

HIGH FIDELITY MUSICIAN'S FILTERS AND AUDITORY  
FIGURE-GROUND PERFORMANCE IN CHILDREN

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of  
AMANDA HOFF find it satisfactory and recommend that it be accepted.

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Chair

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# HIGH FIDELITY MUSICIAN'S FILTERS AND AUDITORY

## FIGURE-GROUND PERFORMANCE IN CHILDREN

### Abstract

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Research defining and investigating Auditory Processing Disorders (APD) in children and adults is becoming more and more prominent in the fields of speech-pathology and audiology. Specifically, research on the management of this heterogeneous disorder among the school-aged population has become important. One area lacking in research is children's performance and abilities in auditory figure-ground (background noise). Individuals with auditory figure-ground disorders have difficulty understanding speech in background noise, in spite of the fact that they have "normal" hearing.

This study was designed to compare the effects high-fidelity musician's filters to evaluate performance during an auditory discrimination task in background noise among students with auditory figure-ground disorders. The results indicated improved performance in background noise for the majority of participants and that musician's filters will effectively decreased the effects of auditory figure-ground disorders in most participants. A pair of ER-20™ musician's filters, manufactured by Etymotic Research, Inc., was used for each participant in this study. The results are congruent with previous studies using earmuffs to achieve occlusion, showing that students' and adults'

performance on auditory figure-ground tasks did improve (Hasbrouck, 1980, 1987, 1989). The results are discussed in terms of the possibility and benefit for prescribing musician's filters for children diagnosed with auditory figure-ground disorders, at the University Programs in Communication Disorders (UPCD) Clinic.

## TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENT.....	iii
ABSTRACT.....	iv
LIST OF FIGURES.....	viii
LIST OF TABLES.....	ix
CHAPTER	
1. REVIEW OF THE LITERATURE.....	1
Introduction.....	1
Learning Disabilities.....	1
Auditory Processing Disorders.....	7
Co-occurring Disorders.....	10
Assessment and Intervention for Auditory Processing Disorders.....	11
Collaboration among Audiologists and Speech-Language Pathologists...18	
UPCD Collaborative Approach to APD Assessment.....	19
Auditory Figure-Ground.....	24
Ear Occlusion.....	25
Musician’s Filters.....	34
2. METHODS.....	41
Participants.....	41
Materials and Equipment.....	42
Procedures.....	43

3. RESULTS.....	46
4. DISCUSSION.....	51
5. CONCLUSION.....	54
REFERENCES.....	55
APPENDIX	
A. Raw Scores (numbers of errors) on the Noise and Noise with Musician’s Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for 10 participants.....	62
B. Percentile Scores on the Noise and Noise with Musician’s Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for 10 participants.....	63

## LIST OF FIGURES

	Page
1. Mean Attenuation of an ER-15 Filters Compared to an Unprotected Ear.....	37
2. Mean Attenuation Characteristics of Musician's Filters.....	37
3. Mean attenuation characteristics of ER-20 musician's filters compared to foam.....	38

## LIST OF TABLES

	Page
1. Means, standard deviations, and ranges of numbers of errors on Quiet, Noise, and Noise with Musician's Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for participants.....	46
2. Percentile means, standard deviations, and ranges of Noise subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination with Musician's Filter(s) Application for participants.....	47
3. Type of response to different filter applications and number of participants exhibiting each type of response.....	49

# CHAPTER ONE

## REVIEW OF THE LITERATURE

### Introduction

The following review of the literature discusses learning and language disabilities; definition, assessment and intervention for Auditory Processing Disorders (APD); ear occlusion, specifically for the auditory figure-ground component of APD; and, finally, the advent of musician's filters to achieve unilateral and bilateral ear occlusion. Auditory figure-ground disorders are defined as difficulties understanding speech in background noise despite normal hearing sensitivity (Hasbrouck, 1987). Previous studies (Hasbrouck 1980, 1987, 1989) examined the use of ear muffs to achieve ear occlusion for adults and children with auditory figure-ground disorders and specific difficulties functioning in background noise. Currently little research exists which examines the efficacy of providing ear occlusion as one type of treatment for auditory figure-ground disorders. This study was designed to examine the effects of musician's filters on performance of an auditory discrimination task in background noise by children with auditory figure-ground disorders.

### Learning Disabilities

Historically, some children have difficulty learning, as compared to their typically developing peers. Difficulties learning may occur due to many different factors and are classified as learning disabilities. Learning disabilities (LD) have been examined for many years. LD affects how children and adults learn and perform in school. The results of LD are tremendous, and explaining their pervasiveness and heterogeneity is difficult. According to the US Department of Education, nearly 50% of referrals for special education are from the LD population, which represents around 5% of the entire school-age population. LD all too often is

considered a mild challenge, however it produces significant results. Many students with identified LD drop out of high school before they graduate (26.7%) and very few pursue postsecondary education (Fine & Kotkin, 2003).

### *Definition of Learning Disabilities*

In 1981, the National Joint Committee for Learning Disabilities developed a definition of learning disabilities that has been accepted by most professional and lay organizations in the field. The definition is as follows:

Learning disabilities is a generic term that refers to a heterogeneous group of disorders manifested by significant difficulties in the acquisition and use of listening, speaking, reading, writing, reasoning, or mathematical abilities. These disorders are intrinsic to the individual and presumed to be due to central nervous dysfunction. Even though a learning disability may occur concomitantly with other handicapping conditions (e.g., sensory impairment, mental retardation, social and emotional disturbance) or environmental influences (e.g., cultural differences, insufficient or inappropriate instruction, psychogenic factors), it is not the direct result of those conditions or influences (Kavanagh & Truss, Jr., 1988, p. 550).

Isolating and diagnosing learning disabilities is a difficult task due to the heterogeneity of the type and severity of difficulties among individuals.

### *History of Learning Disabilities in Adults and Children*

Research in the area of LD is substantial and began in the early nineteenth century when Franz Joseph Gall was involved in the study of LD through his work with brain-injured adults and brain mapping. Many others followed suit and tried to categorize different types of LD among adults with acquired brain injuries. They attempted to localize an area of brain damage,

mostly in adults with aphasia. Even as early as 1860-1870, many researchers began to question children's learning capabilities following brain injury. They began to speculate that the same difficulties that were present in adults, may also be affecting how children learn. This speculation caused concern that difficulty processing visual and auditory information might lead to difficulties speaking and writing among children.

According to Fine & Kotkin (2003), Helmer Myklebust, Sam Kirk, William Cruickshank, and Samuel Orton all contributed to various aspects of the study and definition of LD. They questioned whether or not children who sustained brain injury should be classified differently from children who evidenced lower intellect based on genetic origin (Willeford & Burleigh, 1985). Myklebust's research focused on identifying a relationship between brain function and learning behavior. Kirk and Cruickshank were instrumental in proposing the term specific learning disability, and Kirk was responsible for one of the first working definitions of learning disabilities. Samuel Orton suggested his belief that a fundamental difficulty between translating what was heard and what was actually read, existed (Fine & Kotkin, 2003).

According to Willeford & Burleigh (1985), LD became established as an inclusive field of study with publication of Psychopathology and Education of the Brain Injured Child (1947), in which Strauss and Lehtinen focused on how children learn following brain injury. Strauss worked with brain-injured adults in Germany and later focused his attention on schoolchildren in the United States who were experiencing academic difficulties. Many of the children with whom Strauss worked had language and visual-motor deficiencies. Many of them would perform adequately in certain academic areas and at a low level in others (Willeford & Burleigh, 1985). Strauss' findings provided early evidence and reinforced the heterogeneity and complexity of diagnosing and defining learning disabilities among adults and children.

### *Differentiation of LD Characteristics in Children*

Many professionals began to explore perceptual-motor disabilities, figure-ground disturbances, hyperkinesias, visual-perceptual disorders, language-learning disabilities, and auditory perceptual deficiencies in their research of LD (Tallal, 1988, Willeford & Burleigh, 1985). Specifically, auditory and language factors have been of interest to speech-language pathologists and audiologists (Willeford & Burleigh, 1985). Tallal (1988) discussed normal language development, which requires integration of sensory, attention, perceptual, cognitive, motor, and linguistic functions. When one or more of these functions does not typically develop, a delay or disorder in language development may occur. Language disorders that are due to peripheral or central impairments are considered to be symptoms of a more pervasive disorder, rather than the primary disorder itself (Tallal, 1988). Differentiation among the functions of language development that are disordered in children assists in characterizing the type of delay or disorder that is present.

### *Language and Learning Disorders in Children*

The information-processing theory of language development is concerned with cognitive functioning and characterizing how language is learned (Roseberry-McKibbin & Hegde, 2006). According to Nelson (1998) and Owens (2005), information-processing views the human information processing system as a mechanism that encodes environmental stimuli, interprets those stimuli, stores those results in memory, and allows for the retrieval of previously stored information. Owens (2005) reported that the primary concern for information-processing involves handling incoming and outgoing information. Literature suggests a correlation between information processing and language disorders (Roseberry-McKibbin & Hegde, 2006, Owens, 2005, Reed, 2005, Nelson, 1998).

Specifically, researchers have examined whether or not children with language disorders have co-occurring information processing problems (Conti-Ramsden, 2003; Hoffman & Gillam, 2004; Montgomery, 2002). Ellis Weismer and Evans (2002) suggested two broad categories of information processing and language disorders, which include phonological processing and temporal auditory processing. Phonological processing involves the mental ability to manipulate the phonological aspects of language, including rhyming words, segmenting words, and syllabification. A child who has trouble rhyming words or knowing that “c-a-t” means “cat” is said to have a phonological processing disorder (Ellis Weismer & Evans, 2002). Temporal auditory processing deals with the ability to perceive brief acoustic events that make up speech sounds and track the changes in these events as they occur quickly in the speech of others (Reed, 2005). Auditory and language factors in relation to learning disabilities were of particular interest to speech-language pathologists and audiologists (Willeford & Burleigh, 1985). Most important and relevant to this study were specific investigations of auditory-perceptual disorders and figure-ground disorders.

#### *Learning Disabilities and Auditory Processing in Children*

Researchers are interested in both the overall processing capacity and speed of processing when studying children’s temporal auditory processing skills. For example, researchers might ask if a child with a language disorder is able to listen to a rapid presentation of “3-9-5-6-2”, remember the string of digits, and repeat it back immediately and accurately. The child may have difficulty with the length of the string of digits, the speed at which the string of digits was presented, or both (Roseberry-McKibbin & Hegde, 2006).

