FACIAL EMOTION PERCEPTION AND RECOGNITION IN ADOLESCENTS WITH COCHLEAR IMPLANTS

by

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Dedicated to the memory of my grandmother, Beverly Duvall Haas, whose faith in my ability to be successful made this journey possible.

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WITH COCHLEAR IMPLANTS

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This dissertation compares visual emotion perception and processing in adolescents with cochlear implants (CI) and adolescents with typical hearing (TH) to investigate if differences in emotion recognition underlie difficulties in social-emotional communication experienced by pediatric CI users. Collectively, this series of manuscripts examines the effect of prelingual hearing loss on the emotion perception and interpretation components of social cognition. Chapters 2 and 3 focus on the ability of adolescents with CI and adolescents with TH to interpret facial expressions of varying stimulus motion and emotion intensity levels using traditional behavioral measures of recognition. Chapter 2 (Study 1) reports findings from Warner-Czyz et al. (2019) that compared how adolescent CI users and TH peers (aged 10 ─18 years) interpret static photographs of full-intensity emotions (i.e., 100% of an expression). Adolescents with CI interpreted static photographs of expressions similarly to adolescents with TH. Chapter 3 (Study 2) examines the effect of stimulus motion (i.e., static photographs vs. dynamic video clips) and varying emotion intensity on facial expression recognition for 34 adolescents with CI and 24 adolescents with TH. Results from the static and 100% intensity dynamic trials indicated that CI and TH groups interpreted full-intensity emotions similarly, regardless of stimulus motion, and achieved better emotion recognition on trials of dynamic video clips than static photographs. Comparisons of the CI and TH group on three dynamic tasks of varying emotion intensity showed that adolescents in both groups process the lowest (60%) and highest intensity emotions (100%) similarly but quantitatively differ on trials that depict 80% of an expression. Adolescents with CI interpret more realistic, subtle expressions (i.e., 80% intensity) differently than adolescents with TH. Chapter 4 (Study 3) uses eye tracking methods to explore how adolescent CI users (n = 32) and peers with TH (n = 22) perceive emotion by measuring visual attention to the static photographs of facial expressions. These data indicate adolescents with CI and adolescents with TH demonstrate qualitatively different visual attention patterns to diagnostic facial features (i.e., eyes, mouth) during real-time emotion processing. This series of studies outlines differences in facial expression perception and recognition by adolescents with CI and peers with TH and highlights a potential link between emotion recognition abilities and the social difficulties experienced by adolescent CI users.

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CHAPTER 1

INTRODUCTION

Social cognition, or the processing of social information, encompasses a number of core skills including the ability to recognize and appropriately respond to others' feelings. Social cognitive ability plays a key role in the acquisition of social competence in young children, which in turn influences their emotional and behavioral development (Henry et al., 2015). Throughout childhood and into adolescence, typically developing children increasingly come to rely on a combination of multisensory cues from expressions and the surrounding environment in making social judgements. Difficulty identifying and interpreting such cues can delay development of social competence, affecting confidence in social skills, sense of self, and the ability to form and maintain relationships with peers (Bal et al., 2010).

Sensory deprivation, congenital or acquired, has been linked to impaired multisensory processing and emotion recognition abilities in individuals with hearing or vision loss (Dyck et al., 2004; Fengler et al., 2017). Compared to children with typical hearing (TH), children with severe-to-profound hearing loss (HL) born to hearing parents experience deficits in social understanding and demonstrate significant delays in understanding of emotions (Peterson & Siegal, 2000; Peterson et al., 2016; Sundqvist et al., 2014). Children and adolescents with HL exhibit difficulty with several aspects of social-emotional development (e.g., empathy, loneliness, emotion and behavior regulation) and experience significantly higher rates of peer victimization and social exclusion than children with TH (Fellinger et al., 2009; Schorr, 2006; Warner-Czyz et al., 2018).

For individuals with TH, facial expressions act as a foundational component of social functioning and accurate recognition of expressions plays a key role in monitoring and regulation of human social and emotional behavior. Studies examining facial emotion recognition in children and adolescents with HL who use a cochlear implant (CI) yield divergent results, but generally suggest delayed development compared to peers with TH (Hopyan-Misakyan et al., 2009; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013; Ziv et al., 2013). Several previous studies provide limited understanding of processing emotion cues in pediatric CI users due to variable sample characteristics (e.g., chronological age, implantation age, device experience, language skills) and methodology (e.g., type of behavioral measures, use of static vs. dynamic stimuli) that does not account for differences in visual perception of facial expressions. The series of studies included in this manuscript-style dissertation aim to examine the effect of auditory status and use of static and dynamic stimuli on emotion recognition and visual attention to the face using eye tracking methodology.

1.1 Emotion recognition in children and adolescents

1.1.1 Emotion recognition in children and adolescents with typical development

The ability to recognize emotion cues on the face plays a crucial role in peer social interactions that influence behavior, emotion, and academic outcomes later in life (Blair, 2003; Hoffman et al., 2015). Research has identified six primary emotions as universal because they hold similar meaning, reference, and intent across cultures: happiness, sadness, anger, disgust, surprise, and fear (Ekman, 1972; Montagne et al., 2007). The majority of emotion recognition research with children and adults to date incorporate images of between 4 to 6 of these common facial expressions.

The ability to detect and accurately interpret nonverbal emotion cues develops gradually throughout childhood and adolescence and depends on the type of emotion (Herba et al., 2006; Leitzke & Pollack, 2016). Studies assessing visual habituation and fixation to facial expressions of emotion suggest infants can discriminate, or differentiate, expressions within the first few months of life (Ludemann & Nelson, 1988; Young-Browne et al., 1977). Young-Browne and colleagues (1977) studied discrimination abilities of infants by measuring increases in fixation time to novel expressions during a habituation-recovery task. Results indicated infants as young as 3 months of age could discriminate between expressions of happiness and surprise. When habituated to static facial expressions of both happiness and fear, 7-month-old infants successfully discriminate between happy and fearful expressions and between happy faces of varying emotion intensity (i.e., mildly happy vs. very happy) (Ludemann & Nelson, 1988). Research suggests that by 10 months of age, infants discriminate between broad categories of positive valence (e.g., happiness, surprise) and negative valence emotions (e.g., anger, fear) (Ludemann, 1991), and allow the facial expressions of others to guide their own behavior by the end of the first year of life (Sorce et al., 1985).

Facial emotion recognition continues to improve in typically developing children from preschool and school-age. Children as young as two years recognize basic emotions (e.g., happiness, sadness, surprise) and continue to develop recognition of increasingly complex emotions (e.g., anger, fear, disgust) throughout childhood (Gray et al., 2001; Herba & Phillips, 2004; Philippot & Feldman, 1990). Preschoolers aged 3 to 5 years ($n = 38$) more accurately recognize expressions of happiness than fear or sadness in both static images and videotaped scenarios (Philippot & Feldman, 1990). Additionally, chronologic age also significantly affects emotion recognition accuracy, with 3-year-olds (M = 60.3%) exhibiting less accuracy than 5-year-olds (M = 82.3%) at identifying happiness, fear, and sadness. Odom and Lemond (1972) compared children in kindergarten (M = 5.7 years) to fifth grade students (M = 10.6 years) on an emotion matching task using photographs of eight facial expressions (i.e., fear, anger, joy, distress, surprise, shame, disgust, interest). The older children achieved better emotion perception outcomes than the younger children across all emotions, suggesting accuracy of recognition abilities increases through middle childhood.

In addition to developmental changes in recognition of facial expressions, the visual processing of emotion information from faces changes with age. Information about facial identity and emotion is typically gathered through either featural processing, which focuses on the individual components of a face (e.g., size of eyes, shape of the mouth, etc.), or configural processing, which utilizes spatial relationships between facial components (e.g., distance from the eyes to the mouth) (Bombari et al., 2013). Featural processing strategies, which dominate in early development, precede use of configural processing strategies in typically developing children (Mondloch et al., 2002, 2010; Herba & Phillips, 2004). Schwarzer (2000) examined the processing strategy used by children (7 and 10 years of age) and adults to categorize upright and inverted faces that varied both featurally and configurally. Both groups of children employed a featural processing strategy unaffected by the inversion of faces, whereas adults used a configural strategy negatively impacted by the inversion. Electrophysiological evaluation of emotion recognition in children and adolescents (aged 4–15 years) further supports this developmental shift in processing and suggests that processing of basic emotion expressions mimics the configural or holistic approach of adults by late adolescence (14─15 years of age) (Batty & Taylor, 2006).

In addition to chronologic age, additional factors can affect the development of facial emotion recognition including biological sex and language competence. Females are thought to have an advantage for visual emotion recognition and interpreting nonverbal emotion cues (Herba & Phillips, 2004). A meta-analysis examining sex differences in the development of facial emotion recognition found a female advantage on facial expression processing from infancy into adolescence (McClure, 2000). Biological sex had a significant effect on the performance on a dynamic facial emotion recognition task by typically developing adolescents and adults (16─45 years) (Wingenbach et al., 2018). Although sex did not affect identification of neutral expressions, females attained significantly higher levels of accuracy of facial expressions than men (Females: $M = 53.87$, $SE = 1.36$; Males: $M = 47.64$, $SE = 1.75$). These findings suggest a distinct female advantage throughout life in the identification of facial emotions when viewing dynamic expressions.

Early language competence also affects facial emotion recognition development in typically developing children (Beck et al., 2012; Rosenqvist et al., 2014). A significant yet weak positive correlation ($r = .30$, $p < .001$) exists between language (e.g., comprehension, phonological processing, word generation) and emotion recognition outcomes in preschool-age children (aged 3─6 years) (Rosenqvist et al., 2014). Beck et al. (2012) examined the relationship between facial emotion recognition abilities of 7- to 9-year-old children ($M = 7.9$, $SD = 0.7$) and measures of language competence, including receptive vocabulary, verbal fluency, literacy, narrative structure, and evaluative devices. Receptive vocabulary ($r = .32$, $p < .01$) and literacy (r

= .35, $p < .01$) moderately correlated with emotion recognition outcomes, indicating a link between language competence and emotional competence in middle childhood.

In summary, research has identified six universal emotions, and most pediatric studies incorporate between four to six of these emotions. Basic discrimination of emotion (e.g., happy vs. fear, positive vs. negative valence) begins in infancy for individuals with typical development. From toddlerhood through adolescence, children expand their abilities from discrimination to recognition and from featural to configural processing of both basic and complex emotions. Biological sex and language competence also affect recognition of facial expressions in children with typical development. For instance, better language corresponds to better emotion recognition across childhood. The aforementioned studies focus on children with typical development, without consideration of children who have an exceptionality - particularly one that affects communication, such as HL.

It is possible that children with HL could have similar performance - or even have enhanced performance - on visual emotion recognition tasks. That is, children with HL could attain equal levels of emotion recognition to hearing age-mates because the task does not explicitly require auditory input for completion. Additionally, deficits in one sensory domain (i.e., hearing) can yield compensatory improvements in the visual domain (i.e., visual motion processing) (Armstrong et al., 2002; McCullough & Emmorey, 1997), suggesting children with HL may rely more on visual information due to their lack of auditory input and achieve *better* performance than peers with TH. On the other hand, reduced auditory access to conversational speech, language deficits associated with HL, and compensatory communication strategies such as speechreading could yield poorer visual emotion recognition in these children compared to peers with TH (e.g., Gray et al., 2001).

1.1.2 Emotion recognition in children and adolescents with hearing loss

Congenital HL affects approximately 1 to 3 out of every 1,000 U.S. births (Kemper & Downs, 2000). The auditory system is heavily involved in emotion recognition as it works to analyze speech signals and identify suprasegmental cues (i.e., prosody) necessary for perceiving affect (Globerson et al., 2013). Reliance on the auditory system to transmit affect information to other cognitive systems makes multisensory emotion recognition (i.e., auditory, visual, and audiovisual) difficult for children with HL. Studies of spoken emotion recognition in children with HL who use auditory technology (i.e., CI) have found poorer performance compared to peers with TH (Hopyan-Misakyan et al., 2009; Luo et al., 2007). Despite increased access to the auditory signal, children with HL cannot detect many of the prosodic cues that characterize emotion in speech (Chatterjee et al., 2015).

In addition to receiving degraded auditory input based on a damaged auditory system and/or distorted signal from auditory technology, children with severe-to-profound HL experience less exposure to spoken language and fewer conversational opportunities to discuss thoughts and feelings with others (Moeller & Schick, 2006; Morgan et al., 2014; Rieffe et al., 2015). Deficits in hearing may also negatively influence acquisition of visual emotion recognition abilities because development of these skills relies heavily on experience with social interactions that occur in an auditory-linguistic context (Dunn et al., 1991). For children with HL, accurate perception and interpretation of nonverbal facial expression cues contribute to the success of social communication with their peers. The series of studies included in this dissertation examines the impact of delayed and degraded auditory access on the visual emotion recognition in children and adolescents with HL.

Emotion recognition in children and adolescents with hearing loss without auditory technology. Studies examining facial expression recognition in children with severe-to-profound HL who do not use auditory technology such as a hearing aid (HA) or CI report delayed or poorer emotion recognition abilities compared to children with TH. Ludlow et al. (2010) assessed the effect of auditory status (i.e., HL vs. TH) on emotion recognition performance of children (6—16 years) using a task involving black-and-white human and cartoon faces. Children in the severe-to-profound HL group did not use auditory technology. Half (n = 13) used total communication (i.e., simultaneous sign and spoken language); the remaining children communicated using sign language only (*n* = 7) or spoken language only (n = 6). The children with HL made significantly more errors (*M* = 4.96, *SD* = 1.95) when identifying emotions than children with TH matched for chronologic age (*M* = 1.97, *SD* = 1.69) or mental age (*M* = 2.21, *SD* = 1.57) (Ludlow et al., 2010). No significant effect emerged for mode of communication, indicating equivalent deficits in emotion recognition performance for children with HL using sign language and/or spoken language.

Dyck et al. (2004) examined emotion recognition in children and adolescents (6—18 years) with HL, vision loss, or with TH. Emotion recognition outcomes of children with HL (*M* = 14.44, *SD* = 4.55) and adolescents with HL (*M* = 16.94, *SD* = 2.88) were significantly poorer than children with TH (*M* = 17.73, *SD* = 3.54) and adolescents with TH (*M* = 18.83, *SD* = 2.55). In both auditory status groups, adolescents outperformed children, supporting the presence of a chronologic age effect on emotion recognition. However, comparisons between groups matched for language (i.e., verbal ability) revealed similar performance between participants with HL (M = 17.91, SD = 2.42) and the participants with TH (M = 17.79, SD = 2.29). These findings indicate that emotion recognition is positively correlated with language and verbal ability, similar to the relationship observed between language and emotion recognition outcomes for children with TH (Beck et al., 2012; Rosenqvist et al., 2014).

Previous studies of children with severe-to-profound HL born to hearing parents report impaired performance in other social cognition skills such as theory of mind (Peterson & Siegal, 2000). However, Ziv et al. (2013) suggests such deficits may arise from limited exposure to mental state conversations. Ziv and colleagues examined emotion recognition in a group of native signers or children with HL of deaf parents who communicate fluently with sign language. The children with HL (aged 5—7 years) achieved emotion recognition outcomes similar to peers with TH on labeling and pointing tasks with color photographs of happy, sad, angry, and fearful expressions. This result suggests a potential benefit of shared mode of communication between children with HL and their family, which may provide these children more frequent exposure to the language and mental state conversation necessary for development of emotion recognition (Peterson & Siegal, 1995; Ziv et al., 2013).

Just as in children with TH and typical development, children and adolescents with HL who do not use auditory technology improve their emotion recognition abilities as a function of chronologic age. However, the group with HL exhibits deficits in emotion recognition compared to age-matched peers with TH. Dyck et al. (2004) questioned if the difference by auditory status was confounded by language skills, leading to comparisons in children with and without HL matched on language ability. Children with HL performed similarly to hearing peers when matched for language ability, echoing findings in TH children that better language levels coincide with better emotion recognition. Exposure to language - especially language centered on mental state and emotion - also may bolster emotion intelligence and, subsequently, emotion recognition.

The studies in this section include children with HL who do not use auditory technology such as a hearing aid or a CI. Outcomes in children who do and do not use auditory technology might mirror each other because the HL introduces a distorted signal (even with a hearing aid or CI) compared to typical auditory sensitivity, which could have persistent effects in unaided (i.e., no auditory technology) or aided (i.e., hearing aid or CI) listening conditions. In contrast, children who use CIs may differ from peers who do not use auditory technology due to improved auditory access to the speech signal to intensities approximating typical hearing sensitivity and better-spoken language skills, particularly for those using oral communication modes.

Emotion recognition in children and adolescents with hearing loss who use cochlear implants. For children with severe-to-profound sensorineural HL who do not receive adequate benefit from using a HA, a CI is a promising alternative form of intervention. A CI is a biomedical device that consists of external components, a microphone and a sound processor, and an electrode array surgically implanted in the cochlea. Sound is collected via the microphone and coded for intensity, duration, and frequency by the sound processor. The coded signal is then transmitted transdermally to an electrode array that directly stimulates the auditory nerve, which then transmits the signal to higher auditory pathways in the brain. However, the signal provided by a CI is more distorted and degraded than the input delivered by the auditory system of a child with TH.

Research has shown that children with CIs can use the auditory input received through the device to learn and develop spoken language, though outcomes remain highly variable, ranging from pre-lexical vocalizations to language skills on par with hearing peers (Connor et al., 2006; Holt & Svirsky, 2008; Schramm et al., 2010; Tobey et al., 2013). Several studies report only half of the children implanted before three years of age achieve language outcomes within normal limits by eight to ten years post-implantation (Geers et al., 2016; Hare et al., 2019; Nittrouer et al., 2018). As previously discussed, language outcomes influence the development of emotion recognition abilities in typically developing children and adolescents (Beck et al., 2012; Rosenqvist et al., 2014). It is important to examine whether auditory status affects development of facial emotion recognition in children and adolescent CI users similarly to the impact observed in language development.

Studies of facial emotion recognition abilities across a broad age range of pediatric CI users yield variable and inconclusive findings. Younger children with CI exhibit delayed performance in recognition of four basic emotions (i.e., happiness, sadness, anger, and fear) relative to chronologically age-matched children with TH (Most & Michaelis, 2012; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013). Wang et al. (2011) compared facial emotion recognition abilities of preschool-age children with CI (n = 5; 2.3—3.5 years old) and HA (n = 11; 2.2—6.0 years old) to those of peers with TH (n = 16; 2.3—5.8 years old) on a task with black-and-white or colored photographs of human faces. Across trials of happy, sad, angry, and fearful faces, children with CI (M = 2.00, SD = 1.87) and children with HA (M = 4.36, SD = 2.77) demonstrated poorer emotion recognition than peers with TH (M = 6.81, SD = 2.14). Similarly, pediatric CI users (n = 57) ranging from 2.5 to 5 years of age exhibited deficits on tasks of facial emotion recognition and emotion attribution compared to age-matched children with TH (*n* = 52) (Wiefferink et al., 2013). Analysis revealed a significant main effect of group on both verbal tasks, indicating auditory status affects emotion recognition and understanding outcomes for young children. The trend of delayed performance on emotion recognition continues in kindergarten-age CI and HA users (*n* = 22; aged 2.5—7.0 years) who achieved poorer accuracy than peers with TH (*n* = 22; aged 2.8—6.4 years) when identifying happiness, sadness, anger, and fear from color images of facial expressions (Wang et al., 2016). Most & Michaelis (2012) also reported significantly poorer emotion recognition abilities in children with HL that used a CI and/or HA (*n* = 26; *M* = 68.38, *SD* = 15.22) compared to children with TH (*n* = 14; *M* = 77.38, *SD* = 18.42) when tested between four and six years of age.

