stimulus. Error bars represent one standard deviation of the mean.

Amplitude of the FFR as a Function of Frequency & Amplitude of the FFR as a Function of Time for the Steady-State Portion of the /da/ Syllable in the Presence of Noise (Control Condition)

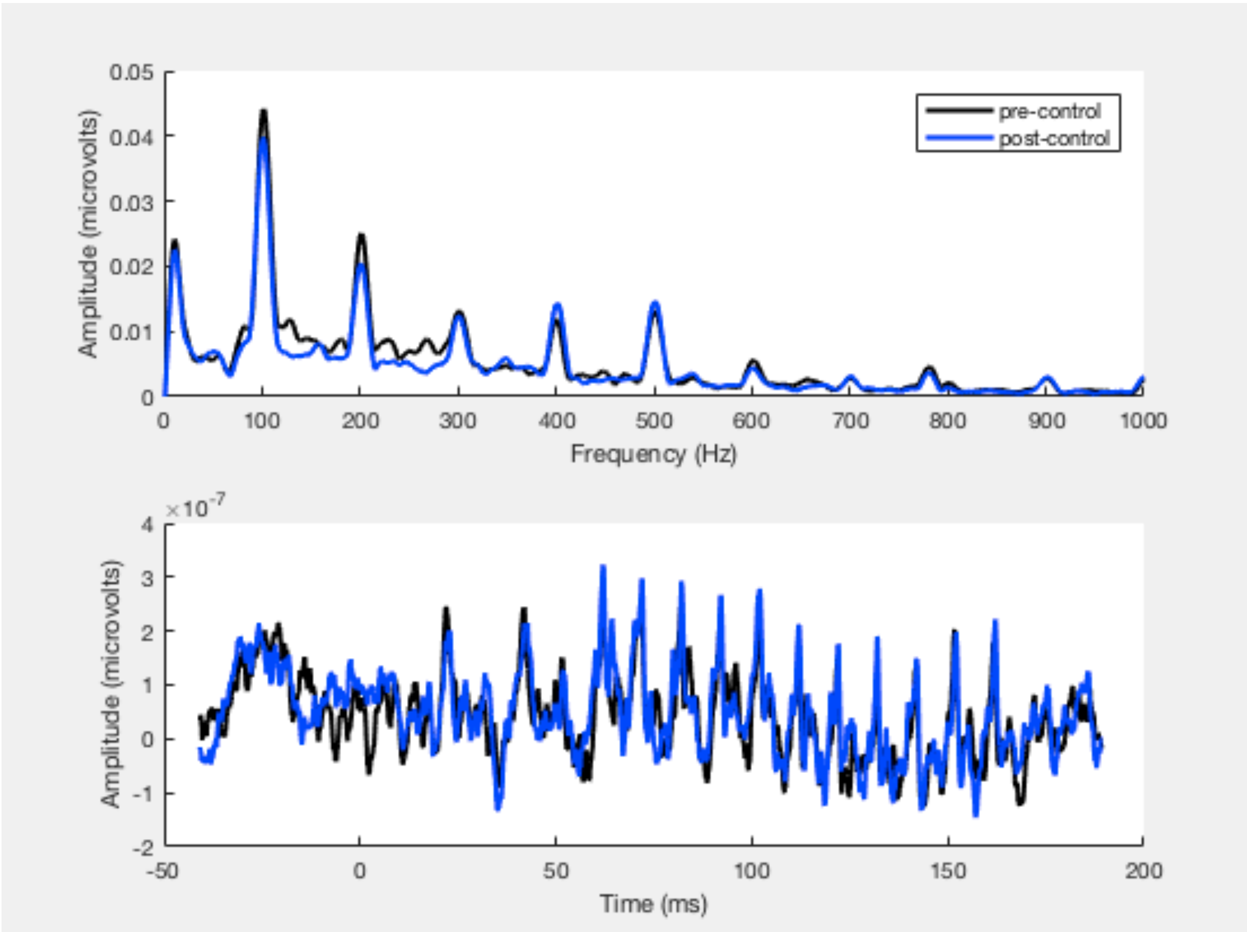

Figure 11: Grand average spectra of the fundamental (100 Hz) and harmonics (200-1000 Hz) calculated evoked responses to the steady-state portion of a /da/ syllable in the presence of noise for the control condition.

Amplitude of the FFR as a Function of Frequency & Amplitude of the FFR as a Function of Time for the Transition Portion of the /da/ Syllable in the Presence of Noise (Listening Condition)