Children with temporal auditory processing disorders may have difficulty with other tasks, as well. They may have difficulty remembering and following complex directions, repeating

sentences verbatim, repeating lists of real and nonsense words, and other tasks that require the ability to hear, remember, and give back information that was heard, especially if the information was presented rapidly (Roseberry-McKibbin & Hegde, 2006).

### *Normal Auditory Processing*

Auditory processing is defined as “how the auditory system utilizes acoustic information” (Stach, 1998, p. 183). Normal auditory processing includes a number of coordinated processes of acoustic stimuli. According to ASHA (1996),

Central auditory processes are the auditory system mechanisms and processes responsible for the following behavioral phenomena: sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition including, temporal resolution, temporal masking, temporal integration, and temporal ordering; auditory performance with competing acoustic signals; and auditory performance with degraded acoustic signals (ASHA, 1996, p. 41).

An auditory processing disorder is an observed deficit in one or more of the previously mentioned areas. Auditory processing disorders occur in the presence of normal auditory sensitivity (Mokhemar, 1999).

### *Peripheral Hearing Mechanism*

According to Stach (1998), the peripheral hearing mechanism is an elaborate series of structures that process sound. The pinna collects and funnels sound waves to the tympanic membrane via the external auditory canal. The tympanic membrane vibrates in response to sound, which then sets the ossicular chain into motion. The motion of the ossicular chain sends the fluids of the cochlea into motion, causing stimulation of the hair cells of the basilar membrane, which in turn send impulses through the VIIIth cranial nerve to the auditory brain

stem. Peripheral hearing loss is a result of problems in the outer, middle, or inner ear and the auditory nerve, while central auditory disorders are due to a disruption of sound transmission between the brainstem and the cerebrum (Stach, 1998).

### *Central Hearing Mechanism*

Stach (1998) and Chermak & Musiek (1997) described the central hearing mechanism, which encompasses the auditory neurological system. The auditory neurological system contains several nuclei which serve as relay stations to transfer auditory stimuli from the cochlea and VIIIth cranial nerve to the cerebral cortex. The nuclei involved are the cochlear nuclei, superior olivary complex, lateral lemniscus, inferior colliculus, and medial geniculate. Each nerve fiber within this complex system synapses ipsilaterally (pertaining to the same side) or contralaterally (pertaining to the opposite side) depending on location. An important function of the auditory system is speech processing, which occurs primarily in the left temporal lobe in most humans. Speech that is detected by the right ear passes through the dominant contralateral auditory channels to the left temporal lobe. Speech that is detected by the left ear proceeds through the dominant contralateral channel to the right cortex and then crosses to the left cortex for processing by means of the corpus callosum. As a result, most humans process speech information in the dominant right ear (Stach, 1998, Chermak & Musiek, 1997).

### Auditory Processing Disorders

The literature which discusses disorders of processing auditory information uses both Auditory Processing Disorders (APD) and Central Auditory Processing Disorders (CAPD) to label the disorder (Jerger & Musiek, 2000, ASHA, 1996). Since auditory processing disorders occur in the presence of normal auditory sensitivity, the central hearing mechanism is affected and the peripheral hearing mechanism is preserved (Mokhemar, 1999). Therefore, the use of the

term, central, is redundant, since it is obviously the affected mechanism. As a result, the term auditory processing disorders (APD) will be used in this paper.

#### *Etiology of Auditory Processing Disorders*

Auditory processing disorders can arise from a great number etiologies including, but not limited to, tumors, traumatic brain injury, asphyxia during birth, various genetic disorders, infections such as meningitis or encephalitis, metabolic disturbances, cerebrovascular diseases, or drug- or chemical-induced problems (Roseberry-McKibbin & Hegde, 2006). The history of research in adult site of lesion studies resulted in the early study of learning disabilities and led to the study of APD. According to Willeford & Burleigh (1985), researchers made the assumption that the information gained in site of lesion testing in adults would similarly transfer to children.

#### *ASHA Consensus Statement*

In 1996, the American Speech-Language Hearing Association (ASHA) convened a task force to develop a consensus statement for central auditory processing disorders (CAPD). The task force identified central auditory system mechanisms and functions that are responsible for six behavioral phenomena. These phenomena include sound localization and lateralization; auditory discrimination; auditory pattern recognition; temporal aspects of audition (including temporal resolution, masking, integration, and ordering); auditory performance deficits with competing acoustic signals; and auditory performance deficits with degraded acoustic signals. Central Auditory Processing Disorder is an observed deficiency in one or more of these behaviors (ASHA, 1996).

#### *Bruton Conference Statement*

Though the ASHA Task Force presented a definition of APD, Jerger (1998) felt that there were significant problems with the consensus statement. He argued that the task force only listed

the deficits that are described in the literature. His issue with their definition was that it does not provide a conceptual framework to help the reader understand the phenomenon of Auditory Processing Disorders (APD) (Jerger, 1998).

At the two-day Bruton Conference, Jerger and Musiek (2000) broadly defined APD as “a deficit in the processing of information that is specific to the auditory modality”. The Bruton Conference comprised fourteen senior scientists and clinicians who met to attempt to reach a consensus regarding the diagnosis of APD in school-age children. The professionals associated APD with difficulties in listening, speech understanding, language development, and learning. In its most simple terms, APD is “a conceptualized deficit in the processing of auditory input” (Jerger & Musiek, 2000).

#### *Characteristics of Auditory Processing Disorders*

According to Katz, (2002); Mencher et al. (1997); and Tye-Murray (2004), typical characteristics of auditory processing disorders are:

- poor auditory discrimination
- poor auditory integration
- poor auditory sequencing skills
- poor auditory closure (e.g. recognizing that “\_anta \_aus” is “Santa Claus”)
- difficulty listening in the presence of background noise
- poor auditory attention
- poor auditory memory
- poor auditory localization, or abilities to locate a sound source in the environment
- difficulty understanding rapid speech and other forms of auditory input that are characterized by reduced redundancy

- difficulty following melody and rhythms of music
- difficulty learning to read aloud, caused by an inability to learn the correct association of visual and auditory symbols

### Co-occurring Disorders

There are several co-occurring disorders that may complicate reaching diagnosis of APD. Some possible co-occurring disorders include a pure auditory disorder or multi-sensory disorder, attention deficit/hyperactivity disorder (ADHD), language impairment, reading disability, learning disability, reduced intellect, or autistic spectrum disorder (Jerger & Musiek, 2000).

By definition, APD, ADHD, and learning disabilities are heterogeneous conditions, which can overlap when assessing children's performance and abilities (Chermak & Musiek, 1997, ASHA, 1996, National Joint Committee on Learning Disabilities, 1991). Although the relationships among APD, ADHD, and learning disabilities are highly complex and not entirely understood, future perspectives and data may lead to possible resolution (Chermak & Musiek, 1997).

Several authors have conceptualized the relationship and differences between ADHD and APD (Chermak, Hall, & Musiek, 1999, Chermak & Musiek, 1997, Musiek & Chermak, 1995). Musiek & Chermak (1995) summarized that APD is an input disorder, based on an inability to process information and ADHD is an output disorder, based on an inability to control behavior. Therefore, the implications of co-occurring disorders with APD have created a great need to differentiate APD from what it is not (i.e. ADHD) by means of specific evaluation procedures.

Individuals with learning disabilities (LD) often experience deficits in processing spoken language, therefore learning disabilities and APD also have been thought to be linked. The frequency of co-occurring LD and APD has led to hypotheses that some portions of learning

disabilities are due to central auditory deficits in adults and children (Chermak, Vonhof, & Bendel, 1989, Chermak & Musiek, 1997). Therefore, it is important to use sensitive measures and an interdisciplinary approach to appropriately evaluate individuals with suspected or diagnosed learning disabilities (Chermak & Musiek, 1997).

#### Assessment and Intervention for Auditory Processing Disorders

The numbers of auditory processing disorders (APD) diagnoses have increased over the past 25 years. Audiologists, and recently, speech-language pathologists have been involved with assessing and treating APD (Roseberry-McKibbin & Hegde, 2006, ASHA, 2005, Friel-Patti, 1999, Bellis, 1996).

##### *Audiology Assessment*

According to ASHA (2005), it is within the audiologist's scope of practice to diagnose, assess, and develop deficit-focused treatment and management plans for individuals with APD. Historically, audiologists and other researchers have been involved with determining and assessing individuals for APD. Since more than the auditory system may be involved in APD, audiologists must select a test battery that can differentiate among other sensory, cognitive, and linguistic system deficits (Chermak & Musiek, 1997).

Individuals with APD typically present with no significant peripheral hearing loss, researchers began to correlate central auditory processing testing with site-of-lesion testing. This led researchers to develop test procedures designed to determine site-of-lesion and central auditory nervous system (CANS) function in adults with neurological disorders (Katz, 2002).

Willeford and Burleigh (1985) discussed the difficulty of assessing and diagnosing children with possible APD. For example, many children with a suspected auditory processing disorder had normal sensitivity to pure tone testing, with the exception of moderate impairment at 8000

Hz, showed normal speech reception thresholds, and scored within normal limits on speech discrimination tasks. Therefore, these children easily passed pure tone screening examinations after being referred by teachers based on the suspicion of hearing loss. However, most of these children were unable to efficiently use and understand auditory information. Willeford and Burleigh (1985) attributed this difficulty to an inefficient central auditory nervous system (CANS), which limits children's practical use of auditory information through sorting and processing meaningful auditory signals. Since there was no peripheral hearing loss present and patients had no difficulties with speech reception and speech discrimination, researchers had to find other ways to assess this population and identify the presence of APD. A common symptom of APD is difficulty understanding distorted speech. Even though all people have difficulty understanding distorted speech, individuals with APD have greater difficulty. Therefore, tests which distorted the speech signal were found to be most effective at differentiating sites of lesion in adults and identifying APD in children.

There are several assessment procedures that may be used to evaluate APD. Assessment procedures are based on several test battery considerations and parameters. In some central auditory tests, speech is presented at a low intensity, compressed in time, masked with noise, periodically interrupted, or filtered by eliminating certain frequencies of speech (Roseberry-McKibbin & Hegde, 2006). Monaural and dichotic testing is conducted by presenting stimuli through earphones. In monaural testing, the signal is heard in one ear at a time. Dichotic testing presents two different signals with simultaneous onset and offset times to both ears (Keith, 1999).