Other studies provide evidence of similar facial emotion recognition performance in children and adolescents with and without HL. Ziv et al. (2013) examined performance of children with CI (*n* = 20) who communicated via spoken language and children with TH (*n* = 23) aged five to seven years (CI: *M* = 6.6 years, *SD* = 0.7; TH: *M* = 5.1 years, *SD* = 0.6) on an emotion identification task with six emotions (i.e., happiness, sadness, anger, fear, surprise, and disgust). No significant difference in emotion identification outcomes emerged based on auditory status. School-age children with CI (*n* = 18; aged 7—13 years old) also achieved accuracy levels similar to those of age- and sex-matched children with TH (*n* = 18) on tasks of emotion recognition from speech and facial expressions (Hopyan-Misakyan et al., 2009). The lack of significant difference in emotion recognition outcomes may reflect the longer experience using the CI (*M* = 7.2 years, *SD* = 1.3) compared to previous research. Equivalent emotion recognition skills between adolescents with CI (*n* = 10) and adolescents with TH (*n* = 10) aged 10 to 18 years old also were observed in Most & Aviner (2009). The findings across these studies suggest potential improvement in emotion recognition abilities with maturation and increased duration of device experience.

When younger and tested on four emotions, the CI group lags behind TH peers. When older, children and adolescents with CI close the gap and attain emotion recognition abilities akin to peers with TH - not only on basic emotions, but also more complex emotions. Recognition of basic and complex emotions improves as a function of chronologic age, regardless of auditory status, likely due to expanded language capacity and real-world social interactions. For the children and adolescents who use CIs, the ability to close the gap also may reflect the age at implantation and duration of device experience. Younger age at implantation and longer duration of device use both coincide with more advanced language skills, which can have cascading effects on the number of opportunities to interact with peers and family and to talk about emotions - experiences that underlie development of emotional intelligence and theory of mind (Mancini et al., 2016).

1.2 Methodological issues in emotion recognition

While a potential pattern of continued development of facial emotion recognition has been observed, several methodological limitations constrain the ability to draw conclusions across studies. The majority of studies have smaller sample sizes (i.e., fewer than 25 per group) and include groups with a wide variation of participant characteristics (e.g., broad range of chronological age, implantation age, device experience, language skills, etc.). Additionally, variation in the measurement of emotion recognition (e.g., accuracy, reaction time, visual attention) and the presentation-style of the stimuli (i.e., static, dynamic) can affect interpretation of the results.

1.2.1 Behavioral measures of emotion recognition: Accuracy and reaction time

The majority of studies investigating emotion recognition in children and adolescents with CI focus on accuracy as the dependent variable. By this measure, pediatric CI users experience an initial delay in emotion recognition accuracy but improve with continued development (Hopyan-Misakyan et al., 2009; Most & Aviner, 2009; Most & Michaelis, 2012; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013). Accurate recognition of facial expressions is key for successful social communication. However, this type of measure is global (i.e., correct or incorrect) and does not assess potential subtle differences in the development of emotion recognition abilities between children and adolescents with CI and peers with TH.

To our knowledge, no studies have examined emotion recognition in pediatric CI users by analyzing reaction time (RT). This could serve as a more sensitive measure to detect subtle differences in the perception of facial expressions between children with CI and children with TH (De Sonneville et al., 2002; Herba & Phillips, 2004). Studies that have examined RT of facial emotion recognition in children and adults with TH have investigated the effect of age and emotion type (De Sonneville et al., 2002; Wells et al., 2016). School-aged children with TH (7—10 years old) were significantly slower to identify facial expressions than adults (aged 21—41 years), indicating an increase in the speed of emotion recognition with age (De Sonneville et al., 2002). In general, positive emotions (i.e., happiness) are recognized as the fastest and negative emotions (i.e., anger, fear) the slowest for children and adults with TH (De Sonneville et al., 2002; Wells et al., 2016).

To gain a thorough understanding of emotion processing and recognition, and to potentially detect subtle differences between participants, it is necessary to examine multiple outcome variables such as simultaneous exploration of accuracy and RT. Though the addition of RT would expand upon previous research in children and adolescents with CI, traditional behavioral measures (i.e., accuracy, RT) do not provide information about the processes that underlie emotion recognition.

1.2.2 Stimulus type in emotion recognition: Static and dynamic stimuli

Many studies of facial emotion recognition have employed some form of static stimuli (e.g., drawings, cartoon faces, human faces). Static images and photographs typically represent distinct and recognizable peaks of facial emotion expressions (Atkinson et al., 2004; Jones et al., 2017). Tasks that incorporate static images provide a measure of whether or not children can accurately identify or name a facial expression at full-emotion intensity. To date, most of the studies examining emotion recognition in children and adolescents with CI and TH use static images or photographs (Hopyan-Misakyan et al., 2009; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013; Ziv et al., 2013). Results from these studies reveal young children with CIs are less successful at identifying emotions than children with TH but improve to achieve comparable results with maturation. However, studies examining only isolated, static images of facial expressions are limited in applicability to real-world social communication. Effective and efficient social communication often requires the perception and interpretation of dynamic emotion cues expressed through changes in facial musculature, movement of features, and body language (Jones et al., 2017). The inclusion of only static stimuli may cause researchers to miss out on key information for understanding the development of social cognition skills (Nelson & Mondloch, 2018).

Dynamic stimuli – moving facial expressions – hold more ecological validity for the movement and temporal cues of expressions that are encountered during social communication (Jones et al., 2017). Adults demonstrate better emotion recognition outcomes and greater activation in the areas of the brain associated with social and affect information (i.e., superior temporal sulci, amygdala) when examining dynamic facial expressions (Kessler et al., 2011; Kilts et al., 2003). Nelson & Mondoch (2018) examined the effect of motion on looking patterns of younger children (*M* = 5.0 years; *SD* = 0.6), older children (*M* = 8.9 years, *SD* = 0.5), and adults (*M* = 19.3 years, *SD* = 1.4). Participants viewed whole-person, face-only, or body-only videos of a woman with varied facial and postural emotion expressions, presented in a static and dynamic version. When expressions were dynamic, all three groups demonstrated longer fixations to the head regardless of whether the face was visible (i.e., whole-body, face-only) or obscured (i.e., body-only). The same looking pattern was not observed for the static stimuli, suggesting that visual attention during emotion perception depends largely on movement of facial features.

Jones et al. (2017) examined the effect of dynamic cues and facial intensity on emotion recognition in children with HL who preferred to communicate in either Sign Supported English or British Sign Language. Compared to children with TH, children with HL (aged 6─12 years) were poorer at recognizing static facial expressions, but the groups did not differ on trials with dynamic faces. Additionally, both groups showed improvements in emotion recognition with increasing emotion intensity. These results suggest that children with HL who sign and children with TH can better identify emotions when expressions are dynamic regardless of the intensity of the expression (Jones et al., 2017). Use of sign language by the children with HL may have assisted in their emotion recognition performance on dynamic trials. Sign language uses facial expression movements to communicate information about both emotion and language (i.e., markers of grammar, semantics, prosodic changes) (Corina & Singleton, 2009; Ludlow et al., 2010).

The majority of studies of emotion recognition in children and adolescents employ static stimuli, either as a photograph or drawing. While static stimuli may represent an easier methodology to implement, replicate, and compare across studies, they do not capture the natural dynamic aspects of facial expressions. Dynamic video clips of facial expressions afford insight into subtle changes in facial expressions over time and offer a more ecologically valid assessment of emotion recognition. Expected issues related to the effect of motion (i.e., static photograph vs. dynamic video clip) on emotion recognition persist across a wide range of ages in individuals with TH and typical development, but few examine both static and dynamic stimuli within the same participants in the same study (citation). No studies to date have directly compared static and dynamic emotion recognition or the effect of varying expression intensity in children with CIs that use spoken language to communicate.

1.2.3 Behavioral measures of emotion recognition: visual attention to the face

Social information, including emotion and language cues, can be gathered by attending to different regions of the face. Visual attention to the face is allocated based on communicative need or what sensory information is most useful during a social interaction. Lewkowicz and Hansen-Tift (2012) examined how chronological age impacted a typically developing infant's visual attention to a communication partner's face. Four-month-old infants demonstrated a preference for attending to a speaker's eyes. Around six months of age, infants begin to shift attention between the eyes and the mouth and showed a bias of longer fixation to the mouth at eight months of age. Greater attention to the mouth region of a face at 6months of age was related to higher expressive language outcomes and increased vocabulary at 24 months of age (Young et al., 2009). Infants demonstrated shared visual attention to the speaker's eyes and mouth while viewing a communication partner's face by 12 months of age (Lewkowicz & Hansen-Tift, 2012; Smith et al., 2013). This shifting pattern of visual attention to a speaker's face during the first year of life coincides with the development of other language and cognitive milestones. The shift in attention between the eyes and mouth occurs when infants begin speech production, or canonical babbling, in addition to speech perception (i.e., 6 months of age) (Lewkowicz & Hansen-Tift, 2012; Oller, 2000). As infants become experts in their native language, greater visual attention is given to the eyes which provide social information that is key to future cognitive development (Langton et al., 2000).

A similar pattern of shifting gaze to the mouth region for speech perception cues is observed in adults, particularly when the auditory signal is obscured due to environmental noise (Vatikiotis-Bateson et al., 1998). Lansing and McConkie (1999) investigated the visual attention of adults with TH (aged 19–28 years) to facial cues in the upper and lower half of the face when presented with prosodic or segmental information. When shown audiovisual speech adults recorded greater proportion of gaze duration to the lower half of the face (Lower: $M = 0.45$, $SEM = 0.05$; Upper: $M = 0.09$, $SEM = 0.02$) for segmental information and to the upper half for intonation cues (Lower: $M = 0.28$, $SEM = 0.04$; Upper: $M = 0.34$, $SEM = 0.04$). The authors proposed that adults with TH use facial cues from the eye region of the face to gain information about prosody and the mouth region for speech understanding (Lansing & McConkie, 1999).

For children and adolescents with HL, frequent fixations to the bottom half of the face may be necessary to obtain the visual and auditory cues necessary for social communication. Children with severe-to-profound HL experience degraded access to or loss of auditory information and depend more on visual, nonverbal cues during social interaction, such as speechreading or lip-reading (Ambert-Dahan et al., 2017). Speechreading is a compensatory strategy commonly implemented by individuals with HL to understand spoken language in difficult or noisy communication situations. It has been proposed that children with HL might miss affect information expressed in the eyes because they are more inclined to look at the mouth for speechreading when interacting with peers (Rigo & Liberman, 1989). Delayed and degraded access to the auditory signal for HA and CI users that communicate via spoken language may result in greater reliance on speechreading, and therefore visual attention to the mouth, to assist communication.

Adults with HL show different patterns of visual attention to the face when processing emotions (Letourneau & Mitchell, 2011), but research on visual processing of facial expressions in children with HL is limited. Wang et al. (2017) investigated gaze patterns in preschool-age children with HA to the top and bottom halves of faces during auditory-visual presentation of congruent and incongruent expressions of neutral and positive emotions. Children with HA demonstrated fewer fixations to the top portion of the face than children with TH after auditory presentation of congruent or incongruent affect. This indicates a preference for looking at the lower portion of the face when an oral statement is made, potentially due to difficulty understanding spoken language even with the improved signal provided by a HA (Wang et al., 2017).

Visual attention to the face changes based on which communication information requires processing (e.g., social, segmental, speech recognition). Differential looking patterns emerge in infancy, with attention to the eyes and mouth aligning with milestones for language and social development. Adults also demonstrate distinct visual attention patterns based on communication goals as a compensatory strategy to look at the mouth to accommodate poorer auditory signals in the presence of competing noise. Individuals with HL across the age span may follow a similar compensatory strategy to direct visual attention to the lower part of the face for speechreading cues to enhance comprehension of the speaker's signal, and away from the upper part of the face (e.g., the eyes) that provide social-emotional cues. Although Wang et al. (2017) investigated visual attention to the face in children with HL, their study included young children with HL who use hearing aids performing a discrimination task. No studies to date have compared visual attention to the eye and mouth regions of the face in identifying emotions in adolescents with HL using CIs and adolescents with TH.

1.3 Purpose of the dissertation

No studies to date examine basic and complex facial expressions in a contemporary sample of adolescents with CI using a variety of measures such as accuracy, reaction time, and visual attention to the face. The purpose of this manuscript dissertation is to expand our understanding of how early auditory deprivation impacts the emotion processing aspect of social cognition in adolescents with CI and shape therapeutic intervention focused on social communication. This dissertation considers the role that emotion recognition delays could play in social and emotional communication and aims to detect subtle differences in emotion processing not examined in previous research. Using a combination of traditional behavioral and innovative eye tracking methodologies, this dissertation examines how emotion recognition abilities are influenced by: (a) auditory status (i.e., CI vs. TH), (b) emotion type (i.e., happiness, sadness, anger, fear, surprise, disgust) and intensity, (c) stimulus motion (i.e., static vs. dynamic), and (d) visual attention to diagnostic facial regions (i.e., eye, mouth, other).

1.4 Dissertation objectives

1.4.1 Study 1: Static emotion recognition

Chapter 2 reports the findings from Warner-Czyz et al. (2019) that examined the static emotion recognition abilities in adolescents with CI and with TH. Previous studies have investigated behavioral accuracy of emotion recognition across a heterogeneous sample of pediatric CI users (i.e., broad age range, implantation age, device experience, sign vs. spoken communication), report divergent results, and may not capture subtle differences in the temporal aspect of emotion perception. Warner-Czyz et al. (2019) fills this gap in current literature by comparing concurrent measures of accuracy and response time of static facial emotion recognition by adolescents who use CI and adolescents with TH. The first aim of the study was to provide a baseline assessment of emotion recognition abilities to determine whether adolescent CI users and peers with TH achieve different or comparable performance. The second aim of the study was to provide a more comprehensive understanding of facial emotion recognition abilities in adolescents with CI using a measure of response time to examine speech of recognition. Warner-Czyz et al. (2019) has been published in *Cochlear Implants International*.

1.4.2 Study 2: Dynamic emotion recognition

This study (Chapter 3) examines the role of stimulus motion and the intensity of emotion in recognition of facial expressions by adolescents with CI and adolescents with TH. Previously published work assessed emotion recognition abilities using static visual or audiovisual stimuli that fails to encompass the complexities of real-time facial processing. This study is one of the first to investigate how auditory status and use of spoken language impacts recognition of dynamic facial expressions using video clips that more accurately reflect real-life expressions. Objectives of this paper include: (a) examining the effects of auditory status and emotion type on recognition abilities, (2) determining the ecological validity of static versus dynamic stimuli to inform clinical intervention, (3) investigating the amount of facial expression intensity necessary for accurate recognition.

1.4.3 Study 3: Visual attention to facial expressions

This study (Chapter 4) examines visual attention to facial expressions during an emotion recognition task for adolescents with CI and adolescents with TH. Research on emotion recognition in pediatric CI users focused on global behavioral measures of accuracy that are limited and unable to assess the emotion processing. Previous studies have indicated that children and adults with HL attend more to the lower part of the face during emotion recognition (Letourneau & Mitchell, 2011; Wang et al., 2017). This study will explore visual processing of facial expressions by adolescents with CI and adolescents with TH using eye tracking technology to record eye gaze during an emotion recognition task. The first objective of this paper is to determine whether auditory status and use of spoken communication affects visual attention to diagnostic features of the face typically responsible for expression of emotion (i.e., eyes, mouth).

The second objective of this study is to examine visual processing of facial expressions during stimulus presentation using time course plots of fixations by adolescents with CIs and adolescents with TH. Comparing eye tracking outcomes between these groups will allow us to examine real-time emotion processing and determine how visual attention to the face impacts emotion recognition abilities of children and adolescents with CIs.

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CHAPTER 2

EFFECT OF AUDITORY STATUS ON VISUAL EMOTION RECOGNITION IN ADOLESCENTS[1]

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2.1 Abstract

Adolescents with severe to profound hearing loss who wear cochlear implants (CIs) experience significantly more peer problems compared to peers with typical hearing (TH). Differences in peer social dynamics may relate to perception not only of message content, but also message intent based on a speaker's emotion from visual (e.g., facial expressions) and auditory (e.g., prosody) cues. Pediatric CI users may experience greater difficulty with auditory emotion recognition due to an impoverished signal representation provided by the device, but the effect of auditory status on visual emotion recognition yields conflicting results. Objectives: The current study examined accuracy and speed of visual emotion recognition in adolescents with CIs and peers with TH. Methods: Participants included 58 adolescents (10-18 years) stratified by auditory status: 34 CI users and 24 TH peers. Participants identified the intended emotion (i.e., happiness, sadness, anger, fear, disgust, and surprise) of static images of faces displayed on a computer screen. Results: No significant differences by auditory status emerged for response accuracy, response time to all trials, or response time to correct trials. Type of emotion significantly affected both accuracy and response time. Conclusion: Adolescents with CIs show similar accuracy and response time in recognizing static facial expressions compared to TH peers. Future studies should explore the association between visual emotion recognition and social well-being to determine the relationship between emotion recognition and overall quality of life in adolescents with CIs.

2.2 Introduction

Effective social interaction requires detection and interpretation of the feelings and intent of other individuals using sensory cues provided via auditory and visual modalities (Batty & Taylor, 2006; Gray, Hosie, Russell, & Ormel, 2001). Cues provided through facial expressions serve a foundational component of social interaction and communication. Individuals with significant hearing loss adapt to the loss of auditory cues by depending more on the visual information provided during social interactions, such as lip reading or speechreading (Ambert-Dahan et al., 2017). This strategy draws attention to the speaker's mouth versus the speaker's eyes, which may inhibit perception of emotional cues conveyed by the eyes. Deficits in accurate identification of emotion can result in cascading developmental delays in social competence and affect future behavioral, emotional, and academic outcomes (Hoffman, Quittner, & Cejas, 2015).

Historical and recent research suggests adolescents with severe to profound hearing loss wearing cochlear implants (CIs) experience significantly more peer problems, lower peer acceptance, and higher rates of peer victimization than age-matched peers with typical hearing (TH) (Huber et al., 2015; Kouwenberg, Rieffe, Theunissen, & de Rooij, 2012; Moeller, 2007; Warner-Czyz, Loy, Pourchot, White, & Cokely, 2018; Wiefferink, Rieffe, Ketelaar, & Frijns, 2012). These disparities in social interaction may reflect difficulties perceiving linguistic cues (i.e., message content) or paralinguistic information (i.e., message intent conveyed via visual cues such as facial expressions or auditory cues such as prosody). Pediatric CI users likely experience greater difficulty perceiving auditory emotion recognition due to an impoverished signal representation provided by the device. Few studies have examined the effect of auditory status on visual emotion recognition, and those that have explored this topic yield conflicting results (Hopyan-Misakyan, Gordon, Dennis, & Papsin, 2009; Most & Aviner, 2009; Most & Michaelis, 2012; Wang, Su, Fang, & Zhou, 2011; Wiefferink, Rieffe, Ketelaar, De Raeve, & Frijns, 2013). The present study examines the effect of auditory status (i.e., CI versus TH) on accuracy and speed of visual emotion recognition in adolescents.

