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The purpose of this study was to examine the effects of timbre and pitch-pattern difficulty on perceptions of same-difference between paired pitch patterns, altered and unaltered by timbre and pattern difficulty, among elementary-aged users of cochlear implants. Three null hypotheses were tested to determine the significant effects of these variables and their interaction on the pitch perceptions of children aged five through twelve, who used cochlear implants ($p \leq .05$). Secondary purposes of the study included the examination of the relationships, if any, among age, age at implantation, and pitch perceptions, and of significant differences between participants' speech processor and pitch perceptions ($p \leq .05$).

The *Adapted Musical Background Questionnaire* was completed by each participant/parent/guardian and used to collect information about each participant's hearing history and musical experiences. The *Pitch Discrimination Test* (PDT) was a researcher-developed, 36-item data collection instrument used to measure pitch perceptions of participants. Three timbres were used as stimuli, including the soprano voice, piano, and violin. Thirteen participant responses to the PDT were recorded individually. Results were analyzed using IBM© SPSS© Statistics Version 22.

Results of the study revealed no effect of timbre ($p = .511$), or pitch-pattern difficulty ($p = .971$) on pitch perceptions. A significant interaction between timbre and pitch-pattern difficulty, however, was found ($p = .046$). Additional analyses revealed that there were significant differences between mean scores of PDT test items presented by violin and soprano voice for difficult patterns ($p = .041$), and items presented by soprano and piano for patterns with moderate difficulty ($p = .041$). The participants discriminated difficult patterns more accurately when the PDT items were presented by soprano voice than piano, but participants discriminated moderate patterns more accurately when the PDT items were presented piano than by soprano voice.

There were no significant positive or negative correlations between age or age at implantation and PDT scores ($p > .05$). Additionally, there were no significant differences between participant scores on the PDT and the type of speech processor used ($p > .05$). Participants who used Cochlear™ devices, however, had higher average scores than participants who used MED-EL® devices. Recommendations were suggested for future research and instruction of children who use cochlear implants in elementary general music classrooms.

THE EFFECTS OF TIMBRE AND PITCH-PATTERN DIFFICULTY ON PITCH PERCEPTIONS OF ELEMENTARY-AGED USERS OF COCHLEAR IMPLANTS

by

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Approved by

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Committee Chair

To my Parents and Husband, Timothy and Laura Churchill, your love of learning and your dedication were my first teachers. Jason Soja, you have always supported me, and most importantly, you believed.

APPROVAL PAGE

This dissertation written by Morgan C. Soja has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro

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CHAPTER I

INTRODUCTION

Music is an aural art form. While experiencing music, listeners make specific and general discriminations of tonally and rhythmically organized sounds and silence across time. To be able to execute such auditory discriminations, typically, a respondent needs to be able to hear. Music educators, however, work frequently with children and other learners who are deaf or hearing impaired. Among some deaf children there are those who have cochlear implants, and it is imperative that music educators understand how children with cochlear implants perceive the tonal and rhythmic components of aurally-presented music. The current study, in part, has been designed to investigate the abilities of elementary-aged children with cochlear implants and their perceptions of pitch across different timbres and pitch-pattern difficulties.

The cochlear implant is an electronic device that has external and internal parts, including components that are inserted under the skin and in the cochlea of the recipient. The component parts of the system are a microphone, a speech processor, transcutaneous link, a receiver/stimulator, a connection cable, and an electrode array (Wilson & Dorman, 2009). The component parts of the implant provide a sense of sound to the user. Although the cochlear implant is a sophisticated electronic device, the sense of sound it provides to a user is different from the sense of sound provided through the natural hearing mechanism. Because of this difference, many users of cochlear implants have difficulty identifying certain sounds. Perception of musical pitch with the cochlear implant is challenging for many users.

Every child deserves a high-quality, comprehensive education in music. Most children who use cochlear implants attend music classes with peers with typical hearing (Gfeller, Witt, Spencer, Stordahl, & Tomblin, 1998). A lack of information about cochlear implants, however, can limit music educators' abilities to provide the best musical experiences for students who use cochlear implants. A fundamental component of music learning is an awareness of same-difference, as related to elements of music, such as pitch, rhythm, and dynamics. Children develop an awareness of same-difference related to music pitches early in their schooling. Children who use cochlear implants often struggle with the development of this awareness because of the limitations of the cochlear implant. The current study is designed to determine if different musical timbre and pitch-pattern difficulty affect perception of pitch among elementary-aged children who use cochlear implants.

Background of the Study

Forty years ago, a diagnosis of profound hearing loss or deafness meant that a person may never hear, or develop an understanding of music (National Institutes of Health, 2011). With the advent of the cochlear implant, some people with severe to profound deafness have experienced the world of sound, including music. Some individuals who use cochlear implants, including children, enjoy listening to music. According to Hsiao and Gfeller (2012), “As outcomes for speech reception have improved, there has been increasing interest in the perception of music…" (p. 5). The cochlear implant (CI); however, may not be equipped to represent the acoustic signals of music appropriately.

> Music participation for children with CIs is complex, in part because music encompasses a diverse continuum of very simple patterns (e.g., electronically generated pure tones) to highly complex combinations…In addition, response to music is likely to differ from one CI recipient to the next given the variability in hearing history, life experiences, and developmental level in functional areas that support musical skills (e.g., cognition, motor skills, etc.) (Hsiao & Gfeller, 2012, pp. 5-6).

Typical Hearing and Hearing with a Cochlear Implant

Hearing occurs automatically for persons with typical hearing; however, the process of converting fluctuations in air pressure into electrical impulses perceived by humans as sound is complex. According to Campbell and Greated (1988),"when a sound wave arrives at the outer ear, part of the wave is transmitted down the ear canal; the resulting fluctuations force the eardrum into vibration" (p. 41). Three components of the middle ear (i.e., malleus, incus, and stapes) are moved by the vibrations of the eardrum. The malleus and incus pivot and cause the stapes to move in and out of a part of the inner ear called the oval window.

The vibrations of the oval window cause movement in the perilymph fluid contained in the vestibular canal of the cochlea. The motions of the perilymph fluid cause a membrane called Reisner's membrane to vibrate. The movement of Reisner's membrane causes movement in the endolymph fluid in the cochlear duct. The vibrations of the perilymph and endolymph fluids create movement in two other membranes: the basilar membrane and the tectorial membrane. Hair cells, located along the basilar membrane, shear against the tectorial membrane. The mechanical energy that caused the movement of the hair cells is converted into electrochemical energy through which sound information is transmitted to the auditory nerve.

Cochlear implants bypass portions of the previously described natural hearing mechanism. A person with typically-developed hearing has hair cells in the cochlea that transduce the physical energy of sound that is processed in the brain. The cochlear implant bypasses the damaged or missing hair cells of the cochlea in people who are deaf. The microphone of the cochlear implant transduces vibrations of air molecules in the environment that are transformed by the speech processor of the implant and sent to the receiver/stimulator of the implant. Electrical signals generated by the receiver/stimulator are sent to the electrode array of the cochlear implant (Wilson & Dorman, 2009). The electrodes of the implant, positioned in the cochlea, stimulate the auditory nerve with electrical currents that create action potentials in the auditory nerve fibers. The resulting action potentials are transmitted to the brain as sound (Grayden & Clark, 2006).

Critical Periods of Language Acquisition

Primary benefits of the first single-electrode cochlear implants include improved speech production and improved lip reading. The first users of cochlear devices reported that their quality of life increased after receiving their cochlear implants (Bilger, 1977). Research pursued in the late 1980s and early 1990s with multi-electrode implants resulted in new speech processing technologies that produced large improvements in speech reception (Wilson, Finley, Lawson, Wolford, Eddington, & Rabinowitz, 1991). Newly developed speech reception capabilities were thought to be beneficial for language development in children who were deaf congenitally, and who without auditory input, often had difficulty producing spoken language.

> Although children make use of visual cues when learning language, audition is of primary importance for language acquisition. The fact that language development can be severely compromised as a consequence of audiometrically-defined hearing impairment is *prima facie* evidence for the role of auditory processing in language development (Baily and Snowling, 2002, p. 135).

Language may develop at any age, but there may be periods in human development that are optimal for the acquisition of language and other auditory skills.

Scholars recognize the existence of critical and sensitive periods of development in the human auditory system. During critical and sensitive periods, the neural systems for hearing are responsive to sound and change when stimulated (Penhune, 2011). Despite potential risks of implantation, some medical professionals recommend that children who are congenitally deaf receive cochlear implants at an early age, because the stimulation provided by the device can help these children organize sounds similarly to children who have typical hearing (Kral & Eggermont, 2007; Sharma, Dorman, & Spahr, 2002). The Food and Drug Administration (FDA) (2000) lowered the age of eligibility for implantation to 12 months of age. The National Institute on Deafness and Other Communication Disorders (NIDCD)(2014) reported that most children who receive implants are between the ages of two and six years of age.

Over 38,000 children in the United States have received cochlear implants (NIDCD, 2014). According to the Center for Hearing and Communication (2013), at least 90% of children who are deaf have parents with typical hearing. Sometimes, parents of children who are diagnosed as deaf prelingually struggle to communicate with their children. Wilson (2011) maintains that hearing parents of children who are deaf often learn how to sign; however, for some parents, learning to sign is a challenge, particularly when signing beyond a basic conversational level. Some parents seek cochlear implants for their child to help their child build auditory experience for the development of spoken language. According to Svirsky, Robbins, Kirk, Pisoni, and Miyamoto (2000), cochlear implants offer the opportunity for children who are deafened profoundly to acquire age-appropriate language skills.

Researchers are encouraged by speech outcomes attained by children with cochlear implants. Although there are differences in the speech capabilities of children with cochlear implants and children with typical hearing, the majority of children with cochlear implants demonstrate language abilities appropriate for their age (Schorr, Roth, and Fox, 2008). Researchers have found that children with cochlear implants demonstrate growths in language similar to peers with typical hearing, but gains in language may occur later in children who use cochlear implants (e.g., Bollard, Chute, Popp & Praisier, 1998; Robbins, Svirsky, & Kirk, 1997; Spencer, Barker, & Tomblin, 2003). Children with cochlear implants who attain age-appropriate language abilities may participate in academic classes alongside peers with typical hearing.

Need for the Study

Researchers have found that children who use cochlear implants usually have language abilities that are appropriate for their age, and children with cochlear implants may participate in music classes with peers who have typical hearing (Gfeller, Witt, Spencer, Stordahl, and Tomblin, 1998; Schorr, Roth, and Fox, 2008). Although many children who use cochlear implants also show greater interest in music after receiving implants than before receiving implants, music educators may lack confidence in providing instruction for children who use cochlear implants. "Music educators' wariness in mainstreaming hearing-impaired students is not only due to the nature of the impairment, but also the lack of specialized information required to adapt procedures that accommodate the needs of the hearing impaired child" (Darrow & Gfeller, 1991, p. 24).

Music educators need to be informed of the best practices for providing students who use cochlear implants with learning experiences that are fulfilling.

> For all students to experience aesthetic education through successful participation in music learning, the music specialist must be provided the training needed to make the best possible choices in terms of expectations and adaptations for students with special needs. (Colwell & Thompson, 2000, p. 218)

Much of the research on perception of music with cochlear implants has been conducted with adult participants, but the number of research studies undertaken to examine music perceptions of children who use cochlear implants is increasing. Research that objectively measures the perceptions of musical elements by children with cochlear implants is essential if music educators are to provide instruction that is effective and based on best instructional practices.

Some elementary general music educators teach students about concepts relating to elements of music, such as pitch, durations, rhythm/melody patterns, harmony, timbre, texture, articulation, dynamics, form, expression, and style. Elementary general music educators often ask students to demonstrate understanding of concepts related to pitch and melody. Students may demonstrate their understanding of concepts related to pitch and melody by identifying whether melodies move up or down, by skip or step, or by patterns and sequences within melodies. Without an understanding of same-difference relative to pitch, children may struggle to demonstrate their understandings of advanced concepts related to pitch and melody. For the purposes of this study, 'same-difference' is defined operationally as paired pitch patterns either being perceived as the same or as different by children who use cochlear implants.

Purpose of the Study

Researchers have examined the abilities of children with cochlear implants to discern same-difference among pitches, and to identify features of a melody; however, results of these studies have been mixed and inconclusive (Chen, Chuang, McMahon, Hsieh, Tung, & Lieber, 2010; Scorpecci, Zagari, Mari, Giannantonio, S'Alatri, DiNardo, & Paludetti, 2012; Vongpaisal, Trehub, Schellenberg, & Papsin, 2004). Few researchers have examined pitch perception of children with cochlear implants across different timbres. Because cochlear implants vary in terms of transforming portions of sound signals, and because speech processors and processing strategies vary by and within cochlear implant brand, some timbres may be more effective for communicating pitch information than others.

The primary purpose of the present study was to examine the effects of timbre and pitch-pattern difficulty on the perceptions of same-difference between paired pitch patterns altered and unaltered by timbre and difficulty, among elementary-aged users of cochlear implants. To accomplish the primary purpose of the study, the following three null hypotheses were tested at the significance level of less than or equal to .05.

1. There will be no effect of timbre on the pitch perception of elementary-aged children who use cochlear implants.
2. There will be no effect of pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.
3. There will be no interaction effect of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.

Secondary purposes of this study were to determine relationships among participants' *Pitch Discrimination* Test (PDT) scores, age, age at cochlear implantation, and whether there were significant differences between participants' PDT scores based on the type of speech processor used ($p \leq .05$). The researcher examined these relationships and differences to fulfill the secondary purposes of the current study.

Limitations of the Study

The number of children who have received cochlear implants has increased in recent years, but obtaining access to a large sample of children who use cochlear implants is difficult. The population of children who use cochlear implants is small and specialized, random selection of participants in this study was not feasible. Due to the use of convenience sampling, a large number of participants in the study used cochlear devices manufactured by the same company, which affected the diversity of speech processors used by participants. The participants in this study have been limited to children ranging in age from five to twelve years for several reasons. The typical age of elementary children is from five to twelve years. Elementary general music teachers help students to discriminate same-difference of musical sounds. This learning goal is addressed regularly with elementary-aged children; therefore examining the pitch discrimination abilities children who attend elementary school is logical.

Although children who use cochlear implants have made language gains similar to peers with typical hearing, children who use cochlear implants often require more repetition of items, and more focused listening than their peers with typical hearing. Children who use cochlear implants, therefore, may need more practice with musical stimuli than their peers with typical hearing. Children under age five may have little to no listening experience in the general music classroom, thus, the youngest children to participate in the study were five years of age.

CHAPTER II

REVIEW OF RELATED LITERATURE

This Chapter provides a review of the literature related to the perception of music with a cochlear implant. A brief overview of the history of the cochlear implant and its intended use are followed by a review of studies in which the researchers focused on the perception of pitch, melody, and timbre among adult and pediatric users of cochlear implants. The conclusions by researchers associated with the reviewed studies within this chapter informed the research design of the current study. The current study was designed to examine the effect of timbre and pitch-pattern difficulty on the pitch perception of same-difference of elementary-aged users of cochlear implants.

History of the Cochlear Implant

The cochlear implant is a sophisticated device that has been developed over many years of research and experimentation. As early as 1800, Alessandro Volta experimented with electric hearing when he placed electrodes connected to batteries into each of his ears (Blume, 2010). Volta did not continue his experimentation, but his is one of the first recorded attempts to stimulate the ear electrically. Additional attempts to determine the viability of electrical hearing were undertaken by researchers and scientists in the 1930s (Gersuni & Volokhov, 1937; Stevens, 1937).

Gersuni and Volokhov (1937) inserted electrodes into the middle ears of two types of participants: those with middle ear structures, and those without middle ear structures. Following stimulation through the electrodes, participants described the sounds they heard. Descriptions of the sounds were similar for all participants regardless of the presence or absence of middle ear structures, which led the researchers to conclude that the middle ear was not a viable point of stimulation for electrically-stimulated hearing. Stevens (1937) found that when the organ of Corti, which contains auditory nerve receptors, was electrically stimulated, it produced neurotransmitters from the hair cells in the cochlea to the auditory nerve. Stevens referred to this process as electrophonic hearing. In many persons who are deaf, the organ of Corti is non-functional, therefore a different point of stimulation was necessary in order for a sensation of hearing to be generated.

In the 1950s, André Djourno researched, fabricated, and tested induction coils used for implantation. The induction coils were used to stimulate nerves through inductive coupling without wires, and Djourno had success stimulating different nerve areas in animal models. Charles Eyriès was an otolaryngologist who specialized in neuroanatomy and facial nerve repairs. Eyriès met Djourno while seeking facial nerve graft material for a patient who happened to be deaf. Eyriès was persuaded to implant an electrode into the patient, because the potential benefit to the patient's hearing was deemed worth the risk of implantation. No additional incisions were needed because the mastoid cavity, which had to be opened for implantation of the coil, would already be exposed during the surgery for the facial nerve repair (Eisen, 2006). In 1957, Djourno and Eyriès implanted the first auditory prosthesis in a patient with bilateral deafness. Following implantation, the patient was unable to discern speech, but he was able to discriminate between sounds at high and low frequencies (Eisen, 2009). Unfortunately, the implant had to be removed from the patient due to infection of tissue surrounding the implant.

William House, a successful surgeon based in Los Angeles, was the first doctor in the United States to perform a cochlear implant surgery. In 1961, after researching the implant and procedure, House implanted a single-electrode device in a patient. Shortly after, House implanted another patient with a five-electrode device. Both patients reported hearing sounds, but were unable to understand speech (Dorman, 1998).

In 1964, Simmons inserted a six-electrode array into a patient. The patient could hear changes in pitch and recognize speech signals as speech, but the patient was not able to comprehend speech (Dorman, 1998). Simmons, Epley, Lummis, Guttman, Frishkopf, Harmon, and Zwicker (1964) concluded that the future of the implant as a speech perception device was uncertain. Despite initial successes with human patients, many researchers questioned the long-term benefits of cochlear implants.

According to Dorman (1998), House, and engineer Jack Urban worked to find solutions to bioengineering problems associated with cochlear implants, which included infections of the surrounding tissue. In 1969, with technical issues controlled, House and Urban began implanting single-electrode systems in patients (Dorman, 1998). The House 3M single-channel implant was the first cochlear implant approved by the Food and Drug

Administration, and more than 1,000 of the devices were implanted into patients between 1972 and the mid-1980s (Eisen, 2009).

Single-channel implants were helpful to patients, but perception of speech was unattainable for most people who used single-channel devices. Clark, Tong, Black, Forster, Patrick, and Dewhurst (1977) stated, "It is generally agreed that if a cochlear implant hearing prosthesis is to enable a patient to understand speech, it must be a multiple electrode system" (p. 935). Two groups of researchers focused on the development of the multi-electrode implant: a group working under Robin Michelson at the University of California at San Francisco, and a group working with Graeme Clark at the University of Melbourne in Australia. The University of California at San Francisco and University of Melbourne groups experimented with technologies developed for the aerospace and computer industries to miniaturize the receiver/stimulator components and improve the safety and durability of electrode arrays. Two devices, the Advanced Bionics Clarion (University of California at San Francisco) and Cochlear Corporation Nucleus (University of Melbourne), were the results of this work (Eisen, 2009).

In 1985, the Nucleus device was the second cochlear implant, and the first multichannel system, to be approved by the Food and Drug Administration. Users of Nucleus devices were able to distinguish speech from other sounds, and some recipients were able to understand speech without lip reading (Blume, 2010). In 1993, Cohen, Waltzman, and Fisher examined the abilities of users of cochlear implants to understand speech. The researchers found that participants who used multichannel implants performed significantly better on speech tasks than participants who used single-channel implants ($p = .02$). Participants who used improved speech processing strategies performed significantly better on speech tasks after using the new processing strategy for three months ($p = .001$) (Cohen, Waltzman, & Fisher, 1993).

The development of cochlear implants and their acceptance by scientific and lay communities have been a long process, and are by no means complete. To improve the quality of life for those who seek cochlear implantation, scholars continue to examine new technology and interventions. The cochlear implant was intended originally to assist language development, therefore, a large body of research has been and continues to be dedicated to speech reception and production.

Speech Outcomes for Users of Cochlear Implants

Not all children with hearing loss learn to speak, even when fitted with appropriate assistive devices. According to Cole and Flexer (2011), however, children with hearing loss can learn language quickly when their assistive devices are worn on a fulltime basis, and when family members and professionals provide “appropriate, meaningful spoken language interactions” for the child (p. 174). As part of the habilitation process, speech and language pathologists and/or audiologists assess the speech and language abilities of children with cochlear implants to determine growth, need for adjustment of the device, or additional therapy. Tests of speech outcomes often include, but are not limited to, closed-set and/or open-set tests of speech perception, audiovisual tests of spoken word recognition, and speech production outcome measures (Kirk & Choi, 2009).