Audiologic APD testing procedures include low redundancy speech tests. Chermak and Musiek (1997) described low-redundancy monaural speech tasks as auditory closure tasks.

These are a group of speech tests in which speech signals are degraded or presented in competition with other acoustic sounds. Speech signals that have been filtered, compressed, expanded, interrupted, and reverberated are used. Standard speech recognition lists, which are slightly distorted, are presented monaurally and the participant is asked to repeat the words. This category of tests does not have high sensitivity or specificity, but it does test processes different from temporal and dichotic procedures. Low-redundancy monaural speech tasks are useful for assessing auditory closure and provide insight into temporal processing problems.

Another procedure uses binaural interaction and fusion tasks which require that two signals, one for each ear, be presented dichotically. The signals are acoustically modified, making them difficult to understand by themselves, but easy to understand once they are fused, hypothetically by the CANS. Both monaural low-redundancy speech tests and binaural interaction tests are useful in determining CANS and low brainstem lesions. The behavioral test results may be compared with site-of-lesion testing (i.e. neuroimaging), which often parallel each other (Chermak & Musiek, 1997).

#### *ASHA Assessment Battery Considerations*

Keith (1999) concurred with the ASHA Task Force on Central Auditory Processing Disorders (1996) regarding the necessary assessment components. The assessment should include a patient history, observation of the patient's auditory behaviors, audiologic test procedures – pure tone, speech recognition, and immittance, temporal processes, localization and lateralization, low redundancy monaural speech, dichotic stimuli, binaural interaction procedures, and speech-language measures (Keith, 1999, ASHA 1996).

Katz (2002) described a variety of assessments to conduct for central auditory processing based upon the skill set(s) the professional wishes to examine. The skill sets Katz presented to

be assessed are: (1) Span of apprehension – the number of units stored in short-term memory. (2) Lexical decoding – the ability to process information accurately and quickly. (3) Short-term memory retention – the ability to recall information from short-term memory. (4) Auditory Integration – includes assessing ear dominance, integrating segmentals and suprasegmentals, and making sound-symbol associations. (5) Sequencing – ordering information. (6) Auditory Attention – which includes figure-ground (speech embedded in noise) and binaural separation (presenting competing stimuli to separate ears). The different aspects of attention include selective attention, divided attention, and sustained attention. He stated that the assessment battery for CAPD depends upon the clinician's view and definition of the disorder (Katz, 2002).

#### *Bruton Conference Assessment Battery Considerations*

Based on collaboration during the Bruton Conference (Jerger & Musiek, 2000), professionals suggested that an APD Test Battery include behavioral tests, electrophysiological and electroacoustic tests, and neuroimaging. Since neuroimaging is very expensive and not widely available, the participants focused on behavioral tests, supplemented by electrophysiological and electroacoustic tests, for a contemporary APD test battery. There are three possible modes by which to present auditory stimuli. In a monotic presentation, stimuli are presented to each ear separately. Diotic stimuli are presented to both ears simultaneously. Dichotic stimuli are different stimuli presented to the two ears simultaneously. Dichotic modes are most frequently used, but monotic assessment is important to detect any significant ear asymmetries (Jerger & Musiek, 2000).

Minimum behavioral testing, according to Jerger & Musiek (2002) should include pure tone audiometry to determine presence and degree of peripheral hearing sensitivity loss. Word recognition testing should be used in order to explore the individual's word recognition abilities

over a wide range of speech levels and compare performance on both ears. A dichotic task should be used to indicate auditory processing problems with dichotic digits, words, or sentences. Finally, frequency or duration pattern sequence testing and temporal gap detection was recommended to measure auditory temporal processing. The electroacoustic and electrophysical measures recommended consist of immittance audiometry, otoacoustic emissions, auditory brain stem response (ABR), and middle latency response (MLR). In order to make a diagnosis of APD, more than one test is needed and recommended. Observation of any patterns in performance on the test battery assists in diagnosis (Jerger & Musiek, 2000).

#### *Role of the Audiologist*

Audiologists play a key role in describing, diagnosing, assessing, and managing APD. The majority of the audiologist's role consists of assessing and diagnosing an auditory processing disorder. Since APD is an auditory deficit, it is the position of ASHA (2005) that the audiologist is the professional who diagnoses the disorder. Many other professionals, including speech-language pathologists, collaborate with audiologists to implement intervention plans (ASHA, 2005).

#### *Role of the Speech-Language Pathologist*

According to ASHA (2005), speech-language pathologists are qualified to determine cognitive-communicative and/or language factors that may be associated with APD. Therefore, a speech-language pathologist serves as part of the professional multidisciplinary team to guide treatment and management for APD and associated deficits (ASHA, 2005).

The role of information processing, also called auditory processing, in language learning has encountered controversy. Many speech-language pathologists provide intervention to children with “auditory-processing problems” with the intended goal of enhancing their language skills

(Gillam, 1999). Research with small numbers of children with language impairments has shown that direct treatment for auditory-processing skills leads to an improvement in language skills (Miller, Merzenich, Saunders, Jenkins, & Tallal, 1997; Tallal, Miller, Bedi, Byma, Wang, Nagarajan, Schreiner, Jenkins, & Merzenich, 1996).

Speech-language pathologists and audiologists would benefit from a better understanding of the intervention options that are available to evaluate and treat children, adolescents, and adults who are diagnosed with APD. While there is much information in the area of assessment, there is a need for more research with larger numbers of participants in terms of intervention. At present, intervention consists of modifying the individual's behavior and/or environment (Katz, 2002, Friel-Patti, 1999, Keith, 1999, Chermak & Musiek, 1997).

Chermak and Musiek (1997) presented a comprehensive approach to management and intervention for individuals with auditory processing disorders. The authors advocated strategies and techniques for intervention that include environmental adaptations, skills development, and adaptive compensation. Two examples of environmental adaptations are implementing assistive listening devices or making acoustic modifications. An example of an assistive listening device for children is implementing an FM system in a child's classroom to amplify the teacher's voice. Making acoustic modifications would include closing the classroom door to minimize hallway noise or preferential seating to reduce the distance from speaker to listener. Acoustic modifications also may include installing carpeting and using rubber tips on chair legs to reduce excess classroom noise. Skills development includes vocabulary building and improving memory skills. One type of vocabulary building strategy is to derive context from word meanings. Memory improvement skills may be enhanced through chunking information, verbal chaining, using mnemonics, rehearsal, summarizing, and/or paraphrasing. An example of an

adaptive compensation is an external aid to benefit memory through the use of a notebook or planner (Chermak & Musiek, 1997).

Friel-Patti (1999) stated that intervention for children diagnosed with auditory processing disorders should involve several approaches. Specifically, intervention should enhance the child's listening environment (i.e. improving signal-to-noise ratios), improve the child's listening strategies, improve cognitive and linguistic abilities, and develop compensatory strategies (Friel-Patti, 1999). The author referred the reader to the ASHA Task Force on Central Auditory Processing Disorders (1996) for specific examples for management. Two areas were highlighted: enhancing the individual's language resources and improving the individual's signal quality. According to the ASHA task force (1996), enhancing language resources includes improving listening strategies and cognitive/linguistic abilities. Teaching the child to pay attention to detail and ask for repetition are two examples of improving listening strategies. To improve cognitive/linguistic abilities, the Task Force suggested teaching vocabulary, phonology, and grammar. Improving signal quality for an individual includes enhancing the listening environment. An FM system or sound field amplification will increase the signal quality to the individual. Modifying the physical classroom environment will decrease background noise and reverberation. Finally, the use of compensatory strategies, such as visual aids, either gesture or graphic displays, will provide environmental and contextual cues to the individual in the classroom (ASHA, 1996).

Keith (1999) made a distinction between remediation and management. Remediation is altering the patient's central nervous system, while management is modifying behavior, performance, or environment by teaching cognitive or compensatory strategies. Management

strategies include changing the environment, perceptual training, and compensatory or cognitive training (Keith, 1999).

Katz (2002) compared three general principles of behavioral intervention to a tripod that needs all three legs to stand. Behavioral intervention programs should equally contain three components: modification of the environment, use of compensatory strategies, and enhancement or improvement of auditory skills (Katz, 2002).

According to Chermak and Musiek (1997), one research priority for management of APD is to examine the efficacy of treatment methodology related to effectiveness of treatments. Since there are standards for assessing APD, there needs to be a link to appropriate treatment for the area that is disordered. Professionals need a better understanding of how to relate auditory test results to specific treatment plans (Keith, 1999).

#### Collaboration among Audiologists and Speech-Language Pathologists

Collaboration among audiologists, speech-language pathologists, and other members of the multi-disciplinary team is essential for providing and developing appropriate screening and assessment, diagnosis, and treatment and management plans. (ASHA, 2005, Chermak & Musiek, 1997, Bellis, 1996). According to Bellis (1996), a team approach to assessment and treatment of APD allows for the collection of educational, social, speech-language, cognitive, and medical characteristics of the individual. Along with audiologists and speech-language pathologists, members of the collaborative team include educators, psychologists, parents, and physicians. The team approach helps to create a full picture of the individual's abilities and needs as related to diagnosis, assessment, treatment, and management (Bellis, 1996).

## UPCD Collaborative Approach to APD Assessment

At the University Programs in Communication Disorders (UPCD) Clinic, a multi-disciplinary approach to APD evaluation takes place. During evaluations, patients are assessed first by audiology, and then by speech-language pathology. The audiology testing takes place in a sound isolated audiology suite and focuses on the patient's central auditory functioning. The speech-language testing takes place in a separate treatment room at the UPCD Clinic using linguistically based tests of auditory processing. The two disciplines confer and develop individualized recommendations for each patient, based on their combined findings. Then the results of testing and appropriate recommendations are presented to the patient and his or her parents. This assessment practice assures thorough evaluation of each patient's audiologic, speech, language, and attention abilities.

### *Audiology Component of UPCD Assessment*

At the UPCD Clinic, a standard protocol and audiological APD testing battery is implemented. The battery is comprised of behavioral testing, electroacoustic and electrophysiological measures, and optional procedures, which are similar to the methods reported by Jerger & Musiek (2000).

### *Minimum Test Battery*

The minimum test battery includes pure tone audiometry, tympanometry, acoustic reflex thresholds, speech reception threshold, dichotic listening tasks involving digits, words, and/or sentences, frequency or duration pattern sequence tests, and temporal gap detection (Nye, Hasbrouck, & Hawkins, 2004).