2.2.1 Accuracy of visual emotion recognition in children

Children with TH and typical development successfully identify visually-expressed happiness, sadness, and fear by 2 years of age, followed by steady development of recognition of angry, disgusted, and surprised facial expressions (Batty & Taylor, 2006; Gray et al., 2001; Herba, Landau, Russell, Ecker, & Phillips, 2006). For example, Batty and Taylor (2006) evaluated visual emotion recognition electrophysiologically in 82 children between the ages 4 to 15 years. Results show systematic emergence of facial expression recognition, with detailed processing of basic emotions approximating adult performance in late adolescence (14 to 15 years of age). However, mature processing patterns do not completely develop until later in life.t

Development of emotion understanding, and recognition occurs in an auditory-linguistic context and depends on interactions with parents and peers. Sensory deficits such as hearing loss underlie well-documented delays in language development and verbal ability early in life, which may contribute to subsequent delays in development of emotion recognition abilities (Herba & Phillips, 2006; Ketelaar, Rieffe, Wiefferink, & Frijns, 2013; Most & Aviner, 2009). Deaf children who do not use auditory technology have delayed or poorer emotion recognition abilities than TH peers (Gray et al., 2007). For instance, Dyck et al. (2004) examined recognition and understanding of emotion among age-matched children and adolescents (6 to 18 years of age) with no sensory deficits, hearing loss, or vision impairment. The group with hearing loss displayed significant deficits on both the emotion recognition and understanding tasks compared to age-matched peers with no sensory deficits. However, the group with hearing loss appears to improve performance with age such that adolescents with hearing loss attain higher scores on both emotion recognition and emotion understanding tasks compared to children with hearing loss. These findings suggest lack of access to auditory information due to hearing loss results in delays in emotion recognition and understanding throughout childhood and adolescence (Dyck et al., 2004).

Several studies examine the effects of earlier access to auditory information in children with hearing loss using cochlear implants (CIs) on emotion recognition abilities in multiple modalities (Hopyan-Misakyan, Gordon, Dennis, & Papsin, 2009; Most & Aviner, 2009; Ziv, Most, & Cohen, 2013). Children with severe-to-profound sensorineural hearing loss (71 dB HL or greater) who do not receive adequate and appropriate benefit from hearing aids (HAs) are potential candidates for a CI as an alternative intervention. A CI is a biomedical device that provides the sensation of sound via electrical stimulation to the auditory nerve. A CI collects sound via a microphone; codes the signal for intensity, frequency, and duration; then transmits the signal transdermally to an electrode array surgically implanted in the cochlea. This electrode array directly stimulates the spiral ganglion cells of the auditory nerve, which transmit the signal to higher auditory pathways. The auditory signal delivered through a CI is distorted and degraded compared to the signal experienced by listeners with TH. Pediatric CI users can learn to interpret the degraded auditory input provided by the implant to develop better auditory perception and language skills, though vast variability exists in communication performance, ranging from pre-lexical vocalizations to language skills within normal limits (Holt & Svirsky, 2008; Tobey et al., 2013).

Some studies report delays in visual emotion recognition for children with CIs or HAs between 2 and 7 years of age compared to age-matched TH peers (Most & Michaelis, 2012; Wang, Su, Fang, & Zhou, 2011; Wiefferink, Rieffe, Ketelaar, De Raeve, & Frijns, 2013). Wang et al. (2011) examined accuracy of preschool children with CI and/or HA (*n* = 16) versus TH (*n* = 16) on a facial emotion recognition task using black and white photographs of happy, sad, fearful, or angry expressions. Children in the TH group significantly outperformed peers in the CI and HA groups, achieving higher identification accuracy for all four emotions. Wiefferink et al. (2013) also reported emotion recognition deficits among children with CI compared to TH peers between 2.5 and 5 years of age. Children with CI exhibited significantly lower accuracy than TH children across all measures of emotion recognition and understanding, suggesting that the negative effects of hearing loss on emotion identification remain despite the additional auditory input provided by a CI. Kindergarten-age children with hearing loss using a HA or CI display developmentally delayed performance on both emotion labeling and emotion matching tasks compared to the performance of age- and gender-matched TH peers (Wang, Su, & Yan, 2016). Although poor perception of emotion in the auditory modality likely relates to the degraded auditory signal delivered through CIs, the cause of poorer performance by CI users occasionally seen in the visual modality does not have a clear explanation (Most & Peled, 2007).

Older children and adolescents with CIs show a developmental progression of emotion recognition abilities. Hopyan-Misakyan et al., (2009) report that school-aged children (7-13 years) with long-term experience using a right unilateral CI (*M* = 7.2 years, *SD* = 1.3 years) achieve similar levels of success in recognizing emotions from facial expressions as age- and gender-matched TH children. Most and Aviner's (2009) comparison of visual emotion recognition performance for adolescents (10 to 18 years of age) with early- or late-implanted CIs, HAs, or TH mirrors Hopyan-Misakyan et al.'s results with school-aged children such that auditory status did not influence accuracy outcomes on a visually-based facial emotion recognition task. However, the CI and HA groups show poorer performance than the TH group on the auditory recognition task. The authors conclude that the information provided by CI technology is not sufficient for accurate auditory emotion recognition but does provide benefit in the visual modality (Most & Aviner, 2009).

Several studies report that the type of emotion also influences recognition accuracy. Results across studies follow a similar pattern such that children and adults identify *happy* most accurately and negative emotions, such as *fear*, least accurately regardless of auditory status (i.e., CI or TH), on tasks of visual emotion recognition (Hopyan-Misakyan et al., 2009; Most & Aviner, 2009; Wang et al., 2016).

In summary, children identify happy and sad expressions earliest and most accurately. Identification and recognition of more complex facial expressions (e.g., anger, surprise, and disgust) develops later in childhood. This pattern holds true regardless of auditory status, although children with hearing loss wearing CIs develop emotion recognition on a slower trajectory relative to hearing peers. Only one study to date has focused on adolescents with hearing loss, but no studies exclusively have examined visual emotion processing in adolescents with CI.

2.2.2 Speed of visual emotion recognition in children

Accuracy of recognition represents one way to measure emotion recognition; speed of recognition, or *response time*, affords another metric to evaluate emotion recognition. Response time could act as a more sensitive measure than accuracy of emotion recognition and could detect perceptual differences in the processing of emotional facial expressions between populations. Few studies have explored response time in visual emotion recognition tasks. Those that do focus on the effect of type of emotion on response time. For instance, De Sonneville et al. (2002) report faster response time for positive emotions (e.g., happiness) than negative emotions (e.g., anger, sadness, fear) for typically developing children and adults. Likewise, Wells, Gillespie, & Rotshtein (2016) described faster, more accurate responses for happy facial expressions and slower, less accurate responses for fearful facial expressions from adult participants on a visual emotion recognition task. To date, no studies have examined the effect of auditory status or auditory technology such as CIs on response time in an emotion recognition task.

2.2.3 Purpose of this study

The lack of information about concurrent accuracy and response time for recognition of facial expressions by adolescents with CI represents a gap in the literature that could inform social problems and peer relationship issues often reported by adolescents with hearing loss. The current study investigates accuracy and speed of visual emotion recognition in adolescents with CI and TH peers to address the following research questions:

(1) What is the effect of auditory status (i.e., CI versus TH) and emotion type (i.e., happiness, sadness, anger, fear, surprise, and disgust) on the accuracy of visual emotion recognition in adolescents?

(2) What is the effect of auditory status (i.e., CI versus TH) and emotion type (i.e., happiness, sadness, anger, fear, surprise, and disgust) on overall response time during a visual emotion recognition task in adolescents?

(3) What is the effect of auditory status (i.e., CI versus TH) on response time for accurately identified emotions on a visual emotion recognition task in adolescents, as assessed for individual emotion types (i.e., happiness, sadness, anger, fear, surprise, and disgust)?

(4) Which demographic (e.g., chronologic age) and audiologic variables (e.g., age at implantation) coincide with accurate emotion recognition in adolescents with TH and adolescents with CI?

2.3 Methods

2.3.1 Participants

Participants include 58 adolescents between 10 and 18 years of age. All participants used spoken language as the primary mode of communication, had normal or corrected vision, and had normal oral and speech motor abilities. Most participants identified as Caucasian (CI: 76.5%; TH: 70.8%) and non-Hispanic or Latino (CI: 94.1%; TH: 95.8%).

Adolescents with CI. Thirty-four participants (20 female, 14 male) had a hearing loss and wore at least one CI. Age at time of testing for the CI group ranged from 9.4 to 17.9 (M = 13.3, SD = 2.2). Identification of hearing loss for all participants in the CI group occurred before 4 years of age (M = 1.08, SD = 1.2). Mean age at first implantation was 2.9 years (SD = 2.2, range: 0.6-10.0 years). Duration of CI experience ranged from 1.9 to 16.6 years (*M* = 10.4, *SD* = 3.1). Most CI recipients employed a bilateral device configuration, either bilateral CI (76.5%) or a CI + contralateral HA (11.8%).

Adolescents with TH. The remaining 24 participants (9 females, 15 males) had hearing sensitivity within normal limits per parent report. Adolescents in the TH group ranged in age from 10.0 to 18.6 (*M* = 13.7, *SD* = 2.5).

The current study compiled data from protocols approved by the Institutional Review Board at The University of Texas at Dallas (IRB #11-11 and 13-50). All participants with CIs were recruited from the Colorado Neurological Institute's (CNI) Cochlear Kids Camp in Estes Park, Colorado. The TH adolescents were recruited both through the CNI camp, social networking sites (e.g., Facebook page of the Children and Infant Listening Laboratory directed by Dr. Andrea Warner-Czyz), word of mouth, and snowball sampling. Two TH adolescents were tested at Callier Dallas in the Child Language and Cognitive Processes Laboratory, directed by Dr. Julia Evans. The remaining TH (*n* = 22) and CI participants (*n* = 34) were tested at the CNI camp sessions during June and August 2016. All participants and families provided assent and consent, respectively.

2.3.2 Task

This study used a variation of the Emotion Recognition Task (ERT), a paradigm in which static images or video clips of neutral facial expressions morph into different emotions. Participants must label the emotion via an alternative forced choice task (Montagne, Kessels, De Haan, & Perrett, 2007). The modification for the current study involved presentation of the last frame of the 100% emotion-intensity video clip as a static image. The ERT has been effectively implemented in the assessment of clinical groups including patients with obsessive-compulsive disorder (Montagne, 2005), social phobia (Montagne, Schutters, Westenberg, Van Honk, Kessels, & De Haan, 2006), autism spectrum disorders (Smith, Montagne, Perrett, Gill, & Gallagher, 2010), and traumatic brain injury (Rigon, Turkstra, Mutlu, & Duff, 2016).

2.3.3 Stimuli

Previous studies have shown no significant difference in expression recognition between static images and video sequences when the static image reflects the peak frame of a dynamic video (e.g., Katsyri & Sams, 2008). Thus, the present study extracted static images (345 x 434 mm) from the last frames of 100% emotion-intensity video clips used in Montagne et al. (2007). The 24 static images include four individuals (2 male, 2 female) each portraying six emotions: happiness, sadness, anger, fear, surprise, and disgust. The presentation order of the static images was randomized, and the same fixed order was presented to each participant for 1500 milliseconds (msec).

In addition to the static images, participants viewed a screen that included rectangular icons (approximately 576 x 136 mm) for each of the six emotions. The screen had a gray background and each emotion icon had a specific color (e.g., red for angry, purple for happy, dark blue for sad, orange for fearful, light blue for surprised, and green for disgusted). Each icon was labeled with the corresponding emotion title (Figure 2.1).

Figure 2.1. The closed-set response slide displayed to participants following the presentation of the facial images. Participants were asked to select one of the six labeled emotion icons that matched the emotion expressed in the previous image. The responses were recorded as mouse-clicks on one of the corresponding areas of interest created in BeGaze™ corresponded to each of the six rectangular emotion icons. Accuracy and response time information were collected from responses recorded on this slide.

2.3.4 Apparatus

Throughout the experiment, the SMI Experiment Center™ software recorded mouse clicks, which allowed analysis of both accuracy and the response time (i.e., time from initial presentation of the response slide to mouse click in msec) for each button click. After testing, the examiner imported experiment results from the SMI Experiment Center™ into SMI BeGaze™ analysis software. Six areas of interest created in BeGaze™ corresponded to each of the six rectangular emotion icons, which afforded accurate information on selection of an emotion to assess both accuracy and response time from 24 trials for each participant. These results were exported and used to calculate overall accuracy, accuracy for six individual emotions, overall response time across all trials, and response time for correctly answered trials.

2.3.5 Procedure

Testing for all participants took place at either the CNI Cochlear Kids camp at the YMCA of the Rockies' Estes Park Center in Colorado or at the Child Language and Cognitive Processes Laboratory at the Callier Center in Dallas, Texas. All testing was completed in one 30-minute session by an examiner in a quiet room. During testing, participants sat in a chair approximately 50 cm in front of a 15.6-inch Dell Latitude (Intel® Core™ i7-3540M CPU 2.99GHz) laptop with a SMI iView X™ RED-m portable eye tracker. The experimenter read aloud instructions for the task to each participant. One of the images then was presented for 1500 msec, followed by the response slide with six emotion-labeled "buttons".

The participants were asked to determine which one of the six proposed emotions each of the faces displayed and select his/her response by clicking on one of the buttons with the mouse, after which the next image would automatically appear. The response slides had no time constraints, meaning participants could take as much time as necessary to select an emotion. Feedback was not provided to participants during the task.

2.3.6 Statistical Analysis

Means and standard deviations were calculated for all variables of interest. All statistical analyses were carried out in SPSS Statistics Version 25. In each repeated measures analysis, participant group (i.e., CI and TH group) always served as the between-subjects factors and emotion type (i.e., happy, sad, angry, fearful, surprised, and disgusted) always served as the within-subjects factors. To address the first research question examining the effects of auditory status and emotion type on accuracy of visual emotion recognition, we conducted a two-way repeated measure analysis of variance (ANOVA) with two levels for participant group and six levels for emotion type, and with *response accuracy* as the dependent variable. To address the effects of auditory status and emotion type on response time for all trials, we conducted a second two-way repeated measures ANOVA with two levels for participant group x six levels for emotion type, with *overall response time* as the dependent variable. Our third research question addresses group differences in response time to correct trials without comparing outcomes by emotion type. The fact that some children obtained 0% accuracy on individual emotion types required us to use a different statistical approach to manage missing data points. Therefore, we conducted six one-way ANOVAs – one for each emotion type – with two levels for participant group and *response time to correct trials* as the dependent variable.

For each ANOVA, based on tests of sphericity, either a Geisser-Greenhouse or Huynh-Feldt corrections were performed to assess main effects and interaction effects of auditory status and emotion type on emotion recognition accuracy and response time. Follow-up pairwise comparisons using a Bonferroni adjustment were conducted after each analysis to examine significant main effects of emotion type on accuracy and response time. Finally, Spearman correlation coefficients (rho) were calculated to assess associations among emotion recognition accuracy, response time, demographic characteristics (e.g., chronologic age) and audiologic variables (e.g., age at implantation, duration of device use). A point bi-serial correlation was used to calculate the association between global self-esteem rating and dichotomous demographic variables (i.e., gender).

2.4 Results

2.4.1 Effect of auditory status and emotion type on accuracy of visual emotion recognition

The TH group, on average, achieved a mean accuracy of 62.2% (*SD* = 32.4%, range: 0-100%) on visual emotion recognition. The CI group obtained similar levels of accuracy (*M* = 58.2%, *SD* = 31.1%, range: 0-100%) for visual emotion recognition. The main effect for group did not reach statistical significance, thereby suggesting that adolescents with CI have similar emotion processing ability to TH peers.

Emotion type significantly affected accuracy of emotion recognition, $F(4.57, 255.75) = 60.83$, $p < .001$, $\eta^2 = .521$. Adolescents in both the CI and TH groups attained the highest accuracy for happy facial expressions (CI: *M* = 94.9%, *SD* = 10.3%; TH: *M* = 97.9%, *SD* = 7.1%) and the lowest accuracy for fearful facial expressions (CI: *M* = 21.3%, *SD* = 25.5%; TH: *M* = 22.9%, *SD* = 23.2%) (Figure 2.2). Pairwise comparisons revealed that adolescents correctly identified happiness significantly more than the other five emotion types regardless of participant group (*M* = 96.4%, *SD* = 1.2%, across groups). Contrastingly, adolescents identified fearful facial expressions significantly less accurately than any of the other five emotion types regardless of participant group (*M* = 22.1%, *SD* = 3.3%, across groups). Results also revealed that adolescents correctly identified angry facial expressions (*M* = 69.0%, *SD* = 3.0%, across groups) significantly more than sad facial expressions (*M* = 52.6%, *SD* = 3.7%, across groups). No other pairwise comparisons or the interaction between group and emotion type reached statistical significance.

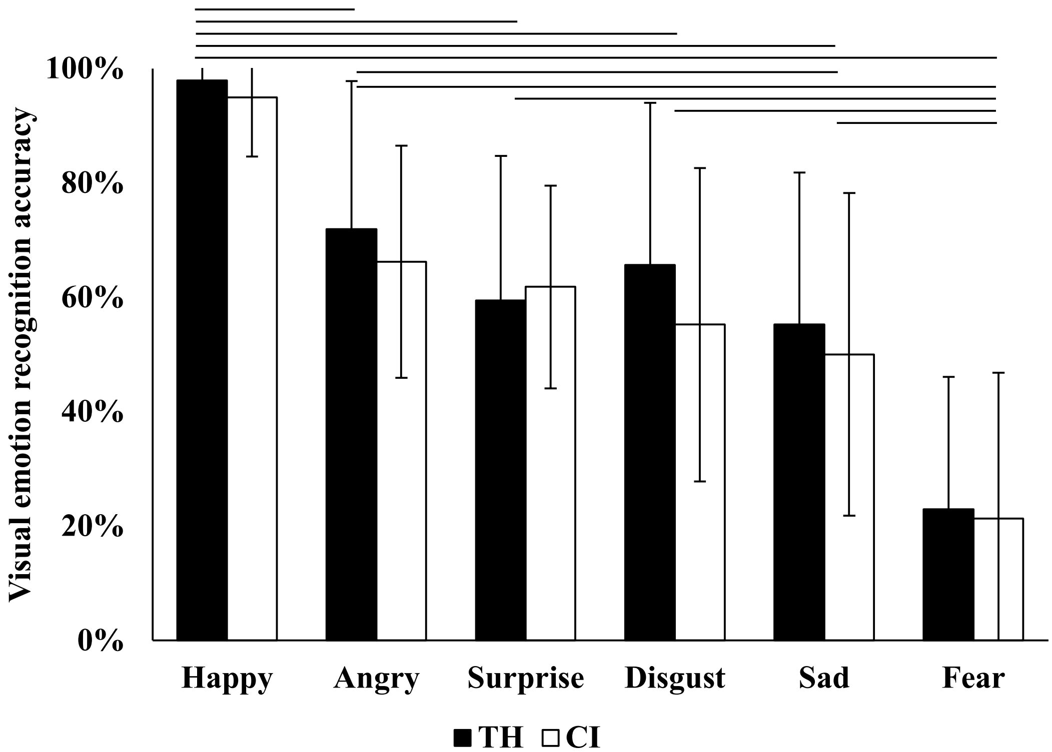

Figure 2.2. The x-axis displays emotion type and the y-axis shows mean accuracy of visual emotion recognition. The black columns represent the TH group and the white columns show the CI group. Error bars indicate standard deviations for each group. Auditory status did not affect accuracy of emotion recognition, but emotion type did. Adolescents in both groups identified happy expressions significantly more accurately than all other emotions and identified fearful expressions significantly less accurately. Additionally, adolescents across groups more accurately recognized angry versus sad facial expressions.

2.4.2 Effect of auditory status and emotion type on overall response time of visual emotion recognition

On the visual emotion recognition task, the TH group obtained a mean response time of 2520.4 msec (SD = 1148.9, range: 952.5-9088.5). The CI group achieved a mean response time of 2920.6 msec (SD = 1652.9, range: 1002.7-12817.9) for visual emotion recognition. No significant main effect emerged for group for overall response time.