The motivation for cochlear implantation in children is axiomatic, and a large body of research has been devoted to pediatric users of cochlear implants' acquisition of spoken language. Spencer, Barker, and Tomblin (2003) examined the language and literacy skills of 32 children, whose mean age was 9.83 years. Sixteen of the participants used cochlear implants, and 16 had typical hearing. All participants completed tests of receptive language skills, expressive language skills, and reading comprehension. Participants' writing was analyzed also for productivity, complexity, and grammar.

Children with cochlear implants performed significantly lower than children with typical hearing on measures of expressive language ($p < .0001$) and receptive language ($p < .05$). Children with cochlear implants also produced fewer words on writing tasks than peers with typical hearing. Despite relatively low performance on speech-outcome measures, children with cochlear implants performed within one standard deviation of children with typical hearing on tests of language comprehension, reading comprehension, and writing accuracy. Only two of the children who used cochlear implants qualified for reading recovery services because their scores were below grade level. The researchers asserted that children who used cochlear implants were capable of attaining age-appropriate language and literacy skills.

Speech Outcomes with Cochlear Implants Based on Age

Researchers also have examined factors associated with acquisition of language skills among children who use cochlear implants. Two factors investigated frequently are the chronological and/or hearing ages of users of cochlear implants. According to Cole and Flexer (2011), hearing age is the relationship between a child's chronological age, and the age at which a child first receives amplification or stimulation from an assistive device like a hearing aid or cochlear implant (p. 399). For example, a child whose chronological age is five years, but whose cochlear implant was activated at age three would have a hearing age of two years. Some researchers have found that longer device use allows children who use cochlear implants to improve scores on tests of speech perception and language production.

Davidson, Geers, Blamey, Tobey, and Brenner (2011) examined the long-term speech abilities of 112 children who used cochlear implants over an extended period. The researchers compared participant scores on the *Lexical Neighborhood Test* (LNT). The researchers found that scores improved significantly from the five-year post-implant test, to the ten-year post-implant test ($p < .0001$). The researchers speculated that auditory and language experiences contributed to increased scores on measures of speech perception. Uziel, Sillon, Vieu, Artieres, Piron, Daures and Mondain (2007) examined long-term speech outcomes of children who used cochlear implants. The researchers used the *Phonetically Balanced Kindergarten Word Test* (PBKWT), and *Connective Discourse Tracking Test* (CDTT) to investigate speech perception. The researchers discovered that test scores on the PBKWT increased by an average of 7% from five years post-implant to ten years post-implant. Scores on the CDTT increased by a mean value of 20 words per minute from five to ten years post-implant ($p < .001$).

Beadle, McKinley, Nikolopoulos, Brough, O'Donoghue, and Archbold (2005) investigated the auditory and speech performance of 30 adolescents and young adults who used cochlear implants. Participants had at least 10 years of experience using their devices. Eighty-seven percent of the participants understood conversations without lip reading. Sixty percent of participants could use the telephone successfully when the other speaker was familiar to the participant. Seventy-seven percent of participants produced speech that was intelligible to the average listener. Finally, one-third to one-half of the participants continued to make improvements in speech perception from five to ten years after their implantation.

Researchers who study speech and language acquisition among users of cochlear implants continue to find that increased chronological/hearing age contributes to higher scores on measures of speech and language acquisition. Because hearing experiences of children who use cochlear implants may also affect their ability to perceive music, chronological age and age at implantation were examined as variables in the present study.

Speech Outcomes with Cochlear Implants Based on Age at Implantation

Researchers have investigated the effect of age at implantation on speech outcomes among children who use cochlear implants. Researchers have hypothesized that earlier implantation shortens the period of deafness and capitalizes on periods of neural plasticity, which allows children who are profoundly deaf opportunities to experience sound, build neural networks that support hearing, and have more time in sound by using the devices for longer periods of time.

Connor, Hieber, Arts, and Zwolan (2000) found that children who received cochlear implants at younger ages achieved higher average scores on measures of consonant production accuracy, receptive spoken vocabulary, and expressive spoken and/or signed vocabulary than scores obtained by children who received cochlear implants at older ages. Uziel, Sillon, Vieu, Artieres, Piron, Daures, and Mondain (2007) assessed 82 children who used cochlear implants on measures of speech perception, speech production, and vocabulary. The researchers found that participants who received their implants before the age of four years had scores on all measures that were significantly higher than scores of children who received their implants after the age of four years, including: (a) Open-set Perception ($p < .0004$), (b) Perception/Production, $p < .00001$, (c) Intelligibility ($p < .0005$), and (d) Receptive Language ($p < .05$).

Tombin, Barker, Spencer, Zhang, and Gantz (2005) found that scores on measures of expressive language were affected by age at implantation. Children who received implants as infants had a greater number of rapid growth periods in expressive language than children who received implants as toddlers. The researchers found that age at initial stimulation accounted for 14.6% of the variance in measures of expressive language. Zwolan, Ashbaugh, Alarfaj, Kileny, Arts, El-Kashlan, and Telian (2004) also investigated the effect of age at implantation on speech outcomes of children who used cochlear implants. Two-hundred ninety-five children were organized into five groups based on age at implantation: (a) 1 to 3 years old (Group 1), (b) 3 to 5 years old (Group 2), (c) 5 to 7 years old (Group 3), (d) 7 to 9 years old (Group 4), and (e) 9 to 11 years old (Group 5). At twelve-month intervals following the activation of their implant(s), all children completed the *Northwestern University – Children's Perception of Speech* (NU-CHIPS) test. The researchers used a repeated-measures analysis of variance (ANOVA), and discovered a significant difference between scores based on group membership ($p =$

0.018). Group 1 scored significantly better than all other groups on the 24-month post-implant tests (i.e., Group 1 vs. 2, $p = .03$; Group 1 vs. 3, $p = .03$; Group 1 vs. 4, $p = .01$; Group 1 vs. 5, $p = .03$) and 36 month (Group 1 vs. 2, $p = .01$; Group 1 vs. 3, $p = .007$; Group 1 vs. 4, $p = .01$; Group 1 vs. 5, $p = .01$). On average, children in all groups improved their scores over time, but children in Group 1 demonstrated greater gains in speech perception than children who were implanted later.

Connor, Craig, Raudenbush, Heavner, and Zwolan (2006) examined speech production and vocabulary growth of children who used cochlear implants. The researchers grouped participants based on their age at implantation: (a) 1 to 2.5 years old (Group 1), (b) 2.6 to 3.5 years old (Group 2), (c) 3.6 to 7 years old (Group 3), and (d) 7.1 to 10 years old (Group 4). Children in Groups 1, 2, and 3 performed better on a measure of consonant production accuracy than children in Group 4. After two years of device use, the rate of language growth for children in Group 1 was significantly greater than the rates of growth for children in all other groups. The burst of language growth was present in Groups 1, 2, and 3, but diminished with increased age at implantation.

Wang, Huang, Wu, and Kirk (2007) examined long-term communication outcomes of children who used cochlear implants. Twenty-nine children, whose native language was Mandarin Chinese, completed tests of speech perception, speech intelligibility, receptive language, expressive language, communication barriers, and mode of communication. The researchers compared the test scores based on age at implantation. On average, children who received their implants before age three scored higher than children who received their implants after age three (i.e., Word Patterns: < 3 years = 90.3% correct, > 3 years = 82.8% correct; Vowels: < 3 years = 92.1% correct, > 3 years = 83.1% correct; Consonants: < 3 years = 95.1% correct, > 3 years = 85% correct; Tones: < 3 years = 72.1% correct, > 3 years = 57.3% correct; Phonetic Balance words: < 3 years = 80% correct, > 3 years = 60.4% correct). Children who received implants before age three years performed better than children who received implants after age three years on tests involving tonal elements of Mandarin Chinese.

Researchers like Connor, Hieber, Arts, and Zwolan, (2000), Uziel et al., (2007), Tomblin, Barker, Spencer, Zhang, and Gantz (2005), Zwolan et al. (2004) and Connor et al. (2006), have found that earlier implantation had positive effects on speech outcomes of children who use cochlear implants. The discoveries made by Wang, Huang, Wu, and Kirk (2007) supported previous research and indicated that earlier implantation may have a positive effect on the ability to perceive tonal elements of speech. To determine whether similar variability is present in a musical context, the relationship between pitch perception and age at implant was examined in the current study.

Speech Outcomes with Cochlear Implants Based on Speech Processing Strategy and Processor Type

Speech processors and speech processing strategies are important elements of the cochlear implant. Speech processing strategies have several functions: (a) to select the number of channels used to reproduce original sounds, (b) to select the number of electrodes activated to generate each channel, (c) to select the number of cycles required to deliver selected channels, and (d) to schedule the activation sequence of the electrodes on the array (Choi & Lee, 2012). As technological advances are made, companies that produce cochlear implants develop new processors and processing strategies to improve speech and hearing outcomes for users of cochlear implants. Researchers, therefore, have investigated how speech outcomes are affected by different speech processors and processing strategies.

Manrique, Huarte, Morea, Caballé, Ramon, Catillo, Garcia-Ibáñez, Estrada, and Juan (2005) examined the speech outcomes of children who used ACE (n = 26) and SPEAK (n = 32) processing strategies. All participants had similar ages at implantation and were tested on several measures of speech perception and speech use at 6, 12, and 24 months after their devices were activated. Participants who used the ACE strategy achieved the maximum score on the *Meaningful Auditory Integration Scale* and *Meaningful Use of Speech Scale* during the two-year observation period. On the 6-and 12-month vowel identification tests, children who used the ACE strategy scored higher than children who used the SPEAK strategy. On the 12 month test of disyllabic word recognition, users of the ACE strategy performed better than users of the SPEAK strategy. Children who used the SPEAK strategy performed better on the Early Speech Perception test at the 12 month test interval. Though the researchers found no significant differences between the performance of children who used the ACE strategy and children who used the SPEAK strategy, the researchers speculated that children who used the ACE strategy gained positive speech outcomes faster than children who used the SPEAK strategy.

Tobey, Geers, Brenner, Altuna, and Gabbert (2003) examined factors that influenced scores on measures of speech production of eight-and nine-year old children who were implanted with cochlear implants before age five. The researchers found that children who had more experience with the SPEAK strategy scored higher on speech production measures than children who had less experience with the SPEAK strategy. The researchers stated that:

> Changes in algorithms, chip design, and processing capacity are likely for the future and data from this study suggest that continual updating of the device will be necessary to provide children with the equipment and resources to maximize their speech production performance (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003, p. 43S).

Geers, Brenner, and Davidson (2003) reached a similar conclusion about the relationship between speech perception and speech processing strategies. The researchers found that children who used an updated speech processing strategy achieved high levels of speech perception, even if the child previously had used an earlier, less advanced strategy. The researchers echoed Tobey, Geers, Brenner, Altuna, and Gabbert (2003) and stated that "no child should be left with an outdated processor, because the benefits of improved technology are so apparent. . . ." (Geers, Brenner, & Davidson, 2003, p. 33S).

Researchers have examined the effects of speech processor and processing strategies on speech outcomes of people who use cochlear implants. Mosnier, Marx, Venail, Loundon, Roux-Vaillard, and Sterkers (2014) investigated the effects of the CP810™ sound processor with 'Everyday' and 'Noise' programs on the speech perception and subjective evaluations of adult users of cochlear implants. Thirty-five participants upgraded to the CP810™ processor from an previous processor. Participants completed tests of speech perception before upgrading to the CP810™ processor and after three months of CP810™ processor use. Tests included perception of monosyllables presented at 50dB and 60dB in quiet conditions; and monosyllables presented in a noisy condition. Scores on tests presented in quiet conditions improved significantly from the baseline test (50dB = 11%, $p < .0001$; 60dB = 8%, $p < .001$). In noisy conditions, there was no significant difference between the baseline test results and the ‘Everyday’ program. However, when participants used the ‘Noise’ program in the noise condition, the increase in scores on the monosyllable perception test was significant ($p < .01$). After upgrading to the CP810™ processor, participants reported a reduction in difficulty when listening to speech presented with background noise.

Santarelli, Magnavita, De Filippi, Ventura, Genovese, and Arslan, (2009) examined speech perception abilities of children who used cochlear implants and changed speech processors. Participants in the study upgraded from SPrint™ or ESPrit3G™ processors to the Freedom™ processor. Children completed several baseline measures of speech perception that were repeated following the processor upgrade. Tests of disyllabic word recognition and vowel recognition in quiet, noisy, and soft presentation conditions were presented with a recorded voice stimulus. Stimuli for tests of consonant identification, disyllabic word recognition, trisyllabic word recognition, and sentence recognition were presented by a human speaker. Children also completed a test of frequency discrimination. After switching to the Freedom™ processor, all children had significantly improved scores on identification of disyllabic words in the soft presentation condition (SPrint™, $p < 0.05$; ESPrit3G™, $p < .05$). Children who upgraded from the ESPrit3G™ processor improved their vowel identification scores significantly following the upgrade (8.89 ± 3.33%, $p = .01$). After the upgrade, children who upgraded from the SPrint™ processor to the Freedom™ processor improved their scores on disyllabic word recognition delivered by a live speaker, consonant identification, and sentence identification tests.

In the Santarelli et al. (2009) study, the researchers found that differences on disyllabic word recognition delivered by a human speaker, consonant identification, and sentence identification tests were not significantly different among children who upgraded to the Freedom™ processor from the ESPrit3G™ processor. Following the upgrade, all participant frequency discrimination test scores improved significantly ($p = .003$).

Researchers, such as Manrique et al. (2005), Tobey, Geers, Brenner, Altuna, and Gabbert (2003), Geers, Brenner, and Davidson (2003), Mosnier et al. (2014), and Santelli et al. (2009), have discovered that different speech processors and processing strategies may affect speech outcomes among people who use cochlear implants. The findings of Santarelli et al. (2009) regarding improved frequency discrimination may have implications for music perception. To determine whether this variability applies to music, the relationship between pitch perception and speech processor was examined in the current study.

Perception of Music with Cochlear Implants

The cochlear implant was intended to aid users with the perception of speech, but many users of cochlear implants enjoy listening to music. Gfeller (2009) stated that most families who consider a cochlear implant for their child are hopeful that the benefits of implants will allow their child to participate in and enjoy music. Many users of cochlear implants, including children, enjoy listening to music and participating in music activities. Researchers, therefore, have examined the perception of elements of music among users of cochlear implants.

In the history of cochlear implantation, adults were the first recipients of cochlear implants, and most early research focused on their perception of music. As children received implants, researchers began to investigate children's perception of the elements of music. Users of cochlear implants who are congenitally or deafened prelingually develop differently than people who experience hearing loss after many years of hearing experience. Perceptions of music elements among children with cochlear implants who were deafened prelingually, and adults with cochlear implants who were deafened postlingually, therefore, may differ. Trehub, Vongpaisal, and Nakata (2009) stated that, "although children must contend with similar device limitations, they do not evaluate music with reference to acoustic standards or the way music used to sound" (p. 535). Adult users of cochlear implants with hearing experience sometimes impose their memories of an element of music onto their current perception of music. Children who have had little or no listening experience before receiving their implant may have no memories of sound to impose on their perception of music.

Contrary to the previous assumption about music perception differences between children and adult users of cochlear implants prelingually and postlingually, respectively, Hsiao's and Gfeller's research did not verify that assumption. Hsiao and Gfeller (2012) found that on tasks of rhythmic, timbre and pitch perception, children who use cochlear implants have outcomes similar to adult users of cochlear implants. Due to the similarities in results of music perception research conducted with adult and pediatric users of cochlear implants, the researchers stated that studies with adult recipients of cochlear implants provided “general trends with regard to the perception of key structural components of music” (p. 6). In this chapter, therefore, research on music perceptions by both adult and pediatric users of cochlear implants were reviewed.

Perception of Pitch with Cochlear Implants - Adults

Methods used to investigate users of cochlear implants’ ability to perceive pitch have included pitch discrimination, pitch ranking, and melodic identification, among others. Gfeller, Turner, Oleson, Zhang, Gantz, Froman and Olszewski (2007) investigated the pitch-ranking abilities of adult users of cochlear implants. The researchers also examined relationships between pitch-ranking abilities and melody recognition, speech reception in background noise, and demographics, such as age, length of profound deafness, and length of implant use. One-hundred and one participants used traditional long electrode cochlear implants, and thirteen used short electrode devices that combine residual acoustic hearing with electronic stimulation. Twenty-one participants with typical hearing also participated in the study.

Participants were presented with three tones, including two identical pitches and a third tone that was higher or lower than the first two tones. Participants identified whether the last tone was higher or lower than the first two tones. The interval sizes of the pitch sets ranged between one and four semitones. Test stimuli were presented in three different octaves from 131Hz to 1048Hz, and the order of presentation of the pitch sets within each octave was randomized. Participants also completed a pitch discrimination task, a familiar melody recognition task, and two speech-in-noise tasks.

Gfeller et al. (2007) found that participants with typical hearing and participants with short electrode hybrid devices performed significantly better on the pitch-ranking task ($p < .05$) than participants with long electrode implants. Participants who used long electrode implants, though less accurate than other groups, performed more accurately when base frequencies of stimuli were high (831Hz) than when base frequencies of stimuli were low (131Hz) ($p < .03$). Participants who used long electrode implants were less accurate than other groups when intervals sizes were decreased, and all groups ranked pitches more accurately when intervals sizes were increased ($p < .0001$).

Gfeller et al. (2007) found that the ability to rank pitches was correlated positively and moderately with melody recognition ($r = .54$). The researchers discovered that length of implant use correlated negatively with pitch-ranking accuracy, indicating that increased implant use may have no effect on the ability to rank pitches. Finally, Gfeller et al. (2007) found no significant differences between the scores of cochlear implant users who used different speech processing strategies ($p > .05$). Participants who used the Hi-Res strategy, which provides more detailed temporal information than earlier speech processing strategies, performed no better on any tasks than users who had older strategies like SPEAK, CIS, or ACE.

Looi, McDermott, McKay and Hickson (2004) examined the pitch-ranking and melody-recognition abilities of adult users of cochlear implants. Each of the fifteen participants who used cochlear implants were implanted with Nucleus® devices, and had between five months and 25 years of experience with their device(s). Nine participants with typical hearing also took part in the study. The stimuli for the pitch-ranking task were the vowels /a/ and /i/ and were produced by one male and one female singer. The intervals between pitches were .25 octave (i.e., minor 3rd), .5 octave (i.e., augmented 4th), and 1 octave. Participants indicated whether the second pitch was higher or lower than the first pitch. Test stimuli for the melody recognition task consisted of ten, 15-second excerpts of popular melodies that were played on an electric keyboard using clarinet and oboe timbres. Participants were asked to select the melody that was played in each trial in a closed-set task.

The researchers found that the pitch ranking abilities of participants who used cochlear implants were not above chance levels when the interval between the first and second pitch was .25 octave. However, participants with cochlear implants performed significantly better when the interval between pitches was .5 octave or 1 octave ($p < .001$) than when the interval between pitches was .25 octave. The researchers conducted a one-way analysis of variance (ANOVA) to determine if the melody recognition of participants with cochlear implants was affected by the melody they were asked to identify. Looi, McDermott, McKay, and Hickson (2004) discovered that there were significant differences between melody-recognition abilities of participants who used cochlear implants ($p = .032$). Using a Tukey post-hoc analysis, the researchers determined that there was a significant difference between the most recognized melody (*Baa, Baa, Black Sheep*) and the least recognized melody (*Old MacDonald*) ($p < .05$).

Participants with cochlear implants were significantly less able to correctly identify familiar melodies than participants with typical hearing (CI = 51% correct, TH = 98% correct; $p < .05$). The researchers also discovered significant moderate and positive correlations between the pitch-ranking scores of participants with cochlear implants 1 octave and .5 octave interval sizes and melody-recognition scores (1 octave - $r = .623$, $p = .013$; .5 octave – $r = .507$, $p = .05$). The researchers concluded that sound processing strategies needed improvement so that users of cochlear implants may have a more accurate representation of spectral information.