Pure-tone audiometry is used to rule out peripheral hearing sensitivity loss. Sound is presented through earphones to test the hearing sensitivity of the entire auditory mechanism.

Tympanometry assesses middle ear function by measuring how acoustic immittance affects the vibration of the middle ear system with varied air pressures in the external ear canal. The maximal transmission of sound occurs when air pressure is equal on both sides of the tympanic membrane (eardrum). In a normal ear, that maximum transmission occurs at, or near, atmospheric pressure. Therefore, when air pressure in the external ear canal equals the air pressure in the middle ear cavity, energy may flow through the system at maximum levels. To assess middle ear pressure, the air pressure in the sealed ear canal is varied until the SPL of the probe tone is at its minimum. This reflects maximum transmission of sound through the middle ear mechanism. However, immittance within the system changes if the air pressure in the external canal is either more than (positive pressure) or less than (negative pressure) the air pressure within the middle ear space. This causes a diminished energy flow (Stach, 1998).

The acoustic reflex threshold is measured when a sound of sufficient intensity elicits the contraction of the stapedius muscle within the middle ear. The acoustic reflex threshold is defined as “the lowest intensity level at which a middle ear immittance change can be detected in response to sound” (Stach, 1998, p. 270). Diagnostically, acoustic reflex thresholds are useful for differential assessment of auditory disorder and predicting hearing sensitivity. The speech reception threshold is the lowest level at which the individual is able to identify 50% of the test stimulus items. Spondaic words, which are two-syllable words spoken with equal emphasis on both syllables, are presented. The individual is asked to repeat the spondees (spondaic words) he or she hears (Stach, 1998).

Dichotic listening tasks measure the individual’s ability to process two different signals which are presented to both ears at the same time (Stach, 1998). Frequency pattern sequence tests require that the individual describe the pitch of three tones presented (i.e. “low” or “high”).

Duration pattern tests require that the individual describe short versus long tones among three tones presented (Chermak & Musiek, 1997).

#### *Minimum Behavioral Testing*

There are three minimum behavioral testing components that include measures of detection, measures of suprathreshold discrimination, and measures of identification. The measures of detection involve pure tone audiogram to determine presence and degree of peripheral hearing loss and temporal integration tasks to examine auditory temporal processing. Temporal integration tasks include dichotic listening and binaural integration and separation, low-redundancy monaural speech tasks for auditory closure, and binaural interaction, lateralization, and localization tasks. Measures of suprathreshold discrimination to further determine temporal processing are comprised of intensity and/or duration tasks, temporal ordering/sequencing tasks, temporal resolution, masking level differences (MLD), backward/forward masking tasks, and spatial lateralization or localization testing. Measures of identification include phonemes, syllables, words, phrases, or sentences.

#### *Other Measures & Procedures*

Electroacoustic and electrophysiological measures can contain immittance audiometry, otoacoustic emissions, and auditory evoked potentials. Other optional procedures consist of comparison of analogous auditory and visual tasks (Hasbrouck & Nye, 2003).

#### *Speech-Language Pathology Component of UPCD Assessment*

The speech-language pathology assessment protocol consists of objective test instruments and subjective observations designed to examine the nine areas of auditory processing. The areas assessed include auditory attention, localization, discrimination, identification, figure-ground, memory, sequencing, closure, and synthesizing (Nye, Hasbrouck, & Hawkins, 2004).

1.) Auditory Attention

Auditory attention is assessed through subjective observation throughout the testing session.

2.) Auditory Localization

Auditory localization is determined by a subjective assessment of the individual's ability to localize sounds in space.

3.) Auditory Discrimination

Auditory discrimination abilities are assessed with the Auditory Word Discrimination Subtest of the Test of Auditory Perceptual Skills (TAPS).

4.) Auditory Identification

Auditory Identification abilities are assessed with the Quiet Subtest of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination.

5.) Auditory Figure-Ground

Auditory Figure-Ground performance is assessed with the Noise Subtest of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination, and three individually randomized copies of the Noise Subtest during three different orders of ear occlusion (right ear only, left ear only, and bilateral occlusion).

6.) Auditory Memory

Auditory Memory is assessed using the Digits Forward and Letters Forward Subtests of the Test of Memory and Learning, the Memory for Words and Memory for Sentences Subtests of the Woodcock-Johnson Tests of Cognitive Ability, and the Listening to Paragraphs and Concepts and Directions Subtests of the Clinical Evaluation of Language Fundamentals-3 (CELF-3).

### 7.) Auditory Sequencing

Auditory Sequencing is assessed through subjective observation of the order of responses during all tests administered. The individual's abilities to repeat sound, word, letter, or number stimuli in the correct order is documented.

### 8.) Auditory Closure

Auditory Closure is assessed with the Incomplete Words and Listening Comprehension Subtests of the Woodcock-Johnson Tests of Cognitive Ability.

### 9.) Auditory Synthesizing

Auditory Synthesizing is objectively assessed with the Sound Blending Subtest of the Woodcock-Johnson Tests of Cognitive Ability; the Word Attack Subtest of the Woodcock Tests of Reading Mastery; and the Lindamood Auditory Conceptualization Test (adequate for the individual's grade level). Auditory Synthesizing is subjectively assessed through subjective observation of the individual's phonemic synthesis and analysis of sound manipulation, grapheme/phoneme association, and phoneme/grapheme association (Nye, Hasbrouck, & Hawkins, 2004).

The joint venture between audiology and speech-language pathology at the UPCD clinic provides a valuable approach to evaluation and identification of individuals suspected of having APD. Upon completion of assessment, the two professions meet to discuss and share the findings and make appropriate recommendations for the individual (Hasbrouck, Nye, & Power, 2004).

## Auditory Figure-Ground

One important aspect of Auditory Processing Disorders (APD) is auditory figure-ground disorder. Individuals with auditory figure-ground disorders have difficulty understanding speech in background noise, in spite of the fact that they have normal hearing acuity (Hasbrouck, 1987). The auditory figure-ground aspect of APD is important, because background noise is a common and often unavoidable listening situation for all individuals. Background noise is a problem for these individuals because it degrades the spoken message, making it difficult to understand for the listener. According to Chermak & Musiek (1997), auditory figure-ground disorders may be objectively assessed and diagnosed using low redundancy speech tests to evaluate speech-in-noise.

Historically, several treatment methods for auditory figure-ground disorders have been used. There are several ways to manage distractibility and inattention in background noise in order to increase the signal-to-noise ratio. This can be achieved through the use of an FM system, preferential seating, and acoustic modifications in the individual's listening environment (Chermak & Musiek, 1997). One way to manage an individual's listening environment in auditory figure ground is to provide him or her with a method of ear occlusion (Hasbrouck, 1980, 1987, 1989, Hasbrouck & Carpenter, 1998). By diminishing the distracting background noise for the individual, he or she may perform better in conditions of auditory figure-ground. The ASHA Task Force on Central Auditory Processing Disorders, however, refuted the enthusiasm for occluding an individual's weaker ear because there is "no theoretical or empirical support for their use" (ASHA, 1996, p. 47).

Keith (1999) stated that there is a need to better understand the relationship between central auditory test results and treatment plans. Furthermore, there is a need to better understand

treatments that work best for children diagnosed with auditory processing disorders and more outcome studies are needed to verify their effectiveness (Keith, 1999). Chermak and Musiek (1997) and Friel-Patti (1999) also suggested evaluating treatment efficacy through the execution of randomized clinical trials.

### Ear Occlusion

In 1967, chemist Ross Gardner, Jr. developed an internal energy-absorbing-resins project that later became the E-A-R plug. The initial intent of the resin project was to control noise and vibration for workers in the foundry industry, where metal is melted and poured into molds. Solid vinyl absorbing resin was produced as a foam sheet material and marketing of earplugs began. Ross found that foam earplugs, produced in cylinders, could be easily compressed and inserted into the ear canal. The foam would then expand inside the ear canal and form a seal, reducing laboratory and low-frequency noise. Earplugs became successful in noisy occupational environments and were cheap, comfortable, and effective at reducing noise levels for workers. The Occupational Safety and Health Administration (OSHA) regulated the use of earplugs in 1971 and again in 1983. In the 1990s, additional unique and important hearing protection products were created, including earmuffs and high-fidelity ear plugs to provide flat and moderate attenuation (Gardner Jr. & Berger, 1994).

Since the 1960s, ear occlusion has involved earmuffs or earplugs as Hearing Protection Devices (HPDs) in industrial and agricultural settings to preserve hearing acuity in noisy occupational environments (Pessina & Guerretti, 2000). The use of a HPD (both earplugs and earmuffs) by workers in these settings showed an average of 10 dB attenuation, depending on the worker, proper wearing method, and wearing time. The authors of this study considered the

average attenuation achieved by the earplugs and earmuffs to be a fairly good and an acceptable result (Pessina & Guerretti, 2000).

In industrial workplaces, HPDs were thought to interfere with communication and awareness of warning signals. A study by Hashimoto, Kumashiro, and Miyake (1996) attempted to estimate the effects of HPDs on speech perception in noise. Three earplugs with different attenuation characteristics were used. Ten adults with normal hearing were presented with monosyllabic words at two speech levels (65 and 85 dB) in signal-to-noise ratios of 0, +5, and +10 dB. Results indicated variability among the type of protector, speech level, and signal-to-noise ratio. The earplug with decreased low frequency attenuation showed less speech intelligibility deterioration at 65 dB, however it did not improve speech intelligibility at 85 dB (Hashimoto, Kumashiro, & Miyake, 1996). This study suggests that an earplug that provided low frequency attenuation yielded better speech intelligibility at lower intensity (65 dB, rather than 85 dB) sounds.

Fernandes (2003) examined the effects of earplugs and earmuffs on speech intelligibility among young adults with normal hearing. Experiments were carried out on five conditions of ear occlusion: one without protectors, two with earplugs, and two with earmuffs. Ambient noise, four test presentation levels (60, 70, 80, and 90 dB), six signal to noise ratios (without noise, +5, +10, zero, -5, and -10 dB), and five repetitions for each case, totaling 60 tests with 10 monosyllables (600 stimuli), were used. Results indicated that at 60 to 70 dB, HPDs reduced speech intelligibility, while in the presence of ambient noise at levels of 80 to 90 dB and unfavorable signal to noise ratios (0, -5, and -10 dB) HPDs improved intelligibility. The study confirmed that the influence of HPDs on speech intelligibility is related to the spectral curve of the HPD's attenuation (Fernandes, 2003). Therefore, when selecting an earplug in industrial

settings, it is important to determine the level of background noise and stimuli presentation level in order to achieve the most optimum speech intelligibility.