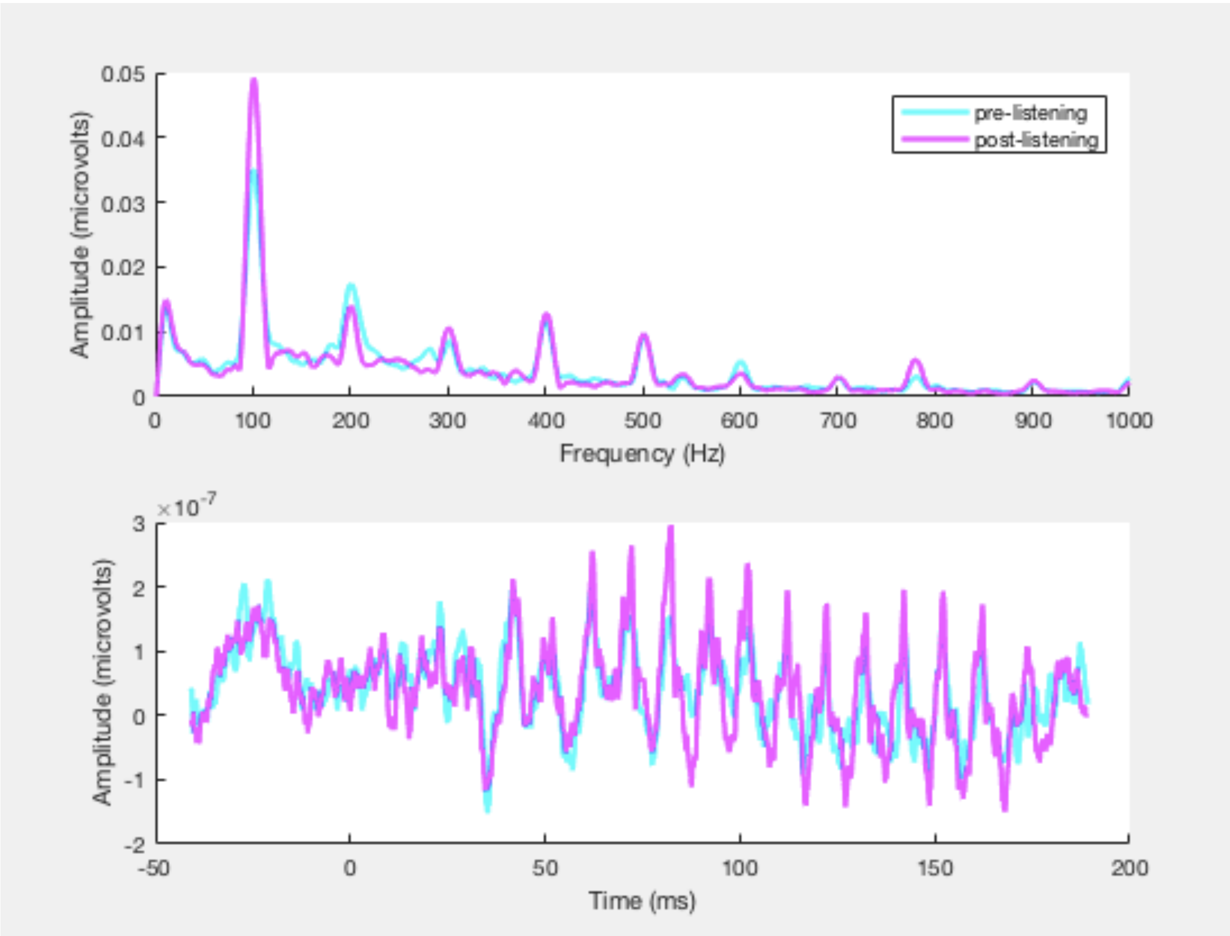

Figure 12: Grand average spectra of the fundamental (100 Hz) and harmonics (200-1000 Hz) calculated evoked responses to the steady-state portion of a /da/ syllable in the presence of noise for the listening condition.

Amplitude of the FFR as a Function of Frequency & Amplitude of the FFR as a Function of Time for the Transition Portion of the /da/ Syllable in the Presence of Noise (Training Condition)

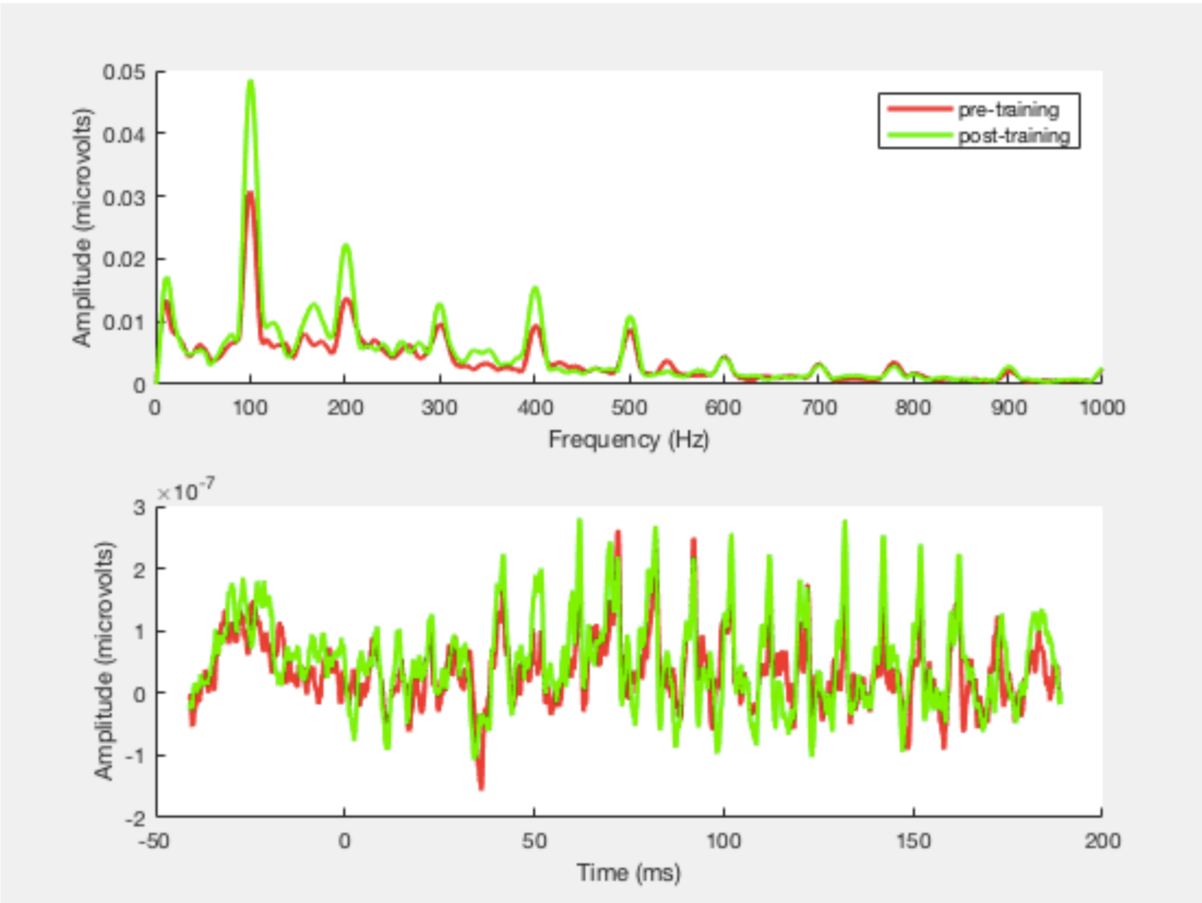

Figure 13: Grand average spectra of the fundamental (100 Hz) and harmonics (200-1000 Hz) calculated evoked responses to the steady-state portion of a /da/ syllable in the presence of noise for the training condition.

Table 8: Between-Subject Effect tests for the post-assessment fundamental frequency and second harmonic of the steady-state portion of the /da/ stimulus. A significant effect of condition can be seen on the post-assessment measurement of the second harmonic of the steady-state portion of the /da/ stimulus.