Swanson, Dawson, and McDermott (2009) examined the pitch perceptions of users of cochlear implants by administering the Modified Melodies test. Six adults who used Cochlear™ Nucleus® cochlear implants participated in the study. The *Modified Melody Test* was a researcher-developed instrument that used the tune *Old MacDonald* and four modifications of the melody as test stimuli. The modifications to the melody were the N2, N5, Exchange, and Backward modifications. For the N2 and N5 modifications, the fifth and sixth pitches of the melody were shifted by two and five semitones respectively. For the Exchange modification, the fifth and sixth pitches of the melody were exchanged with the tenth and eleventh pitches of the melody. For the Backward modification, the entire melodic excerpt was reversed. All test stimuli were presented with pure tones, and the lowest pitch used was 523Hz. For each trial, the melody was transposed randomly by 0, 1, 2, or 3 semitones, creating different stimulation patterns. During each trial, participants were presented with two versions of the melody and asked to choose the melody that was unmodified.

Participants’ ability to identify the melody in the Backward modification was above chance. All participants except P2 were able to identify the melody in the Exchange modification at levels significantly above chance ($p < .05$). Half of the participants were able to identify the melody in the N5 condition at levels significantly above chance ($p < .05$). None of the participants were able to identify the melody in the N2 condition at levels that were above chance ($p > .05$). The researchers concluded that participants with cochlear implants were able to identify large differences in pitch, but less accurately identified modifications with small differences between pitches. Because the rhythms of test stimuli used in the *Modified Melodies Test* were not altered, however, the researchers concluded that users of cochlear implants were able to identify melodies based on pitch cues alone.

Researchers who have investigated pitch perception among users of cochlear implants have found that pitch differences with increased interval size are more easily perceived than pitch differences with decreased interval size (Gfeller et al. 2007; Looi, McDermott, McKay & Hickson, 2004; Swanson, Dawson, & McDermott, 2009). Gfeller et al., (2007) found that users of cochlear implants perceived pitch differences more accurately when base frequencies were high rather than when base frequencies were low. Contrary to findings discovered by speech and language researchers, Gfeller et al. (2007) found that increased use of cochlear implants was correlated negatively to pitch ranking accuracy. Gfeller et al. (2007) also found that differences in speech processing strategies had no effect on pitch perception in users of cochlear implants. Swanson, Dawson, and

McDermott (2009) found that users of cochlear implants were able to identify changes in pitch based on pitch cues alone.

Perception of Pitch with Cochlear Implants - Children

Olszewski, Gfeller, Froman, Stordahl, and Tomblin (2005) examined the influences of hearing history and chronological age on the abilities of participants to identify familiar melodies. Participants ($N = 129$) were members of four different groups including: (a) children with typical hearing (n = 32), (b) adults who were deafened postlingually and used cochlear implants (n = 57), (c) children who were deafened postlingually and used cochlear implants (n = 9), and (d) children who were deafened prelingually and used cochlear implants (n = 32). The melody recognition test consisted of nine melodies that were presented three times during the test protocol. The participants identified the melodies by pointing to the written song title or a picture that represented the song title (e.g., a boat for *Row, Row, Row Your Boat*).

The researchers found a significant effect of hearing status on melody recognition scores ($p < .001$). Participants with typical hearing were significantly more accurate than all participants with cochlear implants (Adults: $p < .00$; Postlingual CI: $p < .01$; Prelingual CI: $p < .01$). Adults with cochlear implants were significantly more accurate on the melody recognition task than both groups of children with cochlear implants (Postlingual: $p \leq .02$; Prelingual: $p < .000$). Children who were deafened postlingually and used cochlear implants were significantly more accurate on the melody recognition task than children who were deafened prelingually and used cochlear implants ($p \leq .01$).

Olszewski, Gfeller, Froman, Stordahl, and Tomblin (2005) found few significant correlations between melody recognition scores and demographic variables of age, length of deafness, or length of implant use. The researchers reported anecdotally that the parents of children who were deafened prelingually and used cochlear implants were astounded when their children did not recognize "*Happy Birthday*" when it was used in the test protocol. The researchers speculated that this anecdotal finding is a possible indication that some children with cochlear implants use other cues such as a party, cake, candles, and gift packages to help them identify the song, rather than the melodic and rhythmic components. The researchers concluded that the weak correlation between age at implantation and melody recognition scores of children who were deafened prelingually and used cochlear implants was interesting; previously researchers who studied speech outcomes with this population found a relationship between young age of implantation and increased speech outcomes.

Vongpaisal, Trehub, Schellenberg, and Papsin (2004) investigated the abilities of children who were prelingually deaf, and used cochlear implants to recognize songs and melodies. Participants in the study ($N = 20$) were children who used cochlear implants ($n = 10$) and an age-matched sample of children with typical hearing ($n = 10$). All participants who used cochlear implants had at least one year of experience with their devices and were familiar with at least three of the songs in the test protocol. The test included four different versions of songs: (a) the original recording, (b) a version identical, or near identical to the original with lyrics deleted, (c) a synthesized piano version of the melody, and (d) a synthesized version of the bass and drum lines only. To indicate their choice, participants selected an image of the artist or band that appeared on a computer screen along with the title of the song. Participants indicated how much they liked each song version by rating it on a five-point Likert-type scale. All participants with cochlear implants completed the Picture Locations subtest of the *Children's Memory Scale* (Cohen, 1997) that was used to estimate visual-spatial working memory. After conducting a two-way, repeated measures ANOVA (i.e., two group by four rendition), the researchers discovered significant main effects for group ($p < .000$) and for rendition ($p < .0001$). The researchers also found a significant interaction between group and rendition ($p = .021$), confirming that a difference between the pattern of performance across renditions by group. Participants who used cochlear implants performed well when identifying the original song version, and the original version with deleted lyrics; although, they were less accurate than participants with typical hearing. Children with cochlear implants were unable to identify piano and bass and drum song versions at levels above chance. The identification scores of children with cochlear implants on songs presented via piano were significantly correlated with age ($p = .021$).

The researchers noted that participants with cochlear implants rated many song versions favorably. Children with cochlear implants rated original song versions, songs versions with lyrics deleted, and the song versions presented via bass and drum significantly higher than neutral on the five-point rating scale (Original: $p < .0001$; Lyrics Deleted: $p = .001$; Bass and Drum: $p = .011$). The researchers noted that despite difficulty identifying song versions presented via bass and drum, children with cochlear implants enjoyed listening to the songs. "The most striking lesson from CI participants in the present study is the positive value they ascribed to the limited musical information that was accessible to them" (p. 196). Because children with cochlear implants had difficulty identifying songs presented via the piano only, the researchers speculated that to identify familiar songs, children with cochlear implants attend to features other than pitch.

Hsiao (2008) examined the abilities of participants with cochlear implants to recognize melodies. The researcher also attempted to determine what information helped participants recognize melodies. Participants in the study ($N = 40$) were children who were prelingually deaf and used cochlear implants ($n = 20$), and children with typical hearing ($n = 20$). All participants who used cochlear implants received their implants between the ages of 18 months and 7 years, and had at least five years of experience with their devices. The test protocol included short phrases from eight songs, presented in MIDI piano timbre and sung by female voice. The pitches used in the stimuli ranged from G3 to A4. Three different versions of each melody were presented to participants, including: (a) melody with eighth-note durations only (i.e., only pitch was modified across the melodic pattern), (b) original melody presented via piano without lyrics (referred to by the researchers as the rhythm condition), and (c) original melody, sung by female voice (referred to by the researchers as the lyrics condition). Participants were asked to identify each melody in the three-foil, forced-choice task by clicking an image on a computer screen that corresponded to the title of each melody. The *Mandarin Musical Background Questionnaire – Children's Version* (MMBQ-C) was administered to all participants. The questionnaire, administered as an interview, quantified participants' formal and informal music experiences and exposure.

The researcher found significant main effects for group ($p < .001$) and for condition ($p < .001$). A significant interaction between group and condition ($p < .001$) was revealed. Participants with typical hearing scored significantly higher than participants with cochlear implants in the pitch only and rhythm conditions ($p < .001$). There were no significant differences between groups in the lyrics renditions. Participants with cochlear implants identified melodies in the lyrics condition significantly better than in rhythm and pitch only conditions ($p < .001$). Participants with cochlear implants identified melodies in the rhythm condition significantly better than in the pitch only condition ($p < .001$). The researcher discovered that participants with typical hearing were involved in greater (number and extent) music experiences than participants with cochlear implants ($p = .003$).

No significant correlations were found between melody recognition scores and demographic variables related to age or length of experience with cochlear implants. Because children with cochlear implants were able to identify songs to the same degree as children with typical hearing in the lyrics condition, the researcher determined that participants with cochlear implants relied most on lyrics to make correct identifications of melodies. The researcher also concluded that casual exposure to music activities did not contribute to melody identification abilities of children with cochlear implants. Finally, the researcher speculated that a program geared toward training children with cochlear implants to perceive elements of music might be necessary.

Scorpecci, Zagari, Mari, Giannantonio, D'Alatri and DiNardo (2012) examined the abilities of children who were prelingually and perilingually deaf and used cochlear implants to recognize songs and melodies. The researchers investigated relationships between song and melody identification scores and demographic variables, such as speech recognition, perception, and production. Participants in the study ($N = 41$) were 18 children who used unilateral cochlear implants and 23 children with typical hearing. Fifteen of the participants with cochlear implants were prelingually deaf, and three participants were perilingually deaf. Stimuli for the song and melody identification tests were digitized excerpts from five popular tunes for children. The songs were featured on popular television shows and were familiar to all participants. Stimuli for the song test were digitized versions of the original songs, and stimuli for the melody identification test were piano versions of the same five tunes. As the song or melody were presented, participants indicated their responses by pointing to a picture of the character associated with the song or melody.

Scorpecci et al. (2012) found participants' performance on each of the tasks varied. Participants with typical hearing scored between 20-100% correct (80% median) on the melody identification test, and between 60-100% (100% median) on the song identification task. Participants with cochlear implants scored between 10-80% (30% median) on melody identification task, and 0-100% (55% median) on the song identification task. Participants with cochlear implants performed significantly above chance on both tasks (Melody: $p = .004$; Song: $p < .001$). The researchers found a significant effect of test type on performance for participants with cochlear implants, who performed significantly better on the song task than on the melody task ($p < .01$). Participants with typical hearing performed significantly better than participants with cochlear implants on both tasks ($p < .001$). The researchers also found that speech perception scores were correlated significantly with melody identification scores ($r = .29$, $p = .02$), and that song identification scores were correlated with age ($r = .25$, $p = .035$), length of cochlear implant use ($r = .238$, $p = .04$), and scores on speech perception tests (Test 1: $r = .308$, $p = .017$; Test 2: $r = .457$, $p = .002$). Although the researchers found significant correlations, several were weak positive correlations that were not generalizable to the population of children who use cochlear implants.

Scorpecci et al. (2012) found that age did not correlate with melody recognition scores, and determined that the ability to recognize melodies does not increase as children with cochlear implants age. The researchers speculated that because cochlear implants provide limited spectral information, it is more difficult for children to identify songs based on melodic information alone. Scorpecci et al. found a correlation between song identification scores and the variables of age and length of cochlear implant use. This finding contrasted with the findings of Hsiao (2008) who found no correlation between age, or duration of cochlear implant use and song identification scores. Scorpecci et al. posited that as children with cochlear implants age and use their implants, they are exposed to more speech sounds, which may account for more accurate performances on the song recognition task.

Finally, Scorpecci et al. (2012) noted that the mean age of implantation among participants in their study was 4.16 years. They speculated that inconsistent implementation of newborn hearing screenings may result in later identification of hearing impairments, which may contribute to later cochlear implantation of children who are candidates. The researchers hypothesized that correlations between age at implantation and song or melody recognition performance might be observed if children who received implants at ages younger than four years serve as participants.

Nakata, Trehub, Chisato, and Kanda (2006) investigated singing among children who used cochlear implants. Participants in the study ($N = 18$) were children who used unilateral cochlear implants ($n = 12$) and children with typical hearing ($n = 6$). Nine of the children who used cochlear implants used a hearing aid in the contralateral ear. Children were asked to sing songs that they knew well. The performances were recorded with a microphone and digital audio recorder. Children with cochlear implants deviated from expected pitches significantly more often than children with typical hearing ($p < .001$). Children with cochlear implants, however, deviated less from the target pitches when the two adjacent notes were the same pitch, as opposed to when adjacent notes ascended or descended ($p < .05$). When the target pitches of the song changed, children with typical hearing were able to match the changes almost perfectly (Mean = .96, SD = .05); $p < .001$), while children with cochlear implants struggled, (Mean = .48, SD = .19). When results were compared, the difference was significant ($p < .001$). Children with cochlear implants also used a significantly smaller range of pitches than children with typical hearing ($p < .001$).

Nakata, Trehub, Chisato, and Kanda (2006) discovered that children with cochlear implants were able to detect when pitches in familiar songs changed, but were not always able to determine whether the pitch that changed was ascending or descending. The researchers speculated that the limited spectral information communicated by cochlear implants may have contributed to difficulties in matching pitch, determining direction of pitch changes, and the small range of pitches used by children who used cochlear implants in their performances of familiar songs.

Chen, Chuang, McMahon, Hsieh, Tung, and Lieber (2010) examined the effect of musical training on the pitch discrimination and pitch ranking abilities of children with cochlear implants. Participants in the study ($N = 27$) were children who were prelingually deaf and used cochlear implants. All of the participants had at least ten months of experience using their devices. Thirteen of the participants attended music classes at the YAMAHA school. Attendance ranged from 2-36 months (Mean = 13.2 months) and children were engaged in listening, singing, score reading, and instrument playing experiences. Two of the participants had music training before receiving their implants. Stimuli for the test protocol consisted of pitch pairs that ranged in frequency from 256Hz – 498Hz. Participants were asked to indicate whether the second pitch in the pair was the same as or different than the first pitch. If the second pitch was different, and the participants indicated that it was different, the participants were asked to indicate whether the second pitch was higher than or lower than the first pitch. Each pitch pair had to be correctly labeled as ‘same’ or ‘different’ and as ‘higher’ or ‘lower’ three times out of five presentations in order to be considered correct. The researchers grouped the performance into six different categories: (a) overall performance, (b) same pitch, (c) ascending interval, (d) ascending interval over a perfect fourth, (e) descending interval, and (f) descending interval over a perfect fourth. Researchers also grouped participants based on age (>6 years, and < 6 years) and length of implant use (> 18 months, and < 18 months). Scores on the pitch perception tasks ranged from 9.5% - 92.5% correct. Fifteen of the participants were unable to identify pitch pairs at better than chance levels.

Chen et al. (2010) found no significant difference between pitch identification due to altered pitch-interval size. The researchers found that duration of training correlated positively at a moderately low levels with overall performance ($r = .389$, $p = .045$) and with correct identification of ascending pitches ($r = .402$, $p = .038$). There also was a significant positive, moderate relationship between training and the correct identification of ascending intervals for participants who were age 6 and younger ($r = .564$, $p < .01$). The positive, moderate correlation between implant use of 18 months or longer and the correct identification of ascending pitches was also significant ($r = .625$, $p = .03$). More than 50% of the participants could not identify pitch pairs at levels higher than chance, therefore the researchers speculated that 18 months might not be a sufficient amount of time for changes in the auditory system to take place (Chen et al., 2006, e797-e798). Because performance on pitch discrimination and pitch-ranking tasks by participants with musical training was better than the performance of participants with no, or little musical training, the researchers concluded that musical training would be beneficial for children with cochlear implants.

Children who have typical hearing perform better than children who use cochlear implants on tasks related to melody or song recognition (Hsiao, 2008; Olszewski, Gfeller, Froman, Stordahl, & Tomblin, 2005; Scorpecci, Zagari, Mari, Giannantonio, D’Alatri &

DiNardo, 2012; Vongpaisal, Trehub, Schellenberg, & Papsin, 2004). Hsiao (2008) and Vongpaisal, Trehub, Schellenberg, and Papsin (2004) found that children who used cochlear implants performed well on melody recognition tasks that used original stimuli. Children who use cochlear implants, however, struggle with melody and/or song recognition tasks when lyrics are removed (Hsiao, 2008; Olszewski, Gfeller, Froman, Stordahl, & Tomblin, 2005; Vongpaisal, Trehub, Schellenberg, & Papsin, 2004). Though Hsiao (2008), Olzewski, Gfeller, Froman, Stordahl, & Tomblin (2005), and Vongpaisal, Trehub, Schellenberg, and Papsin (2004) speculated that children who use cochlear implants rely on features other than pitch to identify melodies or songs, Nakata, Trehub, Chisato, and Kanda (2006) found that many children with cochlear implants were able to detect changes in pitch when asked to sing familiar melodies. Chen, Chuang, McMahon, Hsieh, Tung, and Lieber (2010) also found that children who used cochlear implants were able to detect changes in pitch.

Hsiao (2008) found that correlations between demographics and melody recognition were not significant ($p > .05$). In contrast, Scorpecci et al., (2012) found statistically significant correlations between the ability to identify songs and age, length of device use, and speech perception scores in children who used cochlear implants ($p > .05$). Vongpaisal, Trehub, Schellenberg, and Papsin (2004) found that ability to recognize melodies presented by piano, without lyrics was correlated with age. Chen, Chuang, McMahon, Hsieh, Tung, and Lieber (2010) found that factors contributing to correct identification of ascending pitch patterns included receiving an implant before age six, and duration of training.

Although children who use cochlear implants receive limited spectral information from their devices, researchers have found that children with cochlear implants participate in and enjoy musical activities. Children with cochlear implants struggle with the identification of melodies without the aid of lyrics (Hsiao, 2008; Olszewski, Gfeller, Froman, Stordahl, and Tomblin, 2005; Vongpaisal, Trehub, Schellenberg, & Papsin, 2004), but modification of timbres used to present instrumental versions of sung melodies may aid song and melody recognition among this population. Chen, Chuang, McMahon, Hsieh, Tung, and Lieber (2010) found that children who use cochlear implants are able to discriminate whether pitches are the same or different when stimuli are presented with piano. In elementary general music classrooms, instruments like piano and voice are used commonly. Timbre can affect perception of pitch among listeners with typical hearing, and may have an effect on the abilities of children who use cochlear implants to discriminate between pitch patterns that are the same and pitch patterns that are different. Research of timbre recognition is plentiful, but a thorough examination of the effect of timbre on pitch perception has not been investigated among children who use cochlear implants.

Perception of Timbre with Cochlear Implants - Adults

Leal, Shin, Laborde, Calmels, Verges, Lugarden, Andrieu, Deguine, and Fraysse (2003) determined whether adult users of cochlear implants were able to identify different musical instruments from recorded excerpts. Twenty-nine adult users of cochlear implants listened to short solo melodies played on the trombone, piano, and violin. Twenty of the participants were able to correctly identify all three of the instruments. The researchers speculated that small number of instruments used in the identification task may have contributed to the high identification scores.

Gfeller and Lansing (1991) examined the timbre identification abilities and timbre appraisals of eighteen adult users of cochlear implants who were postlingually deaf. Ten of the participants used Cochlear™ Nucleus® implants, and eight of the participants used Ineraid® implants. Stimuli for the timbre identification and appraisal tasks were tape recorded performances of familiar melodies played by the violin, cello, flute, clarinet, oboe, bassoon, trumpet, and trombone. After listening to each excerpt, participants were asked to identify the melody, and the instrument. Participants also completed the *Music Instrument Quality Rating* (MIQR) and selected bipolar descriptors to rate sounds.

Over 162 trials, participants in the study were only able to identify the melody correctly 5% of the time. Participants were only able to identify the instrument correctly 13.5% of the time. Gfeller and Lansing (1991) noted that many of the participants indicated having little musical training and little knowledge of instruments. Lack of musical experience did not preclude participants from rating timbres positively. Gfeller and Lansing found that users of Ineraid® implants rated a greater variety of instruments as having a pleasant sound when compared to users of Cochlear™ Nucleus® devices. The researchers speculated that the processing device used with the Ineraid® implant may have affected ratings of timbres.

Gfeller, Witt, Woodworth, Mehr, and Knutson (2002) investigated effects of frequency, instrument family, and cochlear implant type on recognition and appraisals of timbre among adults who used cochlear implants. Adults with typical hearing also participated in the study. Stimuli consisted of eight instruments: trumpet, trombone, flute, clarinet, saxophone, violin, cello, and piano. These instruments represented four different instrument families and three different frequency ranges: low (131 to 262Hz), medium (262 to 534Hz), and high (534 to 1068Hz). For the recognition task, participants listened to an excerpt of a solo instrument, and indicated their choice by touching one of 16 pictures on a touch screen computer monitor. Twenty adults with typical hearing and 51 adults who used cochlear implants participated in the timbre-recognition task. Participants with typical hearing scored significantly higher than participants who used cochlear implants on the recognition task ($p = .001$). Adults with cochlear implants recognized the piano more often than other timbres. The researchers found that errors made by participants with typical hearing were often within the same family, (e.g., participants misidentified trombone as trumpet), while errors made by participants with cochlear implants did not make this error. Implant type also affected timbre recognition. The researchers discovered participants who used Clarion® and MED-EL® implants performed significantly better on the recognition task than participants who used Nucleus® implants (Clarion®: $p < .01$; MED-EL®: $p < .02$).