Specifically, Katz (1972) stated that people who wore ear protection on the job during steady noise reported an increased ability to hear warning signals and other people talking to them. Wearing earmuffs or earplugs decreases distortion so that speech and warning signals may be heard more clearly (Katz, 1972). Ear occlusion has also been found to be effective for reducing the effects of auditory figure-ground in individuals with auditory hypersensitivity and Auditory Processing Disorders (APD) (Hasbrouck & Carpenter 1998, Hasbrouck, 1989, Hasbrouck, 1987, Willeford & Burleigh, 1985, Hasbrouck, 1980).

#### *Ear Occlusion and Auditory Hypersensitivity*

In 1998, Hasbrouck and Carpenter reported on the efficacy of DefendEar© Filtered Attenuators when used with a 3 year, 7 month old female with auditory hypersensitivity. It was hypothesized that DefendEar© Filtered Earplugs would increase the participant's tolerance for environmental sounds and therefore, modify her behavior. The child was hypersensitive to environmental stimuli in all sensory modalities since birth and responded by crying, screaming, and covering her ears. She endured several professional evaluations, diagnoses, and treatments. An audiologist referred the child to the authors based on their expertise with central auditory processing disorders (Hasbrouck & Carpenter, 1998).

An audiological evaluation revealed normal hearing acuity and normal central auditory processing abilities. Due to her auditory hypersensitivity, the child was fit with bilateral half-shell DefendEar© Filtered Earplugs. The filters allowed her to hear speech clearly, but at a reduced intensity level. It was recommended that she wear the filters continuously while awake.

The child's mother rated 39 of 44 behaviors, consistently, on a questionnaire provided to her (Hasbrouck & Carpenter, 1998). Based on questionnaire data and the mother's anecdotal descriptions, the DefendEar© Filtered Earplugs improved the child's behavior. Though the filters did not create a "perfect child", the filters significantly improved both the child's and her parents' quality of life (Hasbrouck & Carpenter, 1998). Therefore, further research in the area of unilateral and bilateral musician's filters is necessary to examine both adults' and children's performance in background noise on current assessments of auditory perceptual skills in an audiology suite and in real world applications.

#### *Ear Occlusion and APD*

Willeford & Burleigh (1985) presented the case of RK, a seven-year-old boy, referred due to reported inadequate progress in school. His third grade teacher stated that RK was easily distracted and had difficulty succeeding on academic tasks. He rarely completed assignments and acted as if he did not understand classroom instructions. Assessment results for APD were found to be below the normal range. Recommendations for RK were to wear earmuffs during desk activities to reduce classroom noise and to use an FM system during classroom instruction. Following implementation of the recommendations, RK showed marked improvements in his overall behavior, attention skills, and ability to complete assignments in the classroom.

Willeford and Burleigh (1985) reported that earmuffs and earplugs were a rational approach to treating individuals with auditory processing disorders (APD). Earmuffs or earplugs reduce the stress placed on an individual's impaired neurological system. Occluding the patient's weak ear would allow him or her to better comprehend the message by improving the conditions by which auditory signals arrive to the brain.

Willeford and Burleigh conducted a survey of 81 families with children who were diagnosed with APD and were experimentally using earplugs. Reports from children, parents, and school personnel indicated that plugging one ear did have practical value for improving performance. Unilateral ear occlusion was reported especially helpful when a child was working individually at a desk. Wearing earplugs helped to eliminate classroom background noise and helped the child to improve concentration on assignments by staying on task. One explanation for improved figure-ground listening among children was that blocking sound to the weak ear might have reduced neurological interference from the child's weak ear to the strong ear, which refers to auditory integration.

In real world applications, it is logical that an individual would use environmental positioning and differential combinations of body and head movements to improve listening in background noise. Furthermore, individuals with a unilateral weakness would compensate by positioning their unoccluded strong ear toward the source of the primary message. If the weaker ear did contaminate the individual's bilateral integration skills, then blocking sounds to the weak ear with an earplug would decrease the possibility of the contamination (Willeford, & Burleigh, 1985).

#### *Ear Occlusion and Auditory Figure-Ground Disorders*

There is a paucity of research specifically on the use of unilateral or bilateral ear occlusion as an effective method of intervention for children or adults with auditory figure-ground disorders. Katz (1972) mentioned the use of earmuffs and earplugs for personal hearing protection in industrial or manufacturing places of work. However, there was no reported correlation between ear occlusion and auditory perceptual problems. This information may be attributed to the lack of extensive research in auditory processing disorders in the 1970s.

These methods provide ear occlusion in noisy environments, but foam earplugs with flat attenuation degrade the individual's hearing acuity and ability to understand speech. Therefore, a better and more efficient method for achieving ear occlusion or filtering sound is necessary as well as clinical trials to determine outcomes for individuals with auditory figure-ground disorders.

Some studies have reported that unilateral and bilateral occlusion improves children's and adult's performance on auditory-figure ground tasks (Hasbrouck, 1980, 1987, 1989). Hasbrouck (1980) found that occluded ear conditions produced results that are important from a clinical management aspect as well as provide a better understanding of physiology of auditory-figure ground function and disorder. The study was designed to assess the effects of ear occlusion on children's performance on auditory discrimination tasks in background noise. All children who participated in the study were labeled learning disabled and were referred for further evaluation of their language and auditory perceptual abilities. Participants were considered unable to function adequately in the classroom though they had average or above average intellectual abilities. These criteria were determined by their respective public schools. Twenty-one children ranging from four to seventeen years of age were selected for this study, with a mean age of nine years, eight months. There were 14 males and seven females.

Five stimulus tapes consisting of the Quiet and Noise subtests of the Goldman-Fristoe-Woodcock (GFW) Test of Auditory Discrimination and three randomized copies of the Noise subtest were used. The test was administered in a quiet clinic treatment room and stimuli were presented in the sound field by means of an audio tape recorder. Each participant was administered the standardized Quiet and Noise subtests of the GFW. All participants who scored below the 25th percentile on the Noise subtest and were given three additional individually

randomized Noise subtests. They were administered under one of six counter balanced and randomly assigned conditions of ear occlusion. Conditions of ear occlusion were (1) occlusion of the right ear only, (2) occlusion of the left ear only, or (3) occlusion of both ears simultaneously. Ear occlusion was achieved with Clark Model 117 ear muffs that provided 37 dB of attenuation across the speech frequencies. The Noise Reduction (NRR) rating was not published. On all tests, participants responded by pointing to the picture named and the examiner recorded the response on a protocol sheet.

Hasbrouck found that participants performed better in all noise conditions with ear occlusion than without. There were no significant differences among the three types of ear occlusion conditions. The group trend was that without any condition of ear occlusion the participants scored below the 25th percentile, which was the cut-off designed for this study. However, with conditions of ear occlusion, participants' scores improved considerably. Specifically, 19 of the 21 participants improved performance with ear occlusion. Of the 19, only one failed to improve above the 25th percentile. Hasbrouck stated the need for further research to verify the validity of using ear occlusion to filter background noise.

Hasbrouck (1980) also addressed bilateral auditory integration. By eliminating bilateral auditory integration in those with auditory figure-ground disorder, a patient's auditory figure-ground performance and functioning could be restored. Bilateral auditory integration suggests that normal auditory figure-ground processing is a result of mandatory interaction of both ears to filter background noise. Individuals with normally functioning neurological systems have no disruptions to bilateral integration for filtering background noise. However, in children with auditory figure-ground disorders, there is a unilateral deficit in binaural coordination. That deficit results in a prevention or interference of normal filtering of background noise. Hasbrouck

(1980) found that occlusion of the ear served by the defective neurological system reduced or eliminated auditory figure-ground malfunction and eliminated binaural interference. Therefore, the unaffected ear was able to normally filter background noise, resulting in improvement to auditory figure-ground performance.

Hasbrouck (1980) concluded that each ear might actually be capable of functioning independently to filter background noise. From a clinical perspective, unilateral ear occlusion appeared to improve children's performance and subjective reports from children, parents, and teachers support the use of occlusion. Further research is needed to verify the validity of this hypothesis, specifically bilateral occlusion in relation to auditory integration (Hasbrouck, 1980).

The bilateral interaction component discussed by Delb, Strauss, Hohenberg, and Plinkert (2003) is the arithmetical difference between the sum of the monaurally evoked auditory potentials of each ear and the binaurally evoked brainstem potentials. It is an objective measure of binaural interaction in humans. The authors considered binaural interaction component measurements as possible diagnostic tools for APD in some patients (Delb, Strauss, Hohenberg, Plinkert, 2003). This component of auditory processing in children offers another perspective to management of APD with occlusion.

For adults, similar results were obtained under conditions of unilateral and bilateral ear occlusion. Hasbrouck (1987) found that ear occlusion improved the majority of adult's performance and unilateral ear occlusion eliminated auditory-figure ground disorders in most subjects. This study was designed to assess the performance of adults with auditory figure-ground disorders and normal discrimination abilities on an auditory discrimination task in background noise. Thirty-six adults participated, 21 males and 15 females, ranging in age from 19 to 64 years with a mean age of 31.64 years. To qualify for the study, the adults were required

to have normal hearing, excellent auditory discrimination skills, normal language abilities, and no history of neurological problems. Normal hearing was defined as auditory acuity better than 15 dB at 500, 1000, and 1500 Hz. Auditory discrimination was determined by one error or less on the Goldman-Fristoe-Woodcock (GFW) Test of Auditory Discrimination. Language abilities were determined by informal interviews with participants or from formal test results.

Neurological status was obtained from oral accounts from the participants and a review of their medical charts.

Five stimulus tapes consisting of the Quiet and Noise subtests of the GFW Test of Auditory Discrimination and three randomized copies of the Noise subtest were used. The test was administered in a quiet clinic treatment room and stimuli were presented on an audio tape recorder. Each participant was administered the standardized Quiet and Noise subtests of the GFW Test. All participants scored below the 25th percentile on the Noise subtest and were then given three additional individually randomized Noise subtests. They were administered under one of six counter balanced and randomly assigned conditions of ear occlusion. Conditions of ear occlusion were (1) occlusion of the right ear only, (2) occlusion of the left ear only, or (3) occlusion of both ears simultaneously. Ear occlusion was achieved with Clark Model 117 ear protector muffs that provided 37 dB of attenuation across the speech frequencies. The Noise Reduction Ratios (NRR) rating was not published. On all tests, participants responded by pointing to the picture named and the examiner recorded the response on a protocol sheet.