Tests of Between-Subjects Effects

Dependent Variable: Steady-state F0 Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	3	7.740E-5	1.227	.320
Intercept	.001	1	.001	11.616	.002
Steady-state F0 Pre	.000	1	.000	3.266	.082
Condition	.000	2	5.755E-5	.912	.414
Error	.002	26	6.310E-5		
Total	.016	30			
Corrected Total	.002	29			

a. R Squared = .124 (Adjusted R Squared = .023)

Tests of Between-Subjects Effects

Dependent Variable: Steady-state H2 Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	3	.000	5.195	.006
Intercept	.000	1	.000	8.030	.009
Steady-state H2 Pre	.000	1	.000	9.674	.004
Condition	.000	2	8.377E-5	4.244	.025
Error	.001	26	1.974E-5		
Total	.004	30			
Corrected Total	.001	29			

a. R Squared = .375 (Adjusted R Squared = .303)

Table 9: Post-hoc pairwise comparisons of mean differences between treatment groups for the FFR of the second harmonic of the steady state portion of the /da/ syllable. There is a significant difference between the training and listening groups, but not between the listening and control or training and control groups.

Pairwise Comparisons

Dependent Variable: Average Steady State H2

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Control	Listening	.002	.002	.747	-.003	.008
	Training	-.004	.002	.316	-.009	.002
Listening	Control	-.002	.002	.747	-.008	.003
	Training	-.006*	.002	.022	-.011	-.001
Training	Control	.004	.002	.316	-.002	.009
	Listening	.006*	.002	.022	.001	.011

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Question 3: Behavioral measures of off-task performance

Are there off-task activity-level behavioral changes as a result of auditory training, measureable by behavioral word-recognition tests?

The scores of four QuickSIN tests were averaged in the pre- and post- test sessions to create pre- and post-average QuickSIN scores. A graph of pre- and post- average QuickSIN scores are displayed in Figure 14.

There was a significant improvement in performance on the QuickSIN test for the training group relative to both the Control and Listening groups. An Analysis of Covariance (ANCOVA) was performed on post-QuickSIN Averages with 3-treatment groups (Control, Listening, Training) and with pre-QuickSIN score as the co-variate. Results show a main effect of condition ($F_{2,11.2} = 10.010$, $P < .001$) on post-QuickSIN score. Post-hoc pairwise comparisons with Bonferroni correction show no significant difference between the Control and Listening conditions ($P < .580$) at the .05 level, and a significant difference between both the Training and Control conditions ($P < .000$), and the Training and Listening conditions ($P < .016$), again at the .05 level. Specific values of the ANCOVA and post-hoc pairwise comparisons are displayed in Tables 10 and 11, respectively.

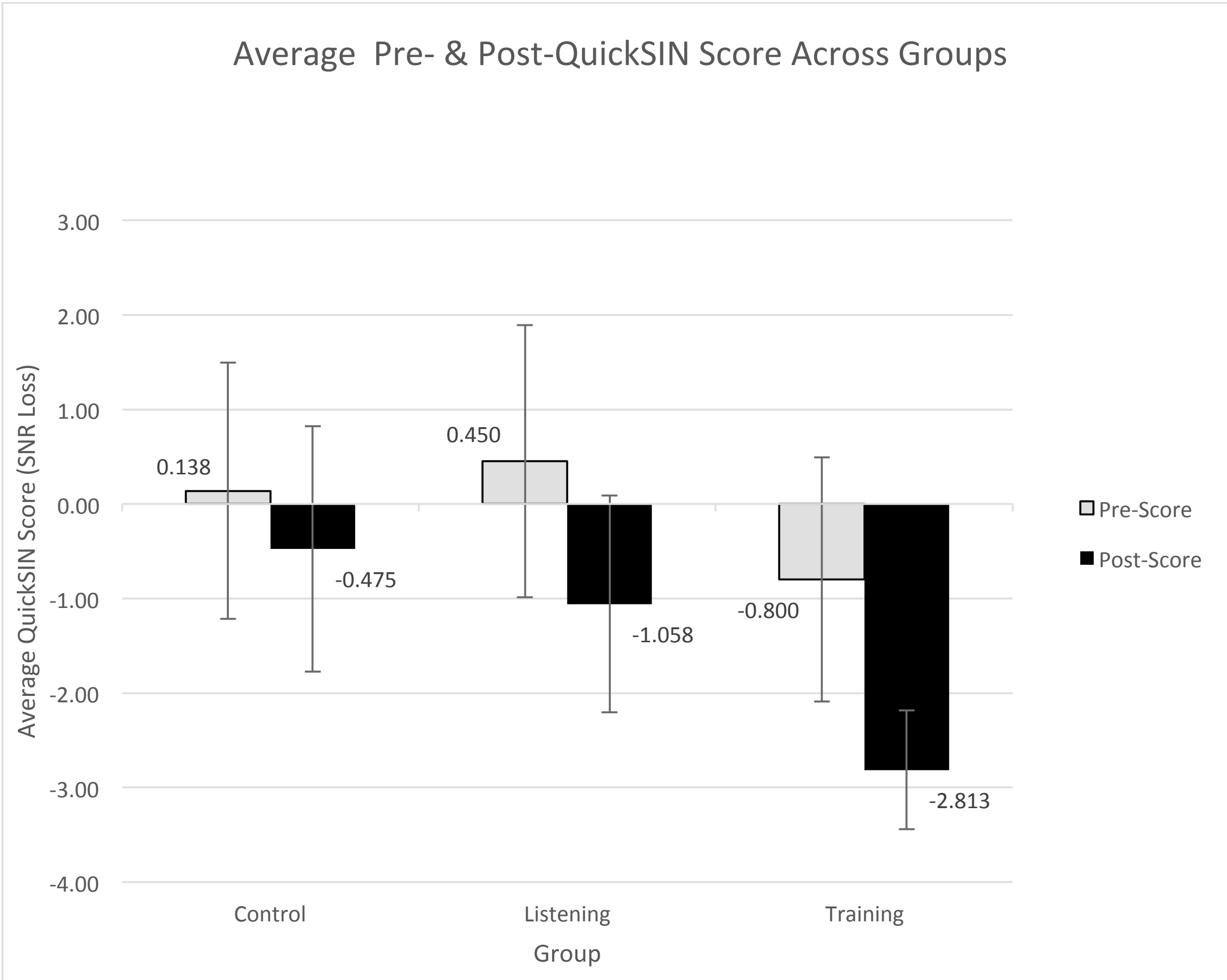

Figure 14: Graph showing the averaged pre- and post- QuickSIN Scores for the three condition groups. Results indicate a significant effect of condition on post QuickSIN score, as determined by an Analysis of Covariance with post-QuickSIN as the dependent variable and pre-QuickSIN score as the covariant ($F_{2,26} = 10.010$, $P < .001$).