Emotion type significantly affected overall mean response time, $F(3.18, 117.96) = 23.19$, $p < .001$, $\eta^2 = .293$. Adolescents in the CI group obtained the quickest response times for happy facial expressions (*M* = 2110.1 msec, *SD* = 616.4). The TH group responded fastest to happy (*M* = 1924.4 msec, *SD* = 602.4) and disgust (*M* = 1797.7 msec, *SD* = 516.2). Both the CI and TH groups showed the slowest response times for sad facial expressions (CI: *M* = 4009.0 msec, *SD* = 2412.3; TH: *M* = 3628.1 msec, *SD* = 1576.3) (Figure 2.3). Pairwise comparisons revealed three significant patterns. First, adolescents identified happiness significantly faster than the other five emotions on all trials, regardless of participant group. Second, across groups, adolescents identified sadness significantly more slowly than the other five facial expressions. Third, disgusted facial expressions were identified significantly faster than angry or fearful expressions, regardless of participant group. No other pairwise comparisons or the interaction between emotion type and participant group reached statistical significance.

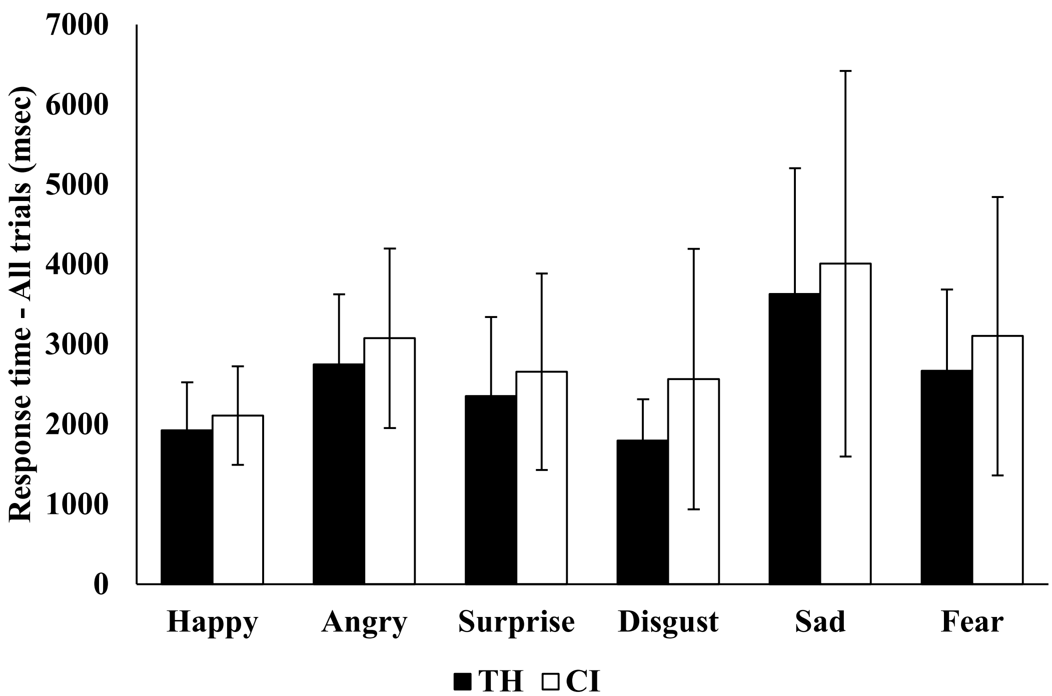

Figure 2.3. The x-axis displays emotion type and the y-axis shows mean response time on all trials for visual emotion recognition. The black columns represent the TH group and the white columns show the CI group. Error bars indicate standard deviations for each group. Auditory status did not significantly affect response time for emotion recognition of static images of facial

expressions. Adolescents across groups accurately identified happy facial expressions significantly more quickly and sad facial expressions significantly more slowly than all other emotions. Additionally, participants in both groups labeled disgusted facial expressions significantly more quickly than sad or angry facial expressions.

2.4.3 Effect of auditory status and emotion type on response time for correct emotion recognition trials

The CI and TH adolescents exhibited the same accuracy and overall response time for each emotion type (i.e., no significant group x emotion type interactions). Therefore, our third research question focused on the correct trials: When adolescents correctly identify an emotion, could the CI group match the response time of the TH group? Including only the correct trials affords a more sensitive way to analyze group differences in response time required for emotion processing. We analyzed each emotion separately because the number of participants who correctly identified the intended emotion at least once within an emotion category varied by emotion type. That is, 19 to 34 adolescents with CI and 14 to 24 adolescents with TH correctly identified at least one of the four faces expressing each emotion type. The group comparison for angry facial expressions approached statistical significance, $F(1, 55) = 3.65$, $p = .061$, partial eta squared = .062, such that the TH group ($n = 23$, $M = 2263.7$, $SD = 659.5$) identified anger faster than the CI group ($n = 32$, $M = 3590.8$, $SD = 2620.8$). However, no significant group difference emerged for any of the six emotion types (Figure 2.4).

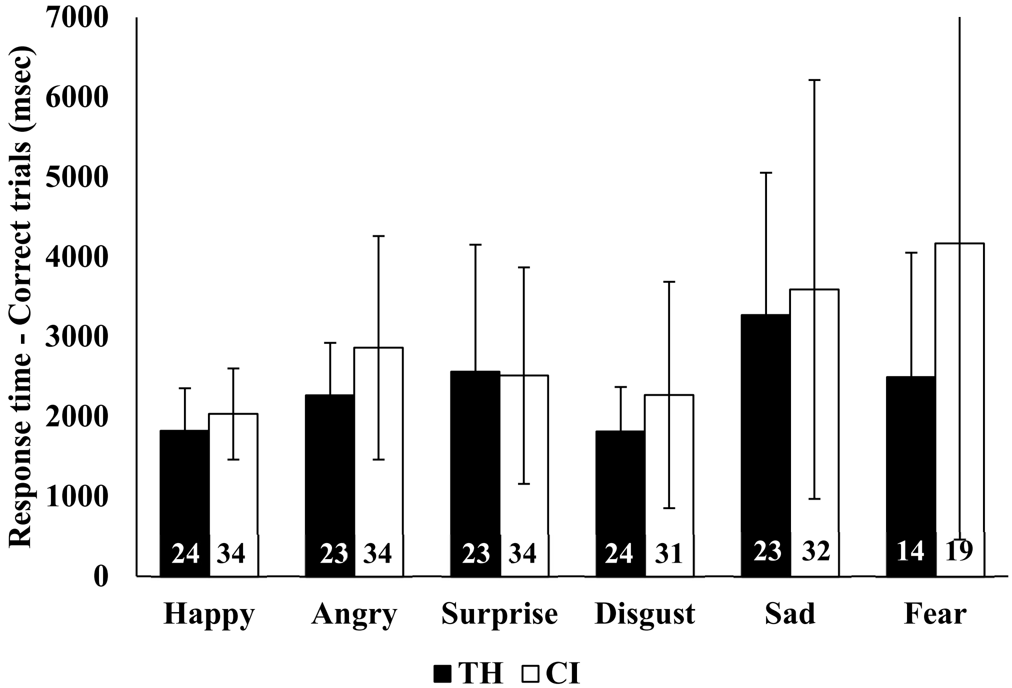

Figure 2.4. The x-axis displays emotion type and the y-axis shows mean response time on correct trials for visual emotion recognition. The black columns represent the TH group and the white columns show the CI group. Error bars indicate standard deviations for each group. The values at the base of each column indicate the number of participants in each group that correctly identified at least one of the static images for that emotion type. Although visual inspection suggests the CI group, on average, had longer response times to identify visual emotions for correct trials, auditory status did not have a significant effect on response time.

2.4.4 Effect of demographic and audiologic variables on accurate emotion recognition

We ran Spearman correlations to determine associations among response accuracy, response time, demographic and audiologic variables. We restricted correlations of response accuracy and response time to comparisons within emotion type (e.g., the association between accuracy and response time for happy expressions, not the association between accuracy for happy expressions and response time for angry expressions). For the CI group, accuracy for expressions of disgust positively correlated with chronologic age such that older adolescents with CI achieved higher percent correct scores for the disgust emotion compared to younger adolescents using CI, $\rho = .36$, $p = .04$. For the TH group, accuracy for angry expressions negatively correlated with overall response time such that more accurate responses coincided with faster response times for angry expressions, $\rho = -.70$, $p < .001$. No other correlations reached statistical significance for either group.

2.5 Discussion

The current study examined the ability of adolescent CI users and hearing peers to perceive emotions through a visual presentation of facial expressions. Adolescents with CIs did not differ significantly from adolescents with TH on response accuracy, overall response time, or response to correctly identified emotions. Type of emotion significantly affected accuracy and overall response time, independent of participant group. Across groups, adolescents identified happy facial expressions with significantly greater accuracy and faster response times than the other emotions, recognized fearful expressions significantly less accurately than the other five emotions, and identified sadness significantly more slowly than the other five facial expressions.

2.5.1 Effect of auditory status on visual emotion recognition

Both groups achieved comparable emotion recognition accuracy in the visual modality, similar to published reports in school-aged children and adolescents using auditory technology (Hopyan-Misakayan et al., 2009; Most & Aviner, 2009). Poorer performance by children with hearing loss relative to hearing peers typically occurred in studies including younger children (aged 2-7 years) (Most & Michaelis, 2012, Wang et al., 2016; Wiefferink et al., 2012). Therefore, divergent results by auditory status may indicate a stabilization of accurate emotion recognition abilities in children with hearing loss – particularly those with CIs – as they move from early childhood to adolescence, a pattern shown in children with TH.

Not only did auditory status have no significant effect on accuracy, but also response time during a visual emotion recognition task – regardless of inclusion of either all trials or only correct trials. Thus, when provided a full complement of cues to identify the emotion portrayed in a static image, adolescents with CIs match the abilities of their hearing peers based on both accuracy and response time.

2.5.2 Effect of emotion type on visual emotion recognition

This study not only compared accuracy and response time by auditory status, but also by emotion type. The effect of type of emotion persisted across participant group. Both groups identified happy and angry as the most accurately recognized emotions, and sadness and fear as the least accurately recognized emotions. These results converge with previous research on children and adolescents with TH, CIs, and HAs, which also report happiness as the easiest emotion to recognize and fear as the most difficult (Hopyan-Misakyan et al., 2009; Memisevic, Mujkanovic, & Ibralic-Biscevic, 2016; Most & Aviner, 2009; Most & Michaelis, 2012).

Response times also varied based on emotion type and followed the same pattern regardless of auditory status. Across all trials, happiness and disgust were identified in the shortest amount of time, whereas sadness required the longest period of time. This pattern held with consideration of only trials yielding correct emotion recognition, with the exception of the CI group taking an average of ~500-600 msec longer to correctly fear versus sadness in facial expressions. Our results for response time in a visual emotion recognition task follow those found in De Sonneville et al. (2002) and Wells et al. (2016), with faster response times for positive emotions (e.g., happiness) and slowest response time for negative emotions (e.g., sadness) in children and adults with typical development and assumed TH. The fact that these established patterns persisted across auditory status suggests that adolescents with hearing loss using CIs can process an array visually displayed emotions equally as well as hearing peers.

2.5.3 Strengths and limitations of the current study

This study is not without limitations. Medical records were not received for all CI participants in this study. This precluded analysis of factors such as age at onset and language skills. Knowledge of the age at onset of hearing loss (i.e., congenital versus acquired) could provide information regarding the effect of early or delayed auditory access on the development of emotion recognition skills. Additionally, information of each child's language level could have allowed direct comparison to the study by Dyck et al. (2004), which showed delays in acquisition of emotion recognition are consistent with observed delays in language and speech in children with hearing loss. Another participant-related limitation involves inclusion criteria for the TH group, which based auditory status on parent report versus a hearing screening. Considering most participants in the TH group had a sibling with hearing loss, we assumed that the parents accurately reported their adolescents' auditory status.

A second limitation of the current study is that performance on emotion recognition was assessed using only static images. Nonverbal communication requires accurate perception and interpretation of dynamic expressions that include real-time facial movement and additional sensory cues from body language and the surrounding environment (Jones, Gutierrez, & Ludlow, 2018). Facial expressions of emotions can vary in the intensity, as well. Static images tend to focus on an exact moment of an emotional facial expression, where as a dynamic presentation of an emotional facial expression would allow for observation of moment-by-moment, subtle changes in the facial features (Jones, Gutierrez, & Ludlow, 2018). That being said, the literature reports vast similarities between emotion recognition using a static image of the peak frame of a dynamic video, as in the present study, and a complete video sequences (e.g., Dobs et al., 2018; Fiorentini & Viviani, 2011; Gold et al, 2013; Katsyri & Sams, 2008). Future research should incorporate video stimuli to directly assess the association between static and dynamic images in visual emotion recognition in adolescents with and without hearing loss.

Another limitation of the current study is that measures such as accuracy and response time may not be sensitive enough to detect differences that occur between the two participant groups. For example, these measures can provide only limited information about facial information processing and speed of processing. On the other hand, using a methodology such as eye tracking would allow for analysis of individual gaze patterns of facial expression. It has been proposed that individuals with hearing loss communicating via spoken language might miss crucial information expressed in the eyes because they are more inclined to look at the mouth to lip-read or speechread when interacting with another individual (Rigo & Liberman, 1989). If this is the case, eye tracking results would likely indicate that individuals with CIs spend more time looking at the mouth than the eyes in contrast to TH peers. Our research group plans to incorporate an analysis technique that would afford more information about potential differences in attention to specific regions of the face (e.g., eyes versus mouth) that may underlie how adolescents with and without hearing loss process facial expressions.

The current study has several strengths. First, the study included a sample that allowed for the examination of the effects of early auditory deprivation on visual emotion recognition through comparison of adolescents with CIs and peers with TH. Second, the analysis examined not only accuracy, but also response time for recognition of emotions via facial expressions.

Measures of response time may detect subtle differences in visual emotion recognition performance that could be missed by solely focusing on accuracy metrics (De Sonneville et al., 2002). The fact that no group differences emerged on either accuracy or response time to a static image on a visual emotion recognition task suggests that adolescents with CIs can, on average, identify emotions as well as TH peers, and do so with similar response times (albeit with greater variability). To our knowledge, this study marks the first examination of the impact of access to auditory information on response time on an emotion recognition task.

2.5.4 Future directions

Future studies should include a broader age range of children and adolescents with CI and TH to examine differences not only in performance, but also in rate of development of visual emotion recognition abilities across multiple age ranges. The impact of variables such as age of implantation, duration of CI use, and the presence of co-morbid conditions on accuracy and response time outcomes should be examined. In addition, it is possible the effect of auditory status may become more apparent when viewing dynamic versus static stimuli. The present study showed no difference of auditory status with presentation of 100% of visual emotion information, but adolescents with CIs may differ from hearing peers in a gated visual emotion recognition task, in which viewers predict emotion type as a face in a dynamic video morphs from a neutral expression to a different emotion type (e.g., happy, sad) based on a proportion of the entire video (e.g., 60%, 80%). The two groups also could diverge on areas of fixations within a face such that adolescents with CIs focus more on the mouth in efforts to speechread – even in the absence of auditory information – whereas adolescents with TH fixate more on the eyes to gather information about emotion from facial expressions. Furthermore, research should simultaneously examine emotion recognition abilities in conjunction with measures of social well-being such as number of friends, quality of friendship, and peer victimization to evaluate the possible contribution of poorer perception of paralinguistic cues (such as eye contact) to peer social dynamics in adolescents.

2.5.5 Conclusion

In conclusion, adolescents with CIs achieve comparable accuracy and response times for visual emotion recognition relative to peers with TH when viewing static images containing complete information about emotion. This convergence in recognition of facial expressions will bode well for adolescents with CIs, should the pattern extend from static images to dynamic videos and social interfaces. Parents and professionals working with adolescents with CIs need a more comprehensive understanding of the role of attention to paralinguistic cues such as facial expressions and prosody to peer interactions and, subsequently, social well-being. Such knowledge can contribute to development of effective therapeutic intervention programs to improve the communication and social competence in adolescents with CIs.

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CHAPTER 3

THE ROLE OF STIMULUS MOTION AND EMOTION INTENSITY IN FACIAL EMOTION RECOGNITION BY ADOLESCENT COCHLEAR IMPLANT USERS[2]

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3.1 Introduction

Emotion recognition, or the ability to detect and discriminate between emotions based on auditory or visual cues, plays a key role in social communication (Blair, 2003). Poor facial emotion recognition is associated with negative social outcomes such as difficulty with social interactions, poor social integration, and emotional and behavioral problems (Bal et al., 2010; Hoffman, Quittner & Cejas, 2015; Greenberg & Kusché, 1993). Children with severe-to-profound hearing loss (HL) have impaired access to the multisensory cues necessary for social-emotional development and, in turn, experience delays in emotion understanding. Several studies have examined emotion recognition in children with HL who use a cochlear implant (CI) (Hopyan-Misakyan et al., 2009; Most & Aviner, 2009; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013; Ziv et al., 2013), but results have been inconsistent and few have assessed emotion recognition with stimuli that reflects the varying motion and intensity of real-life facial expressions. The current study examines the effect of auditory status (i.e., adolescents using CI versus typical hearing (TH), stimulus motion (i.e., static versus dynamic), and varying emotion intensity on emotion recognition.

3.1.1 Emotion recognition in children with TH

In individuals with TH, an understanding of emotions and use in social interactions develops through interacting with peers and observing discussion about emotions between other people. Emotion recognition development requires both access to language and opportunities to experience discussions about mental states and emotions. The ability to recognize facial expressions emerges within the first few months of life (Ludemann & Nelson 1988; Young-Browne et al., 1977) and continues to develop through childhood and adolescence with additional social experience (Herba et al., 2006; Philippot & Feldman, 1990). The developmental trajectory of emotion recognition varies by emotion type, with children beginning to recognize happiness and sadness around 2 years of age and progressively developing the ability to recognize emotions such as anger, surprise, fear, and disgust (Gray et al., 2001; Philippot & Feldman, 1990). Emotion recognition abilities continue to develop through middle childhood. A threshold in emotion recognition is thought to be reached around 11-years-old with little improvement in outcomes occurring after that age (Herba & Phillips, 2004; Tonks et al., 2007).

Better language competence and, by extension, greater participation in conversations about mental state have been connected to improvements in emotion recognition. Language outcomes in preschool children aged 3─6 years (e.g., language comprehension, phonological processing) and children aged 7─9 years old (e.g., receptive vocabulary, verbal fluency, and literacy) are positively correlated with emotion recognition outcomes (Beck et al., 2012; Rosenqvist et al., 2014).

3.1.2 Emotion recognition in children with HL

Emotion recognition develops in an auditory-linguistic context and depends largely on language competency and experience communicating about emotions. For children with severe-to-profound HL, receptive and expressive language skills remain delayed in comparison to chronologically age-matched peers with TH (Niparko et al., 2010). Poorer language outcomes could lead to poorer emotion recognition abilities in children with HL. Dyck et al. (2004) compared groups of children and adolescents (6─18 years) with HL, vision loss, or were typically developing on an emotion recognition task. Children (M = 14.44, SD = 4.55) and adolescents (M = 16.94, SD = 2.88) with HL demonstrated significantly poorer emotion recognition outcomes than chronologically age-matched children (*M* = 17.73, *SD* = 3.54) and adolescents (*M* = 18.83, *SD* = 2.55) with TH. Alternatively, when matched according to verbal ability, the group with HL achieved emotion recognition outcomes comparable to or better than the group with TH (HL: *M* = 17.91, *SD* = 2.42; TH: *M* = 17.79, *SD* = 2.92). The findings of this study suggest that language is a more important predictor of emotion recognition abilities than chronological age.