Results indicated that the participants performed better under quiet conditions than under the noise conditions. Though there were no significant differences among the three types of ear occlusion conditions, the percentile data showed positive effects of ear occlusion with this population. Of the 36 participants, 28 showed improved performance in noise with ear

occlusion. Out of those 28 subjects who improved, 22 participants improved to scores greater than the 25th percentile. These results indicated that 61% of the adults improved to within normal limits in their ability to hear in noise under a condition of ear occlusion.

Among the 22 participants who improved to above the 25th percentile, 20 of them did so under one or both of the conditions of unilateral or bilateral ear occlusion. Results indicated a trend of right ear advantage in the effectiveness of unilateral occlusion appeared within in this specific group. One important conclusion to this study was that unilateral ear occlusion seemed to be a more practical and individualized method for treating adults with auditory figure-ground disorders. Subjective reports after both short-term (one week) and long-term (one year) interviews from participants who wore an earplug to attain unilateral ear occlusion revealed that their quality of life had improved.

#### Musician's Filters

Recently, research in the area of protecting professional musicians' hearing has emerged. Hall & Santucci (1995) described the dangers of exposure to high-intensity sound levels to the professional ear. Musicians may be exposed to potentially damaging levels of sounds at high intensities, no matter what the performance genre or instrument. The authors' discussed the challenges of providing protection to the musician's ear, including: consideration for a variety of performance settings (i.e. recording studios, clubs, and auditoriums), varied performance types of the music (i.e. low intensity in one section of a composition, but high intensity in another), audience expectations, and hearing protection devices not fitting the image of the performer (Hall & Santucci, 1995).

Though musicians know that exposure to high-intensity sounds can damage their hearing sensitivity over time, some are unwilling to wear an earplug, for fear of compromising their

proficiency in monitoring their own performance. Brinskey & Paulson (1999) discussed the exposure to potentially damaging levels of noise among high school band members. They recommended that band and orchestra members use earplugs for hearing protection. Most earplugs, however, have a flat attenuation and prevent musicians from hearing the music. Brinskey & Paulson discussed the use of the patented ER-15™, and ER-20™, ER-25™ musician's filters, made by Etymotic Research, Inc. to filter incoming sounds and gently reduce their intensity. The filters attenuate incoming sounds at 15 dB, 20 dB, and 25 dB, respectively and allow the user to hear sounds clearly, but at a reduced intensity. The ER-20™ high-fidelity filter was designed as a universally fitting, lower cost alternative to the ER-15™ and ER-25™. The ER-20™ filters provide more uniform attenuation, compared to foam earplugs. They reduce the intensity of incoming sounds by about 20 dB (Brinskey & Paulson, 1999).

Conventional earplugs or earmuffs reduce sound more in the high frequencies than in the mid- and low frequencies, and make music and voices unclear and unnatural. Deeply inserted foam earplugs provide 30 to 40 dB of sound reduction, while only a small amount is actually needed. (Etymotic Research, Inc., 2005).

ETY-Plugs™ (ER-20 High Fidelity Musician's Filters), made by Etymotic Research, Inc., are one-size-fits-most high fidelity earplugs. High fidelity means they replicate the ear's natural response to sound. Therefore, the user hears the original sound at the same frequency response, but perceives it at lower intensity. "The goal of the ETY-Plug™ design is the same as for Musician's Earplugs: to reduce noise but preserve sound quality; in effect, to turn down the noise but not muffle voices, environmental sounds, or music." The Noise Reduction Rating (NRR) of the ER-20 filter was reported by Etymotic Research, Inc. (2005) at 12 dB. However in actual

clinical measurements of properly inserted ER-20 earplugs, an almost equal sound reduction of 20 dB was provided across the range of hearing (Etymotic Research, Inc., 2005).

Etymotic Research Inc. currently offers four types of musician's filters, three that require an ear mold to be cast and one universal fit musician's filter. They are: the ER-9, the ER-15, the ER-25, and the ER-20. The ER-9 filter provides 9 dB of flat sound reduction through the mid range, with the same high-frequency attenuation as the ER-15. The ER-15 was the first musician's filter and is the standard from which all other ER attenuators were designed. It provides uniform sound reduction across all frequencies at 15 dB. Finally, the ER-25 provides relatively flat attenuation across all frequencies. The Noise Reduction Rating (NRR) for Etymotic Research, Inc.'s existing hearing protectors is approximately 0 to 30 dB. Higher numbers of NRR indicate greater effectiveness (Etymotic Research, Inc., 2005).

Figure 1 illustrates the comparison of an ER-15 Musician's Filter to an unprotected ear. The open ear response of the average ear was measured in a diffuse field or reverberant room. The response of the ER-15 Musicians Filter indicates a 15 dB reduction in eardrum sound pressure at each frequency.

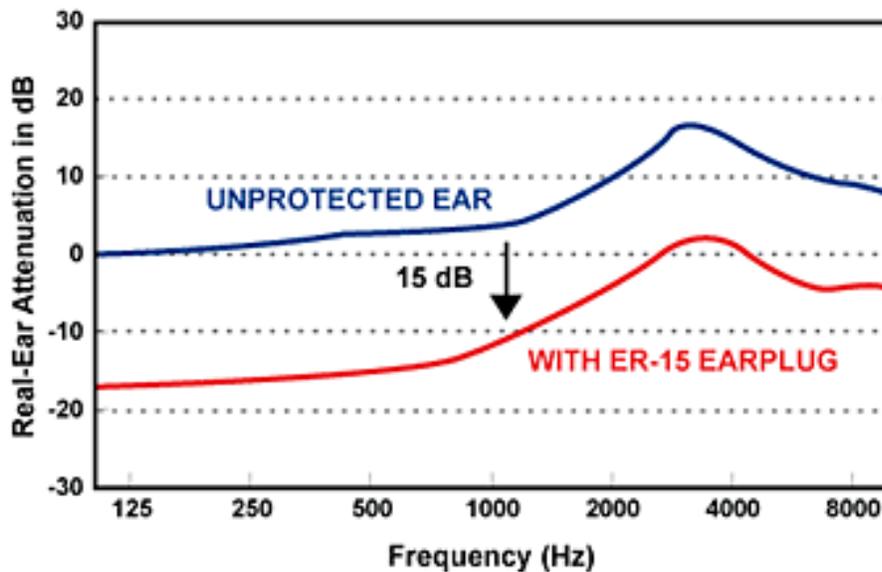


Figure 1. Mean Attenuation of an ER-15 Musician’s Filter Compared to an Unprotected Ear (Etymotic Research, 2005, <http://www.etymotic.com/pdf/erme-brochure.pdf>)

Figure 2 illustrates the comparison of the average attenuation characteristics among the ER-9, the ER-15, and the ER-25 musician’s filters and foam earplugs.

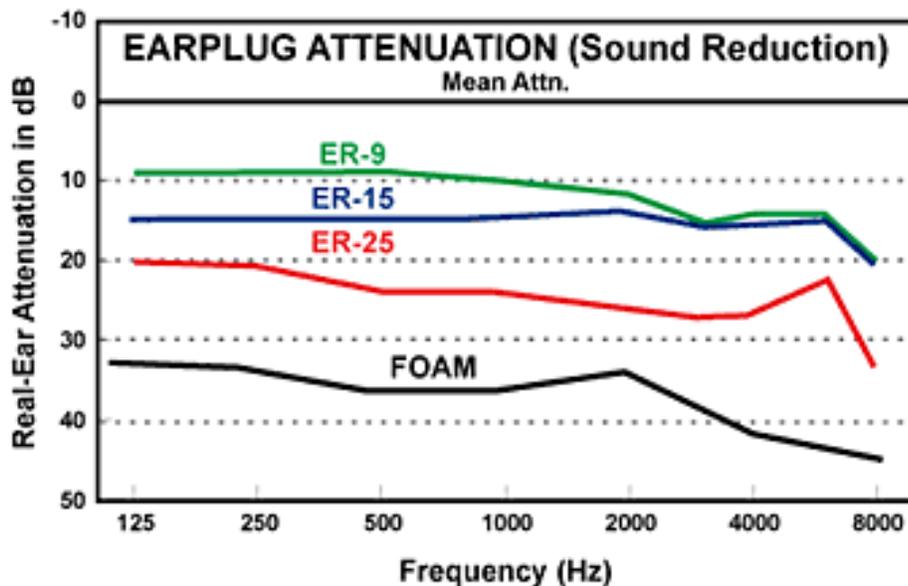


Figure 2. Mean Attenuation Characteristics of Musician’s Filters

(Etymotic Research, 2005, <http://www.etymotic.com/pdf/erme-brochure.pdf>)

The ER-20 is the universally fitting filter that is recommended for any person in any listening environment. It is a high fidelity set of filters that preserve sound quality while reducing sound levels approximately 20 dB at all frequencies. The ER-20 filters reduce environmental background sounds without distorting speech and music (Etymotic Research, Inc, 2005).

Figure 3 illustrates the comparison of the attenuation of ER-20 musician’s filters to shallow and deeply inserted foam earplugs.