Table 10: Between-Subjects Effects table for ANCOVA examining the effect of condition on post-QuickSIN score with pre-QuickSIN Score as a co-variate. There was a significant effect of condition on post-QuickSIN Score, taking into account pre-QuickSIN Score as a co-variate.

Tests of Between-Subjects Effects for Average QuickSIN Score

Dependent Variable: Average Post QuickSIN Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	31.036[a]	3	10.345	9.238	.000	.516
Intercept	61.711	1	61.711	55.103	.000	.679
Average Pre-QKSN Score	1.425	1	1.425	1.273	.270	.047
Condition	22.421	2	11.210	10.010*	.001	.435
Error	29.118	26	1.120			
Total	123.084	30				
Corrected Total	60.154	29				

*. The effect is significant at the .05 level.

Table 11: Post-hoc Pairwise Comparisons of mean differences between treatment groups. There is a significant difference between the Training group and both the Control and Listening groups. There is no significant difference between the Listening and Training groups.

Pairwise Comparisons

Dependent Variable: Average Post QuickSIN Score

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Control	Listening	.635	.476	.580	-.582	1.852
	Training	2.179*	.494	.000	.916	3.442
Listening	Control	-.635	.476	.580	-1.852	.582
	Training	1.544*	.509	.016	.242	2.846
Training	Control	-2.179*	.494	.000	-3.442	-.916
	Listening	-1.544*	.509	.016	-2.846	-.242

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Question 4: Self-Reported Measures of Off-task Performance

Are there off-task activity level self-report changes as a result of auditory training?

Five separate analyses were performed to examine effects of training group on measurements of the SSQ. The five lowest scoring items on the SSQ from normal hearing 18-25 year old subjects, as reported by Demeester and colleagues in the development of the SSQ-5 (Demeester, et al., 2012) were tested each in separate analyses of covariance. The reasoning behind the selection of these five questions was that, for examining normal hearing listeners, these questions would have the lowest score and highest variability out of all 45 items on the full SSQ. Note that these five questions are distinct from the 5 questions that ultimately wound up comprising the SSQ-5, whose questions were decided based on their correlation with a speech in noise task.

Each separate ANCOVA analyses took the post-SSQ answer as a dependent variable and the pre-SSQ answer as a covariate. The questions examined were as follows:

- Speech 6: You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation?
- Spatial 8: In the street, can you tell how far away someone is, from the sound of their voice or footsteps?
- Spatial 9: Can you tell how far away a bus or truck is, from the sound?
- Speech 10: You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?
- Speech 14: You are listening to someone on the telephone and someone next to you starts talking. Can you follow what's being said by both speakers?

(Gatehouse & Noble, 2004)

For all five items examined from the SSQ, there were no statistically significant effects of condition on SSQ rating at the .05 level. Neither the training, listening, or control groups experienced a difference between their pre-and post-condition assessments of SSQ report. Graphs of pre- and post-scores of the SSQ questions can be seen in Figure 15. Breakdowns of specific ANCOVA numbers can be seen in Tables 12-16.

Table 12: Between-Subjects Effects table and post-hoc pairwise comparisons for the ANCOVA examining the effect of condition on Post-SSQ 6 score with Pre-SSQ 6 Score as co-variate. There is no significant effect of condition on Post-SSQ 6 score. There is no significant difference between any means across the three conditions when looking at pairwise comparisons with Bonferroni correction.

Speech 6 Question: You are in a group of about 5 people in a busy restaurant. You *cannot* see everyone else in the group. Can you follow the conversation?

Tests of Between-Subjects Effects

Dependent Variable: SSQ 6

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	28.868[a]	3	9.623	5.973	.003	.408
Intercept	22.131	1	22.131	13.738	.001	.346
PRESSQ6	13.692	1	13.692	8.499	.007	.246
Condition	2.819	2	1.409	.875	.429	.063
Error	41.884	26	1.611			
Total	1557.600	30				
Corrected Total	70.752	29				

Table 13: Between-Subjects Effects table and post-hoc pairwise comparisons for the ANCOVA examining the effect of condition on Post-SSQ 8 score with Pre-SSQ 8 score as co-variate. There is no significant effect of condition on Post-SSQ 8 score. There is no significant difference between any means across the three conditions when looking at pairwise comparisons with Bonferroni correction.

Spatial 8 Question: In the street, can you tell how far away someone is, from the sound of their voice or footsteps??

Tests of Between-Subjects Effects

Dependent Variable: SSQ 8

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.181	3	4.727	5.626	.004	.394
Intercept	23.594	1	23.594	28.079	.000	.519
PRESSQ8	10.323	1	10.323	12.286	.002	.321
Condition	2.069	2	1.035	1.231	.308	.087
Error	21.847	26	.840			
Total	2369.800	30				
Corrected Total	36.028	29				

Table 14: Between-Subjects Effects table and post-hoc pairwise comparisons for the ANCOVA examining the effect of condition on Post-SSQ 9 score with Pre-SSQ 9 score as co-variate. There is no significant effect of condition on Post-SSQ 9 score. There is no significant difference between any means across the three conditions when looking at pairwise comparisons with Bonferroni correction.

Spatial 9 Question: Can you tell how far away a bus or truck is, from the sound?

Tests of Between-Subjects Effects

Dependent Variable: SSQ 9

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.620	3	.873	1.036	.393	.107
Intercept	8.161	1	8.161	9.681	.004	.271
PRESSQ9	1.287	1	1.287	1.527	.228	.055
Condition	.686	2	.343	.407	.670	.030
Error	21.919	26	.843			
Total	2458.140	30				
Corrected Total	24.539	29				

Table 15: Between-Subjects Effects table and post-hoc pairwise comparisons for the ANCOVA examining the effect of condition on Post-SSQ 10 score with Pre-SSQ 10 score as co-variate. There is no significant effect of condition on Post-SSQ 10 score. There is no significant difference between any means across the three conditions when looking at pairwise comparisons with Bonferroni correction.

Speech 10 Question: You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?