Additionally, children with HL often experience less exposure to conversations about mental state, limited opportunities for incidental learning, and fewer chances to communicate with others about their feelings (Moeller & Schick, 2006; Morgan et al., 2014). Poorer outcomes in emotion recognition and theory of mind are often observed in deaf children born to parents with TH (Peterson& Siegal, 2000). Ziv et al. (2013) demonstrated the benefit of shared language by examining emotion recognition in a group of children with HL, ranging from 5 to 7 years of age, and their deaf parents who communicated using sign language. The children with HL performed similarly to children with TH when asked to label photographs of expressions of happiness, anger, sadness, and fear, supporting a link between better emotion recognition and shared language with parents. Shared mode of communication with family members may provide children with HL more frequent opportunities to discuss emotions and experience social interactions (Peterson & Siegal, 1995; Ziv et al., 2013).

3.1.3 Emotion recognition in children with CI

Children with HL who use a CI, a biomedical device that collects an auditory signal via an external component (i.e., the speech processor) and electrically stimulates the auditory nerve via an electrode array surgically implanted in the cochlea, have greater access to auditory information and language compared to children with HL who do not use auditory technology. However, the auditory signal delivered through a CI remains degraded and distorted compared to the signal produced by the auditory system of a child with TH. Children who receive their CI before 18 months of age show improved trajectory in language comprehension, but their outcomes remain highly variable (Niparko et al., 2010). Only half of pediatric CI users who receive their implant before three years of age achieve language outcomes and comprehension abilities considered within normal limits by eight to ten years post-implantation (Geers et al., 2016; Nittrouer et al., 2018). Language competence and emotional competence are correlated in children with TH, so delays in language development could negatively impact emotion recognition in children with CI.

Research examining facial emotion recognition abilities across a broad age range of pediatric CI users yield variable and inconclusive findings. Studies of younger children with CI show delayed emotion recognition of basic emotions (i.e., happiness, sadness, anger, and fear) compared to age-matched children with TH. Wang et al. (2011) found that preschool-age children with CI (2.3─3.5 years; M = 2.00, SD = 1.87) and HA (2.2─6.0 years; M = 4.36, SD = 2.77) show poorer recognition of emotion from static photographs than children with TH (2.3─5.8 years; M = 6.81, SD = 2.14). Wiefferink et al. (2013) also reported poorer outcomes for children with CIs compared to children with TH, ranging from 2.5 to 5 years of age, on a task of emotion recognition using static images of human facial expressions. The trend of delayed performance on emotion recognition continues in kindergarten-age CI and HA users (n = 22; aged 2.5─7.0 years) who achieved poorer outcomes than children with TH (n = 22; aged 2.8─6.4 years) when identifying happiness, sadness, anger, and fear from color images of facial expressions (Wang et al., 2016). Most & Michaelis (2012) also reported significantly poorer emotion recognition abilities in children with HL who used a CI and/or HA (n = 26; M = 68.38, SD = 15.22) compared to children with TH (n = 14; M = 77.38, SD = 18.42) when tested between four and six years of age.

Other studies suggest that older children and adolescents with CIs achieve emotion recognition abilities similar to those of peers with TH. Ziv and colleagues (2013) found that children with CIs aged 5—7 years of age achieved outcomes similar to children with TH when asked to identify static images of the six universal emotions. Likewise, school-age children with CIs and children with TH matched on chronological age (7—13 years of age), performed similarly on speech and facial emotion recognition tasks (Hopyan-Misakyan et a., 2009). Comparable emotion recognition outcomes have been observed in adolescent CI users and adolescents with TH aged 10 to 18 years on tasks using static photographs (Warner-Czyz et al., 2019) and video clips of human facial expressions (Most & Aviner, 2009). Overall, these results suggest that facial emotion recognition is delayed in younger children with CIs but improves with age to abilities comparable to peers with TH in adolescence.

3.1.4 Dynamic stimuli

Facial expressions of emotions, such as happiness, sadness, anger, fear, surprise, and disgust, are produced by movements of facial musculature that differ depending on the emotion being produced (Smith, et al., 2005). Social interactions involve visual emotion recognition and requires efficient perception and interpretation of subtle changes in the facial musculature of our conversation partner. The static photographs and images used in many previous emotion recognition studies may not reflect an individual’s abilities and emotion recognition outcomes are limited in their applicability to real-time social communication. Alternatively, tasks that utilize dynamic stimuli, or moving facial expressions, could offer a more ecologically valid method of assessing emotion recognition.

Research with adults with TH suggests a potential dynamic advantage in visual emotion recognition over static stimuli, because the dynamic stimuli allow for recognition of subtle changes in facial affect (Krumhuber et al., 2013). One study by Nelson & Mondoch (2018) examined the effect of motion on visual attention during emotion recognition in younger children with a mean age of 5.0 years (*SD* = 0.6), older children with a mean age of 8.9 years (*SD* = 0.5), and adults with a mean age of 19.3 years (*SD* = 1.4). Participants in each group made longer fixations to the head or face when shown dynamic expressions but did not demonstrate the same looking pattern when shown static stimuli. This finding suggests that visual attention is influenced by motion during emotion recognition and indicates that children and adults with TH processed dynamic emotional stimuli in a qualitatively different manner than static images. Additionally, viewing dynamic facial expressions causes increases in brain activity in regions linked to social information processing (superior temporal sulci) and affect processing (amygdala) (Kessler et al., 2011; Kilts et al., 2003).

Limited access, if any, to auditory information may cause individuals with HL to develop an enhanced reactivity to motion and lead them to use facial motion as a compensatory role in emotion recognition (Armstrong et al., 2002). Studies that have examined emotion recognition using dynamic stimuli in children with HL provide evidence of a dynamic advantage. Jones et al. (2017) compared dynamic and static emotion recognition in children with HL who used a HA or CI and communicated using Signed Supported English or British Sign Language to that of children with TH. Children with HL made significantly more errors in emotion recognition on the static task than children with TH, but the two groups did not differ on the number of errors made during dynamic emotion recognition. Within the group of children with HL, participants that used a CI made significantly fewer errors (n = 11, M = 1.24, SD = 0.30, 41%) than the children with HA (n = 15, M = 5.07, SD = 3.26, 20%) across emotion recognition tasks. These findings suggest a dynamic advantage for children with HL that communicate through sign language, indicating that motion plays a compensatory role in facial emotion recognition for children with HL (Jones et al., 2017). To date, no studies have examined the role of stimulus motion (i.e., static vs. dynamic) in emotion recognition by adolescents with CIs that use spoken language to communicate.

3.1.5 Emotion Intensity

During social interactions, facial expressions are dynamic and vary in intensity, with some expressions being fleeting and subtle while others are exaggerated and intense. The emotion intensity of an expression is the amount the facial muscles move from a neutral face to an expression of a specific emotion (Hess et al., 1997). The temporal patterns of facial expressions vary, in part, based on the intensity of the emotion being expressed and can be useful to determine the timeline of emotion recognition (Sato et al., 2004; Smith et al., 2005). Higher intensity expressions provide emotion information through additional facial movements that are not apparent in subtle, low-intensity expressions and that benefit emotion recognition. In general, high-intensity expressions are easier to identify based on dramatic movement of facial features, while recognition of subtle expressions is difficult and develops into adulthood in individuals with TH (Herba et al., 2006; Montagne et al., 2007).

Emotion intensity has been shown to mediate emotion recognition in children and adults with TH. Herba et al. (2006) asked children with TH (*n* = 153, 4─5 years old) to complete an emotion-matching task using photographs of a human face expressing five emotions (i.e., anger, disgust, fear, sadness, happiness) at four emotion intensity levels (i.e., 25%, 50%, 75%, 100%). Most emotion types, particularly happiness and fear, were recognized more from expressions of high-level emotion intensity (i.e., 50%, 75%, 100%) compared to low-level intensity photographs (i.e., 25%). Similarly, Chronaki et al. (2015) found an effect of emotion intensity on facial emotion recognition of preschoolers (*n* = 23, 3.5─5.5 years), young children (*n* = 44, 6.0─9.0 years), older children (*n* = 21, 10.0─11.0 years), and adults (*n* = 21, 21.7─45.8 years). Participants were asked to classify the emotion type (i.e., anger, happiness, sadness) from photographs of expressions of mild (50%), moderate (75%), and high (100%) emotion intensity. Overall, participants from each age group identified the target emotions more frequently when expressions were high – 100% and moderate – 75% intensity than mild – 50% intensity emotions ($p < .001$). This effect also varied by emotion type with participants demonstrating significantly better outcomes on high – 100% intensity than low – 50% intensity expressions of anger but not sadness. The gap between emotion recognition at subtle, less intense levels and moderate intensity suggests that these emotion intensity levels could provide the best measure of subtle differences in emotion recognition based on emotion cues from the face.

Contrary to research focused on individuals with TH, Jones et al. (2017) explored the role of emotion intensity by examining emotion recognition abilities of signing children with HL using dynamic stimuli. Participants were shown video clips of human faces expressing six emotions (i.e., happiness, sadness, anger, disgust, fear, and surprise). The videos were divided into four 500 msec clips of varying levels of emotion intensity: neutral or 0%─25%, 25─50%, 50─75%, and 75─100% of an expression. Both children with HL (*n* = 18, 6;11─11;6 (years; months) and children with TH (*n* = 18, 6;9─11;5) demonstrated increases in emotion recognition performance as the emotion intensity levels of stimulus increased. Results from this study suggest the advantage provided by motion in the dynamic stimuli assists children with HL in identifying facial expressions, regardless of emotion intensity (Jones et al., 2017). However, sign language relies on facial expressions to communicate certain linguistic aspects, so it is possible that the group of children with HL in this study benefited on emotion recognition due to their use of sign language to communicate (Ludlow et al., 2010)

No studies have examined the role of emotion intensity in adolescents with CIs who communicate primarily with spoken language. Adolescents with CIs that have earlier access to auditory information and use of spoken language may interpret emotion information from varying emotion intensity levels differently compared to groups of children with HL in previous studies that relied on sign language to communicate (Jones et al., 2017).

3.1.6 Purpose of study

Current research on emotion recognition has not examined adolescents with CIs that communicate with spoken language. Additionally, most studies have assessed emotion recognition using static photographs of limited expressions that do not capture the subtle changes in facial musculature observed in real-time social communication. Investigating emotion recognition using dynamic expressions of varying emotion intensity will reveal whether additional emotion information, not visible in static stimuli, assists CI users in interpreting facial expressions. As such, the current study aims to examine how stimulus motion and emotion intensity impacts facial expression recognition in adolescents with CI and adolescents with TH. This study compares emotion recognition by adolescents with CIs and adolescents with TH using realistic, dynamic clips to determine if stimulus motion benefits both groups in recognizing facial expressions. Previous research with children and adolescents with TH indicates that adult-like recognition abilities are achieved for several emotions around 11-years-old and dynamic stimuli provides an advantage in emotion recognition over the more traditionally used static photographs (Nelson & Mondoch, 2018; Tonks et al., 2007). We predict that both adolescents with CI and adolescents with TH will achieve better outcomes on dynamic than static emotion recognition tasks (i.e., dynamic advantage). Additionally, we expect that the effect of stimulus motion will not be as large for the adolescent CI users compared to adolescents with TH.

This study also examines the role of emotion intensity in dynamic emotion recognition in adolescents with CIs and adolescents with TH using three dynamic tasks of varying intensity expressions (i.e., 60%, 80%, 100%). We hypothesize that adolescents with CI and adolescents with TH will interpret full-intensity expressions (100% dynamic) similarly but will differ on trials of low-intensity expressions (i.e., 60% and 80%). Typically developing children and adolescents struggle with the demands of identifying subtle, low-intensity expressions (Herba et al., 2006). We predict that the adolescents with CI will need additional emotion information from facial movements to interpret emotion. We also expect that all participants will better recognize basic emotions (e.g., happiness, anger, sadness) than more complex emotions (e.g., disgust, fear) regardless of emotion intensity.

3.2 Methods

3.2.1 Participants

Participants in the current study also participated in our previous study investigating accuracy and reaction time on static emotion recognition (Warner-Czyz et al., 2019). A total of 34 adolescents with CI (female = 21) and 24 adolescents with TH (female = 9) were included in this study. All participants met the following criteria: aged between 10-18 years old, normal or corrected vision, and no known history of any known medical or neurological disorders. Specific inclusionary criteria for the adolescents with CI were: (a) use of at least one CI, (b) use of spoken language as their primary mode of communication, and (b) have normal speech-motor abilities. Participants with TH had to have hearing sensitivity within normal limits per parent report to enroll in the study. Participants were recruited from the Colorado Neurological Institute's Cochlear Kids Camp in Estes Park, social networking, and word of mouth.

The CI group ranged in age from 9;4 (years; months) to 17;11 (*M* = 13.2 years, *SD* = 2.2) and all users had severe-to-profound HL identified by a mean age of 1.1 years (*SD* = 1.2; range: 0─4 years). Adolescents with CI received their first device at a mean age of 2.8 years (*SD* = 2.3; range: 0.6 ─ 10.0 years). One of the participants had a progressive HL and did not receive their implant until 10 years of age. Mean duration of experience with CI ranged from 1;11 to 16;7 (*M* = 10.3 years, *SD* = 3.1). Thirty adolescents in this group used either a bilateral (*n* = 26) or bimodal device configuration (i.e., CI + contralateral HA) (*n* = 4). The remaining four participants used a unilateral CI with no contralateral HA. Adolescents in the TH group ranged in age from 10;0 to 18;7 (*M* = 13.6 years, *SD* = 2.5) at time of testing. Additional demographic information can be found in Table 3.1.

Table 3.1. Demographic characteristics of participants

	CI (*n* = 34)		**TH (*n* = 24)**	
Variable	***N***	**%**	***N***	**%**
Gender				
Female	21	61.8	9	37.5
Male	13	38.2	15	62.5
Race				
White or Caucasian	26	76.5	17	70.8
Black or African-American	1	2.9	2	8.3
Asian	3	8.8	2	8.3
Unknown or not reported	2	5.9	1	4.2
Other	2	5.9	2	8.3
Ethnicity				
Hispanic/Latino	2	5.9	1	4.2
Non-Hispanic/Latino	32	94.1	23	95.8

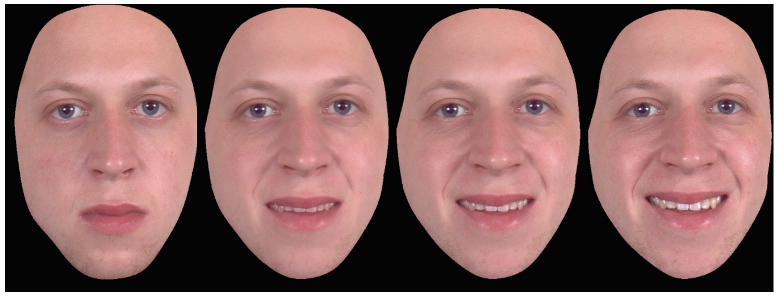
Note. CI = Cochlear Implant; TH = Typical Hearing. The “other” category includes all other races not previously listed, including Native Hawaiians or other Pacific Islanders, Native Americans, and respondents of two or more races. Data from participants includes a separate self-report of ethnicity and race. The “unknown or not reported” category for adolescents in both groups includes participants who identified as having Hispanic or Latino origin.

Data were collected based on protocols approved by the Institutional Review Board at The University of Texas at Dallas (IRB #11-11 and 13-50) and written, informed assent and consent was obtained for all participants and parents prior to testing. For all participants with CI (*n* = 34) and most participants with TH (*n* = 22) testing took place at the Colorado Neurological Institute’s Cochlear Kids Camp. Two participants with TH completed testing in the Child Language and Cognitive Processes Laboratory at The University of Texas at Dallas in Dallas, Texas. Testing consisted of one 30-minute session led by a member of the Children and Infant Listening Laboratory, directed by Dr. Andrea Warner-Czyz, and/or the Child Language and

Cognitive Processes Laboratory, directed by Dr. Julia L. Evans. Prior to beginning the task, the examiner explained the study to the participant and read the instructions aloud. Participants completed the task independently and examiners provided no additional feedback once the task began.

3.2.2 Emotion Recognition Task

This study used an adapted version of the Emotion Recognition Task (ERT) (Kessels et al., 2007; Montagne et al., 2007), a computer-based facial emotion recognition measure. The task typically involves videos of faces gradually morphing from neutral expressions to expressions of varying emotions. The three dynamic tasks included video clips of expressions morphing to different levels of emotion intensity (60%, 80%, and 100%). Presentation time varied by task with the 60% videos visible for an average of 1265 msec (*SD* = 18.7 msec), 80% videos for 1670 msec (*SD* = 21.2 msec), and 100% videos for approximately 2074 msec (*SD* = 20.3 msec) across all trials. Each task included 24 trials morphing expression videos (345 x 434 mm) of four actors (two males, two females) expressing one of six emotions: happiness, sadness, anger, fear, surprise, and disgust. Figure 3.1 depicts one actor’s expressions of happiness and anger in the initial neutral frame and the final frames of the 60%, 80%, and 100% morphs. The static portion of the task utilized photographs of static facial expressions, or the final frame of the dynamic video clips that depict a full-intensity expression. A detailed description of the static ERT can be found in Warner-Czyz et al. (2019).

a) 

b) 

Figure 3.1. Images from the Emotion Recognition Task (ERT) (Montagne et al., 2007) of the apex frame for the three dynamic tasks (left to right: neutral or 0%, 60%, 80%, and 100%) for expressions of (a) happiness and (b) anger

3.2.3 Procedure

Participants individually completed each task seated approximately 50 cm in front of a 15.6-inch Dell Latitude laptop (Intel® Core™ i7-3540M CPU 2.99GHz) with a SMI iView X™ RED-m portable eye tracker. The presentation order of the tasks was fixed so that each participant completed the static version of the task followed by the three dynamic tasks in order of increasing emotion intensity (i.e., 60%, 80%, then 100%) (Figure 3.2). The static image was presented for 1500 msec and the dynamic tasks ranged in presentation length from 1265 msec for 60% intensity, 1670 msec for 80% intensity, and 2074 msec for 100% intensity. Immediately following each trial, participants were asked to categorize the previously shown facial expression by selecting, via mouse click, one of six emotion label buttons (i.e., happiness, sadness, anger, fear, surprise, or disgust) that appeared on a response slide. Participants were given as much time as necessary to select one of the emotion labeled buttons. Regions of interest, created within SMI

BeGaze^{TM} software, covered each of the labeled buttons on the response slide. Using the responses collected we calculated participants' percent choice to target emotions for each trial. Percent choice to target emotion was used to compare emotion recognition of adolescents with CI and adolescents with TH instead of accuracy, which reflects the percent agreement with interpretation of emotion by adults (Montagne et al., 2007).