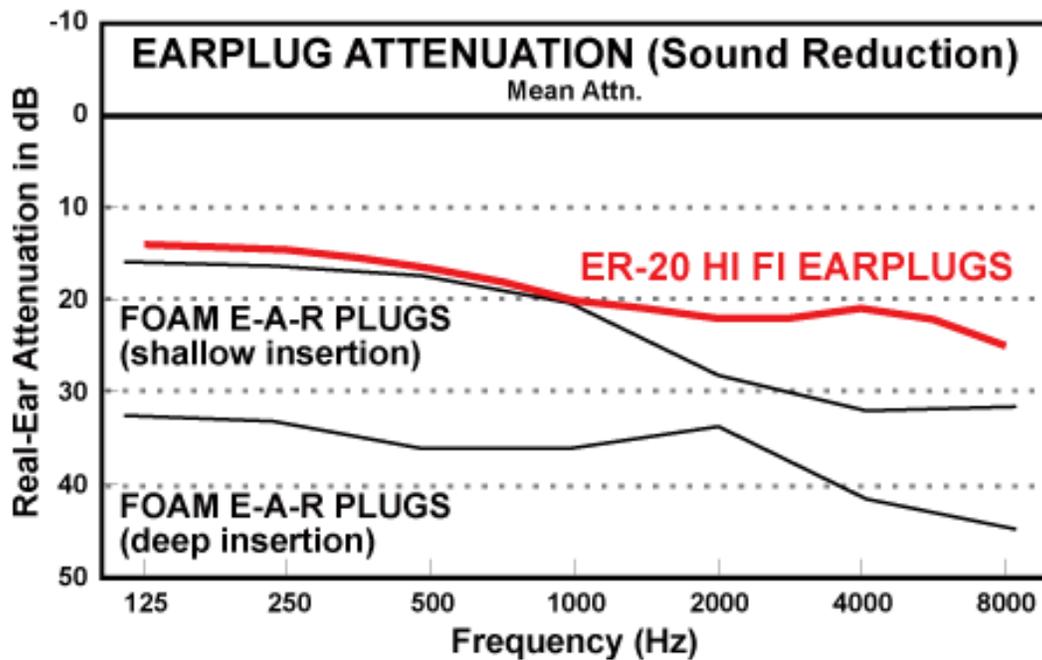


Figure 3. Mean attenuation characteristics of ER-20 Musician’s Filters compared to foam (Etymotic Research, Inc., 2005, <http://www.etymotic.com/ephp/er20-ts.aspx>)

If the filters protect and maintain musician’s abilities to hear in noisy environments, a possibility for filtering speech from background noise to assist individuals with auditory figure-ground disorders may exist. With the advent of musician’s filters, researchers have the opportunity to go beyond the current information about occlusion. Rather than earmuffs or

earplugs, musician's filters may offer a better and more practical way to reduce the adverse effects of noise in auditory figure-ground disorder. They filter approximately 20 dB within the speech frequencies (500, 1000, and 2000 Hz). By filtering 20 dB within the speech frequencies, musician's filters could avoid altering auditory neurological acuity and perception by eliminating an artificial conductive hearing loss as created by earplugs (Hasbrouck, 1980, 1987, and 1989).

Chermak & Musiek (1997) described altered structure and/or disordered function of the auditory neurological system due to auditory deprivation. In humans, clinical cases of auditory deprivation have included individuals with otitis media (ear infection) or sensorineural hearing loss. These clinical cases may be compared to the effects of foam earplugs when used with children and adults. Musician's filters may be a better solution for treating auditory figure-ground disorders, rather than earplugs or earmuffs, because they allow speech to pass with better efficiency. It may be speculated that musician's filters should not interfere with the auditory neurological development of children.

Therefore, if found to be effective, musician's filters could be offered as a treatment option at the University Programs in Communication Disorders (UPCD) Clinic, with little or no risk of damaging hearing sensitivity. The results could also lead to further study of children's performance outside the clinic, in many different settings (i.e. school, home, recreation activities.)

According to some studies (Hasbrouck, 1980, 1987, 1989), unilateral and bilateral ear occlusion with earplugs improves performance in many children and adults with auditory figure-ground disorders. Though not all auditory processing disorders include specific difficulties in auditory-figure ground, it is a common complaint among individuals with and without a diagnosis of APD.

The current study will build upon current research and knowledge in the area of children's performance on auditory figure-ground subtests under the conditions of unilateral and bilateral ear occlusion. It is hypothesized that the use of unilateral and bilateral musician's filters will improve children's performance on a standardized subtest for auditory-figure ground.

Research Question: Does the use of unilateral or bilateral musician's filters improve the performance of children with auditory figure-ground disorder on a standardized speech-in-noise subtest?

## CHAPTER TWO

### METHODS

#### Participants

Participants were recruited from the University Programs in Communication Disorders (UPCD) Auditory Processing Disorders (APD) Clinic and the Hearing and Speech Clinic at Washington State University Spokane. Only the parents or guardians of clients who expressed in writing a desire to be recruited for research opportunities were contacted. In order to be recruited for the study, participants had to have been previously identified as having an auditory figure-ground disorder. For this study, an auditory figure-ground disorder was determined by a score at or below the 25<sup>th</sup> percentile on the Noise subtest of the *Test of Auditory Discrimination* (1970) during the initial UPCD evaluation. Initially, the parents or guardians of forty-two UPCD Clinic clients were contacted and invited to participate in this study, via a mailed letter. Then, for each participant who agreed to participate, telephone contact was made by the principal investigator in order to schedule a testing time.

In order to participate in the testing sessions, each participant had to meet specific qualification requirements. All participants had to range in age from seven to 18 years. All children participating had to demonstrate acceptable otoscopy/visual inspection results of both ear canals. Participants had to meet established visual inspection criteria to ensure proper fit and secure placement of the ER-20 musician's filters used in the study. Participants had to demonstrate Type A (normal) tympanograms to ensure adequate tympanic membrane compliance and rule out possible middle ear disorder. Also, participants had to demonstrate pure-tone hearing thresholds at or below 20 dB HL at 500, 1000, 2000, and 4000 Hz,

symmetrically. Finally, participants had to score below the 25<sup>th</sup> percentile on the Noise subtest of the *Test of Auditory Discrimination* (1970), prior to testing with the filters.

A total of 14 children volunteered to participate in this study, however only 10 scored below the 25<sup>th</sup> percentile on the Noise subtest of the *Test of Auditory Discrimination* (1970), and were thus qualified to undergo the musician's filter application for this study.

### Materials and Equipment

Visual inspection, tympanometry, and pure-tone hearing testing were performed using UPCD equipment. Visual inspection was accomplished using an otoscope. A GSI TymStar tympanometer set to screen mode, calibrated September 2005 (ANSI S3.39, 1987), was used to measure the tympanogram. A Grayson-Stadler model GSI 61 audiometer, calibrated September 2005 (ANSI S3.6, 1989), was used for establishing pure-tone thresholds for each participant. Pure-tone hearing thresholds were determined using ER-3A insert earphones.

This study utilized the Training Procedure, Noise subtest, and three individually randomized copies of the Noise subtest of the Goldman-Fristoe-Woodcock *Test of Auditory Discrimination* (1970), recorded on cassette tapes; the three individually randomized copies of the Noise subtest were used to eliminate a test-practice effect. All test stimuli from the Noise subtests were presented at a speech-to-noise ratio of +9 dB, through GSI sound field system speakers and an Ashly FTX 1501 stereo power amplifier.

Participants were seated at a table, next to the principal investigator, in the sound suite equidistant between two speakers, which were located 1 meter away. Standardized stimulus booklets containing black-and-white line drawings, corresponding to recorded test stimuli, were used for all test administrations. Each stimulus plate contained four pictures per page. One pair of ER-20™ musician's filters, which provided approximately 20 dB of attenuation at all

frequencies, was used for each participant during the three individually randomized Noise subtests.

## Procedures

All testing took place in an audiometric sound isolated suite at the University Programs in Communication Disorders (UPCD) Clinic meeting current ANSI standards for maximum permissible ambient noise levels for testing (ANSI S3.1, 1991). Each participant was tested individually, and during testing, participants sat on a chair at a table in the audiology booth, next to the principal investigator. Each participant's parent or guardian was invited and allowed to observe the testing session in the sound isolated suite.

Visual inspection and tympanometry of each participant's ear canals was performed first. Next, each participant's pure-tone hearing thresholds were recorded across the following frequencies: 500, 1000, 2000, and 4000 Hz. Once the three screening procedures had been administered and appropriate results obtained, training and testing commenced.

Prior to testing with the Noise Subtests of the *Test of Auditory Discrimination* (1970), a training procedure, containing 32 stimulus items was conducted. The principal investigator instructed the participant using the standardized procedures outlined in the test manual. The participant was asked to point to and say the number of the corresponding stimulus item, following the live, verbal presentation of the stimulus by the principal investigator. The principal investigator recorded the participant's response and turned the stimulus pages. During the training procedure, participants were encouraged to ask questions for clarification before standardized testing began.

Following the training procedure, the Noise Subtest of the *Test of Auditory Discrimination* (1970) was presented by an assistant, other than the principal investigator (i.e. the

project faculty advisor, audiology clinic coordinator, or another graduate student) via audio cassette tape. This person was located in the control room adjacent to the test booth and controlled the presentation of the auditory test stimuli by means of cassette tape at 60 dB SL. Stimuli were presented in sound field by means of GSI sound field system speakers located one meter from the participant. Instructions for the Noise Subtest were delivered via the cassette tape. No condition of musician's filter(s) application(s) were used for this first administration. The participant responded to each stimulus item by pointing to the picture named and/or saying the corresponding number of the picture choice, in the standard stimulus booklet. The examiner recorded his or her response on a protocol sheet and turned the stimulus booklet pages following the participant's response. No repetitions of test stimuli or pausing of the cassette tape were allowed during test administration.

Participants who scored below the 25th percentile on the Noise Subtest each received three versions of the Noise subtest, individually randomized to eliminate a test practice effect. The Noise subtests were presented with a musician's filter in the right ear only (R), a filter in the left ear only (L), and a filter in both ears (B). In order to eliminate an order effect, the Noise subtests were administered under one of six counterbalanced conditions of musician's filter application. The six counterbalanced conditions of musician's filter application were: RLB, LRB, BLR, BRL, RBL, and LBR. Each participant was randomly assigned to one of the six orders of musician's filter application. The musician's filters were inserted by the examiner and checked to ensure proper fit according to manufacturer instructions. Each participant was consulted regarding the comfort of fit of the musician's filter(s). During all three versions of the Noise subtests, participants responded by pointing to the picture named and/or saying the corresponding number of the picture choice, using the standard stimulus booklet. The examiner

recorded the responses on a protocol sheet and turned the stimulus booklet pages. No repetitions of test stimuli or pausing of the cassette tape were allowed during test administration.

At the end of the test procedure, participants were allowed to keep the filters used during the testing. Based on test results, parents and participants were informed of the best condition of musician's filter application, if they chose to use the filters later.

## CHAPTER THREE

### RESULTS

The purpose of this study was to investigate the effects of musician's filters on the performance of children with auditory figure-ground disorders during a standardized speech-in-noise subtest. The results of performance on the Noise subtest without musician's filter application and the results after the three orders of musician's filter application were subjected to analysis by means of a single-factor repeated measures analysis of variance (ANOVA).

The raw scores and percentile scores for each of the 10 participants in the study are presented in Appendix A and Appendix B, respectively.

Table 1 illustrates the means, standard deviations, and ranges of errors for raw scores produced by 10 participants when tested in noise without musician's filters and in noise with musician's filters.