Tests of Between-Subjects Effects

Dependent Variable: SSQ 10

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	23.805	3	7.935	3.387	.033	.281
Intercept	41.670	1	41.670	17.787	.000	.406
PRESSQ10	18.817	1	18.817	8.032	.009	.236
Condition	2.581	2	1.291	.551	.583	.041
Error	60.909	26	2.343			
Total	1491.020	30				
Corrected Total	84.715	29				

Table 16: Between-Subjects Effects table and post-hoc pairwise comparisons for the ANCOVA examining the effect of condition on Post-SSQ 14 score with Pre-SSQ 14 score as co-variate. There is no significant effect of condition on Post-SSQ 14 score. There is no significant difference between any means across the three conditions when looking at pairwise comparisons with Bonferroni correction.

Speech 14 Question: You are listening to someone on the telephone and someone next to you starts talking. Can you follow what's being said by both speakers?

Tests of Between-Subjects Effects

Dependent Variable: SSQ 14

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	10.000[a]	3	3.333	1.090	.371	.112
Intercept	86.980	1	86.980	28.436	.000	.522
PRESSQ14	9.179	1	9.179	3.001	.095	.103
Condition	1.953	2	.976	.319	.730	.024
Error	79.528	26	3.059			
Total	1639.692	30				
Corrected Total	89.528	29				

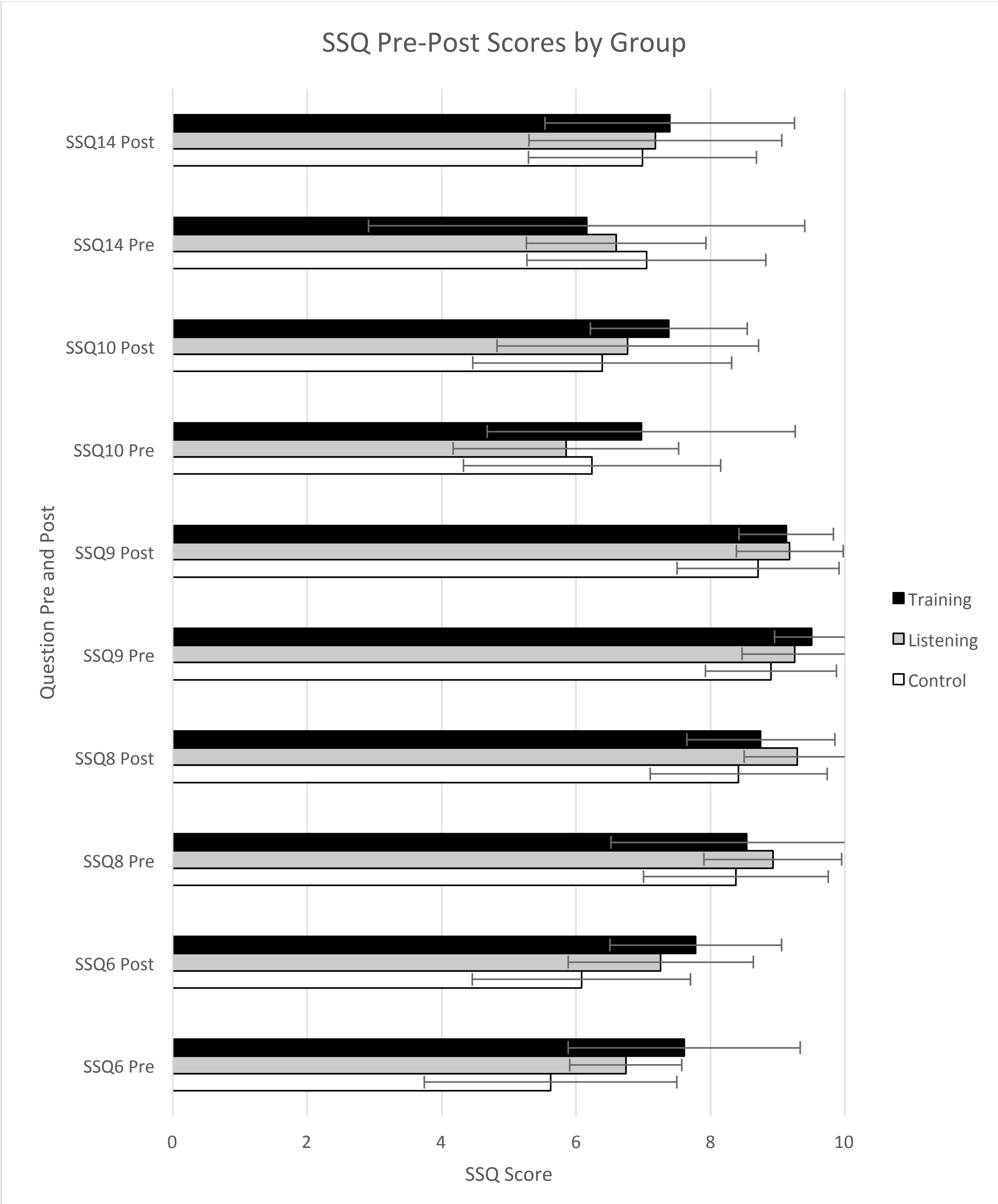

Figure 15: Average pre-condition scores and post-condition scores for questions 6, 8, and 9 of the SSQ. There were no statistically significant differences between the pre- and post-scores for any question in any condition.

Chapter IV – DISCUSSION

This project sought to examine four different questions relating to speech tracking training performed by normal hearing listeners in the presence of noise:

Question 1: On-task changes as a result of training

One of the measurements that should be taken into consideration for any training regimen are the on-task changes as a result of auditory training. Put simply: do participants who engage in auditory training get better at the task they are performing for that training? Dubno (2013) reaffirms that the minimum expectation for auditory training should be that ability to complete the training task should improve over the course of the training. In a speech-tracking paradigm, it can be taken to mean that success at the speech-tracking task would be indicated by an increase in the rate at which speech tracking occurs, and by a decrease in the rate of mistakes made during each tracking session.

The results of this experiment indicate that there are significant on-task changes as a result of engaging in speech-tracking training in the presence of noise. Both average tracking rate and average blocking rate made across average session were found to significantly improve over the training sessions.

These findings are in agreement with several studies that examine effectiveness of auditory training. Both Tobey and colleagues (2005), and Bernstein and colleagues (2012) found similar improvements with speech-tracking training in the auditory only modality (Tobey, et al., 2005; Bernstein, et al., 2012). Both of these studies examined the effects of speech tracking as an auditory training method for individuals using cochlear implants, and both found evidence of improvement seen as an increase in the overall tracking rate of participants throughout the training sessions.