Grasmeder and Lutman (2006) examined the self-reported timbre-identification abilities of adult users of cochlear implants and compared them to adults with typical hearing. Seventy-two adults who were postlingually deaf and used cochlear implants rated their perceived ability to identify the drum, piano, guitar, trumpet, violin, cymbal, flute, saxophone, tuba, and clarinet. The researchers created sounds files for each of the instruments and used a filter that simulated the frequency characteristics of front end processing for a Nucleus® processor. The resulting sound files were analyzed with Cochlear™ Nucleus® Implant Communicator (CNIC) software. Grasmeder and Lutman examined the resulting electrodograms and spectrograms of the sound files. The self-reported abilities of participants with typical hearing were significantly higher than abilities reported by participants with cochlear implants ($p < .001$). The researchers found that many discrete frequencies of harmonics are lost when processed by the cochlear implant. When the electrodograms were analyzed, the researchers found little sound energy present above 3000Hz and a reduction of intensity of fundamental frequencies. Because some onset cues were retained, Grasmeder and Lutman concluded that instruments with percussive onsets and middle frequency steady states might be easier for users of cochlear implants to identify.

Perception of Timbre with Cochlear Implants - Children

Sucher, McDermott, and Galvin (2006) assessed timbre perception among children who used cochlear implants. Children with typical hearing and children with cochlear implants listened to recordings of different instruments and identified them from a closed set of 12. All participants were asked to rate each excerpt on a scale of 1 to 5, with 1 signifying that the participant really disliked the sound, and 5 signifying that the participant really liked the sound. Children who used cochlear implants performed more poorly than children with typical hearing on the recognition task but appraisal ratings between the two groups were similar.

Olszewski, Gfeller, and Driscoll (2006) investigated the effect of a computerized training program on timbre recognition among children who used cochlear implants.

Twelve children who used cochlear implants completed open-and closed-set tests of timbre recognition before participating in a computerized training protocol. After completing the training program, participants again completed the open-and closed-set tests. The pretest scores for instrument recognition were 27.8% correct (open-set), and 52.8% (closed-set) correct. Posttest scores were 77.8% correct (open-set), and 77.8% (closet-set) correct. After conducting a repeated-measures ANOVA, researchers determined that open-set instrument identification following training was significantly more accurate than before training ($p < .002$).

Researchers who have studied timbre perception and appraisal among users of cochlear implants have found that both adults and children may have difficulty identifying instruments by perception of their timbres (Gfeller & Lansing, 1991; Gfeller, Witt, Woodworth, Mehr, & Knutson, 2002; and Sucher, McDermott, & Galvin, 2006). In response, some researchers have developed training programs designed to assist users of cochlear implant identify instruments (Olszewski, Gfeller, & Driscoll, 2006). Despite some successes with training programs, researchers continue to examine speech processors and speech-processing strategies in an attempt to determine what sound characteristics users of cochlear implants are able to perceive (Grasmeder & Lutman, 2006). Although children who use cochlear implants experience difficulties with timbre recognition, they provide favorable ratings of instrument timbres (Sucher, McDermott, & Galvin, 2006). Because some timbres may be more easily perceived by users of cochlear implants than other timbres, spectral information, such as pitch, also may be communicated and perceived more effectively through the devices than instrument timbres. The effect of timbre and pattern difficulty on the pitch perception of elementary-aged children with cochlear implants was examined in the current research.

Effects of Timbre on Pitch Perception

Tatem (1990) studied the effects of timbre, task, age level, and gender on the vocal pitch matching accuracy of children in grades kindergarten through third grade. He found that timbre affected the pitch matching accuracy of the participants. Participants matched pitches performed by resonator bells least accurately and matched pitches performed by soprano voice most accurately. The researcher found that participants were also able to match pitch when asked to match violin, trumpet, and oboe.

Galvin, Fu, and Oba (2008) measured the ability of adult users of cochlear implants to identify melodic contours across timbres. Participants were eight users of cochlear implants who were deafened postlingually, and eight participants with typical hearing. Melodic contours were presented by six different timbres: organ, glockenspiel, trumpet, clarinet, violin, and piano. Users of cochlear implants scored more poorly than adults with typical hearing on a task of melodic contour identification. Melodic contour identification was best for users of cochlear implants when stimuli were played by the organ (70.4% correct) and poorest when stimuli were played by the piano (54.2% correct). The effect of timbre was not significant for users of cochlear implants. The effect of intonation patterns on melodic contour identification was significant for users of cochlear implants ($p < .001$). However, researchers found that for four of the users of cochlear implants, the effect of instrument timbre was significant, and affected their melodic contour identification performance ($p < .05$). The researchers found that users of cochlear implants who had musical training were less susceptible to the effects of timbre. Galvin III, Fu, and Oba (2008) speculated that timbre may have affected melodic contour identification among cochlear implant users because high frequency components may be truncated by implant speech processing strategies.

Galvin III, Fu, and Oba (2008) found that melodic contour identification abilities of four adult users of cochlear implants were significantly affected by timbre. The researchers also found the melodic contour pattern had a significant effect on the ability of adult cochlear implant users to identify melodic contours. Researchers have investigated perception of pitch and perception of timbre among children who use cochlear implants, but the effect of timbre and pitch-pattern difficulty on pitch perception has not been investigated specifically. The timbres examined in the present study: piano, soprano voice, and violin represent instruments used commonly in the elementary general music classroom, and instruments shown to be effective in pitch perception among children with typical hearing (Campbell & Scott-Kassner, 2010; Tatem Jr., 1990).

Related Literature and Purposes of the Current Study

Researchers have investigated a multitude of problems related to perception of speech and music among users of cochlear implants. Although discoveries have been made regarding perception of pitch and timbre among users of cochlear implants, few studies have focused on the effects of timbre and pitch-pattern difficulty on pitch perception among children who use cochlear implants. The primary purpose of this study was to determine the effects of instrument timbre and pitch-pattern difficulty on pitch perceptions of elementary-aged users of cochlear implants. For the purposes of this study, pitch perception was defined as the perception of same-difference between paired pitch patterns that were altered or unaltered by instrument timbre and pitch-pattern difficulty. A secondary purpose of this study was to determine relationships among participants' *Pitch Discrimination Test* (PDT) scores, age, and age at cochlear implantation. An additional secondary purpose of the study was to determine if there were significant differences between participants' PDT scores based on the type of speech processor used ($p \leq .05$).

CHAPTER III

PROCEDURES

The primary purpose of this study was to determine effects of instrument timbre and pitch-pattern difficulty on pitch perceptions of elementary-aged users of cochlear implants. Secondary purposes of this study were to determine relationships among participants' *Pitch Discrimination* Test (PDT) scores, age, age at cochlear implantation, and whether there were significant differences between participants' PDT scores based on the type of speech processor used ($p \leq .05$). For the purposes of this study, pitch perception was defined as the perception of same-difference between paired pitch patterns that were altered or unaltered by instrument timbre and/or pitch-pattern difficulty. The participants' pitch perceptions were measured via the researcher-developed *Pitch Discrimination Test* (PDT). Participants and their parent(s)/guardian(s) also completed the *Adapted Musical Background Questionnaire* (AMBQ) which was used to collect data about participants' demographic information and musical experiences. This chapter includes descriptions of participants in the study, measurement instruments, procedures for collecting data, and procedures analyzing data.

Participants

The study was conducted in public elementary schools in metropolitan areas of North Carolina. In addition to approval by the Institutional Review Board at UNCG, permission to conduct the research was granted by the public county school systems of students who participated in the study. For each school system, separate research applications and associated materials were submitted. Following approval by each school system, principals at schools with hearing-impaired populations were contacted via e-mail. If principals agreed to permit the research to occur in their schools, specialists working with hearing-impaired populations were contacted via e-mail and/or telephone. Participating specialists distributed and collected a packet of study-related materials, and allowed the researcher to test students at the school site. Specialists were sent packets that included:

1. Recruitment letter that explained the study to parents/guardians (Appendix A);
2. Parental consent for minor form (Appendix B);
3. Minor assent form (Appendix C); and
4. *Adapted Musical Background Questionnaire – Children's Version* (Appendix D).

Although approximately 38,000 children in the United States use cochlear implants, locating a large number of children who use cochlear implants and live in the same geographical region was difficult. Selection of participants, therefore, was not randomized.

Participants (N = 13) were children, ages six to ten years, who use cochlear implants. Specifically, participants' ages ranged from 5.92 years (71 months) to 12.25 years (147 months), with a mean age of approximately 9 years. Five participants were male, and eight participants were female. All participants used at least one cochlear implant, and ten of the participants used bilateral cochlear implants. Participants received their first cochlear implant between 1.5 and 10 years of age ($\tilde{x}$ = 3.93 years). Ten of the participants received their second cochlear implant between the ages of 1.92 and 11.08 years ($\tilde{x}$ = 5.94 years). Participants' experiences with their first implant ranged from 8 months to 9.67 years ($\tilde{x}$ = 5.54 years). The range of experiences with a second implant ranged from 3 months to 6.67 years ($\tilde{x}$ = 3.88 years). All participants had nearly one year of experience using at least one of their implants.

Five participants used the Cochlear™ Nucleus® Freedom 5 speech processor. Three participants used the Cochlear™ Nucleus® Freedom 6 speech processor. Two participants used the MED-EL® Rondo™ speech processor. One participant used the MED-EL® Sonata 2™ speech processor. One participant used a combination of the Cochlear™ Nucleus® 24, and Cochlear™ Nucleus® Freedom 5 speech processors. One participant used a combination of the Cochlear™ Nucleus® Freedom 5 and Cochlear™ Nucleus® CI 512 speech processors. Table 1 shows the demographic characteristics of the participants.

Table 1

Participant Demographics

Participant			Implant Age*		Device Use*		Processor	
#	Sex	Age*	LE**	RE**	LE**	RE**	LE	RE
P1	F	7.67	2.67	N/A	5.00	N/A	MED-EL® Rondo™	N/A
P2	F	10.58	5.17	6.17	5.42	4.42	MED-EL® Rondo™	MED-EL® Rondo™
P3	M	8.00	N/A	1.58	N/A	6.42	N/A	Cochlear™ Nucleus® Freedom 5
P4	F	9.83	5.50	5.08	4.33	4.75	MED-EL® Sonata 2™	MED-EL® Sonata 2™
P5	F	8.00	2.08	3.50	5.92	4.50	Cochlear™ Nucleus® Freedom 5	Cochlear™ Nucleus® Freedom 5
P6	M	12.25	5.58	2.58	6.67	9.67	Cochlear™ Nucleus® 24	Cochlear™ Nucleus® Freedom 5
P7	M	5.92	1.33	1.92	4.48	4.00	Cochlear™ Nucleus® Freedom 5	Cochlear™ Nucleus® Freedom 5
P8	M	9.58	3.17	5.25	6.42	4.33	Cochlear™ Nucleus® Freedom 5	Cochlear™ Nucleus® Freedom 5
P9	F	11.33	6.00	9.00	5.33	2.33	Cochlear™ Nucleus® Freedom 6	Cochlear™ Nucleus® Freedom 6
P10	M	9.83	3.25	5.42	6.58	4.42	Cochlear™ Nucleus® Freedom 5	Cochlear™ Nucleus® CI 512
P11	F	11.33	10.00	11.08	1.33	.25	Cochlear™ Nucleus® Freedom 6	Cochlear™ Nucleus® Freedom 6
P12	F	7.17	6.50	N/A	.67	N/A	Cochlear™ Nucleus® Freedom 6	N/A
P13	F	9.58	1.58	6.00	8.00	3.58	Cochlear™ Nucleus® Freedom 5	Cochlear™ Nucleus® Freedom 5

**Years **LE = Left Ear, RE = Right Ear*

Measurement Instruments

Adapted Musical Background Questionnaire

The *Musical Background Questionnaire* was developed and used by Gfeller and Lansing (1991). Since 1991, numerous researchers have used the questionnaire to measure formal and informal music experiences of adult users of cochlear implants (Driscoll, Oleson, Jiang, & Gfeller, 2009; Gfeller, Christ et al., 2000; Gfeller, Oleson et al., 2008; and Olszewski, Gfeller, Froman, Stordahl, & Tomblin, 2005). Stordahl (2002) adapted the adult version of the *Musical Background Questionnaire* for use with children who use cochlear implants.

Convenience sampling was used in the current study, and participants' demographic information was not available prior to testing. Purposes of the current study included examining the relationships between pitch perception and age, and age at implant, and the effect of processor type on pitch discrimination scores, therefore collection of demographic and hearing data was necessary.

The *Musical Background Questionnaire – Children's Version* (Stordahl, 2002), was adapted to include questions about etiology of deafness (i.e., if known), hearing history, use of hearing aids, age at implantation, age at activation, cochlear implant type(s), speech processor type, and cochlear implant use. The version of the *Musical Background Questionnaire – Children's Version* used by Stordahl (2002) also included questions about band, orchestra, choral, and music instrument lesson experiences, but Stordahl's youngest participants were in fourth grade. Because participants in the present study were five to twelve years of age, options for kindergarten, first, second, and third grades were added to the response set of the *Musical Background Questionnaire – Children's Version* (Stordahl, 2002). Participants in the present study attended elementary schools, so choices above grade six were eliminated from Stordahl's *Questionnaire*. The *Adapted Musical Background Questionnaire* used in the current study is included in Appendix D.

Pitch Discrimination Test

The researcher-developed the *Pitch Discrimination Test* (PDT) was administered to measure the pitch perception abilities of participants. For purposes of this study, pitch perception was defined as the perception of same-difference between paired pitch patterns that were altered or unaltered by instrument timbre and/or pitch-pattern difficulty. The PDT was a 36-item, two-option, forced-choice test (Appendix E). Stimuli consisted of tonal patterns selected from *Learning Sequences in Music: Skill, Content, and Patterns* (Gordon, 1980).

Within Gordon's *Learning Sequences in Music* (1980), tonal patterns were organized by difficulty, but users of cochlear implants participating in the current study may have found Gordon's 'easy' patterns difficult to perceive. Previous research revealed that pitch-ranking abilities of users of cochlear implants varied considerably, with thresholds ranging from one to twenty-four semitones (Fujita & Ito, 1999; Gfeller, Turner, Mehr, Woodworth, Fearn, Knutson, et al. 2002). According to several researchers, abilities of users of cochlear implants to discriminate pitches, and/or identify melodic contours correctly increased as interval sizes increased (Galvin III, Fu, & Nogaki, 2007; Gfeller, Turner, Oleson, Zhang, Gantz, Froman, & Olszewski, 2007; Leal, Shin, Laborde, et al. 2003; Looi, McDermott, McKay & Hickson, 2008; Sucher & McDermott, 2007; Swanson, Dawson, & McDermott, 2009). Previous research findings demonstrated that mapping of electrodes in cochlear implants may affect how users of cochlear implants perceive pitch. Gfeller, Driscoll, Kenworthy and VanVoorst (2011) reported that some electrodes were mapped such that one electrode may be assigned a wide range of frequencies, with as many as eight to ten semitones represented on one electrode.

In the major mode, pitch patterns classified by Gordon (1980) as ‘easy’ had pitch differences that ranged between five and eight semitones, and patterns classified as ‘difficult’ had pitch differences that ranged from four to twelve semitones. Based on findings within these summarized research studies, persons with cochlear implants more accurately discriminated pitch differences and melodic contours with increased interval sizes than with decreased interval sizes (e.g., Galvin III, Fu, & Nogaki, 2007; Gfeller, Turner, Oleson, Zhang, Gantz, Froman, & Olszewski, 2007; and Swanson, Dawson, & McDermott, 2009). Increased interval sizes have more semitones than do decreased interval sizes. Easy to difficult classifications of pitch patterns perceived by users of cochlear implants, therefore, would be the opposite of Gordon's classifications (1980). Pitch patterns, categorized by Gordon (1980) as ‘easy’, therefore, served as ‘difficult’ stimuli; and pitch patterns categorized as ‘difficult’ by Gordon served as ‘easy’ stimuli in the PDT.

Gfeller, Driscoll, Kenworthy and VanVoorst (2011) stated that because the cochlear implant has a frequency range that is limited (i.e., ranging from 120-8000Hz), fundamental frequencies produced by some instruments in bass and tenor ranges may not be transferred through the implant (p. 43). Singh, Kong, and Zeng (2009) discovered that the frequency range of a melody significantly affected melody identification by users of cochlear implants ($p < 0.001$). Performance was best when melodies were presented within a high frequency range (414-1046Hz). Finally, users of cochlear implants were able to detect a five-semitone change of pitch in a melody that ranged in frequency from 523-1046Hz (Swanson, Dawson, & McDermott, 2009). Because the soprano voice usually performs within a limited range in the elementary general music classroom, stimuli for the PDT reflected a range often observed in that context. Stimuli for the PDT range from 261 Hz to 659 Hz. Table 2 shows the stimuli of the PDT.

Classification	Pitch Pattern
Easy	
Moderate	
Difficult	

Figure 1. Pitch Discrimination Test Stimuli

The *Pitch Discrimination Test* stimuli included soprano voice, piano, and violin. The soprano voice and piano are used often in elementary general music instruction. Tatem (1990) examined the vocal pitch matching abilities of elementary-aged children when examples were presented by soprano voice, trumpet, violin, oboe, piano, and resonator bells. Tatem (1990) reported that students were most accurate when matching soprano voice. Tatem (1990) discovered that there were no significant differences between participants' abilities to vocally match pitches as presented by trumpet, violin, oboe, and piano ($p > .05$), although pitch matching accuracy was lower for piano than trumpet, violin, or oboe. Participants in Tatem's study matched pitches least accurately when stimuli were performed on resonator bells. Because of the prevalence of the soprano voice and piano in the general music classroom, and because the soprano voice, piano, and violin appear to accurately communicate pitch information to elementary-aged children, these timbres were selected for inclusion in the PDT.

Pitch patterns were performed by graduate music students from the School of Music, Theatre and Dance at the University of North Carolina at Greensboro. Pitch patterns were recorded using a Fostex® FR-2 field recorder and Neumann® condenser microphone. Using Audacity™ software, the digitally recorded pitch patterns were normalized, which set the maximum intensity level to -1.0dB. Pitch patterns were edited to lengths of approximately two seconds for difficult patterns, and approximately three seconds for moderate and easy patterns.

For each of the three levels of pitch-pattern difficulty within the PDT, 12 items were created. As shown in Figure 1 (p. 63), two pitch patterns were selected for each level of difficulty. To avoid an ordering effect on pitch perception, all four combinations of the easy patterns, all four combinations of moderate patterns, and all four combinations of difficult patterns were included on the PDT. The random number generator within Microsoft Excel® was used to assign a value between 0 and 1 to each set of patterns (i.e., easy, moderate, and difficult). The 12 easy pattern combinations, across all three timbres (soprano voice, piano, and violin) were assigned a number from 0 to 1 and were ordered randomly. The same procedure was followed for the 12 moderate patterns, and the 12 difficult patterns. The pattern combinations were ordered from least to greatest, which determined the order of presentation for each level of difficulty. Results of the random number generation are shown in Table 2.