Table 1. Raw score means, standard deviations, and ranges of numbers of errors on the Noise and Noise with Musician's Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for 10 participants.

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	Noise Subtest	Noise Subtest: Right Ear Occluded	Noise Subtest: Left Ear Occluded	Noise Subtest: Both Ears Occluded
Mean	12.9	9.6	8.7	9.6
Standard Deviation	1.5	2.7	2.1	2.9
Range	10 – 16	5 – 10	7 – 13	6 – 13

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Table 2 illustrates the means, standard deviations, and ranges for the percentile data for the same participants when tested in noise without musician’s filters, and in noise under the three conditions of musician’s filter(s) application.

Table 2. Percentile means, standard deviations, and ranges of Noise and Noise with Musician’s Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for 10 participants.

	Noise Subtest	Noise Subtest: Right Ear Occluded	Noise Subtest: Left Ear Occluded	Noise Subtest: Both Ears Occluded
Mean	9.6	38.2	49.3	42.3
Standard Deviation	7.4	25.8	22.5	31.3
Range	1 – 22	5 – 91	15 – 78	2 – 81

The raw scores and percentiles for the 10 participants were analyzed by means of a single-factor repeated measures analyses of variance (Winer, 1971). The results for both raw scores and percentiles were statistically significant. Comparison of each of the three noise conditions with musician’s filter application(s) to the noise condition without filters produced a significant difference for raw scores [ $F(3, 27) = 10.06, p < 0.05$ ] and for percentiles [ $F(3, 27) = 6.78, p < 0.05$ ]. These results demonstrated that for both raw scores and percentile scores, there was a significant difference in performance among the four different noise conditions.

Post-hoc analyses using a Newman-Keuls test (Winer, 1971) indicated that, for both raw scores and percentile scores, the noise condition without musician's filters differed significantly ( $p < 0.05$ ) from each one of the conditions of musician's filter application and, that none of the musician's filter conditions differed significantly from one another.

Examination of the percentile data indicated that, not only did the participants' performance improve with musician's filter application, but, as a group, participants' performance in noise with musician's filter application improved to above the cutoff point for failure ( $<25^{\text{th}}$  percentile) on the *Test of Auditory Discrimination* (1970). Further examination of the data revealed that 9 of the 10 participants improved to within normal limits in noise ( $>25^{\text{th}}$  percentile) with musician's filter application. Five participants improved to above the  $25^{\text{th}}$  percentile in all three conditions of musician's filter application, three participants improved to above the  $25^{\text{th}}$  percentile in two of the three conditions of musician's filter application, while one participant improved to above the  $25^{\text{th}}$  percentile in one of the three conditions.

Analysis of percentile data for best performance with musician's filter application yielded mixed results. Table 3 illustrates that two participants each performed best with both, left, and right musician's filter applications. One participant demonstrated equal performance with filters in the left and right ears and one participant demonstrated equal performance with filters applied to the left and both ears. One participant demonstrated equal performance under all three musician's filter applications.

Table 3. Type of response to different filter conditions and number of participants exhibiting each type of response.

Type of Response	Number of Participants
Greatest improvement with filter in right ear	2
Greatest improvement with filter in left ear	2
Greatest improvement with filters in both ears	2
Equal improvement with filters in right and left ear	1
Equal improvement with filters in left and both ears	1
Equal improvement with filters in left, right, and both ears	1
No significant improvement with any condition of filters	1
Total (N)	10

Among the percentile data for all three conditions of musician’s filter application, there was a slightly improved group performance noted with musician’s filter application to the left ear only (mean percentile score: 49.3), as compared to both ears (mean percentile score: 42.3), as compared to the right ear only (mean percentile score: 38.2). Based upon these scores, a trend for right ear dominance was observed among the participants of this study. As previously stated, according to Stach (1998), most humans demonstrate a right ear dominance for processing speech information. Therefore it may be hypothesized, based on these results, that the left ear only condition of musician’s filter application allowed the right ear to efficiently process sound.

Obviously, further research with greater numbers of participants would increase support for this hypothesis.

## CHAPTER FOUR

### DISCUSSION

The results of this study are significant and extremely important with regard to the clinical management of auditory figure-ground disorders. Data describing the efficacy of specific treatment procedures for children with auditory figure-ground disorders are sparse and inconclusive. Although the literature discusses improving the listening environment, specific skill development, and compensatory strategies as management approaches for auditory processing disorders, in general, no specific treatment procedures are described which deal directly with auditory figure-ground disorders (Katz, 2002, Friel-Patti, 1999, Keith, 1999, Chermak & Musiek, 1997).

Studies by Hasbrouck (1980, 1987, and 1989) described the use of earmuffs for adults and children diagnosed with auditory perceptual disorders, specifically to address difficulties in auditory figure-ground. Results indicated improved performance among both children and adults with the use of unilateral or bilateral ear occlusion during auditory figure-ground tasks. In addition, Hasbrouck and Carpenter (1998) described the use of Defendear© earplugs with a preschool child who demonstrated auditory hypersensitivity.

This study extended the procedures used in the Hasbrouck (1980, 1987, and 1989) studies, using musician's filters instead of earmuffs. This study was conducted in order to examine the clinical effects of musician's filters for a specific population of children with auditory figure-ground disorders. The results indicated improved performance in all but one participant during an auditory figure-ground task. These results mean that musician's filters have the possibility for reducing the negative effects of the auditory figure-ground component of APD for some children. This information can be used in the future for further research and

treatment for the disorder. The information obtained in this study is most important for the real world benefits for children, parents, teachers, SLPs, audiologists, and other professionals working with this population. Musician's filters offer another treatment option which is practical, efficient, and safe for use with children and adults.

The results of the current study indicated that as a group, there was no significant difference among the three orders of musician's filter application. However, individual participants performed differently under different conditions of ear occlusion. This is important, from a clinical point of view, in fitting children with filters as a means to remediate auditory figure-ground disorders. These results indicated that each child found to have a figure-ground disorder should be tested with right, left, and bilateral filters to determine if filters are effective, and if so, which fitting is most effective.

There is an advantage for using high fidelity musician's filters over earmuffs or earplugs in the real world. Since musician's filters are high fidelity, they are designed to preserve the quality of sounds making them clear and natural. Sound is not muffled for the individual, as occurs with earmuffs or earplugs. In addition, the ER-20 musician's filters attenuate sound equally at all frequencies, while conventional earplugs create increased loss in the higher frequencies, especially the speech frequencies. Since musician's filters decrease noise, and do not muffle voices, there are no adverse effects to children's auditory neurological development and hearing in general. Musician's filters are also small and discrete, making them easy to wear, practical, and convenient in real world applications.

The effect of musician's filters for children with auditory figure-ground disorders impacts clinical practices and service delivery options at the University Programs in Communication Disorders (UPCD) Clinic. Participants and their parents now have the benefit of exploring

further service options using musician's filters for management of auditory figure-ground disorders. Unilateral and/or bilateral musician's filters have been shown, in this study, to improve the performance of children with auditory figure-ground disorders in background noise, compared to the use of no filters. Musician's filters may now be offered as a treatment option at UPCD and lead to further study of children's performance within and outside the clinic, in many different settings, such as school, home, or recreation activities.

The strengths of this study are the data and insight gained regarding the effects of musician's filters on the performance of children with auditory figure-ground disorders on a speech-in-noise subtest; the use of musician's filters instead of earplugs or earmuffs; and the improved reliability and standardization of the procedures used for conducting this type of study.

The weaknesses include the small sample size, the use of dated (1970) test stimuli, and the environment in which the study was conducted. The sound treated audiology booth does not provide true indication of a participant's performance in the real world, however it allows for standardization of procedures and control of presentation of test stimuli.

Suggestions for further research include testing a larger sample size under the same conditions as were described in this study. Further suggestions include observation of the effects of musician's filters in other settings, to include school, home, or during recreational activities. A survey of participants', parents', teachers', and other professionals' opinions comparing participant's performance when using musician's filters to no filters would also yield valuable subjective information. Overall, this study provided substantial insight into the performance of children with auditory figure-ground disorders during a speech-in-noise subtest while subjected to conditions of musician's filter application.

## CHAPTER FIVE

### CONCLUSION

In conclusion, musician's filters may revolutionize how auditory figure-ground disorders may be managed in children and adults. Filters should be used instead of earmuffs or earplugs, because they are high fidelity, allow for natural response to sound, and do not adversely affect hearing or auditory neurological development. Children who wear bilateral musician's filters are still able to hear voices, music, and other sounds clearly. They are still able to receive auditory stimulation without the harmful structural or physiological effects of auditory deprivation.

Everyone, not just children, may benefit from the use of musician's filters for management of auditory figure-ground disorders. When children hear the main message clearly with reduced background noise, they will be more successful in academic, home, personal, and recreational pursuits. Musician's filters offer an enhanced condition for hearing and gaining information and a better environment in which to pay attention. They enhance individuals' abilities to receive information and therefore obtain an education efficiently. When children receive the main message in the classroom, while using filters, there is a decreased possibility that they will act out, due to lack of attention or participation. Teachers, parents, other professionals, and children themselves can all benefit from increased attention, participation, and enhanced learning opportunities that the musician's filters may offer.

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## Appendix A

Raw Scores (numbers of errors) on the Noise and Noise with Musician's Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for 10 participants.

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Participant	Noise Subtest	Noise Subtest: Right Ear Filter Only	Noise Subtest: Left Ear Filter Only	Noise Subtest: Both Ear Filters	Total
1	13	10	7	6	36
2	12	10	11	7	40
3	14	10	8	13	45
4	13	5	7	13	38
5	12	11	7	8	38
6	10	6	8	7	31
7	16	15	13	13	57
8	13	9	9	12	43
9	13	10	10	10	43
10	13	10	7	7	37
Total	129	96	87	96	408

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## Appendix B

Percentile Scores on the Noise and Noise with Musician's Filter(s) subtests of the Goldman-Fristoe-Woodcock Test of Auditory Discrimination for 10 participants.

Participant	Noise Subtest	Noise Subtest: Right Ear Filter Only	Noise Subtest: Left Ear Filter Only	Noise Subtest: Both Ear Filters	Total
1	7	27	70	81	185
2	11	27	19	70	127
3	1	20	48	2	71
4	7	91	70	7	175
5	22	32	78	67	199
6	17	73	43	57	190
7	3	5	15	15	38
8	2	32	32	6	72
9	19	48	48	48	163
10	7	27	70	70	174
Total	96	382	493	423	1394