On-task improvements as a result of auditory training are not limited to speech-tracking training. In a review of efficacy of computer-based auditory training programs, Henshaw and Ferguson (2013) included 10 studies where on-task measures of auditory performance improved after various computer-based auditory training programs. Only three of these studies met the author's criteria for "moderate" quality evidence, however. The other seven were criticized for issues of randomization, blinding, control group issues, or problems with compliance and follow-up and deemed to be low- or very low-quality evidence. The on-task improvements noted in these studies should be interpreted conservatively, as the authors note issues of methodological design in the descriptions of the research.

For the data described in this experiment, both ceiling and floor effects occurred with the tracking-rate and block rate R-ANOVA analyses, respectively. For the tracking rate, post-hoc pair-wise comparisons of differences between individual training visits reveal no significant differences between average tracking rate of visits 5-8, visible in Table 4. Similarly, there was no significant differences between average block rate for participants from visits, visible in table 5. On average, participants reached a point where they were no longer able to increase their tracking-rate or decrease their block-rate.

A possible reason for this ceiling effect might be approaching the limiting rate for human conversation. Conversational speech is broadly estimated to be between 140 and 200 words per minute (Abrams, Goffard, Kryter, Miller, Miller, & Sanford, 1944; Picheny, Durlach, & Braida, 1986). Bearing in mind that the tracking rate measured in speech tracking training must take into account both the rate of speech of the trainer and the trainee, the combined speed of speech in this experiment approached 240 words per minute in the final training sessions. At such high speeds, tracking rate was likely limited by the factors that accompany natural fast speech, including an increased demand on the perceptual and motor demands of having to normalize acoustic changes that occur in fast talkers (Guiraud, Bedoin, Krifi-Papoz, Herbillon, Caillot-Bascoul, Gonzalez-Monge, Boulenger, 2018).

The floor-effect for the block-rate encountered in speech tracking training is comparatively easy to explain: as training sessions progressed, the average number of blocks made during each session approached zero. The participants engaged in this experiment all had normal hearing, and reported not having particular difficulties listening in noise. In more traditional aural rehabilitation, this would be less likely to occur, as the training material would be adjusted to be more appropriately challenging. For the purposes of this experiment, however, the training material was not changed during the course of the auditory training so as to allow for proper analyses of a repeated measures design.

Question 2. Off-task activity-level behavioral changes as a result of auditory training

For many experiments analyzing auditory training, one of the more common measurements is the use of some form of behavioral assessment to measure generalizability of the auditory training. Barcroft and colleagues (2016) suggest that in order to maximize generalizability, task, talker, and stimulus used should exhibit overlap between training and assessment (Barcroft, Spehar, Tye-Murray, & Sommers, 2016). The more overlap, the greater the gain demonstrated in the assessment. For the evaluation of this type of auditory training, the QuickSIN was used because of its similarity to the task at hand: namely, word recognition amongst 6 talker babble.

The results of this experiment indicated that there was a significant effect of condition on QuickSIN score. Post-hoc pair-wise comparisons indicated a significant difference between the training treatment condition and the control condition, as well as between the training treatment condition and the listening condition. Participants in the training condition improved in their performance on the QuickSIN after participating in the experiment, whereas there was no significant improvement in either the control or listening conditions.

These results seem to be in line with several studies that use the speech recognition in noise tests in the presence of noise as an outcome measure examining the effectiveness of auditory training. Song and colleagues (2012) used the QuickSIN and the HINT assessments when looking at generalizability of listening in noise for normal listeners using the LACE computerized auditory training. Participants in that study's experimental group similarly experienced a significant improvement in performance on both the QuickSIN and the HINT test. Participants in the training group of this experiment experienced comparable changes.

This also is in line with a study performed by Sweetow & Henderson-Sabes (2006), who examined the effects of LACE auditory training in an experimental group made up of both normal-hearing and hearing-impaired individuals (Sweetow & Henderson-Sabes, 2006). They also found statistically significant improvements on both the HINT test and the QuickSIN. The authors note that in their study, the average improvement on the SNR in the experimental group was a 1.5 dB SNR improvement between pre and post conditions, which for the three QuickSIN lists used in this study to determine the SNR Loss measurement is not a clinically significant improvement (Killion, et al., 2004). However, 42% of participants in the experimental group did exhibit a clinically significant improvement of at least a 1.6 dB SNR improvement on the QuickSIN. In the current study, participants in the training group exhibited a 2.01 dB SNR improvement, which is not only a statistically significant improvement, but considered to be a clinically significant improvement, as well.

However, there is also a significant body of evidence for auditory training studies showing that there is not a generalization effect for auditory training based on behavioral assessments. In a large randomly controlled study examining efficacy of LACE auditory training for hearing aid users, Saunders and colleagues (2016) examined performance on a word recognition in noise task, a compressed speech task, and a word recognition task among competing speech. They found no significant effects of training on these tests. Olson & colleagues (2013) found similar results for new hearing aid users utilizing LACE training, with an insignificant effect of training on performance on the QuickSIN. Both articles discuss age of participant and experience with amplification as factors that may have had significant influence in performance on the off-task behavioral measures used. Participants in the current study were comparatively young (mean age 22.33 years, SD = 4.35), and none had any hearing difficulty. This lack of age variance is a limitation to the study, and may be a reason why similar results were found for off-task behavior measures when comparing results to Song and colleagues (2012), where participants were of a similar age and a similar audiometric classification.

Question 3. Off-task activity-level self-report changes as a result of auditory training

In lieu of behavioral assessments, many experiments use self-reported measures to document participative change in response to auditory training. The Speech and Spatial Qualities of Hearing Questionnaire (SSQ) was selected for this project as a self-report measure of activity-level changes in response to auditory training. It was hypothesized that there would be no significant changes between pre-assessment and post-assessment for the training group (or any of the groups), as all participants enrolled in this study were young adults with normal hearing.

In an effort to reduce the number of statistical analyses for purposes of reducing issues with multiple comparisons, analyses of variance were performed for 5 items from the SSQ which had the most variability for normal hearing listeners. Based on those analyses, experimental condition did not have any significant effect on any of the questions analyzed from the SSQ.

Age likely has a significant impact on the results of these data. Demeester and colleagues (2012), in a study looking at both young (18-25) and older (55-65) normal hearing populations, found that there is a significant effect of age on reported hearing disability, with older persons reporting more hearing disability, regardless of hearing level. Von Gablenz and colleagues (2018) add to this in their examination of the German SSQ in normal hearing listeners by noting that there are possible effects of education and gender to the measurement of activity-level issues related to hearing.