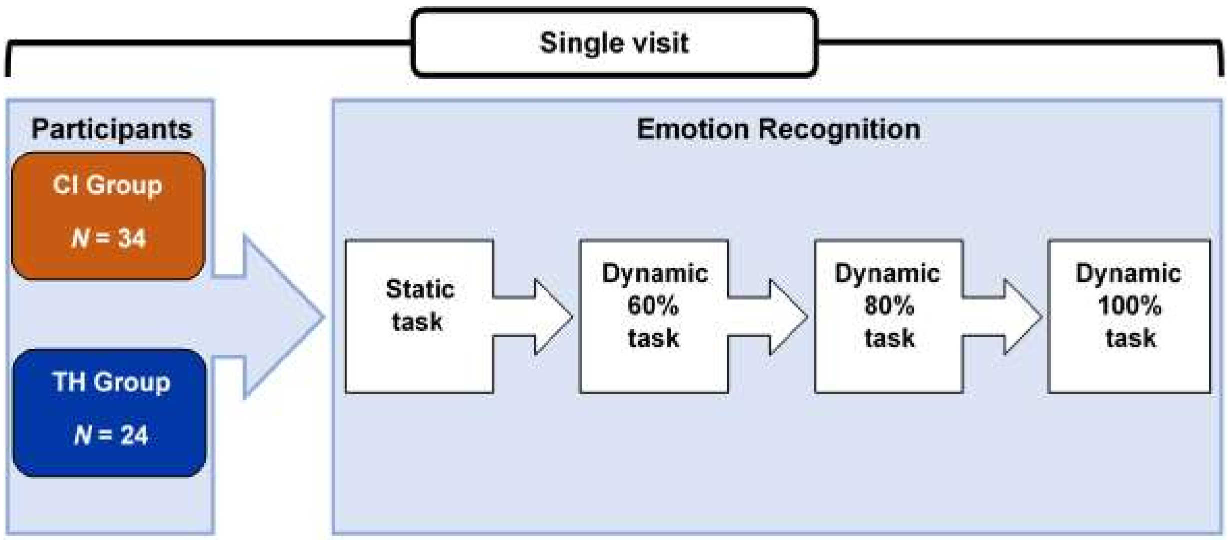


Figure 3.2. CI = Cochlear implant; TH = typical hearing. Outline of the order participants completed the emotion recognition tasks during the single testing session. The static task was administered first and then the three dynamic tasks in order of increasing emotion intensity. Participants did not receive any feedback between tasks regarding their choices on the previous task.

3.2.4 Statistical Analysis

Means and standard deviations were calculated for percent choice across all trials of the static and dynamic emotion recognition tasks. Statistical analyses were completed using IBM SPSS Statistics (Version 25.0). To examine the main effect of auditory status, stimulus motion, and emotion type, we conducted a 2x2x6 repeated measures ANOVA. Auditory status (CI vs. TH) served as the between-subjects factor, stimulus motion (static vs. 100% dynamic) and emotion type (happiness, sadness, anger, fear, surprise, disgust) were the within-subjects factors, and percent choice to target emotion was the dependent variable.

To examine the effect of participant group, emotion type, and emotion intensity on percent choice outcomes of dynamic emotion recognition, three separate 2 x 6 repeated measures analysis of variance (ANOVA) were conducted with group (CI vs. TH) as the between-subjects factor, emotion type (happiness, sadness, anger, fear, surprise, disgust) as the within-subjects factor, and percent choice to target emotion on 60%, 80%, or 100% trials as the dependent variable. An additional repeated measures ANOVA was conducted to investigate the effect of emotion intensity and the presence of interactions among auditory status, emotion type, and emotion intensity. Participant group served as the between-subjects factor, while emotion type and emotion intensity (60%, 80%, 100%) served as within-subjects factors. Percent choice to target emotion was also the dependent variable in this analysis.

Based on tests of sphericity, Geisser-Greenhouse or Huynh-Feldt corrections were applied for main effects and interaction effects of each variable of interest on percent choice outcomes. The amount of total variability explained by differences between participant groups, emotion types, stimulus motion, and emotion intensity was examined by computing partial eta squared ($\eta_p{}^2$) effect sizes. Cohen's (1988) guidelines were used to interpret effect sizes as small (0.01), moderate (0.06), or large (0.14). Post hoc analyses were completed with pairwise comparisons using Bonferroni adjustments and with simple main effects to compare effects of within-subjects factors and effects of emotion type and emotion intensity. Finally, confusion matrices of emotion recognition for static and all three dynamic trials were calculated to provide information about the distribution of errors for each of the six types of facial expressions.

3.3 Results

3.3.1 Static versus 100% intensity dynamic emotion recognition

Mean percent choice and standard deviation for each participant group, stimulus motion, and emotion type are displayed in Table 3.2. A 2x3x6 repeated measures ANOVA was conducted with percent choice to target emotion as the dependent variable and with participant group (CI vs. TH), emotion type, and stimulus motion (static vs. 100% intensity dynamic) as the independent variables. Participant group had a significant main effect on overall emotion recognition, F (1, 56) = 4.22, p = .045, $\eta_p{}^2$ = .07 power = .52, suggesting that the emotion recognition performance of adolescents with CI significantly differed from that of adolescents with TH. The effect of participant group is significant, but the effect size is moderate with only 7% of total variance in emotion recognition explained by participant group. On average, the adolescents with TH made significantly higher percent choice to target emotions (M = 64.4%, SD = 21.6%) than the adolescents with CI (M = 59.8%, SD = 22.4%) independent of stimulus motion or emotion type. There were also significant effects of stimulus motion, F (1, 56) = 6.04, p = .017, $\eta_p{}^2$ = .10, power = .68, and emotion type, F (4.59, 257.23) = 99.02, p < .001, $\eta_p{}^2$ = .64, power = 1.00. The effect size of stimulus motion was moderate, explaining 10% of total variance, but the effect of emotion type was large and explained 64% of total variance in full-intensity emotion recognition.

Participants on both static and 100% intensity dynamic trials had the highest percent choice of happiness, followed by anger, disgust, surprise, sadness, and fear. Pairwise comparisons revealed that happiness was chosen when it was the target emotion significantly more than all other emotions (p < .001; Table 3.2), regardless of participant group or stimulus motion. Fear had significantly lower percent choice outcomes than all other emotions, independent of participant group and stimulus motion ($p < .001$; Table 3.2).

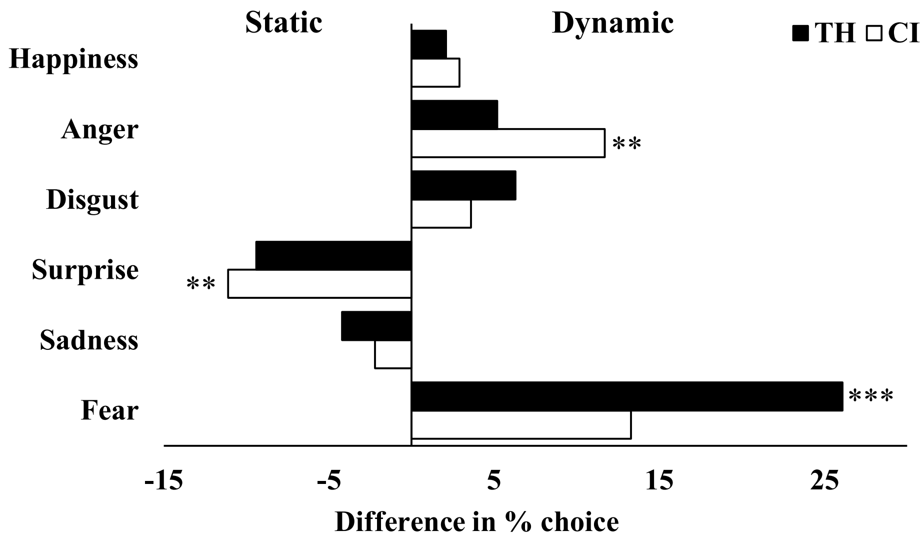


Figure 3.3. $^{**}p < .01$; $^{***}p < .001$. Differences between static and dynamic percent choice outcomes for adolescents with CI and adolescents with TH for each emotion type. The x-axis displays the difference in percent choice outcomes between dynamic and static emotion recognition tasks. The y-axis shows the six emotion types tested. White bars represent the CI group and black bars represent the TH group. Bars extending to the left of the center line indicate that the target emotion was chosen more on the static task and bars extending to the right of the center line reflect better outcomes on the dynamic tasks.

Results also revealed a significant interaction between stimulus motion and emotion type, $F\ (4.56, 255.13) = 6.48$, $p < .001$, $\eta_p{}^2 = .10$, power = 1.00, suggesting that the dynamic advantage is dependent upon emotion type (Figure 3.3). These results indicate that the interaction between stimulus motion and emotion type was moderate and accounted for 10% of total variance in emotion recognition outcomes. Simple main effects analyses were conducted for the CI and TH groups to further examine the interaction. Adolescents with CI and adolescents with TH interpret expressions of happiness, anger, disgust, and fear in the same way when viewing 100% intensity dynamic videos of the emotions. Significantly higher percent choice was reported on 100% intensity dynamic trials of anger and fear for adolescents with CI, F (1, 33) = 10.15, p = .003, $\eta_p{}^2$ = .24, power = .87 and adolescents with TH, F (1, 23) = 22.22, p < .001, $\eta_p{}^2$ = .49, power = 1.00, respectively. The effect sizes were large, suggesting that stimulus motion explained 24% of the total variability in recognition of anger for adolescents with CI and 49% of overall variability in recognition of fear for adolescents with TH. Alternatively, higher percent choice to the target emotion by adolescents in the CI and TH groups was reported for static expressions of surprise (CI: p = .026; TH: p = .153) and sadness (CI: p .738; TH: p = .575).

Table 3.2 provides the emotion recognition outcomes for each group and emotion type on dynamic trials. Means and standard deviations for percent choice outcomes on the static task can be found in Warner-Czyz et al. (2019). Finally, the participant group x stimulus motion interaction, F (1, 56) = 0.18, p = .673, $\eta_p{}^2$ = .00, power = .07, the participant group x emotion type interaction, F (4.59, 257.23) = 1.10, p = .359, $\eta_p{}^2$ = .02, power = .37, and the participant group x stimulus motion x emotion type interaction, F (4.56, 255.13) = 0.66, p = .643, $\eta_p{}^2$ = .01, power = .23, did not reach significance. Each of these interactions were responsible for a small amount (<2%) of the total variance in emotion recognition.

Table 3.2. Emotion recognition percent choice to target emotion for dynamic 60%, 80%, and 100% emotion intensity.

		60% Emotion Intensity		80% Emotion Intensity		100% Emotion Intensity		Total (all emotion intensities)	
	Emotion Type	***M*** **(%)**	***SD*** **(%)**	***M*** **(%)**	***SD*** **(%)**	***M*** **(%)**	***SD*** **(%)**	***M*** **(%)**	***SD*** **(%)**
CI (*n* = 34)	**Happiness**	92.7	13.1	95.6	9.8	97.8	7.2	**95.3**	**10.4**
	Anger	70.6	22.6	75.0	19.5	77.9	17.2	**74.5**	**19.9**
	Disgust	44.9	29.4	48.5	30.7	58.8	28.1	**50.7**	**29.7**
	Surprise	43.4	23.3	41.9	24.4	50.7	20.9	**45.3**	**23.0**
	Sadness	27.9	22.0	38.2	23.2	47.8	24.9	**38.0**	**24.6**
	Fear	24.3	21.7	29.4	26.5	34.6	29.5	**29.4**	**26.2**
	Total (all emotions)	**50.6**	**32.8**	**54.8**	**32.6**	**61.3**	**30.6**	**55.6**	**32.3**
TH (*n* = 24)	**Happiness**	95.8	9.5	97.9	7.1	100.0	0.0	**97.9**	**7.0**
	Anger	69.8	22.1	76.0	20.2	77.1	20.7	**74.3**	**21.0**
	Disgust	56.3	30.6	61.5	29.5	71.9	30.7	**63.2**	**30.5**
	Surprise	46.9	21.2	53.1	21.3	50.0	22.1	**50.0**	**21.4**
	Sadness	34.4	20.6	44.8	25.5	51.0	22.7	**43.4**	**23.7**
	Fear	26.0	22.7	40.6	26.4	49.0	28.1	**38.5**	**27.2**
	Total (all emotions)	**54.9**	**31.7**	**62.3**	**29.9**	**66.5**	**29.3**	**61.2**	**30.6**

Note. CI = cochlear implant; TH = typical hearing.

3.3.2 Emotion recognition with varying emotion intensity

Table 3.2 displays the mean percent choice outcomes and standard deviations of adolescents with CI and adolescents with TH for all emotion types on 60%, 80%, and 100% emotion intensity trials. A 2 x 3 x 6 repeated measures ANOVA with group (CI vs. TH), emotion intensity (60% vs. 80% vs. 100% intensity), and emotion type as the independent variables and percent choice to target emotion as the dependent variable. Analysis revealed a significant effect of participant group on percent choice across all trials of dynamic emotion recognition, F (1, 56) = 6.22, p = .016, $\eta_p{}^2$ = .10, power = .69, suggesting that the percent choice to target emotion of adolescents with CI significantly differed from adolescents with TH, independent of emotion intensity or emotion type. The effect size is moderate suggesting 10% of total variance in outcomes were explained by participant group. Overall, across all emotion intensity trials, adolescents with CI achieved significantly lower percent choice (M = 55.6%, SD = 32.3%, range: 0-100%) than the TH group (M = 61.2%, SD = 30.6%, range: 0-100%), indicating that adolescents with CI and adolescents with TH interpret dynamic expressions differently.

Emotion type had a significant main effect on emotion recognition, F (4.34, 243.15) = 12.16, p < .001, $\eta_p{}^2$ = .70, power = 1.00, with a large effect size indicating the emotion type accounted for more than 70% of the total variance in dynamic emotion recognition. Regardless of emotion intensity or participant group, adolescents achieved significantly higher percent choice outcomes for happiness than any of the other five emotions (M = 96.4%, SD = 9.2%, all p < .001). Anger was identified as the target emotion significantly more than sadness, fear, or surprise regardless of participant group or emotion intensity (M = 74.4%, SD = 20.3%, all p < .001). Percent choice to fearful expressions was significantly lower than all other emotions, except for sadness, regardless of participant group or emotion intensity (*M* = 33.2%, *SD* = 26.9%, all $p < .002$). Interactions between participant group and emotion type, F (9.53, 533.46) = 1.57, $p = .115$, $\eta_p^2 = .03$, power = .40, did not reach statistical significance and explained less than 3% of total variance (i.e., small effect size).

As hypothesized, a significant effect of emotion intensity on percent choice to target emotion emerged independent of participant group and emotion type, F (2, 112) = 26.85, $p < .001$, $\eta_p^2 = .32$, power = 1.00. This result indicated a large effect size and that emotion intensity explained more than 30% of the total variance in dynamic emotion recognition outcomes. Additional post-hoc analysis with Bonferroni corrections indicated a significant difference between 60% and 80% emotion intensity ($p = .004$) and 100% emotion intensity compared to both 60% and 80% emotion intensity ($p < .001$). No significant interaction emerged between participant group and emotion intensity, F (2, 112) = .62, $p = .539$, $\eta_p^2 = .01$, power = .15, suggesting higher percent choice to the target emotion was observed with increasing emotion intensity for participants in both groups. The result was not significant, and the effect size was small indicating that the interaction between participant group and emotion intensity accounted for only 1% of total variance in outcomes.

To determine if adolescents with CI or TH require greater emotion information from facial movement to recognize emotions, we ran three separate 2 x 6 repeated measures ANOVAs with percent choice to target emotion on 60%, 80%, or 100% intensity trials as the dependent variable and participant group (CI vs TH) and emotion type as the independent variables (Figure 3.4). Analysis revealed a significant main effect of group on 80% emotion intensity trials, F (1, 56) = 5.83, $p = .019$, $\eta_p^2 = .09$, power = .66. The effect size of participant group was moderate indicating that group explained less than 10% of the total variance in emotion recognition outcomes when participants were shown 80% of a facial expression. The main effect of participant group did not reach significance for 60% intensity, $F\,(1, 56) = 2.77$, $p = .102$, $\eta_p^{\,2} = .05$, power = .37, or 100% intensity, $F\,(1, 56) = 3.20$, $p = .079$, $\eta_p^{\,2} = .05$, power = .42. The effect was small for the 60% intensity task and moderate on the 100% task, indicating that participant group explained 5% of the overall variance. On trials where only 80% of a full-intensity expression is provided, the adolescents with TH achieved significantly higher percent choice to target emotion (*M* = 62.3%, *SD* = 29.9%, range: 0-100%) than the adolescents with CI (*M* = 54.8%, *SD* = 32.6%, range: 0-100%). As hypothesized, there was a significant effect of participant group on lower-intensity trials (i.e., 80% intensity) and no effect on higher-intensity trials (i.e., 100% intensity). While the adolescents with CI achieved lower percent choice than adolescents with TH when shown expressions of 80% emotion intensity, there was no difference between the two groups when viewing facial expressions of the lowest and highest emotion intensities (i.e., 60% and 100%). These findings suggest adolescents with CI require greater visual emotion information from movement of facial muscles to achieve a significant improvement in dynamic emotion recognition similar to adolescents with TH.

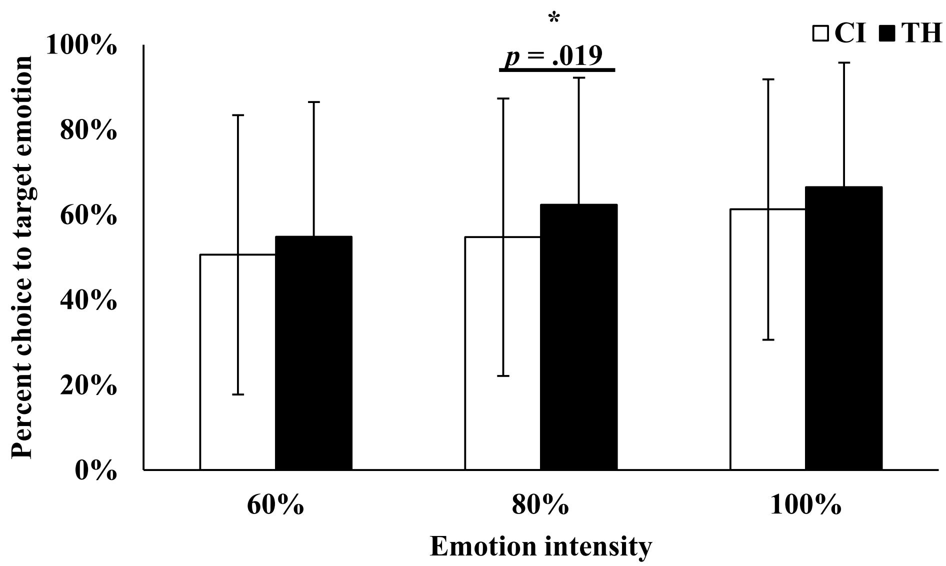


Figure 3.4. Overall percent choice to target emotion on dynamic emotion recognition for 60%, 80%, and 100% emotion intensity. The x-axis shows emotion intensity tasks and the y-axis show mean percent choice to target for dynamic emotion recognition. The white bars show results for the CI group and the black bars show results for the TH group. Adolescents with CI achieved significantly lower percent choice to target emotion outcomes than adolescents with TH on the dynamic 80% emotion intensity task. No significant group differences emerged on the 60% or 100% dynamic emotion intensity tasks.

3.3.3 Distribution of errors on emotion recognition

To examine whether there were any group differences in error patterns on the static and dynamic emotion recognition tasks, we constructed confusion matrices for adolescents with CI and adolescents with TH showing which emotion labels were chosen if the target emotion was misidentified (Table 3.3-3.6). The numbers in the distribution of overall percent errors section of each table reflect the percentage of times adolescents chose that emotion type when they incorrectly identified the target emotion. On the static trials, the overall percent choice to target emotion for adolescents with CI was 58.2% (*SD* = 31.1%) and the adolescents with TH achieved percent choice outcomes of 62.2% (*SD* = 32.4%). Overall outcomes on the each of the dynamic trials increased with emotion intensity such that the lowest percent choice for both groups were achieved on the 60% intensity trials (CI: *M* = 50.6, *SD* = 32.8; TH: *M* = 54.9, *SD* = 31.7), then the 80% intensity trials (CI: *M* = 54.8, *SD* = 32.6; TH: *M* = 62.3, *SD* = 29.9), and the highest were achieved on 100% intensity trials (CI: *M* = 61.3, *SD* = 30.6; TH: *M* = 66.5, *SD* = 29.3). On all static and dynamic emotion recognition tasks, both groups achieved the highest percent choice for expressions of happiness and anger and the lowest percent choice for fear.