Table 2

Randomizing of Patterns within Difficulty by Timbre

Pattern 1	Pattern 2	Generated Random #	Test Item
Piano Easy 1	Piano Easy 1	0.34244369	4
Piano Easy 1	Piano Easy 2	0.69713109	9
Piano Easy 2	Piano Easy 2	0.56016206	7
Piano Easy 2	Piano easy 1	0.06675491	1
Soprano Easy1	Soprano Easy 1	0.45180736	6
Soprano Easy 1	Soprano Easy 2	0.39895293	5
Soprano Easy 2	Soprano Easy 2	0.82235358	10
Soprano Easy 2	Soprano Easy 1	0.84723494	11
Violin Easy 1	Violin Easy 1	0.66671296	8
Violin Easy 1	Violin Easy 2	0.09644902	2
Violin Easy 2	Violin Easy 2	0.10059496	3
Violin Easy 2	Violin Easy 1	0.94452753	12
Piano Moderate 1	Piano Moderate 1	0.31338566	18
Piano Moderate 1	Piano Moderate 2	0.56237885	23
Piano Moderate 2	Piano Moderate 2	0.22472802	16
Piano Moderate 2	Piano Moderate 1	0.52592728	22
Soprano Moderate 1	Soprano Moderate 1	0.27442712	17
Soprano Moderate 1	Soprano Moderate 2	0.49840700	21
Soprano Moderate 2	Soprano Moderate 2	0.33175801	19
Soprano Moderate 2	Soprano Moderate 1	0.35666534	20
Violin Moderate 1	Violin Moderate 1	0.12790082	14
Violin Moderate 1	Violin Moderate 2	0.64750719	24
Violin Moderate 2	Violin Moderate 2	0.07684998	13
Violin Moderate 2	Violin Moderate 1	0.14691684	15
Piano Difficult 1	Piano Difficult 1	0.15768485	25
Piano Difficult 1	Piano Difficult 2	0.68617395	31
Piano Difficult 2	Piano Difficult 2	0.35993694	27
Piano Difficult 2	Piano Difficult 1	0.81984664	35
Soprano Difficult 1	Soprano Difficult 1	0.39966283	28
Soprano Difficult 1	Soprano Difficult 2	0.65638367	30
Soprano Difficult 2	Soprano Difficult 2	0.39979471	29
Soprano Difficult 2	Soprano Difficult 1	0.97579634	36
Violin Difficult 1	Violin Difficult 1	0.69461747	32
Violin Difficult 1	Violin Difficult 2	0.24106563	26
Violin Difficult 2	Violin Difficult 2	0.79146425	34
Violin Difficult 2	Violin Difficult 1	0.75714125	33

Following data collection, the difficulty of each item on the PDT was calculated using the Cox-Vargas item difficulty formula (Boyle & Radocy, 1987). The initial item difficulty classification, based on frequency range, and the Cox-Vargas item difficulty index and classification obtained following data collection are shown in Table 3. Hopkins (1998) classified the ranges of the Cox-Vargas difficulty indices as Easy (1.00 to .67), Moderate (.66 to .33), and Difficult (.32 to 0). Based on the Cox-Vargas difficulty classifications of each item, items 4, 6, 7, 11, and 12 in the "easy" section of the PDT could be classified as easy items. Items, 1, 2, 3, 5, 8, 9, and 10 in the "easy" section of the PDT were classified as moderately difficult items. Items in the "moderate" section of the PDT with moderate difficulty were items 13, 16, 17, 18, and 19. Items 14, 15, 20, 21, 23, and 24 had easy difficulty levels. Item 22 in the "moderate" section of the PDT was the only item on the test categorized as difficult. No items in the "difficult" section of the PDT had a difficult Cox-Vargas item difficult index. Items 25, 26, 33, 34, and 36 were classified as easy, and items 27, 28, 29, 30, 31, 32, and 35 were classified as having moderate difficulty.

Based on the Cox-Vargas analyses, presented in Table 3, only five of the 12 easy items (42%) were "easy", based on participants' responses, with 58% (n = 7) of the easy items identified as "moderate", based on participants' responses. Only five of the 12 moderate items (42%) were "moderate", based on participants' responses, with 50% (n =6) and 8% (n = 1) of the moderate items identified as "easy" and "difficult", respectively, based on participants' responses. None of the difficulty items were "difficult", based on the participants' responses. Of the 12 difficult items and based on participants' responses, five difficulty items (42%) were identified as "easy", and seven difficulty items (58%) were identified as "moderate". Based on the Cox-Vargas item difficulty analyses, there were some violations of construct validity within the PDT, as related to pitch-pattern difficulty. Caution was applied when reviewing and discussing analyses associated with effects of pattern difficulty on participants' pitch perceptions.

Table 3

Item Difficulty Classifications

Test Item	Initial Difficulty Classification	Cox-Vargas Item Difficulty Index	Cox-Vargas Difficulty Classification
1	Easy	.6154	Moderate
2	Easy	.5348	Moderate
3	Easy	.4615	Moderate
4	Easy	.8461	Easy
5	Easy	.6154	Moderate
6	Easy	.8461	Easy
7	Easy	.6923	Easy
8	Easy	.6154	Moderate
9	Easy	.5384	Moderate
10	Easy	.5384	Moderate
11	Easy	.6923	Easy
12	Easy	.6923	Easy
13	Moderate	.6154	Moderate
14	Moderate	.8461	Easy
15	Moderate	.6923	Easy
16	Moderate	.6154	Moderate
17	Moderate	.5384	Moderate
18	Moderate	.6154	Moderate
19	Moderate	.6154	Moderate
20	Moderate	.7692	Easy
21	Moderate	.7692	Easy
22	Moderate	.2307	Difficult
23	Moderate	.8461	Easy
24	Moderate	.6923	Easy
25	Difficult	.7692	Easy
26	Difficult	.6923	Easy
27	Difficult	.5384	Moderate
28	Difficult	.5384	Moderate
29	Difficult	.5384	Moderate
30	Difficult	.6154	Moderate
31	Difficult	.4615	Moderate
32	Difficult	.6154	Moderate
33	Difficult	.6923	Easy
34	Difficult	.7692	Easy
35	Difficult	.6154	Moderate
36	Difficult	.9231	Easy

To determine the reliability of the PDT, the Kuder-Richardson, Formula 20 (1937) test of internal consistency was used. The Kuder-Richardson test is a measure of reliability for measures with dichotomous choices. Results of Kuder-Richardson analyses range from 0.00-1.00, and a coefficient at .70 and above indicates that the test has acceptable reliability and measures consistently. The reliability of the PDT was .9167, indicating that the PDT measured consistently and had acceptable reliability. The standard error of measure for the PDT was 2.11 points, representing 5.87% error, which is just above the percentage of error considered to be acceptable (i.e., 5% error). The researcher considered the reliability and error to be acceptable for this initial study of pitch perceptions, modified by timbre and pitch-pattern difficulty.

The answer sheet used for the PDT was adapted from an answer sheet developed by Gordon (1979) for the *Primary Measures of Music Audiation* (PMMA) (Appendix F). After listening to each item, participants circled two smiling faces when they believed the two pitch patterns sounded the same, and circled a smiling face and a frowning face when they believed the two pitch patterns sounded different. The original PMMA answer sheet used only pictures to identify each answer space. Number identifiers were added to each answer space on the PDT. In addition, the original PMMA answer sheet had four practice item answer spaces, while the PDT answer sheet included only two practice item answer spaces.

Data Collection Procedures

Participants and their parent(s)/guardian(s) completed the *Adapted Musical Background Questionnaire* (AMBQ) prior to the administration of the *Pitch Discrimination Test* (PDT). Educators and paraprofessionals at each school collected the AMBQ from participants and/or parents/guardians, and returned the packets to the researcher on the day(s) of data collection.

The PDT was administered to each participant individually. Following brief introductions, directions for the PDT were read aloud by the researcher. Using an Asus™ 1015PN laptop computer or a MacBook Pro® laptop computer, the PDT stimuli were presented aurally using a Bose™ speaker or a Front Row™ Juno speaker, positioned three feet from participants. Prior to administering the PDT, the researcher measured the intensity of sample test items with an X Tech Instruments™ 407762 sound pressure level meter at a distance of three feet to ensure that stimuli were presented approximately at 70dBA. Numerous researchers, who have investigated users of cochlear implants' perceptions of speech and musical sound, presented stimuli at 70dBA (Davidson, Geers, Blamey, Tobey, & Brenner, 2010; Galvin, Fu, & Nogaki, 2007; Galvin, Fu, & Oba, 2008; Geers, Brenner, & Davidson, 2003; Mitani, Nakata, Trehub, Kanda, Kumagami, Takasaki, Miyamoto, & Takahashi, 2007; Olszewski, Gfeller, Froman, Stordahl, & Tomblin, 2005; Santarelli, Magnavita, De Filippi, Ventura, Genovese, & Arslan, 2009; Stabej, Smid, Gros, Zargi, Kosir, & Vatovec, 2012; Tobey, Geers, Sundarrajan, & Shin, 2010; Vongpaisal, Trehub, Schellenberg, 2006; Wang, Huang, Wu, & Kirk, 2007; and Yucel, Sennaroglu, & Belgin, 2009).

The PDT stimuli ranged from 261-659Hz (C4-E5), and were performed independently by a violinist, soprano vocalist, and pianist. For each item of the PDT, a pitch pattern was presented aurally, followed by one second of silence and an aural presentation of a second pitch pattern for comparison. Participants indicated whether the second pitch pattern was the same as or different from the first pattern by circling a set of two smiling faces for 'same', and a set of one smiling face and one frowning face for 'different'. Participants completed two practice items before completing the 36 items of the PDT. All 12'easy' patterns were presented first, followed by all 'moderate' patterns, and followed by all 'difficult' patterns. Participants were encouraged by the researcher to complete each test item. For each item identified correctly, participants received one point. The highest achievable PDT score was 36 points, and the closer the PDT score was to 36 points indicated increased pitch-perception acuity of participants.

Data Analysis

Following data collection, correct and incorrect responses for each participant were recorded, and the mean and standard deviation of all scores were calculated. To test the effects of timbre and pitch-pattern difficulty on pitch perception, a 3 (timbre) by 3 (pitch-pattern difficulty) factorial analysis of variance (ANOVA) with repeated measures was used to analyze the participants' scores, with timbre and pitch-pattern difficulty serving as repeated measures. Three null hypotheses were tested as specified below:

1. There will be no effect of timbre on the pitch perception of elementary-aged children who use cochlear implants.

2. There will be no effect of pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.

3. There will be no interaction effect of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.

Bonferroni pairwise comparisons were calculated to determine if significant differences existed between participant scores for each timbre, and for each level of pattern difficulty ($p \leq .05$). To fulfill the secondary purposes of the current study, Pearson Product Moment Correlation analyses were used to determine the relationships among participant PDT score, age, and age at cochlear implantation. A one-way ANOVA was used to determine if there were any significant differences between participants' PDT scores and the type of speech processor used ($p \leq .05$).

CHAPTER IV

RESULTS

The primary purpose of this study was to determine the effects of instrument timbre and pitch-pattern difficulty on the pitch perception of elementary-aged users of cochlear implants. For the purposes of this study, pitch perception was defined as the perception of same-difference between paired pitch patterns that were altered or unaltered by instrument timbre and/or pitch-pattern difficulty. Results of the study were determined by testing the following null hypotheses at a significance level of less than or equal to .05.

1. There will be no effect of timbre on the pitch perception of elementary-aged children who use cochlear implants.
2. There will be no effect of pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.
3. There will be no interaction effect of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.

To test the null hypotheses, a three (timbre) by three (pitch-pattern difficulty) analysis of variance (ANOVA) with repeated measures was used to analyze participants' PDT scores with timbre and pitch-pattern difficulty serving as repeated measures. Bonferroni pairwise comparisons were calculated to determine if significant differences existed between participant scores for each timbre, and for each level of pattern difficulty

($p \leq .05$). To fulfill the secondary purpose of this study, Pearson Product Moment Correlation analyses were used to examine the relationships between participant *Pitch Discrimination Test* (PDT) score, age, and age at implantation. A one-way ANOVA was used to determine if there were any significant differences between participants' scores on the PDT based on their speech processor ($p \leq .05$). Results of the data analyses are presented in three sections related to the purposes of the study. A discussion of the descriptive analyses of the PDT data is followed by the results of testing the null hypotheses, the results of examining the relationships among PDT score, age, and age at implantation, and the results of examining pitch perception differences due to speech processor.

Descriptive Analysis of the Pitch Discrimination Test

The *Pitch Discrimination Test* (PDT) was administered to measure the pitch perceptions of participants. The PDT was a 36-item, two-option, forced-choice test (Appendix E). The paired, aurally-presented pitch patterns of each item were unaltered or altered by changes in timbre and/or pitch-pattern difficulty. Participants' scores were calculated by determining the number of correct responses out of 36 possible items (the maximum number of attainable PDT points was 36 points).

Participants' scores on the PDT ranged from 13 to 34. The mean score on the PDT was 23.307 and the standard deviation was 7.319. The mean scores and standard deviations for items by timbre, difficulty, and timbre by difficulty are shown in Table 4.

Table 4

Descriptive Statistics for the PDT

Test Section	Min. Score	Max Score	Range	$\bar{x}$	SD
PDT Total	13	34	21	23.307	7.319
Soprano	4	11	7	7.615	2.256
Piano	4	12	8	7.615	2.873
Violin	5	11	6	8.077	2.532
Easy	3	12	9	7.769	2.976
Moderate	5	11	6	7.846	1.908
Difficult	2	12	10	7.769	3.444
Soprano Easy	1	4	3	2.615	.961
Soprano Moderate	1	4	3	2.153	.899
Soprano Difficult	1	4	3	2.923	1.038
Piano Easy	1	4	3	2.539	1.127
Piano Moderate	0	4	4	2.769	1.166
Piano Difficult	0	4	4	2.308	1.377
Violin Easy	1	4	3	2.539	1.127
Violin Moderate	2	4	2	2.923	.494
Violin Difficult	0	4	4	2.615	1.502

Demographic information related to participants' hearing history was not available prior to data collection, therefore the *Adapted Musical Background Questionnaire* (AMBQ) was distributed to participants and their parent(s)/guardian(s) prior to test. The AMBQ included questions about the participants' cochlear implant use, including age at implantation, device use, and the type of speech processor used. The age, age at implantation, device use, and *Pitch Discrimination Test* (PDT) score for each participant is shown in Table 5.

Table 5

Descriptive Statistics for the PDT by Age, Age at Implant, and Device Use

		Age at Implant		Device Use		
Participant	Age (years.)	Left Ear (years.)	Right Ear (years.)	Left Ear (years.)	Right Ear (years.)	PDT Score
1	7.67	2.67	N/A	5.00	N/A	15
2	10.58	5.17	6.17	5.42	4.42	28
3	8.00	N/A	1.58	N/A	6.42	20
4	9.83	5.50	5.08	4.33	4.75	13
5	8.00	2.08	3.50	5.92	4.50	34
6	12.25	5.58	2.58	6.67	9.67	34
7	5.92	1.33	1.92	4.58	4.00	22
8	9.58	3.17	5.25	6.42	4.33	26
9	11.33	6.00	9.00	5.33	2.33	31
10	9.83	3.25	5.42	6.58	4.42	18
11	11.33	10.00	11.08	1.33	.25	28
12	7.17	6.50	N/A	.67	N/A	19
13	9.58	1.58	6.00	8.00	3.58	15

Participants who used MED-EL® devices scored more poorly on the PDT than participants who used Cochlear™ devices in both ears. The descriptive statistics for the PDT by speech processor are shown in Table 6.

Table 6

Descriptive Statistics for the PDT by Processor Type

Left Ear				Right Ear			
Processor	N	$\bar{x}$ PDT	SD PDT	Processor	N	$\bar{x}$ PDT	SD PDT
MED-EL® Rondo™	2	21.50	9.19	Med-El® Rondo™	1	15.00	N/A
MED-EL® Sonata™	1	13.00	N/A	Med-El® Sonata™	1	13.00	N/A
Cochlear® Nucleus™ Freedom 5	5	23.00	7.42	Cochlear® Nucleus™ Freedom 5	6	25.17	3.15
Cochlear® Nucleus™ Freedom 6	3	26.00	6.25	Cochlear® Nucleus™ Freedom 6	2	29.50	2.12
Cochlear® Nucleus™ 24	1	34.00	N/A	Cochlear® Nucleus™ 512	1	18.00	N/A

Primary Purposes of the Study

Null Hypothesis One – Effect of Timbre on Pitch Perception

Null hypothesis one was tested to determine if timbre significantly affected participants' pitch perception ($p \leq .05$). Prior to analyzing the PDT data using a three (timbre) by three (pitch-pattern difficulty) analysis of variance with repeated measures, the PDT data were analyzed using descriptive statistics. Participants' scores on the PDT ranged from 13 to 34. The mean score on the PDT was 23.307 and the standard deviation was 7.319. The mean scores and standard deviations for items by timbre, difficulty, and timbre by difficulty are shown in Table 7.

Table 7

Descriptive Statistics for the PDT

Test Section	Min. Score	Max Score	Range	$\bar{x}$	SD
PDT Total	13	34	21	23.307	7.319
Soprano	4	11	7	7.615	2.256
Piano	4	12	8	7.615	2.873
Violin	5	11	6	8.077	2.532
Easy	3	12	9	7.769	2.976
Moderate	5	11	6	7.846	1.908
Difficult	2	12	10	7.769	3.444
Soprano Easy	1	4	3	2.615	.961
Soprano Moderate	1	4	3	2.153	.899
Soprano Difficult	1	4	3	2.923	1.038
Piano Easy	1	4	3	2.539	1.127
Piano Moderate	0	4	4	2.769	1.166
Piano Difficult	0	4	4	2.615	1.377
Violin Easy	1	4	3	2.539	1.127
Violin Moderate	2	4	2	2.923	.494
Violin Difficult	0	4	4	2.308	1.502

A three (timbre) by three (pitch-pattern difficulty) ANOVA with repeated measures was performed to determine if significant differences existed between the means of participant scores on items presented by the soprano voice, the violin, and the piano. When variances of all possible pairs of groups or levels of independent variables are equal, the assumption of sphericity is met. Sphericity is an important condition of conducting a repeated-measures ANOVA. Without the assumption of sphericity, F ratios generated by the analysis may have distributions that are atypical, resulting in an increased risk of Type I error (Howell, 2010). Mauchly's Test of Sphericity determines if the assumption of sphericity is met. If Mauchly's Test is significant, sphericity cannot be assumed and F ratios must be interpreted with caution (Mauchly, 1940). Results of

Mauchly's Test of Sphericity for the three (pattern) by three (pitch-pattern difficulty) ANOVA with repeated measures indicated that sphericity could not be assumed for the effects of timbre (*p* = .033). The Huynh-Feldt (1976) correction, which adjusted the degrees of freedom to reduce the Type I error rate was used to interpret results of the three by three ANOVA with repeated-measures. Results of Mauchly's Test of Sphericity and the three by three ANOVA with repeated measures are shown in Table 8 and Table 9 respectively.

Table 8

Mauchly's Test of Sphericity

					Epsilon		
Within-Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse Geisser	Huynh -Feldt	Lower -bound
Timbre	.537	6.841	2	.033	.683	.742	.500
Difficulty	.986	.153	2	.927	.986	1.000	.500
Timbre * Difficulty	.183	17.668	9	.041	.664	.871	.250

Table 9

Three (Timbre) by Three (Pitch-Pattern Difficulty) ANOVA with Repeated Measures

	SS	df	MS	F	Sig.	Partial Eta Squared
Timbre	.530	1.483	.357	.601	.511	.048
Pattern Difficulty	.068	2.000	.034	.030	.971	.002
Timbre * Pattern Difficulty	6.291	3.485	1.805	2.769	.046*	.187
Timbre Error	10.581	17.798	.595			
Pattern Difficulty Error	27.709	24.00	1.155			
Timbre*Pattern Difficulty Error	27.265	41.815	.652			

**p* < .05 (Statistically Significant)

The three (timbre) by three (pitch-pattern difficulty) ANOVA revealed that there was no significant effect of timbre on the pitch perceptions of participants ($p = .511$). PDT scores by timbre were extremely similar (See Table 7). The mean scores of PDT items presented by soprano voice and piano were both 7.615. The mean score of PDT items presented by violin was 8.077. There were no practical or significant differences in PDT mean scores due to timbre. The null hypothesis that there would be no effect of timbre on the pitch perception of elementary-aged children who use cochlear implants was retained.

Null Hypothesis Two – Effect of Pitch-Pattern Difficulty on Pitch Perception

Null hypothesis two was tested to determine if pitch-pattern difficulty significantly affected the pitch perception of participants ($p \leq .05$). A three (timbre) by three (pitch-pattern difficulty) ANOVA with repeated measures was performed to determine if significant differences existed between participant PTD scores that were categorized as easy, moderate and difficult. Results of Mauchly's Test of Sphericity for the three (timbre) by three (pattern difficulty) ANOVA with repeated measures revealed that sphericity could be assumed for the effects of pattern difficulty on pitch perception (p = .927, see Table 8). There was no violation of Type I error in the results of the ANOVA. There was no significant effect of pattern difficulty on participants' pitch perception of same-difference (p = .971, see Table 8). The mean scores on PDT items by pattern difficulty were 7.769 (Easy and Difficult), and 7.846 (Moderate) respectively. There were no practical or significant differences in PDT mean scores due to pattern difficulty. The null hypothesis that there will be no effect of pitch-pattern difficulty on pitch perception of elementary-aged users of cochlear implants was retained.