Self-report measures have been used in auditory training experiments to demonstrate changes as a result of training. Bernstein and colleagues (2012) used measurements from the COSI to show a significant effect of speech-tracking training on self-reported deficit. Sweetow and Henderson-Sabes (2006), also demonstrate a reduction in participation level deficit via the HHIE/A as a result of their training paradigm, however they note that this reduction, while statistically significant, is not clinically significant. Gil and Iorio (2010), in a study examining changes in adult hearing aid users in response to an analytic auditory training program, administered the APHAB as a pre- and post-measure, but found no significant effects. As the APHAB is primarily designed as a means of measuring hearing aid benefit, clearly which test is selected to measure auditory disability and auditory handicap is an important decision to make in terms of sensitivity to the desired variable being measured.

In the beginning of this dissertation, it was argued that in order to properly assess changes to the auditory system as a result of auditory training, assessments should be performed to measure not only structure-level changes, but activity- and participation-level changes as well. This project examined only structure- and activity-level changes as a result of auditory training. The primary reasons for not attempting to assess participation-level changes has to do with the make-up of participants that were recruited for this study. In recruiting participants with normal levels of hearing, it was theorized that they wouldn't have any participation-level deficits to measure. If the experimental paradigm described here is adapted in the future to hearing loss populations, it would continue to be worthwhile to include a self-report measure, as participants with actual hearing loss are more likely to experience levels of auditory disability and auditory handicap that a self-reported outcome measure would be more sensitive to. Vermiglio and colleagues note that self-report measures continue to be a good reference standard along-side behavioral measures (Vermiglio, Soli, & Fang, 2017). In addition to providing a valuable counseling tool for aural rehabilitation in real-life clinical applications, it provides another metric that may be more sensitive to auditory participation level deficits than a behavioral or objective outcome measure.

Question 4. Off-task changes structure-level changes as a result of auditory training

There is evidence for electrophysiological changes corresponding to neurophysiological changes as a result of auditory training (Russo, et al., 2005; Song, et al., 2012; Anderson, Skoe, Chandrasekaran, & Kraus, 2010). One of the purposes of this project was to examine if such changes were detectable as a result of KTH speech tracking training in the presence of noise. For this study, changes to the fundamental frequency (F0) and second Harmonic (H2) for the consonant and vowel portions of the cABR in response to a /da/ stimulus in the presence of noise were examined to determine if there was an electrophysiological change brought about as a result of the auditory training.

Analyses of Covariance were performed for the consonant portion of the /da/ stimulus for both the fundamental frequency and second harmonic. There were no significant effects of training condition on either the fundamental frequency or second harmonic for the consonant portion of the stimulus.

Analyses of Covariance were also performed for the vowel portion of the /da/ stimulus for the fundamental frequency and second harmonic. There was not a significant effect of training condition on the fundamental frequency of the vowel, however there was a significant effect of training condition for the second harmonic of the vowel portion of the stimulus. Post-hoc pair-wise comparisons between the three conditions yield a significant difference between the training condition and listening condition, but not a significant difference between the training condition and the control condition.

The statistical analyses of these electrophysiological measurements were likely influenced by several factors during the process of this experiment. Foremost, there were several issues obtaining consistent reliable electrophysiological measurements from participants, which were traced ultimately to electrical issues between the recording computer and the electrophysiological equipment. This explains some of the variability between participants in terms of amplitudes for the recordings.

The type of the auditory training might also be playing a part in the lack of a significant difference in comparison of training group evoked potentials to the other groups. Kelly Tremblay (2006) discussed how it is the analytic components of auditory training that are reflected by the spectral and temporal cues measured via electrophysiology. It might be the case that speech tracking training, a highly synthetic form of auditory training, might not provide enough focus on individual perceptual foci of a more analytic form of auditory training. However, Tremblay also argues in the same article that it may be neural mechanisms associated with the synthetic aspects of auditory training, auditory attention, memory and decision-making processes that contribute to post-training evoked potential findings.

Another possible explanation for the lack of statistical significance for these analyses might be the small sample size. Song et al. (2012) found significant electrophysiological results in a similar experimental method, however they were examining pre- and post-training changes for two groups of 28 and 32 participants each, compared with the three groups of 10 participants each used in this study. For future studies, each group included in this study should include more than 10 participants, to further reduce variability of the data. Small sample groups were determined *a priori* via power analysis and by what was a conceivable number of people to run through the experimental protocol during the data collection window.

Conclusions

In this study, a variety of outcome measures were utilized to try to measure structure- and activity-level changes in normal hearing individuals after engaging in KTH speech tracking training in the presence of noise. It was hypothesized that engaging in auditory training would yield both on-task and off-task changes, measurable in these outcome measures. Like other studies examining auditory training, results are mixed. Behavioral assessments of activity-level changes and on-task assessments of activity-level changes showed significant changes, but structure-level assessments and self-report activity-level assessments did not show a significant effect of speech-tracking training.

These data and their analyses were performed on normal hearing individuals as a demonstration of feasibility of assessment of auditory training, and out of a desire to address concerns brought up in many reviews of auditory training which note the need for evidence of methodological merit and rigorous adherence to proper scientific design. The result is data from a randomly controlled study with both subjective and objective testing demonstrating changes as a result of this form of auditory training. The participants in this study who engaged in speech-tracking training demonstrated improvements to the point of experiencing a ceiling effect of performance. The training should be designed in future research to be more difficult, and thus more resistant to a ceiling effect.

Similar to other studies examining auditory training, the amount of change measurable from the auditory training varied from participant to participant. In this study, all participants experienced changes as a result of the auditory training, but the individual differences in particular measures varied from participant to participant. Further research is necessary to isolate what, if any, aspects of a person are predictors of more or less success at an auditory training regimen.

The results suggest that engaging in auditory training in the presence of noise can produce measurable changes on both on- and off-task measurements. This auditory training was highly synthetic in nature, the idea being that if gains are desired for listening ability in the presence of noise, training should mimic listening the spoken word in the presence of noise. Further research is required to determine if gains and benefit from this type of auditory training persist for individuals with hearing loss, if the use of amplification or a cochlear implant in conjunction with this training has effect on results, and to determine if adjustment to dosage of the auditory training has an effect on measured change or benefit. Speech-tracking training remains an option for the aural rehabilitationist for the possible amelioration of structure- and activity-level deficits that arise as a result of hearing loss.