The CI and TH groups demonstrated similar error patterns across emotions and consistently misidentified certain target emotions with the same choices. When the target emotion was misidentified, the adolescents selected an easily confusable emotion type of similar positive or negative valence. For example, on the static and three dynamic tasks, both groups most commonly misrecognized anger as disgust, fear as surprise, disgust as anger, and surprise as happiness. Happiness had the lowest error rate and was the only emotion in which the most common misclassification consistently differed between groups. For the static and all three dynamic tasks (i.e., 60%, 80%, 100%), the adolescents with CI misrecognized happiness as fear or anger, while the adolescents with TH misidentified happiness as disgust or anger. Misclassifications of sadness varied by stimulus motion with both groups misclassifying sadness as disgust (CI: 41.2%; TH: 48.8%) on the static task (Table 3.3). However, on all of the dynamic tasks, adolescents with TH most often mislabeled expressions of sadness as fear, while the adolescents with CI chose fear and surprise as responses (see Tables 3.4-3.6).

Table 3.3. Confusion matrix and distribution of errors for static emotion recognition.

	Target Emotion	Choice Overall (%)	Error Overall (%)	Distribution of Overall Percent Error: Happiness (%)	Anger (%)	Disgust (%)	Surprise (%)	Sadness (%)	Fear (%)
CI (*n* = 34)	**Happiness**	94.9	5.1	-	14.3	14.3	0.0	28.6	**42.8**
	Anger	66.2	33.8	2.2	-	**58.7**	10.9	21.7	6.5
	Disgust	55.1	44.9	0.0	**86.9**	-	1.6	6.6	4.9
	Surprise	61.8	38.2	**89.5**	0.0	9.0	-	0.0	1.5
	Sadness	50.0	50.0	4.4	8.8	**41.2**	13.2	-	32.4
	Fear	21.3	78.7	1.9	0.0	9.3	**88.8**	0.0	-
TH (*n* = 24)	**Happiness**	97.9	2.1	-	0.0	**50.0**	0.0	0.0	**50.0**
	Anger	71.9	28.1	0.0	-	**55.6**	3.7	18.5	22.2
	Disgust	65.6	34.4	0.0	**81.8**	-	3.0	6.1	9.1
	Surprise	59.4	40.6	**76.9**	2.6	5.1	-	5.1	10.3
	Sadness	55.2	44.8	7.0	2.4	**48.8**	20.9	-	20.9
	Fear	22.9	77.1	0.0	0.0	2.7	**93.2**	4.1	-

Note. CI = cochlear implant; TH = typical hearing

Error patterns on the dynamic tasks for most emotion types (i.e., fear, surprise, disgust) revealed a potential process of elimination for misclassifications as emotion intensity increases. For expressions of surprise, both groups increasingly misrecognized the emotion as happiness from the 60% intensity (CI: 84.4%; TH: 88.2%), 80% intensity (CI: 87.3%; TH: 93.3%), and 100% intensity trials (CI: 89.6%; TH: 95.8%). The adolescents with TH increasingly misidentified sadness as fear with greater emotion intensity. Adolescents with CI continued to confuse sadness as fear, surprise, disgust, and anger with similar error rates across 60%, 80%, and 100% dynamic trials. This suggests that the process of recognizing facial expressions is influenced by the additional visual emotion information provided through facial movements of increasing emotion intensity. For the adolescents with CI, the benefit of these facial expression cues may vary by emotion type suggesting a potential difference in visual processing of facial movements.

Table 3.4. Confusion matrix and distribution of errors for 60% dynamic emotion recognition.

	Target Emotion	Choice Overall (%)	Error Overall (%)	Distribution of Overall Percent Error					
				Happiness (%)	**Anger (%)**	**Disgust (%)**	**Surprise (%)**	**Sadness (%)**	**Fear (%)**
CI (*n* = 34)	**Happiness**	92.6	7.4	-	10.0	20.0	10.0	20.0	**40.0**
	Anger	70.6	29.4	10.0	-	**62.5**	0.0	10.0	17.5
	Disgust	44.9	55.1	0.0	**93.3**	-	1.3	2.7	2.7
	Surprise	43.4	56.6	**84.4**	0.0	2.6	-	2.6	10.4
	Sadness	27.9	72.1	0.0	3.1	29.9	29.9	-	**37.1**
	Fear	23.5	76.5	2.9	3.8	15.4	**75.0**	2.9	-
TH (*n* = 24)	**Happiness**	95.8	4.2	-	25.0	**50.0**	0.0	0.0	25.0
	Anger	69.8	30.2	10.3	-	**31.0**	24.2	6.9	27.6
	Disgust	56.3	43.7	2.4	**81.0**	-	4.8	4.8	7.0
	Surprise	46.9	53.1	**88.2**	0.0	0.0	-	2.0	9.8
	Sadness	34.4	65.6	1.6	11.1	22.2	27.0	-	**38.1**
	Fear	26.0	74.0	4.2	1.4	12.7	**80.3**	1.4	-

Note. CI = cochlear implant; TH = typical hearing

Table 3.5. Confusion matrix and distribution of errors for 80% dynamic emotion recognition.

	Target Emotion	Choice Overall (%)	Error Overall (%)	Distribution of Overall Percent Error					
				Happiness (%)	**Anger (%)**	**Disgust (%)**	**Surprise (%)**	**Sadness (%)**	**Fear (%)**
CI (*n* = 34)	**Happiness**	95.6	4.4	-	**33.3**	16.7	**33.3**	16.7	0.0
	Anger	75.0	25.0	0.0	-	**52.9**	8.8	11.8	26.5
	Disgust	48.5	51.5	0.0	**95.7**	-	0.0	1.4	2.9
	Surprise	41.9	58.1	**87.3**	1.3	1.3	-	0.0	10.1
	Sadness	38.2	61.8	1.2	8.3	23.8	28.6	-	**38.1**
	Fear	29.4	70.6	3.1	0.0	8.4	**88.5**	0.0	-
TH (*n* = 24)	**Happiness**	97.9	2.1	-	**50.0**	0.0	**50.0**	0.0	0.0
	Anger	76.0	24.0	0.0	-	**47.8**	13.0	26.2	13.0
	Disgust	61.5	38.5	2.7	**86.5**	-	2.7	2.7	5.4
	Surprise	53.1	46.9	**93.3**	0.0	0.0	-	2.3	4.4
	Sadness	44.8	55.2	0.0	11.3	13.2	18.9	-	**56.6**
	Fear	40.6	59.4	1.8	1.8	1.8	**94.6**	0.0	-

Note. CI = cochlear implant; TH = typical hearing

Table 3.6. Confusion matrix and distribution of errors for 100% dynamic emotion recognition.

	Target Emotion	Choice Overall (%)	Error Overall (%)	Distribution of Overall Percent Error					
				Happiness (%)	**Anger (%)**	**Disgust (%)**	**Surprise (%)**	**Sadness (%)**	**Fear (%)**
CI (*n* = 34)	**Happiness**	97.8	2.2	-	0.0	0.0	33.3	0.0	**66.7**
	Anger	78.7	21.3	0.0	-	**65.5**	10.3	10.3	13.9
	Disgust	58.8	41.2	0.0	**95.7**	-	0.0	1.4	2.9
	Surprise	50.7	49.3	**89.5**	0.0	9.0	-	0.0	1.5
	Sadness	47.8	52.2	0.0	9.9	23.9	32.4	-	**33.8**
	Fear	34.6	65.4	0.0	0.0	9.0	**91.0**	0.0	-
TH (*n* = 24)	**Happiness**	100.0	0.0	-	0.0	0.0	0.0	0.0	0.0
	Anger	77.1	22.9	0.0	-	**36.4**	18.2	31.8	13.6
	Disgust	69.8	30.2	0.0	**86.2**	-	0.0	3.5	10.3
	Surprise	50.0	50.0	**95.8**	0.0	2.1	-	0.0	2.1
	Sadness	51.0	49.0	0.0	11.3	13.2	18.9	-	**56.6**
	Fear	49.0	51.0	0.0	2.0	6.2	**91.8**	0.0	-

Note. CI = cochlear implant; TH = typical hearing

3.4 Discussion

This study was the first to examine the effect of stimulus motion and emotion intensity on facial emotion recognition in adolescents with CI and adolescents with TH. Adolescents with CI interpreted emotions similarly to adolescents with TH when shown static and 100% intensity dynamic facial expressions. However, percent choice outcomes differed by group on dynamic tasks, independent of emotion intensity. Participants in both groups interpreted emotions similarly when shown the lowest (60%) and highest (100%) intensity expressions, but differently when shown only 80% of facial expressions.

3.4.1 Similarities in emotion recognition of intense facial expressions

Adolescents with CI interpreted static and dynamic, full-intensity facial expressions similarly to adolescents with TH. Previous research reported that children with CIs (aged 2─7 years old) exhibit poorer emotion recognition than children with TH on static and dynamic tasks (Most & Michaelis, 2012; Wang et al., 2016). However, emotion recognition improves with maturation and CI users demonstrate comparable emotion recognition abilities to adolescents with TH (Hopyan-Misakyan et al.,2009; Most & Aviner, 2009; Warner-Czyz, et al., 2019). Combined with previous findings, our results provide support for a stabilization of emotion recognition skills by adolescents in CI users.

Previous studies with typically developing children and adults found no advantage for dynamic stimuli over static photographs when assessing recognition of intense facial expressions (Bould & Morris, 2008; Widen & Russell, 2015). Our study showed that adolescents in both groups achieved improved recognition outcomes on the expressions in the dynamic video versus static photograph conditions. These results mirror published reports of a dynamic advantage for children with HL (Jones et al., 2017), suggesting motion plays a compensatory role in identifying expressions for adolescents with CI. Stimulus motion also influenced interpretation of specific emotions, independent of auditory status. Both adolescent groups identified surprised and sad faces better with static photographs than dynamic video clips. In contrast, expressions of happiness, anger, fear, and disgust were better recognized by participants of both groups when shown using dynamic video clips of faces. The dynamic advantage depends on emotion type, indicating that stimulus motion may not be essential for interpreting certain emotions.

3.4.2 Differences in emotion recognition: The effect of emotion intensity

To date, the majority of emotion recognition studies with CI users employ either static photographs or dynamic clips of full-intensity expressions (Most & Aviner, 2009; Most & Michaelis, 2012; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013; Ziv et al., 2013). However, facial expressions observed in typical social interactions are subtle and fleeting, rather than intense and steady. Findings from the current study partially support our hypothesis that adolescents with CI interpret facial expressions differently than adolescents with TH when identifying low-intensity, subtle emotions but achieve comparable results on intense expressions.

Participants from both groups showed a pattern of improvement in emotion recognition with increased emotion intensity (i.e., 60% < 80% <100%), similar to the previous findings with children with HL and children with TH (aged 6–11 years) (Jones et al., 2017). Further analysis of the effect of auditory status on emotion recognition at each intensity level revealed that the two groups interpreted emotions similarly when viewing 60% of the facial expression. It’s possible that 60% of an expression provides insufficient emotion information for either group to interpret emotions, preventing the detection of subtle differences between the CI and TH groups.

Studies examining emotion recognition in typically developing children and adults show poorer emotion recognition of low-intensity (50%) than moderate- or high-intensity expressions (75% and 100%, respectively) (Chronaki et al., 2015). As previously mentioned, the two groups performed similarly on the 100% dynamic task providing further evidence that intense facial expressions are easier to identify than more subtle expressions due to the dramatic difference in movement of facial muscles (Montagne, et al., 2007).

Importantly, adolescents with CI significantly differed from adolescents with TH when interpreting emotion from 80% of a facial expression. Participants in the CI group achieved lower percent choice to the target emotion than the TH group, regardless of emotion type. This suggests that adolescents with TH process the emotion information necessary for recognition from 80% intensity facial expressions more consistently with adults. On the other hand, adolescents with CI require more emotion information, or the full-intensity expression, to interpret emotion similar to adolescents with TH. Differences in interpretation of subtle expressions could make social interactions with peers increasingly difficult and may underlie that social difficulties experienced by CI users.

3.4.3 Emotion recognition and error patterns

The interaction effects for participant group and emotion type were not significant on any of the emotion recognition tasks completed in this study (i.e., static and 60%, 80%, 100% dynamic), indicating that the CI and TH groups demonstrated a similar choice pattern when interpreting facial expressions. Happiness and anger were the most correctly recognized emotions and fear the least accurate, independent of stimulus motion or emotion intensity. These findings align with previous studies that observed poorer recognition of fear-related emotions (i.e., afraid, frightened) and a tendency to prioritize positivity (i.e., "happiness superiority effect") in children with HL and individuals with TH (Elfenbein & Ambady, 2002; Sidera et al., 2017; Wang et al., 2011; Craig et al., 2014).

This study also compared error patterns of adolescents with and without HL on the static and all three dynamic tasks. On all tasks, several of the error patterns of adolescents in both groups reflect easily confused emotions of similar positive or negative valence: anger as disgust, surprise as happiness, disgust as anger. Participants also misclassified emotions such as fear and surprise, which use similar facial movements (i.e., eye-widening), resulting in perceptual congruity (Calder et al., 2003; Calder & Young, 2005; Rapcsak et al., 2000). Adolescents in both groups frequently identified sadness as disgust or fear. Increasing emotion intensity was often related to an increase in proportion of errors to the most common misclassification for each target emotion. However, the adolescents with CI strayed from this trend and exhibited consistent error patterns for certain emotions across 60%, 80%, and 100% emotion intensity trials.

3.4.4 Strengths and limitations

The current study adds to literature addressing emotion recognition in adolescents with CI by implementing life-like dynamic stimuli to assess emotion recognition in individuals with prelingual HL. Outcomes from this study reflect the complexities of recognizing real-time facial emotion, which varies in movement and intensity, for children and adolescents with CI. This study also compares performance on static and dynamic tasks to investigate the ecological validity of each type of stimulus with adolescents with CIs. In addition, this study expands the current literature by focusing on emotion recognition in adolescents with CIs who communicate using spoken language. While previous studies have examined recognition of dynamic expressions in children with HL who use sign language, focusing on oral communicators provides information on whether communication experience influences emotion understanding.

This study has limitations. Medical and speech-language records were incomplete for the majority of the adolescents with CI, restricting the ability to assess the link between language competence and emotion recognition. Delays in language and verbal ability have been correlated to poorer emotion recognition and emotion understanding in children with HL (Dyck et al., 2004; Wiefferink et al., 2013). As such, records about language outcomes or inclusion of a measure of language competence could have allowed us to determine the language relates to dynamic emotion recognition proficiency or delays in adolescents with CIs. In addition, this study relied on parent report for information about hearing levels of adolescents with TH and did not perform a hearing screening for these participants. Another limitation of this study is the order in which participants completed the static and dynamic emotion recognition tasks. Adolescents in the CI and TH groups completed the tasks in the following order: static, 60% intensity, 80% intensity, and 100% intensity. While participants did not receive any additional feedback regarding their choices between tasks, seeing the full-intensity expressions in static photographs before completing the 100% dynamic task could have primed participants to the facial expressions. Finally, the behavioral measures emotion recognition examined in this study provided limited information about real-time processing of facial expression.

3.5 Conclusion

Overall, emotion recognition outcomes revealed that adolescents with CIs show recognition abilities comparable to adolescents with TH when emotions are expressed at full-intensity (i.e., static and 100% dynamic). Both groups improved on emotion recognition when expressions included facial movement, indicating dynamic tasks may be more ecologically valid for clinical assessment of emotion recognition in CI users. This study also revealed that adolescents with CI interpret subtle facial expressions differently from adolescents with TH. If adolescents with CI require additional social and emotional cues for interpretation of emotion, social interactions with peers may be disrupted and possibly awkward. Future studies and clinical intervention should focus on differences in social cognition between adolescents with CI and adolescents with TH to improve social-emotional well-being in CI users.

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CHAPTER 4

VISUAL PROCESSING OF STATIC FACIAL EXPRESSIONS BY ADOLESCENTS WITH COCHLEAR IMPLANTS[3]

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4.1 Introduction

Successful social communication necessitates the ability to perceive and process both auditory and visual information about others' mental states and emotion. In particular, the processing of facial expressions is essential for social interactions as human faces (i.e., the eyes) play a key role in the communication of emotion (O'Donnell & Bruce, 2001). Individuals with typical development can distinguish and recognize emotion with few fixations to the face (Schurgin et al., 2014), but often rely on information provided through multisensory cues expressed by their communication partners. Sensory deprivation, congenital or acquired, has been linked to impaired multisensory processing and variable emotion recognition abilities in individuals with hearing loss (HL) (Dyck et al., 2004; Fengler et al., 2017). Children with severe-to-profound HL have limited access to the auditory input and depend more on nonverbal visual cues such as speechreading for communication compared to peers with typical hearing (TH). In turn, children with HL may develop a different strategy to visually process facial expressions to compensate for the degraded auditory signal that results from decreases in hearing sensitivity, processing limitations in auditory technology (e.g., hearing aid, cochlear implant (CI), or a combination of the two). This study explores the emotion recognition strategies employed during visual processing of facial expressions by adolescents with HL who use a CI compared to adolescents with TH using an eye tracking paradigm.

4.1.1 Emotion perception and recognition in children and adolescents with HL

The ability to perceive and interpret visual (i.e., facial expressions) and auditory (i.e., speech, prosody) cues of emotion plays a large role in development of social competence (Mayer et al., 2004). Individuals born with severe-to-profound HL (71 dB HL or greater) have limited access to verbal (i.e., speech) and nonverbal (i.e., prosody, intonation) emotion information typically gathered via the auditory system (Globerson et al., 2013). Emotion recognition requires the perception of multisensory cues (i.e., auditory, visual, and audiovisual), making the process difficult for children with HL. Additionally, children with severe-to-profound HL have not only less exposure to speech and language in general compared to peers with TH, but also fewer opportunities to overhear dialogue or communicate with others about emotions (Moeller & Schick, 2006; Morgan et al., 2014; Rieffe et al., 2015). For children with HL, effective perception and interpretation of emotion through visual emotion cues such as facial expressions are essential to achieving social skills similar to their peers with TH.

For some children with HL who do not benefit from the use of a hearing aid, a CI serves as an alternative form of intervention. A CI is a biomedical device designed to provide the sensation of sound to individuals via electrical stimulation of the auditory nerve. The auditory signal provided through the electrical stimulation of a CI is an inaccurate representation of the fine temporal information and speech quality delivered by the auditory system of individuals with TH (Rubenstein, 2004). Some pediatric CI users learn to successfully interpret the auditory signal received through a CI and develop auditory perception and spoken language abilities similar to peers with TH. However, a great deal of individual variability in communication abilities remains in the broader population of CI users (Holt & Svirsky, 2008; Tobey et al., 2013); only half of the children with HL that receive a CI before three years show language abilities within normal limits by eight to ten years post-implantation (Geers et al., 2016; Hare et al., 2019; Nittrouer et al., 2018).