Null Hypothesis Three – Interaction Effect of Timbre and Pitch-Pattern Difficulty on Pitch Perception

Null hypothesis three was tested to determine if there was a significant interaction effect of timbre and pitch-pattern difficulty on participants' pitch perception of same-difference ($p \leq .05$). To test the interaction effects of timbre and pitch-pattern difficulty on pitch perception, a three (timbre) by three (pattern difficulty) analysis of variance (ANOVA) with repeated measures was used to analyze the participants' scores, with timbre and pitch-pattern difficulty serving as repeated measures. Results of Mauchly's Test of Sphericity indicated that sphericity could not be assumed for the interaction between timbre and pattern difficulty (p = .041, see Table 7). The Huynh-Feldt correction, which adjusted the degrees of freedom to reduce the Type I error rate was used to interpret results of the repeated-measures analysis. A statistically significant interaction effect was found between timbre and pattern difficulty (*p* = .046, see Table 8). The null hypothesis that there would be no interaction effect of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants was rejected. The size of the interaction effect was .187 (See Table 8), indicating a small but meaningful effect (Cohen, 1988). The observed power was .671. A graph illustrating the interaction effect of timbre and difficulty on PDT mean scores is shown in Figure 2.

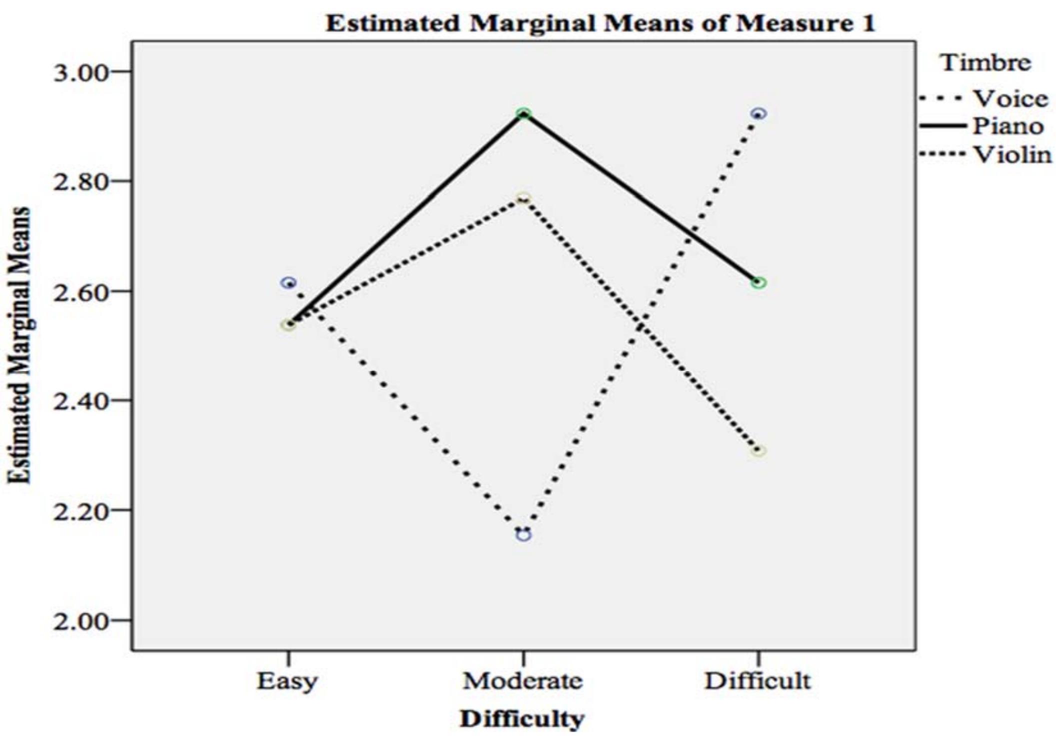

Figure 2. Profile Plot of Interaction Between Timbre and Pitch-Pattern Difficulty

To determine which timbre and/or pattern difficulty contributed to the significant interaction between timbre and pitch-pattern difficulty (p = .046), six one-way analyses of variance with repeated measures for timbres and pattern difficulties were performed (Table 10). Six repeated measures ANOVAs were performed to examine mean PDT scores for voice, for violin and for piano by each level of pitch-pattern difficulty (i.e., easy, moderate, and difficult), and mean PDT scores for easy, moderate, and difficult patterns by each timbre (i.e., voice, violin, and piano). Results of the six one-way ANOVAs with repeated measures on timbre and on pitch patterns for each timbre and pitch-pattern difficulty held constant are shown in Table 10. Sphericity could not be assumed for easy by PDT timbres, moderate by PDT timbres, and difficult by PDT timbres analyses. The Huynh-Feldt correction was used to interpret the results of the ANOVAs with the pattern difficulty held constant by timbres as repeated measures.

Table 10

One-Way ANOVAs with Repeated Measures by Each Timbre and Pitch-Pattern Difficulty

	SS	df	MS	F	Sig.	Partial Eta Squared
Voice by Pitch-Pattern Difficulties						
Voice	3.897	2	1.949	3.316	.530	.217
Error	14.103	24	.588			
Violin by Pitch-Pattern Difficulties						
Violin	1.077	2	.538	.660	.526	.520
Error	19.590	24	.816			
Piano by Pitch-Pattern Difficulties						
Piano	1.385	2	.692	.781	.469	.061
Error	21.282	24	.887			
Easy by Timbres						
Easy	.510	1.790	.290	.103	.883	.009
Error	5.949	21.500	.276			
Moderate by Timbres						
Moderate	4.308	1.480	2.913	3.60	.060	.231
Error	14.359	17.740	.809			
Difficult by Timbres						
Difficult	2.462	1.290	1.906	1.694	.217	.123
Error	17.538	15.500	1.131			

* $p \leq .05$ (Statistically Significant)

None of the one-way ANOVAs with repeated measures for timbres and pitch-pattern difficulties showed a significant difference between PDT mean scores with each timbre and each pattern difficulty held constant. The one-way ANOVA for mean PDT Voice scores by the three pattern difficulties, and the one-way ANOVA for mean PDT Difficult scores by the three timbres approached significance ($p = .053$; $p = .060$). The graph of the PDT mean scores (see Figure 2, p. 81) illustrated that PDT mean scores for moderate pattern-difficulty presented by the soprano voice were lower than mean scores for all other timbre and pattern difficulty combinations. Additionally, the graph showed that there were notable differences between the PDT mean scores for difficult patterns presented by each timbre.

To confirm the observations acquired from the one-way ANOVAs with repeated measures, Bonferroni pairwise comparisons were performed to determine if there were significant differences between PDT mean scores of each timbre by pattern difficulty combination. Results of Bonferroni pairwise comparisons are presented in Table 11.

Table 11

Bonferroni Pairwise Comparisons for Each Timbre and Pattern Difficulty Combination

Voice by Difficulty				
		Mean Diff	Std. Error	Sig.
Voice Easy	Voice Moderate	.462	.291	.417
Voice Easy	Voice Difficult	-.308	.263	.793
Voice Moderate	Voice Difficult	-.769	.343	.133
Violin by Difficulty				
		Mean Diff	Std. Error	Sig.
Violin Easy	Violin Moderate	-.385	.266	.524
Violin Easy	Violin Difficult	-.077	.366	1.000
Violin Moderate	Violin Difficult	.308	.414	1.000
Piano by Difficulty				
		Mean Diff	Std. Error	Sig.
Piano Easy	Piano Moderate	-.231	.411	1.000
Piano Easy	Piano Difficult	.231	.378	1.000
Piano Moderate	Piano Difficult	.462	.312	.496
Easy by Timbres				
		Mean Diff	Std. Error	Sig.
Voice Easy	Violin Easy	.077	.178	1.000
Voice Easy	Piano Easy	.077	.239	1.000
Violin Easy	Piano Easy	.000	.160	1.000
Moderate by Timbres				
		Mean Diff	Std. Error	Sig.
Voice Moderate	Violin Moderate	-.769	.281	.054
Voice Moderate	Piano Moderate	-.615*	.213	.041
Violin Moderate	Piano Moderate	.154	.390	1.000
Difficult by Timbres				
		Mean Diff	Std. Error	Sig.
Voice Difficult	Violin Difficult	-.615*	.213	.041
Voice Difficult	Piano Difficult	.308	.308	1.000
Violin Difficult	Piano Difficult	.308	.444	1.000

* $p \leq .05$ (Statistically Significant)

The results of Bonferroni pairwise comparisons revealed that there were significant differences between the mean scores of PDT test items presented by violin and by soprano voice for difficult patterns ($p = .041$). The results of pairwise comparisons also showed that there were significant differences between the mean scores of PDT test items presented by soprano voice and by piano for patterns with moderate difficulty ($p = .041$). These results in part confirm and identify the interaction effect that was discussed previously. The participants discriminated difficult pitch patterns more accurately when the PDT items were presented by soprano voice than by the other timbres. Participants discriminated moderate pitch patterns more accurately when the PDT items were presented by piano and violin than by soprano voice. This result seems to contradict information provided by participants and their parent(s)/guardian(s) on the *Adapted Musical Background Questionnaire* (AMBQ)(Appendix D) because participants were reported to have most experience listening to music genres that featured singing. Results of pairwise comparisons also revealed that the differences between the mean scores of PDT test items presented by the soprano voice and violin for patterns with moderate difficulty approached significance ($p = .054$).

Only three of the participants indicated that their listening habits included music that was solely instrumental (“Classical” or “Symphonies”). One participant disliked classical music. Twelve of the thirteen participants listed styles of music that feature the voice as their favorite types of music. Participants struggled most with identifying same-difference when patterns were presented by the soprano voice in the moderate difficulty. This finding is interesting since most parent(s)/guardian(s)/participants reported that participants had the most listening experience with music featuring singing. The presence of a statistically significant interaction effect between timbre and pattern difficulty combined with a small, but meaningful effect size indicated that additional research examining the effects of timbre and pattern difficulty in isolation is necessary; considering participants did their best identification of same-difference when voice was used to present easy and difficult patterns, but their performance was weaker on moderate patterns presented by soprano voice when compared with the piano and violin timbres.

Secondary Purposes of the Study

Relationship Between Age and Pitch Perception

The relationships between participants' ages and pitch perceptions as measured by the PDT across timbres and across pitch-pattern difficulties were analyzed using Pearson Product Moment Correlation analyses. The correlations between age and pitch perceptions, as measured by the composite PDT, each timbre score, and each pattern difficulty score. The correlation coefficients are presented in Table 12. Correlations between participants' age and their scores ranged from weak, positive correlations (r = .208) to moderate, positive correlations (r = .544). There were no significant correlations between the participants' age and their scores on PDT, and across each timbre and each pattern difficulty ($p > .05$). The moderate and positive correlation coefficients for piano and age (r = .477) and for moderate pattern difficulty and age (r = .544) approached significance (p = .099 and p = .055). Though some older participants achieved high scores on the piano section, and the moderate difficulty section of the PDT, being older did not guarantee that participants would achieve a higher score than younger participants. For example, participant 5, who was 8 years old, scored higher on the moderate and piano sections of the PDT than participant 11, who was 11.33 years old.

Table 12

Pearson Product Moment Correlations: Age and PDT Mean Scores

	PDT Score	Voice Score	Violin Score	Piano Score	Easy Score	Moderate Score	Difficult Score
Age	.432	.365	.351	.478	.208	.544	.440

Relationship Between Age at Implantation and Pitch Perception

Relationships between participants' ages at implantation (left and right ears) and pitch perceptions as measured by the PDT across timbres and across pattern difficulties were analyzed using Pearson Product Moment Correlation analyses. Correlations between participants' age at implantation ranged from ranged from mostly weak, positive correlations to moderate, positive correlations (r = .051 to .358). Participants' age at implantation in the right ear and their scores on the easy items of the PDT produced a weak, negative correlation (r = -.068). There were no significant relationships between the participants' age when receiving their implants and mean scores on the PDT or mean scores on individual sections of the PDT (p .≤ .05). The correlations between age at implantation and mean scores on the PDT are shown in Table 13.

Table 13

Pearson Product Moment Correlations: Age at Implantation and PDT Mean Scores

	PDT Score	Voice Score	Violin Score	Piano Score	Easy Score	Moderate Score	Difficult Score
Implant Age Left Ear	.258	.243	.107	.272	.051	.214	.358
Implant Age Right Ear	.115	.035	.117	.102	-.068	.163	.237

Effects of Left-Ear and Right-Ear Speech Processors on Pitch Perception

Two one-way ANOVAs were used to determine if there were statistically significant differences between the participants' pitch perception due to the type of speech processor used by participants' right-ear and left-ear cochlear implants. There were no significant difference between participants' PDT mean scores based on the speech processor used (Left: p = .413; Right: p = .313). Results of the one-way ANOVA are shown in Tables 14. Although there were no significant differences between participants' PDT mean scores, participants who used Cochlear® Nucleus™ processors, achieved higher mean scores (See Table 15).

Table 14

One-Way ANOVAs: Effects of Left and Right Ear Processors on Pitch Perception

Source	SS	df	MS	F	Sig.
Left Ear: Processors	248.417	4	62.104	1.137	.413
Error	630.917	11			
Source	SS	df	MS	F	Sig.
Right Ear: Processors	300.848	4	75.212	1.498	.313
Error	602.182	10			

Table 15

Descriptive Statistics for the PDT by Processor Type

Processor Left Ear	N	$\bar{x}$ PDT	SD PDT	Processor Right Ear	N	$\bar{x}$ PDT	SD PDT
MED-EL® Rondo™	2	21.50	9.19	Med-El® Rondo™	1	15.00	N/A
Med-El® Sonata™	1	13.00	N/A	Med-El® Sonata™	1	13.00	N/A
Cochlear™ Nucleus® Freedom 5	5	23.00	7.42	Cochlear™ Nucleus® Freedom 5	6	25.17	3.15
Cochlear™ Nucleus® Freedom 6	3	26.00	6.25	Cochlear™ Nucleus® Freedom 6	2	29.50	2.12
Cochlear™ Nucleus® 24	1	34.00	N/A	Cochlear™ Nucleus® 512	1	18.00	N/A

Summary

The primary purpose of this study was to determine if instrument timbre and pitch-pattern difficulty significantly affected the pitch perception of same-difference by elementary-aged users of cochlear implants. For the purposes of this study, pitch perception was defined as the perception of same-difference between paired pitch patterns that were altered or unaltered by instrument timbre and/or pitch-pattern difficulty. The null hypothesis that there would be no significant effect of timbre on pitch perception of same-difference by elementary-aged children who use cochlear implants was retained (p = .511). The null hypothesis that there would be no effect of pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants was retained (p = .971). The null hypothesis that the interaction of timbre and pattern difficulty would have no effect on the pitch perception of elementary-aged children who use cochlear implants was rejected. A statistically significant interaction effect was found between timbre and pitch-pattern difficulty (p = .046).

To determine which timbre and/or pitch-pattern difficulty contributed to the significant (p = .046) interaction between timbre and pitch-pattern difficulty, six one by three ANOVA with repeated measures were used. Though none of the one by three ANOVAs with repeated measures showed a significant difference between mean scores on different sections of the PDT, the one by three ANOVA examining mean voice section scores by the three pitch-pattern difficulties, and the one by three ANOVA examining mean difficulty scores by the three timbres used on the PDT approached significance (p = .053; p = .060).

Bonferroni pairwise comparisons were also computed to determine if significant differences occurred between timbres and/or pitch-pattern difficulties. The results of the Bonferroni analyses revealed that there were significant differences between mean scores of PDT test sections: violin with difficult pattern difficulty and soprano voice with difficult pattern difficulty (p = .041); and soprano voice with moderate difficulty, and piano with moderate difficulty (p = .041). A near significant difference was found between PDT items presented by soprano voice with moderate difficulty, and PDT items presented by violin with moderate difficulty (p = .054). Participants had more difficulty identifying same-difference when moderate patterns were presented by the soprano voice when compared to patterns presented by violin and piano. This result seems to contradict information provided by participants and their parent(s)/guardian(s) on the AMBQ (Appendix D) because it was reported that participants had the most listening experience with musical contexts featuring singing.

To fulfill the secondary purposes of the current study, Pearson Product Moment Correlation analyses were used to determine the relationships among participants' PDT scores and age, and age at cochlear implantation. There were no significant relationships between age, or age at implantation and participants' PDT scores, though piano section scores and age, and moderate difficulty scores and age correlations approached significance (p = .099, and p = .055). A one-way ANOVA was used to determine if there were any significant differences between participants' scores on the PDT and their speech processor. There were no statistically significant differences between participant scores on the PDT and processor (p > .05), but participants who used MED-EL® devices had lower mean scores on the PDT than participants who used Cochlear™ devices. Participants in the current study only used implants made by two manufacturers, and the number of children using a specific speech processing strategies varied. For example, six participants used the Cochlear™ Nucleus® Freedom 5 processing strategy in their right ears while only one participant used the MED-EL® Rondo™ strategy in their right ear. Perhaps if each type of speech processor were represented equally throughout the sample, correlations between speech processors and PDT scores may have been statistically and practically significant.

CHAPTER V

DISCUSSION

The primary purpose of this study was to determine the effect of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged users of cochlear implants. Three null hypotheses were associated with the primary purpose of the study:

1. There will be no effect of timbre on the pitch perception of elementary-aged children who use cochlear implants.
2. There will be no effect of pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.
3. There will be no interaction effect of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants.

To address the primary purpose of the study, the *Pitch Discrimination Test* (PDT) was administered to measure the pitch perceptions of participants. The PDT was a 36-item, two-option, forced-choice test (Appendix E). Stimuli consisted of tonal patterns selected from *Learning Sequences in Music: Skill, Content, and Patterns* (Gordon, 1980). To determine the reliability of the PDT, the Kuder-Richardson Formula 20 (1937) test of internal consistency was used. The reliability of the PDT was .9167. Following data collection, a three (timbre) by three (pitch-pattern difficulty) factorial analysis of variance (ANOVA) with repeated measures was used to determine if timbre and pitch-pattern difficulty, affected the PDT scores of participants.

Secondary purposes of this study were to determine relationships among participants' *Pitch Discrimination* Test (PDT) scores, age, age at cochlear implantation, and whether there were significant differences between participants' PDT scores based on the type of speech processor used ($p \leq .05$). To address the secondary purpose of the present study, participants and/or their parent(s)/guardian(s) completed the *Adapted Musical Background Questionnaire* (AMBQ) (Appendix D) which included questions about etiology of deafness (i.e., if known), hearing history, age at implantation, age at activation, cochlear implant type(s), speech processor type(s), and cochlear implant use. To fulfill the secondary purposes of this study, Pearson Product Moment Correlation analyses were used to examine the relationships among participants' *Pitch Discrimination Test* (PDT) scores and age, and age at implantation. A one-way ANOVA was used to determine if there were any significant differences between participants' scores on the PDT and their speech processor.

Summary of Results

Participants (N = 13) were children ages six to ten years that use cochlear implants. Participants' ages ranged from 5.92 years (71 months) to 12.25 years (147 months) ($\tilde{x}$ = approximately 9 years). Five participants were male, and eight participants were female. Ten participants were implanted bilaterally and three were implanted unilaterally. Participants received their first cochlear implant between the ages of 1.5 and 10 years of age ($\tilde{x}$ = 3.93 years). Ten of the participants received their second cochlear implant between the ages of 1.92 and 11.08 years ($\tilde{x}$ = 5.94 years). Participants' experience with their first implants ranged from 8 months to 9.67 years ($\tilde{x}$ = 5.54 years). The range of experience with a second implant ranged from 3 months to 6.67 years ($\tilde{x}$ = 3.88 years). All participants had nearly one year of experience using at least one of their implants. Table 1 (p. 54) shows the demographic characteristics of the participants in the present study.

A primary purpose of the study was to determine if instrument timbre affected the pitch perception of participants. A three (timbre) by three (pitch-pattern difficulty) factorial analysis of variance (ANOVA) with repeated measures was used to determine if there were statistically significant differences between participants' scores on the sections of the *Pitch Discrimination Test* (PDT) presented by voice, violin, and piano timbres. The mean scores of PDT items presented by soprano voice and piano were both 7.615. The mean score of PDT items presented by violin was 8.077. There were no practical or significant differences between PDT mean scores due to timbre. The effect of timbre was not significant (p = .511) and null hypothesis one, that there would be no effect of timbre on the pitch perception of elementary-aged children who use cochlear implants was retained.

Null hypothesis two was designed to determine if pitch-pattern difficulty affected the pitch perception of participants in the present study. A three (timbre) by three (pitch-pattern difficulty) ANOVA with repeated measures was used to determine if there were statistically significant differences between participants' scores on the easy, moderate, and difficult sections of the PDT ($p \leq .05$). The effect of pitch-pattern difficulty was not significant (p = .971). The mean scores on PDT items by pitch-pattern difficulty were

7.769 (Easy and Difficult), and 7.846 (Moderate). There were no significant differences between PDT mean scores due to pitch-pattern difficulty. Null hypothesis two, that there would be no effect of pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants was retained.