Appendices

Appendix A – QuickSIN Instructions & Sample List

"Imagine that you are at a party. There will be a woman talking and several other talkers in the background. The woman's voice is easy to hear at first, because her voice is louder than the others. Repeat each sentence the woman says. The background talkers will gradually become louder, making it difficult to understand the woman's voice, but please guess and repeat as much of each sentence as possible." (Niquette et al., 2001)

Screening List

A **white silk jacket** goes with **any shoes**	____
The **child crawled into** the **dense grass**	____
Footprints showed the **path** he **took** up the **beach**	____
A **vent near** the **edge** brought in **fresh air**	____
It is a **band** of **steel three inches wide**	____
The **weight** of the **package** was **seen** on the **high scale**	____
Total	**____/30**

QuickSIN Score: _______________ 25.5-total achieved

Pass: <15 dB ☐ Yes ☐ No

Appendix B – Dichotic Digits Test

Instructions: You will hear two numbers in each of your ears. Listen carefully in both ears, and repeat all of the numbers you hear. Do not worry about repeating the numbers in any special order. If you are not sure about the numbers you heard, please guess. Now, let's practice.

Ext. B	**Ext. A**
Practice	**Practice**
5, 4	2, 1
8, 3	6, 4
2, 8	3, 5
Real	**Real**
6, 1	8, 2
2, 5	10, 4
4, 3	9, 5
8, 6	3, 1
9, 2	4, 6
3, 10	2, 4
5, 8	1, 10
2, 9	5, 3
10, 5	4, 9
1, 9	6, 4
3, 1	8, 6
5, 3	2, 9
2, 4	3, 10
8, 2	6, 1
10, 4	2, 5
9, 5	4, 3
4, 9	10, 5
6, 4	1, 9
1, 10	5, 8
4, 6	9, 2
Ext. B _________/40	**Ext. A ________/ 40**
Ext. B _____%	**Ext. A _____%**

Appendix C – Speech and Spatial Qualities of Hearing

Speech questions

1. You are talking with one other person and there is a TV on in the same room. Without turning the TV down, can you follow what the person you're talking to says?
2. You are talking with one other person in a quiet, carpeted lounge-room. Can you follow what the other person says?
3. You are in a group of about five people, sitting round a table. It is an otherwise quiet place. You can see everyone else in the group. Can you follow the conversation?
4. You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation.
5. You are talking with one other person. There is continuous background noise, such as a fan or running water. Can you follow what the person says?
6. You are in a group of about five people in a busy restaurant. You CANNOT see everyone else in the group. Can you follow the conversation?
7. You are talking to someone in a place where there are a lot of echoes, such as a church or railway terminus building. Can you follow what the other person says?
8. Can you have a conversation with someone when another person is speaking whose voice is the same pitch as the person you're talking to?
9. Can you have a conversation with someone when another person is speaking whose voice is different in pitch from the person you're talking to?
10. You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?
11. You are in conversation with one person in a room where there are many other people talking. Can you follow what the person you are talking to is saying?
12. You are with a group and the conversation switches from one person to another. Can you easily follow the conversation without missing the start of what each new speaker is saying?
13. Can you easily have a conversation on the telephone?
14. You are listening to someone on the telephone and someone next to you starts talking. Can you follow what is being said by both speakers?

Spatial hearing

1. You are outdoors in an unfamiliar place. You hear someone using a lawnmower. You can't see where they are. Can you tell right away where the sound is coming from?
2. You are sitting around a table or at a meeting with several people. You can't see everyone. Can you tell where any person is as soon as they start speaking?
3. You are sitting in between two people. One of them starts to speak. Can you tell right away whether it is the person on your left or your right, without having to look?
4. You are in an unfamiliar house. It is quiet. You hear a door slam. Can you tell right away where that sound came from?

5. You are in the stairwell of a building with floors above and below you. You can hear sounds from another floor. Can you readily tell where the sound is coming from?
6. You are outside. A dog barks loudly. Can you tell immediately where it is, without having to look?
7. You are standing on the footpath of a busy street. Can you hear right away which direction a bus or truck is coming from before you see it?
8. In the street, can you tell how far away someone is, from the sound of their voice or footsteps?
9. Can you tell how far away a bus or a truck is, from the sound?
10. Can you tell from the sound which direction a bus or truck is moving, for example, from your left to your right or right to left?
11. Can you tell from the sound of their voice or footsteps which direction a person is moving, for example, from your left to your right, or right to left?
12. Can you tell from their voice or footsteps whether the person is coming towards you or going away?
13. Can you tell from the sound whether a bus or truck is coming towards you or going away?
14. Do the sounds of things you are able to hear seem to be inside your head rather than out there in the world?
15. Do the sounds of people or things you hear, but cannot see at first, turn out to be closer than expected when you first see them?
16. Do the sounds of people or things you hear, but cannot see at first turn out to be further away than expected when you do see them?
17. Do you have the impression of sounds being exactly where you would expect them to be?

Qualities of hearing

1. Think of when you hear two things at once, for example, water running into a basin and, at the same time, a radio playing. Do you have the impression of these as sounding separate from each other?
2. When you hear more than one sound at a time, do you have the impression that it seems like a single jumbled sound?
3. You are in a room, and there is music on the radio. Someone else in the room is talking. Can you hear the voice as something separate from the music?
4. Do you find it easy to recognize different people you know by the sound of each one's voice?
5. Do you find it easy to distinguish different pieces of music that you are familiar with?
6. Can you tell the difference between different sounds, for example, a car versus a bus; water boiling in a pot versus food cooking in a frypan?
7. When you listen to music, can you make out what instruments are playing?
8. When you listen to music, does it sound clear and natural?
9. Do everyday sounds that you can hear easily seem clear to you (not blurred)?
10. Do other people's voices sound clear and natural?
11. Do everyday sounds that you hear seem to have an artificial or unnatural quality?

12. Does your own voice sound natural to you?
13. Can you easily judge another person’s mood from the sound of their voice?
14. Do you have to concentrate very much when listening to someone or something?
15. Do you have to put in a lot of effort to hear what is being said in conversation with others?
16. When you are the driver in a car, can you easily hear what someone is saying who is sitting alongside you?
17. When you are a passenger, can you easily hear what the driver is saying sitting alongside you?
18. Can you easily ignore other sounds when trying to listen to something?

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