The purpose of null hypothesis three was to determine if the interaction between timbre and pitch-pattern difficulty significantly affected the pitch perception of participants in the present study. The three (timbre) by three (pitch-pattern difficulty) ANOVA revealed a statistically significant interaction between timbre and pattern difficulty (p = .046). The null hypothesis that the interaction of timbre and pattern difficulty had no effect on the pitch perception of elementary-aged children who use cochlear implants was rejected. The size of the interaction effect was .187 (See Table 9 p.77), indicating a small but meaningful effect (Cohen, 1988), with an observed power was .671.

Bonferroni pairwise comparisons were computed to determine if significant differences occurred between timbres and/or pattern difficulties that contributed to the significant interaction between timbre and pattern difficulty (p = .046). Results of Bonferroni pairwise comparisons revealed that there were significant differences between the mean scores of PDT test items presented by the violin with difficult pitch patterns and PDT test items presented by the soprano voice with difficult pitch patterns (p = .041). Results of pairwise comparisons also showed that there were significant differences between the mean scores of PDT test items presented by the soprano, and by the piano with moderate difficulty (p = .041), with the soprano voice providing the least accurate moderate pattern difficulty scores. These results seems to contradict information provided by participants and their parent(s)/guardian(s) on the *Adapted Musical Background Questionnaire* (AMBQ)(Appendix D). Because it was reported that participants had the most experience listening to music genres focused on singing, the researcher expected participants to most accurately perceive pitch differences when items were presented by the soprano voice. That expectation was not confirmed when soprano voice was used to present moderate pitch patterns. Finally, the results of Bonferroni pairwise comparisons also revealed that the differences between the mean scores of PDT test items presented by the soprano voice with moderate difficulty, and PDT test items presented by the violin with moderate difficulty approached significance (p = .054).

One of the secondary purposes of the study was to determine if there were relationships between participants' ages and mean scores on the PDT, mean scores across timbres with pattern difficulty collapsed, and mean scores across difficulties with timbres collapsed. Scores and participant ages were analyzed using Pearson Product Moment Correlation analyses. Correlations between participants' age and their scores ranged from weak, positive correlations (r = .208) to strong, positive correlations (r = .544). There were no significant relationships between participants' ages and their mean scores on any section of the PDT, although piano and age (r = .477), and moderate difficulty and age (r = .544) approached significance (p = .099, and p = .055). Although some correlation coefficients approached significance, older participants did not achieve higher scores on piano and moderate difficulty items of the PDT than younger participants. For example, participant 5, who was 8 years old, scored higher on moderately difficult items presented by the piano than participant 11, who was 11.33 years old.

Another secondary purpose of the study was to determine if there were relationships between participants' ages at implantation (for left and right ears), mean scores on the PDT, mean scores across timbres, and mean scores across difficulties. Scores and participants' ages at implantation were analyzed using Pearson Product Moment Correlation analyses. The analyses revealed that the correlations between participants' age at implantation ranged from were mostly weak, positive correlations to moderate, positive correlations (r = .051 to r = .358). Participants' age at implantation in the right ear and their scores on the easy items of the PDT had a weak, negative correlation (r = -.068). There were no significant correlations between the participants' ages at implantation and mean scores as measured by the PDT.

A secondary purpose of the study was to determine if there were statistically significant differences between participants' mean scores on the PDT based on the type of speech processor used with participants' right and/or left implants. A one-way ANOVA was used to determine if there were any significant differences between PDT mean scores and processing strategies. There were no significant difference between participants' PDT mean scores based on the speech processor used (Left p = .413; Right p = .313). Participants who used Cochlear™ Nucleus® processors however, achieved higher mean scores than participants who used MED-EL® processors.

Discussion of Results and Conclusion

Perception of same-difference in pitch is a fundamental skill in music, which elementary general music educators help students develop in music classes. Although many researchers have investigated the abilities of children with cochlear implants to identify melodies (Hsiao, 2008; Olszewski, Gfeller, Froman, Stordahl, & Tombin, 2005; Scorpecci, Zagari, Mari, Giannantonio, D'Alatri, & DiNardo, 2012; and Vongpaisal, Trehub, Schellenberg, & Papsin, 2004), few researchers have focused solely on the perception of same-difference in pitch. One research study has been conducted on the effect of timbre on melodic contour identification with adult users of cochlear implants (Galvin, Fu, & Oba, 2008), but no researchers have investigated the effect of timbre and pitch-pattern difficulty on pitch perceptions of children who use cochlear implants. The primary purpose of the current study was to determine if instrument timbre and pitch-pattern difficulty affected the pitch perceptions of elementary-aged children who use cochlear implants.

Effects of Timbre on Pitch Perception

As in a previous study (Galvin, Fu, & Oba, 2008), results of the current study revealed that timbre had no significant effect on the pitch perceptions of users of cochlear implants ($p > .05$). The findings of the current study contrast those of Tatem (1990) who found that timbre affected the pitch-matching abilities of children in kindergarten through third grades. Tatem (1990), however, conducted research with children who had typical hearing, and the current study focused on children who used cochlear implants. Because the current study did not isolate timbre from pitch-pattern difficulty, additional research is necessary to determine if some instrument timbres are more effective than other timbres for communicating information about pitch to children who use cochlear implants.

Effect of Pitch-Pattern Difficulty on Pitch Perception

There are a multitude of research studies designed to examine musical behaviors as related to pitch perceptions, but few researchers have examined the abilities of children who use cochlear implants to perceive same-difference in pitch by manipulating pitch-pattern difficulty. Several researchers found that children who use cochlear implants were able to identify original versions of songs or familiar melodies, but performed poorly when original songs and/or melodies were altered by removing lyrics, and other melodic instruments (Hsiao, 2008; Scorpecci, Zagari, Mari, Giannantonio, D'Alatri, and DiNardo, 2012; Vongpaisal, Trehub, Schellenberg, & Papsin, 2004). Other researchers have examined the abilities of adult users of cochlear implants to identify melodies, or rank pitches to examine pitch perception. In each study, the effect of pattern difficulty on assigned tasks was found to be significant ($p \leq .05$), with adult users of cochlear implants performing significantly better on identification or ranking tasks when intervals between pitches were increased, than when intervals between pitches were decreased (Gfeller, Turner, Oleson, Zhang, Gantz, Froman, & Olszewski, 2007; Looi, McDermott, McKay, & Hickson, 2004; Swanson, Dawson, & McDermott, 2009).

Results of the current study showed that there was no significant effect of pitch-pattern difficulty on the pitch perceptions of elementary-aged children who used cochlear implants ($p = .05$). Children performed similarly across all pattern difficulties. On pitch patterns determined to be easy, however, six participants obtained their lowest scores. Eight participants earned their highest scores on items containing difficult pitch patterns. Pitch patterns classified as difficult contained only two pitches, with intervals that ranged from four to seven semitones, while patterns classified as moderate and easy contained three pitches per pattern and contained intervals that ranged from five to twelve semitones.

Because previous research has indicated that people who use cochlear implants more accurately discriminated pitch differences and melodic contours with increased intervals sized than with decreased interval sizes, easy and moderate patterns in the current study contained larger intervals than difficult patterns (Galvin, Fu, & Nogaki, 2007; Gfeller, Tuerner, Oleson, Zhang, Gantz, Froman, & Olszewski, 2007; and Swanson, Dawson, & McDermott, 2009). Pitch patterns on the PDT were selected from *Learning sequences in music: Skill, content, and patterns* (Gordon, 1980). Perhaps attending to fewer pitches allowed participants to attain higher scores in the difficult section. In addition to examining these factors, the effect of the interaction between pitch-pattern difficulty and timbre revealed that additional research is needed to isolate the effects of timbre and pitch-pattern difficulty on pitch perception of same-difference.

Effects of Timbre and Pitch-Pattern Difficulty on Pitch Perception

In the present study, there were no significant independent effects of timbre and pitch-pattern difficulty on participants' perceptions of same-difference (i.e., $p = .511$, $p = .971$, respectively). The interaction effect of timbre and pitch-pattern difficulty on pitch perception, however, was significant ($p = .046$). The findings of the current study are similar to the findings of Galvin, Fu, and Oba (2008) who discovered an interaction effect between timbre and intonation pattern when measuring abilities to identify melodic contours of adult users of cochlear implants ($p < .001$). While Galvin, Fu, and Oba (2008) found no significant effect of timbre on perceptions of melodic contour ($p > .05$), intonation pattern significantly affected adult users of cochlear implants' ability to identify melodic contours ($p < 0.001$).

In the current study, Bonferroni pairwise comparisons were used to determine if significant differences occurred between timbres and/or pitch-pattern difficulties. Results of Bonferroni pairwise comparisons showed significant differences between the mean scores on PDT test items with difficult pitch patterns presented by the violin, and the soprano voice ($p = .041$). Results of pairwise comparisons also showed that there were significant differences between the mean scores of PDT test items presented by the soprano voice and by the piano with moderate pitch pattern difficulty ($p = .041$). This result contradicted the researcher's expectations based on information provided by participants and their parent(s)/guardian(s) on the *Adapted Musical Background Questionnaire* (AMBQ)(Appendix D) and previous research. In response to AMBQ items, parents/guardians/participants reported that participants listened to music genres featuring singers more often than music genres without singing.

Based on these results, one would expect pitch perceptions to be more accurate for music presented with soprano voice than with instrumental timbres only. Results of pairwise comparisons also revealed that differences between the mean scores of PDT test items presented by the soprano voice and violin with moderate difficulty approached significance (p = .054). This result was unique in the moderate condition and contradicted other research findings that indicated that children who use cochlear implants are often more successful identifying music that features singers when compared to music that features instruments only (Hsiao, 2008; Olszewski, Gfeller, Froman, Stordahl, & Tomblin, 2005; Vongpaisal, Trehub, Schellenberg, & Papsin, 2004).

Three of the participants indicated that their listening habits included music that was solely instrumental ("Classical" or "Symphonies"). One participant listed classical music as a dislike. Twelve of the thirteen participants listed styles of music that feature the voice as their favorite types of music. That participants struggled most with identifying same-difference when patterns were presented by the soprano voice in the moderate difficulty is curious, because participants in the present study were reported to have the most listening experience with music featuring singing. The presence of a statistically significant interaction effect between the soprano voice timbre and pattern difficulty combined with a small, but meaningful effect size indicated that additional research examining the effects of timbre and pattern difficulty in isolation is necessary.

The findings of the current study confirm and refute findings of previous research. Galvin, Fu, and Oba (2008) determined that adult users of cochlear implants performed poorest when identifying melodic contours played by piano. In the current study, participant performances on items presented by piano was not significantly worse than on items presented by other timbres. Tatem (1990) found that children with typical hearing matched pitches most accurately when they were presented by the soprano voice. Participants in the present study were able to identify same-difference on items presented by the soprano voice better than items presented by other timbres when pattern difficulties were easy, and when pattern difficulties were difficult. Participants in the current study, however, scored lower when identifying patterns of moderate difficulty presented by the soprano voice ($\bar{x}$ = 2.153) than when identifying patterns of moderate difficulty presented by the violin ($\bar{x}$ = 2.923) and the piano ($\bar{x}$ = 2.769). Additionally, participants in the current study scored significantly higher on difficult patterns presented by the soprano voice ($\bar{x}$ = 2.923) than on difficult patterns presented by the piano ($\bar{x}$ = 2.307).

The design and purpose of the cochlear implant may provide an explanation for participants' success identifying patterns presented by soprano voice in the easy and difficult pattern conditions. The cochlear implant was designed for speech perception, and may represent sounds produced by the human voice more accurately than sounds created by other musical instruments. The interaction between pitch-pattern difficulty and the inconsistencies with previous research support the premise that additional research is needed.

Relationships Between PDT Scores and Age

Researchers who have examined speech perception abilities of adults and children who use cochlear implants have found that age of persons who use cochlear implants can positively affect speech outcomes (Beadle, McKinley, Nikolopoulos, Brough, O'Donoghue, & Archbold, 2005; Davidson, Geers, Blamey, Tobey, & Brenner, 2011). The current study showed no significant relationship between participants' scores on the PDT and their chronological age ($p > .05$). This finding refutes findings by Scorpecci, Zagari, Mari, Giannantonio, D'Alatri, and DiNardo (2012) and Vongpaisal, Trehub, Schellenburg, and Papsin (2004), but supports findings by Hsiao (2008). Although Vongpaisal, Trehub, Schellenburg, and Papsin (2004), and Hsiao (2008) used samples of subjects with similar age ranges (ages 8-18 and ages 7-15), and with similar sample sizes (n = 10 and n = 20); the researchers arrived at disparate conclusions. The current study used a sample similar to Scorpecci, Zagari, Mari, Giannantonio, D'Alatri, and DiNardo (2012) whose participants were 18 children aged 5-12. With small sample sizes, it may be difficult to clearly identify relationships based on age. The disparity between studies supports the need for additional research with increased sample sizes.

Relationships Between PDT Scores and Age at Implantation

Although there is some disagreement, several researchers studying speech outcomes among individuals who use cochlear implants have found that early implantation of cochlear devices may result in improved speech outcomes (Conner, Craig, Radenbush, Heavner, & Zwolan, 2006; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005; Uziel et al., 2007; Wang, Huang, Wu, & Kirk, 2007; Zwolan et al., 2004). The current study showed no significant relationship (i.e., from positively or negatively strong to weak) between participants' PDT scores and the age at which they received their cochlear devices. This finding refutes the conclusions of Scorpecci, Zagari, Mari, Giannantonio, D'Alatri, and DiNardo (2012) who found a significant correlation between song identification scores and length of device use in children who used cochlear implants ($r = 0.238$, $p = 0.04$). The findings from the current study support previous research conducted by Gfeller et al., (2007), Hsiao (2008), and Olszewski, Gfeller, Froman, Stordahl, and Tombin (2005) who also found no significant relationships between the abilities of cochlear implant users to rank pitches and recognize melodies, and their age at implantation and/or length of device use ($p > .05$).

In each of the above-referenced studies, the average age at implantation was relatively high. The participants in Gfeller et al. (2007) were adult participants who received their implants postlingually. Participants in research conducted by Hsiao (2008), Olszewski, Gfeller, Froman, Stordahl, and Tomblin (2005), and Scorpecci, Zagari, Mari, Giannantonion, D'Alatri, and DiNardo (2012) received their implants between an average of 3.83 years, and 5.58 years of age. Participants in the current study received their implants at an average age of 4.33 (left ear) and 5.17 (right ear) years of age. Because children who use cochlear implants are receiving implants at younger ages than previously, continued research is necessary to determine relationships between age at implantation and pitch perception.

Effect of Speech Processor on PDT Scores

Each cochlear implant manufacturer offers different speech processors and processing strategies, even among the same brand of cochlear implant, so researchers have investigated the relationships between speech outcomes and cochlear implant speech processors and processing strategies. Several researchers have found that the type of speech processor and/or processing strategy used by children who use cochlear implants can affect speech outcomes (Geers, Brenner, & Davidson, 2003; Manrique et al., 2005; and Santarelli et al., 2009). The findings of the current study support findings by Gfeller et al. (2007) who found no significant relationship between speech processing strategy and pitch ranking ability among adult users of cochlear implants ($p > .05$). In the current study, the speech processor used by participants had no effect on their PDT scores, although participants using Cochlear™ devices performed better than those who used MED-EL® devices. Because children who receive cochlear implants may have auditory development vastly different from adult recipients of cochlear implants, additional research with increased sample sizes and with children who use a diverse array of processor types is necessary to determine if any generalizable relationships between pitch perception and speech processing type used exist.

Implications for Future Research

Limitations

Although approximately 38,000 children in the United States have received cochlear implants, it is difficult to recruit a large sample of elementary-aged children who use cochlear implants. Participants were recruited from public schools, and lack of control of the return of recruitment materials hindered the participation rate. Because random sampling was not feasible, generalizing the results of the current study to a population of children who use cochlear implants must be approached with caution. To reduce the limitations of the current study, the acquisition of increased sample sizes is necessary in future studies. Additionally, children who received their cochlear implants as infants and children who received their implants at older ages may illuminate differences between pitch perceptions, based on age of implantation.

Classifications of pitch-pattern difficulties resulted in a limitation in this study, as demonstrated by the Cox-Vargas analysis, and by the significant interaction effect that was related to pattern difficulty. No more than 42% of the initial pitch-pattern difficulty classifications were correct across all sections of the PDT, based on the modification of reversing patterns used previously by Gordon (1980). Easy patterns contained three pitches each with intervals of twelve semitones, and five semitones. Moderate patterns contained three pitches each with intervals of five semitones and eight semitones. Difficult patterns contained two pitches each with intervals of four semitones and seven semitones. Perhaps the addition of a third pitch, in moderate and easy patterns made them more difficult for participants in the current study to perceive. Current results support the premise that the combination of instrument timbre and pitch-pattern difficulty affect the pitch perceptions of elementary-aged children who use cochlear implants. To determine the specificity of the effects of timbre and/or pattern difficulty on pitch perception, future research is necessary.

Implications for Future Research and Music Education

Purposes of the current research were to determine the effects of timbre and pitch-pattern difficulty on the pitch perception of elementary-aged children who use cochlear implants; and to determine if there were relationships between pitch perception and participant age, age at implantation, and type of speech processor used. The findings of the current study confirm that additional research is necessary.

Interaction of timbre and pitch-pattern difficulty significantly affected pitch perception, therefore additional studies that isolate the effects of timbre and the effect of pitch-pattern difficulty on pitch perception are warranted. Participants in the study performed best when identifying same-difference in easy and difficult patterns presented by the soprano voice. Participant performance on moderate patterns presented by soprano voice was notably lower than when moderate patterns were presented by the piano and violin. Results of the Cox-Vargas analyses indicated that classification of pitch-pattern difficulties for the current study was inaccurate. Further research is necessary to determine what characteristics of a pitch pattern make it “easy”, “moderate”, or “difficult” for children who use cochlear implants.

Research that investigates the effect of musical experiences, such as listening, singing, and playing melodic instruments, on the pitch perceptions of children who use cochlear implants also may reveal effective strategies for developing accurate pitch perception of this population of children. The *Adapted Musical Background Questionnaire* may need to be further adapted than it was for the current study to include items about participants’ musical behaviors related to pitch, such as singing. Additionally, a full study of the reliability and validity of the *Adapted Musical Background Questionnaire* should be pursued.

Due to the ever-changing nature of cochlear-implant technology, it is essential to continue investigating relationships among pitch perceptions and variables, such as age, age at implantation, and type of speech processor/strategy, as associated with cochlear implants. Because the results of cochlear implantation are highly individualized, it is difficult to make generalizations about the success of users of cochlear implants to perceive music. Case study and collaborative research may reveal additional information that can lead to advances in training and education—both for users of cochlear implants, and for music educators are suggested. Future research questions might explore the efficacy of musical training programs for children who use cochlear implants. Additional research also may be designed to explore the perceived effectiveness of such training programs in music classrooms.

Results of cochlear implantation vary widely among users, and it is difficult to make generalizations about the pitch perceptions of the population of children who use cochlear implants. Music educators who serve children who use cochlear implants may find it beneficial to seek out their students' audiograms, if they exist. An audiogram is a visual representation of the hearing sensitivity of an individual user of a cochlear device at specific frequencies. Music educators working with children who use cochlear implants may find it helpful to communicate often with audiologists, speech pathologists, other teachers, parents, and children to determine the specific strengths and needs of students who use cochlear devices.

In the current study, although participants' pitch perceptions were most accurate on easy and difficult pitch patterns when presented by a soprano voice, participants struggled to discriminate patterns of moderate difficulty that were presented by the soprano voice. Music educators may find it beneficial to administer a musical audiogram similar to that suggested by Schraer-Joiner and Prause-Weber (2009). For example, a teacher selects a musical phrase with which the student is familiar, and then, aurally present the phrase in different registers and with different instrument timbres to determine the students' level of comfort and ability to perceive pitches. Results of future research, and attention to the individual listening characteristics of children who use cochlear implants will assist music educators in the selection of appropriate materials and instructional strategies. This information will help music educators provide satisfying and successful education in music for children who use cochlear implants.

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APPENDIX A

RECRUITMENT LETTER

Hello!

My name is Morgan Soja, (PhD student at the University of North Carolina at Greensboro). You have received this letter because your child uses a cochlear implant and I would like to learn how different instruments affect your child's ability to perceive and understand music. With this research project my goal is to help make music classes more effective for students who use cochlear implants.

Study Procedures

1. *Adapted Musical Background Questionnaire – Children's Version*
   This is a brief questionnaire containing questions relating to your child's hearing history and musical activities. While completing this questionnaire, please ask your child about their musical activities. Completing the questionnaire should require less than 30 minutes.

2. *Pitch Discrimination Test*
   This is a same-different music pairs test. The test is comprised of 36, two and three note music pairs. For example, your child will listen to a three-note pattern, and following a pause, will listen to a second three note pattern. Your child would indicate if the pairs are the same by circling a smiling face, or different by circling a frowning face. Completion of the test will take require less than 30 minutes.

What If I Have Questions?
You may contact me, Morgan Soja at any time at:
(216) 469-6529 or mcsoja@uncg.edu

What Do I Need To Do To Give Consent?
Complete and return the following:

1. "Parental Consent for a Minor" form
2. "Minor Assent" form
3. *Adapted Musical Background Questionnaire – Children's Version*

Approved IRB
3/13/14

Return to: ____

I want to help children who use cochlear implants have the best experiences with music, and I hope that this research will help inform developers of technology as well as teaching practices.

Thank you for your time,

Morgan Soja

APPENDIX B

PARENTAL CONSENT FOR MINOR FORM

UNIVERSITY OF NORTH CAROLINA AT GREENSBORO

CONSENT FOR A MINOR TO ACT AS A HUMAN PARTICIPANT

Project Title: The effect of timbre on pitch perception of elementary-aged cochlear implant users

Project Director: Morgan Soja
Dr. Patricia Sink (Faculty Advisor)

Participant's Name: ____

What is the study about?
This is a research project. Your child's participation in this project is voluntary. I would like to learn more about how different instruments affect the way children who use cochlear implants hear pitch. I would like to know about your child's involvement with music, and also test their ability to discriminate between pitch patterns played by different instruments.

Why are you asking my child?
I am asking your child because they have a cochlear implant(s) and are between 5 and 12 years old.

What will you ask my child to do if I agree to let him or her be in the study?
If you consent for your child to participate in the study, they will complete the following:

1. *Adapted Musical Background Questionnaire – Children's Version*
   This is a brief questionnaire containing questions relating to your child's hearing history and musical activities. While completing this questionnaire, please ask your child about their musical activities. Completing the questionnaire should require less than 30 minutes.

2. *Pitch Discrimination Test*
   This is a same-different music pairs test. The test is comprised of 36, two and three note music pairs. For example, your child will listen to a three-note pattern, and following a pause, will listen to a second three note pattern. Your child would indicate if the pairs are the same by circling a smiling face, or different by circling a frowning face. Completion of the test will take require less than 30 minutes.

Is there any audio/video recording of my child?
No.

What are the dangers to my child?
The Institutional Review Board at the University of North Carolina at Greensboro has determined that participation in this study poses minimal risk to participants. Your child may miss less than 30 minutes of instructional time by participating in this study. Scheduling of the test is at the discretion of your child's teacher. If your child is uncomfortable at any time, they may stop participating in the study. If you have any concerns about your child's rights, how they are being treated or if you have questions, want more information or have suggestions, please contact the Office of Research Integrity at UNCG toll-free at (855)-251-2351.
Questions about this project or benefits or risks associated with being in this study can be answered by Morgan Soja who may be contacted at (216)469-6529 or mcsoja@uncg.edu, or Dr. Patricia Sink at pesink@uncg.edu.

UNCG IRB
Approved Consent Form
Valid from:
3/13/14 to 3/12/15

Are there any benefits to society as a result of my child taking part in this research?
As a result of this research we may learn more about how children who use cochlear implants hear and process music.

Are there any benefits to *my child* as a result of participation in this research study?
No.

Will my child get paid for being in the study? Will it cost me anything for my child to be in this study?
No.

How will my child's information be kept confidential?
Consent forms will be stored in a locked file cabinet, test data will be stored on a computer with password protection, and test forms will be coded with an alpha numeric code. The master list that links coded identification information to names of participants will be stored on a password protected flash drive. All information obtained in this study is strictly confidential unless disclosure is required by law.

What if my child wants to leave the study or I want him/her to leave the study?
You have the right to refuse to allow your child to participate or to withdraw him or her at any time, without penalty. If your child does withdraw, it will not affect you or your child in any way. If you or your child chooses to withdraw, you may request that any data which has been collected be destroyed unless it is in a de-identifiable state. There are no adverse consequences to you or your child for withdrawing from the study, or for choosing not to participate in the study.

What about new information/changes in the study?
If significant new information relating to the study becomes available which may relate to your willingness allow your child to continue to participate, this information will be provided to you.

Voluntary Consent by Participant:
By signing this consent form, you are agreeing that you have read it or it has been read to you, you fully understand the contents of this document and consent to your child taking part in this study. All of your questions concerning this study have been answered. By signing this form, you are agreeing that you are the legal parent or guardian of the child who wishes to participate in this study described to you by Morgan Soja.

___________________________________ Date: ________________
Participant's Parent/Legal Guardian's Signature

UNCG IRB
Approved Consent Form
Valid from:
3/13/14 to 3/12/15

APPENDIX C

MINOR ASSENT FORM

MINOR ASSENT FORM

Study Title: The effect of timbre on pitch perception of elementary-aged cochlear implant users

My name is: Morgan Soja

What is this about?
I would like to talk to you about the way you hear music. I want to learn whether different instruments like voice, piano, or violin help you hear music.

Did my parents say it was ok?
Your parent(s)/guardian(s) said it was ok for you to be in this study and have signed a form like this one.

Why me?
I would like you to take part because you have a cochlear implant and take music classes at your school.

What if I want to stop?
You do not have to say "yes", if you do not want to take part. We will not punish you if you say "no". Even if you say "yes" now and change your mind after you start doing this study, you can stop and no one will be mad at you.

What will I have to do?
Before the test, you can help your parents answer questions about how you listen to or play music. During the test, you will listen to pairs of music sounds and circle a smiling face if they sound the same, and a frowning face if they sound different. That's it!

Will anything bad happen to me?
No.

Will anything good happen to me?
We can learn more about how people who use cochlear implants hear music.

Do I get anything for being in this study?
No.

What if I have questions?
You are free to ask questions at any time.

If you understand this study and want to be in it, please write your name below.

______________________________ ____________________
Signature of child **Date**

UNCG IRB
Approved Consent Form
Valid from:
3/13/14 to 3/12/15

APPENDIX D

ADAPTED MUSICAL BACKGROUND QUESTIONNAIRE

ID ______

Adapted Musical Background Questionnaire

Participant's Name: ____

Participant's Date of Birth: ____

At what age (in months) was your child diagnosed with hearing loss?: ____________________

Do you know the cause of your child's deafness? (check one): Yes ______ No ______

If yes, describe: ____

Did your child use hearing aids before they received a CI? (check one): Yes ______ No ______

If yes, which ear(s)? (check all that apply): Left ______ Right ______

How long did your child use hearing aid(s)? (in months): Left _______ Right_______

At what age (in months) did your child receive their first CI?: ________________________

At what age (in months) was your child's first CI activated?: ________________________

If your child has bilateral implants, at what age (in months) did your child receive their second CI?:

____

If your child has bilateral implants, at what age In months) was your child's second CI activated?:

____

What type of CI(s) does your child use?: Right_________________ Left_________________

Which speech processing strategy does your child use?: Right __________ Left ___________

On average, how many hours a day does your child use their CI(s)?: ____________________

ID ______

Have you had music classes in school? Check all that apply:

General Music

______ Kindergarten	______ 4^{th} Grade
______ 1^{st} Grade	______ 5^{th} Grade
______ 2^{nd} Grade	______ 6^{th} Grade
______ 3^{rd} Grade	

Band, Jazz Band, Orchestra

______ Kindergarten	______ 4^{th} Grade
______ 1^{st} Grade	______ 5^{th} Grade
______ 2^{nd} Grade	______ 6^{th} Grade
______ 3^{rd} Grade	

Choir

______ Kindergarten	______ 4^{th} Grade
______ 1^{st} Grade	______ 5^{th} Grade
______ 2^{nd} Grade	______ 6^{th} Grade
______ 3^{rd} Grade	

Music Lessons – Which instrument(s)?: ____

______ Kindergarten	______ 4^{th} Grade
______ 1^{st} Grade	______ 5^{th} Grade
______ 2^{nd} Grade	______ 6^{th} Grade
______ 3^{rd} Grade	

Comments: ____

____

ID ______

Do you listen to music at home?: Yes _______ No _______

Do you listen to music with friends?: Yes _______ No _______

How often do you listen to music?:

_______ Every day

_______ Almost every day

_______ 3-4 days a week

_______ 1-2 times a week

_______ 1-2 times a month

Do you watch music videos?: Yes _______ No _______

What musical activities do you like to participate in? Check all that apply:

______ Dancing ______ Listening to CDs/MP3s

______ Going to concerts ______ Listening to the radio

Other(s)? ____

____

Which style(s) of music do you like? Check all that apply:

______ Pop ______ Alternative

______ Rock ______ Jazz

______ Hard Rock ______ Country

______ Rap ______ Classical

Other(s)?: ____

____

ID _____

Are there any songs you can name just by hearing them? (Children's songs? Songs from early childhood? Songs from the radio?) If so, please list:

____

____

____

What is your favorite style of music?: ____

Who are your favorite singers or bands?: ____

____

What are your favorite songs?: ____

____

Do you have a least favorite music? If so, what is it, and why do you dislike it?: ___________

____

____

Where do you usually listen to music?: ____

____

APPENDIX E

PITCH DISCRIMINATION TEST

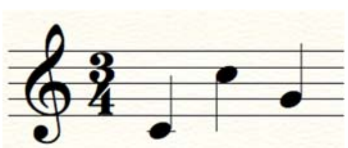
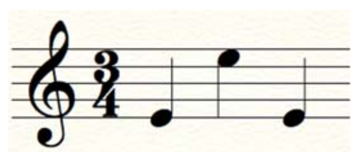
Sample Item 1 – Soprano Voice:

Sample Item 2 – Soprano Voice:

Item 1 – Soprano Voice: Easy

Item 2 – Violin: Easy

Item 3 – Piano: Easy

Item 4 – Soprano Voice: Easy

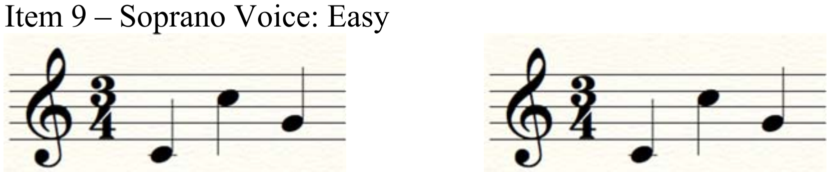
Item 5 – Violin: Easy

Item 6 – Piano: Easy

Item 7 – Piano: Easy

Item 8 – Soprano Voice: Easy

Item 9 – Soprano Voice: Easy



Item 10 – Piano: Easy

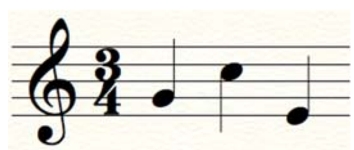
Item 11 – Violin: Easy

Item 12 – Violin: Easy

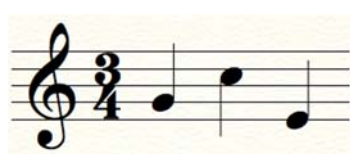
Item 13 – Soprano Voice: Moderate

Item 14 – Piano: Moderate

Item 15 – Piano: Moderate

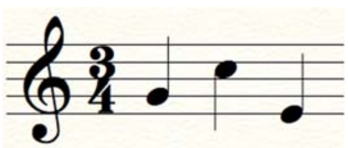
Item 16 – Piano: Moderate

Item 17 – Violin: Moderate

Item 18 – Piano: Moderate

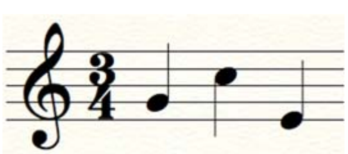
Item 19 – Soprano Voice: Moderate

Item 20 – Violin: Moderate

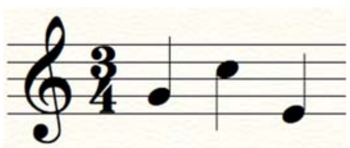
Item 21 – Violin: Moderate

Item 22 – Soprano Voice: Moderate

Item 23 – Violin: Moderate

Item 24 – Soprano Voice: Moderate



Item 25 – Soprano Voice: Difficult

Item 26 – Piano: Difficult

Item 27 – Soprano Voice: Difficult

Item 28 – Piano: Difficult

Item 29 – Violin: Difficult

Item 30 – Violin: Difficult

Item 31 – Piano: Difficult

Item 32 – Piano: Difficult

Item 33 – Violin: Difficult

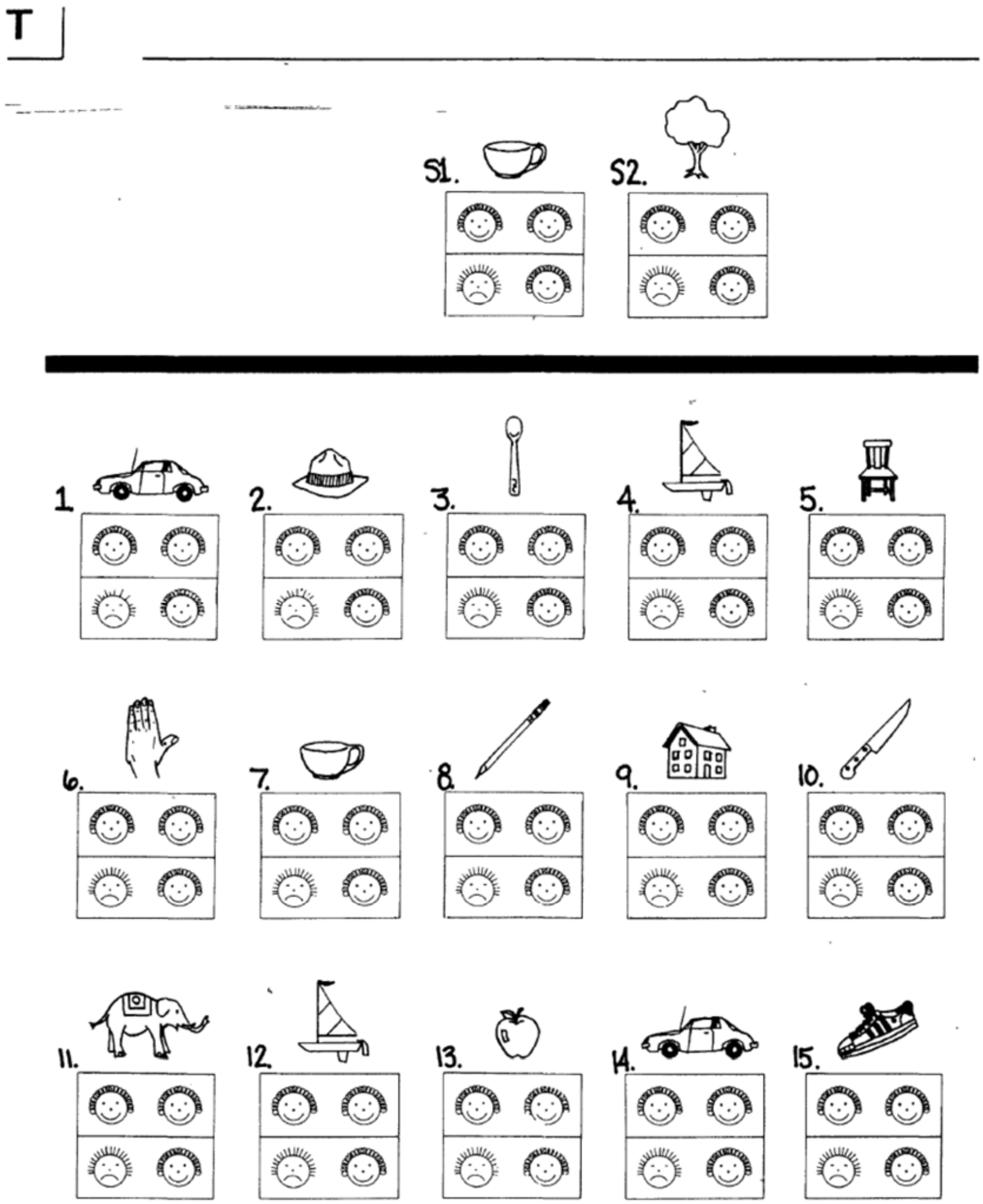
Item 34 – Violin: Difficult


Item 35 – Soprano Voice: Difficult


Item 36 – Soprano Voice: Difficult


APPENDIX F

PITCH DISCRIMINATION TEST – ANSWER SHEET



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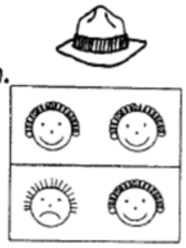

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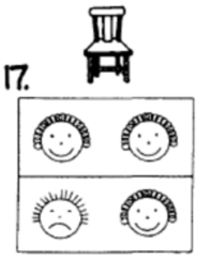

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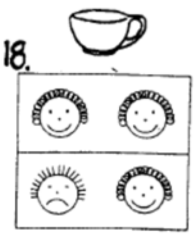

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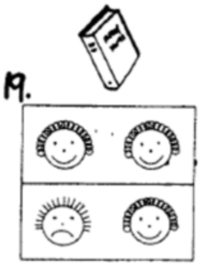

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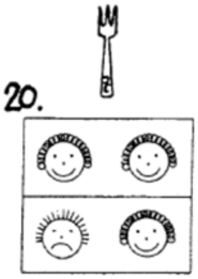

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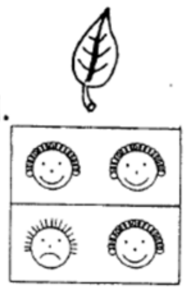

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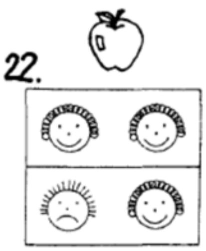

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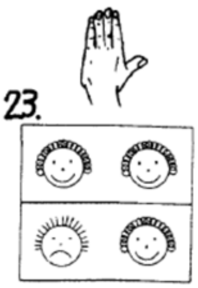

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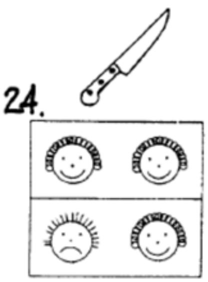

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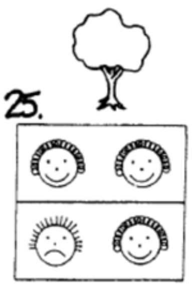

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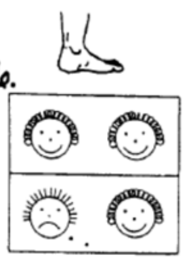

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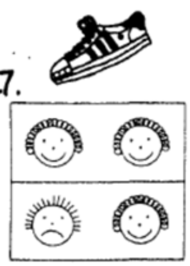

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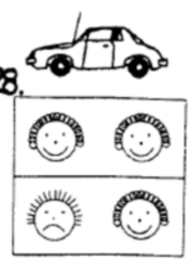

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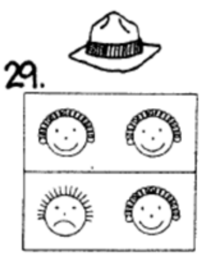

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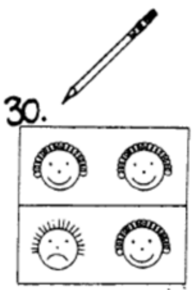

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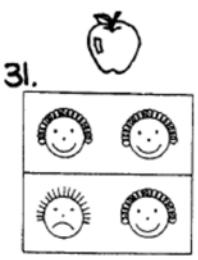

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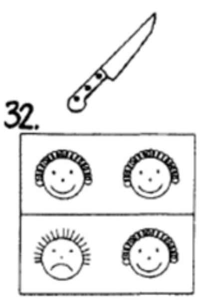

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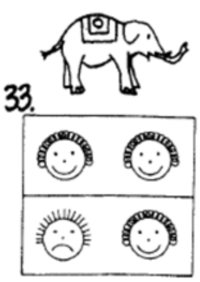

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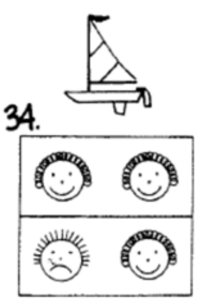

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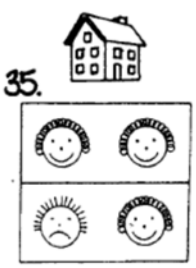

36.