4.1.2 Recognition of emotion in children and adolescents with CIs

Children and adolescents with HL who do not use auditory technology (i.e., hearing aids or CIs) show poorer emotion recognition of cartoons and images of faces than chronologically age-matched peers with TH (Dyck et al., 2004; Ludlow et al., 2010). Younger children who gain earlier access to sound with CIs also demonstrate poorer emotion recognition abilities compared to peers with TH (Most & Michaelis, 2012; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013). For instance, when shown facial expressions of happiness, anger, sadness, and fear, preschool-age children with CI or hearing aids exhibited poorer identification of emotion in the images than age-matched children with TH (Wang et al., 2011; Wiefferink et al., 2013). Wang et al. (2016) found that kindergarten-age CI users (2.5─7.0 years of age) had poorer recognition of color photographs of the same four emotions than children with TH (2.8─6.4 years). Deficits in emotion recognition extend beyond only visual emotion recognition in pediatric CI users. Most and Michaelis (2012) reported that recognition of emotion was higher for children with TH, aged four to six years old, than outcomes for children with CI across tasks of varying sensory modalities: only visual cues, only auditory cues, and auditory-visual cues.

Alternatively, studies of school-age children and adolescent CI users suggest facial emotion recognition abilities comparable to those developed by peers with TH (Hopyan-Misakyan et al., 2009, Most & Aviner, 2009). These studies assessed recognition of facial expressions of six emotions (i.e., happiness, anger, sadness, fear, surprise, and disgust) using photographs of human faces. Hopyan-Misakyan et al. (2009) found that CI users aged 7 to 13 years achieved performance similar to age- and gender-matched children with TH on measures of speech and facial emotion recognition. Similarly, Most and Aviner (2009) showed that adolescent CI users (aged 10–18 years) achieved emotion recognition outcomes comparable to controls with TH on visual and auditory-visual emotion recognition tasks. In our previous studies examining recognition of static and dynamic facial expressions, adolescent CI users (9.3–17.9 years old) did not significantly differ in identification of emotion or reaction time compared to adolescents with TH (10.0–18.5 years old) (Warner-Czyz et al., 2019; Evans et al., 2020). These results suggest that emotion recognition abilities may be initially delayed but improve with increased chronological age and greater experience using CI during social communication with peers.

Most studies to date examining facial emotion recognition in children and adolescent CI users rely on behavioral measures to assess facial expression processing. While accurate recognition is necessary, use of a global measure of accuracy may miss subtle differences between groups and provides a limited understanding of the complexities of visual processing of facial emotion.

4.1.3 Visual attention to the face during emotion recognition

Facial expressions of basic emotions (i.e., happiness, anger) are produced with distinct feature configurations and movement of facial musculature that provide a perceptual basis for recognition of visual emotion (Ekman & Friesen, 1978). For example, happiness is often expressed by a flexing of muscles around the mouth upward and a restriction of the eyes, while expressions of fear are associated with a widening of the eyes and alternative flexing of the mouth (Ekman & Friesen, 1978). Certain facial regions are thought to provide key information necessary to identify and categorize facial expressions.

Eye tracking technology has been employed in several studies to measure visual attention and eye gaze to different regions of the face during facial expression processing (Lim, Mountstephens, & Teo, 2020; Schurgin et al., 2014). In general, typically developing children and adults primarily direct their gaze toward diagnostic facial regions, especially the eyes, during emotion recognition. Increased attention to these diagnostic facial regions has been correlated with improved emotion recognition performance (Wong et al., 2005). Looking to the eye region of the face leads to better identification of anger and sadness, whereas looking to the mouth leads to better identification of happiness (Beaudry et al., 2014; Schurgin et al., 2014). Overall, these findings suggest a relationship between visual attention to salient facial regions and successful emotional communication.

4.1.4 Effect of hearing loss on visual attention to the face

Visual attention to the face is thought to be influenced by communicative demand and previous social communication experience. For example, adults with TH focus on the eye region more than the mouth during presentation of audiovisual speech without background noise (Smith et al., 2013), but shift their gaze to the mouth when audiovisual speech is presented with noise to compensate for the disrupted auditory signal (Vatikiotis-Bateson et al., 1998). The role of visual information in audiovisual speech perception is increasingly important for children with HL with CI who have limited access to the speech signal. Children with CI show superior speechreading skills to peers with TH and rely more on speechreading to aid with speech perception during social communication (Kyle et al., 2013). Itis possible that children and adolescents with CI perceive emotion cues from the face in a different manner than peers with TH to compensate for distorted auditory input.

Worster et al. (2018) used eye tracking to determine whether pediatric hearing aid and CI users (aged 5–8 years) accessed visual speech in a different manner than children with TH. Participants viewed videos of silently spoken sentences and were asked to repeat as much of the sentence as they could. Results revealed that children with HL and children with TH did not significantly differ in speechreading accuracy or amount of time spent watching the mouth when speechreading. Eye gaze data indicated that children from both groups demonstrated a social-tuning pattern in which they began each trial fixated on the eyes, shifted their gaze to the mouth when speech began, and returned to the eyes after the actor stopped speaking. This social-tuning pattern significantly related to the number of words correctly identified through speechreading and reading proficiency in the children with HL but not in the children with TH. The authors concluded that speechreading training in children with HL may relate to increased visual attention to a communication partner's mouth (Worster et al., 2018).

These findings from previous research suggest that children with HL who rely more on speechreading might focus more visual attention toward the mouth when processing the face. It's possible that an inclination for attending to the mouth for speechreading during social communication, might cause children with HL to miss visual cues of emotion expressed in other areas of the face (i.e., eyes) (Rigo & Liberman, 1989). Social cognitive processes (e.g., emotion recognition, theory of mind) depend on the perception of multisensory (i.e., visual, auditory, auditory-visual) cues. Poor perception of visual cues due to visual attention patterns centered on speechreading may underlie the emotion recognition and theory of mind delays observed in children with CI (Peterson & Siegal, 2000; Peterson et al., 2016; Sundqvist et al., 2014).

4.1.5 Eye tracking studies on emotion recognition in children and adolescents with HL

Limited research exists examining facial emotion recognition and visual attention to the face in children and adolescents who use assistive devices (i.e., hearing aids or CIs). Wang et al. (2017) examined eye gaze in preschool-age children with hearing aids (n = 39; Age: M = 60 months, SD = 12) who communicated using spoken language and children with TH (n = 39; Age: M = 62 months, SD = 8). The participants watched videos of a facial expression followed by an oral statement that that either matched the valence expressed in the video (i.e., congruent; positive expression-positive statement) or expressed a conflicting emotion (i.e., incongruent; positive expression-neutral statement). The children with hearing aids made fewer fixations to the top halves of facial expressions than children with TH on trials of congruent and incongruent auditory-visual emotion. Similar to the findings from Worster et al. (2018), the authors suggest children with hearing aids focus on the lower halves of the face when auditory information is presented in an effort to improve speech perception. To our knowledge, no studies to date have examined visual attention to the eye and mouth regions of the face in identifying emotions in children or adolescents with and without HL.

4.1.6 Purpose of the study

Broad measures (i.e., behavioral measures of accuracy) of facial emotion processing reveal differences in labeling of emotions between children with and without HL, but these broad comparisons may not capture subtle differences in how auditory status influences facial emotion processing in children. Children with CIs demonstrate greater visual attention to the mouth region during speechreading tasks (Worster et al., 2018), but we do not know whether this difference in visual attention to the mouth persists in all facial processing tasks. Knowledge of subtle differences in facial emotion processing could extend our understanding of social and emotional deficits reported by and observed in adolescents with HL. The current study conducts exploratory analyses using eye tracking to determine if visual attention to diagnostic regions of facial expressions (i.e., eyes, mouth, other) differs between adolescents with CI and adolescents with TH. We predict that adolescent CI users will devote more visual attention to primary emotion regions (i.e., eyes and mouth) than adolescents with TH. Eye tracking also enables us to examine visual processing emotion across the time course of the facial expression image presentation. We expect that visual attention patterns to the eye region, mouth, and other regions of facial expressions will differ across emotions for both groups, with a greater proportion of CI users than adolescents with TH fixating on the mouth.

4.2 Methods

4.2.1 Participants

A total of 58 adolescents completed a static emotion recognition task, including 34 adolescents with hearing loss who use CI and 24 adolescents with TH (Warner-Czyz et al., 2019). Data were removed from analysis of this study for any participants who received a low tracking ratio or showed an overall major loss of eye tracking during the task (i.e., less than 75% of the viewing time across trials) (CI: n= 2; TH: n = 2) . The current study includes data for 34 adolescents with CI (20 female) ranging in age from 9 years 5 months to 17 years 11 months (*M* = 13 years, 4 months, *SD* = 2 years 3 months) and 22 TH adolescents (8 female) ranging in age from 10 years to 18 years 7 months (*M* = 13 years 9 months, *SD* = 2 years 6 months). All of the participants included in the study were recruited from through the Colorado Neurological Institute’s (CNI) Cochlear Kids Camp in Estes Park or by word of mouth. The study was approved by the Institutional Review Board of the first author's institution (IRB #11-11 and 13-50).

Participant inclusion was determined based on information provided via parent report. Adolescents included in this study had normal or corrected vision, no major neurological abnormalities, and came from an English-speaking home. All participants in the CI group preferred to use an auditory-based communication mode (auditory verbal: $n = 29$; auditory oral: $n = 3$). The majority of adolescents with CIs were implanted before 3 years of age ($n = 21$; 3—5 years = 6; >5 years = 4). One of the participants implanted after 5 years of age had progressive HL. Most adolescents with CIs wore bilateral CIs ($n = 24$); the remainder used either a bimodal CI + contralateral HA configuration ($n = 4$) or a unilateral CI with no device on the contralateral ear ($n = 4$). Participants in the TH group had hearing within the normal range, per parent report. The two groups did not differ significantly in mean chronological age or gender (Table 4.1).

Table 4.1. Details of participants in study:

	CI (n = 32)			**TH (n = 22)**			**Group comparisons**
Variable	***M***	***SD***	**Range**	***M***	***SD***	**Range**	
Chronological age (years; months)	13;4	2;3	9;5—17;11	13;9	2;6	10;0—18;7	$t(52) = -0.64$, $p = 0.53$
Gender (female/male)	20/12			8/14			$X^2 = 3.57$, $p = 0.06$
Age of HL identification (years; months)	1;1	1;2	0;0—4;0				
Age at CI (years; months)	2;10	2;3	0;7—10;0				
Duration of CI experience (years; months)	10;5	3;2	1;11—16;7				

Note. CI = Cochlear Implant; TH = Typical Hearing; HL = Hearing Loss.

4.2.2 Emotion recognition task

The procedure and stimuli used in the current eye tracking study is described in detail in Warner-Czyz et al. (2019). Participants viewed 24 photographs of six full-intensity facial emotions (i.e., happiness, anger, sadness, fear, surprise, disgust) of two male and two female actors taken from the Emotion Recognition Task (ERT) (Kessels et al., 2007; Montagne et al., 2007). The color photographs were 345 x 434 mm. The photographs were initially randomized and then presented to all participants in the same fixed order. Following the presentation of each image, participants were shown a response slide with six emotion labeled buttons corresponding to the emotions included in the task. The adapted version of the task used in this study was created using SMI Experiment Center™ software.

4.2.3 Eye tracking apparatus and procedure

A SMI iView X™ RED-m portable eye tracker recorded eye movements at a sampling rate of 60 Hz. The device was connected to a 15.6-inch Dell Latitude (Intel® Core™ i7-3540M CPU 2.99GHz) laptop and was fixed below the screen. We used a triangular measuring tool to position the eye tracker at a depth of 40mm and height of 10 mm from the screen before each participant began the task. Participants were seated in a room approximately 50 cm from the laptop and their position was monitored throughout the experiment to maintain the integrity of the eye tracking results. Prior to the start of the task, each participant completed a calibration procedure and validation routine by looking at five predefined points (i.e., animated circles) on the screen. If the average deviation from the validation points was less than one degree (X: M = 0.5 degrees, SD = 0.2; Y: M = 0.4 degrees, SD = 0.2) then calibrations were accepted.

The experimenter orally provided the instructions to the participant once at the beginning of the task. Between each trial, a slide with a central fixation cross was presented for 500 msec, followed by the presentation of one of the photographs of a facial expression for 1500 msec. Each trial ended with the presentation of a response slide with six emotion labeled buttons that was visible until the participant chose an answer via mouse-click. No time constraint was placed on the response slides and the next trial would begin automatically after the participant selected a response. Testing was completed on a one-on-one basis during a single 30-minute session at either the CNI Cochlear Kid's Camp or at the Child Language and Cognitive Processes Laboratory in Dallas, Texas.

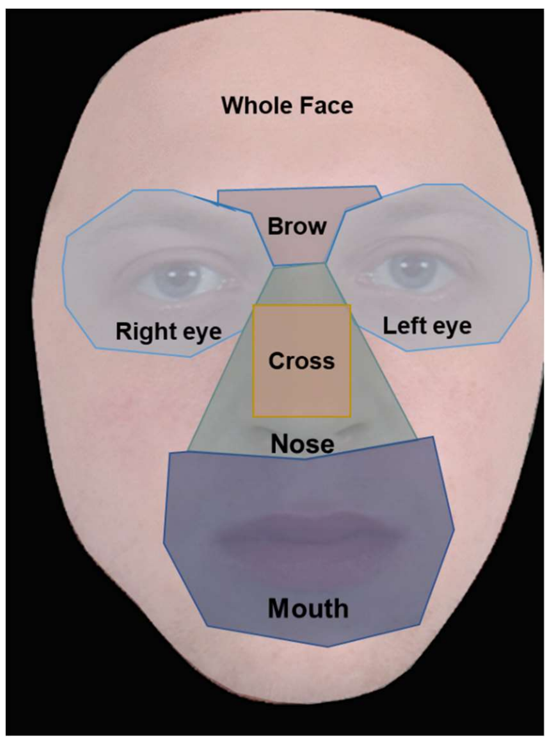

Figure 4.1. Photograph of human face with the hand-mapped ROIs created in SMI BeGaze™. The ROIs were defined as the mouth, eye region (i.e., right eye, left eye, brow), and other face (i.e., cross, nose, outside).

4.2.4 Eye tracking analysis

For eye tracking analysis, regions of interest (ROI) were hand mapped for each of the faces in the twenty-four photographs using SMI BeGaze™ analysis software. A ROI was marked around the fixation cross to distinguish first looks at the beginning of each trial from meaningful visual emotion processing. The ROIs were defined as the mouth, eye region (i.e., right eye, left eye, brow), and other face (i.e., cross, nose, outside) (Figure 4.1). These areas were chosen based on previous research indicating the importance of the eyes and mouth in emotion recognition (Bombari et al., 2013; Ekman, 1993; Smith et al., 2005). Fixations were defined as participants' looking to a given ROI for 100 msec or longer.

Proportion of fixations. For each emotion type, proportion of fixations represents the total number of fixations made to the primary emotion ROIs, or to the eye region and mouth ROIs, divided by the total number of fixations made to all three relevant ROIs (i.e., eye region, mouth, other) across the four trials of the given emotion type. A 2 (Group) x 6 (Emotion type) mixed repeated measures design was used with participant group (CI vs. TH) as the between-subjects factor and emotion type as the within-subject factor. Proportion of fixations and average fixation duration (msec) to the primary emotion ROIs served as the dependent variable of the two analyses, respectively. Post hoc comparisons using Bonferroni corrections were used to further examine the effects of each factor. If homogeneity of variance assumption was not met, results were reported with Greenhouse-Geisser or Huynh-Feldt corrections accordingly. Guidelines proposed by Cohen (1988) were used to interpret the effect size results (i.e., small = 0.01, moderate = 0.06, large = 0.14) to determine how much variability was explained by differences between factors.

Average fixation duration. Average fixation duration (msec) for each emotion type was calculated by dividing the sum of the duration of all fixations made to the primary emotion ROIs (eye region and mouth) by the total number of trials for the emotion type (i.e., four per emotion). We conducted a 2 (Group) x 6 (Emotion type) mixed repeated measures analysis of variance (ANOVA) with average fixation duration as the dependent variable. Participant group (CI vs. TH) served as the between-subjects factor and emotion type served as the within-subjects factor. As with the analysis for proportion of fixations, post hoc comparisons using Bonferroni corrections were used to further examine significant effects and Greenhouse-Geisser or Huynh-Feldt corrections were made based on homogeneity of variance results. The same effect size guidelines used in the previous analysis (i.e., 0.01for small, 0.06 for medium, and 0.14 for large effects) were used to examine the percentage of variance identified by partial eta squared ($\eta_p{}^2$) (Cohen, 1988).

First fixation location. SMI BeGaze™ calculated fixation order to the created ROIs based on entry time, or the start of time of the first fixation to enter an ROI. The provided fixation order was used to determine whether participants' first fixation inside of the primary emotion regions was directed toward the eye region or the mouth. For each emotion type, the ratio of observed to expected frequencies of first fixation counts to the eye region and mouth ROIs were calculated for the both participant groups to examine first fixation patterns. Chi-square tests of independence were used to compare the observed first fixations to the eye region and mouth to the expected frequencies for the CI and TH groups.

Time course analysis. Finally, we binned the fixation data to mouth, eye region, and other ROIs for each participant into 100-ms intervals to examine the time course of visual attention to the face during emotion recognition. This exploratory qualitative analysis was performed to examine how distribution of fixations varied between adolescents with CI and adolescents with TH during the presentation of a facial expression.

4.3 Results

4.3.1 Proportion of fixations to primary emotion ROIs

A 2 (Group) x 6 (Emotion type) mixed repeated measures ANOVA was conducted with participant group as the between-subjects variable, emotion type as the within-subjects factor, and proportion of fixations made to the primary emotion ROIs (i.e., eye region and mouth) during stimulus presentation as the dependent variable. A significant main effect of participant group, F (1, 52) = 7.38, p = .009, $\eta_p{}^2$ = .12, power = .76, with a moderate-to-large effect size indicating that participant group explained 12% of the total variance in proportion of fixations. The ANOVA results also revealed a significant main effect of emotion type, F (4.64, 241.51) = 19.76, p < .001, $\eta_p{}^2$ = .28, power = 1.00, indicating that proportion of fixations made to the primary emotion ROIs differed by emotion. The effect size for this result was large, with emotion type accounting for 28% of the total variance in proportion of fixations made to the primary emotion regions.

There was significant interaction between the effects of participant group and emotion type on proportion of fixations to the eye region and mouth compared to the other ROI of the face, F (4.64, 241.51) = 4.69, p .001, $\eta_p{}^2$ = .08, power = .97. This interaction effect was significant and moderate in size, explaining 8% of the total variance in proportion of fixations. Post hoc comparisons were conducted with Bonferroni corrections applied to the p-values for multiple comparisons. Simple main effects analyses showed that adolescents with CIs made a significantly greater proportion fixations to these primary emotion ROIs than adolescents with TH when processing expressions of sadness, F (1, 52) = 10.40, p = .002, $\eta_p{}^2$ = .17, power = .68, surprise, F (1, 52) = 11.95, p = .001, $\eta_p{}^2$ = .19, power = .75, and disgust, F (1, 52) = 10.86, p = .002, $\eta_p{}^2$ = .17, power = .70. The effect sizes for expressions of sadness, surprise, and disgust were all large and indicated that participant group accounted for between 17─19% of the total variance in proportion of fixations for these three emotions. The simple main effects of participant group approached significance for happiness, F (1, 52) = 4.01, p = .051, $\eta_p{}^2$ = .07, power = .24, and did not reach significance for expressions of anger, F (1, 52) = 0.26, p = .615, $\eta_p{}^2$ = .01, power = .02, or fear, F (1, 52) = 0.00, p = .983, $\eta_p{}^2$ = .00, power = .01. While the effect size for happiness was moderate (7%), the effects for anger and fear were small and indicated that participant group explained less than 1% of the total variance in proportion of fixations for those expressions. Figure 4.2 displays the means and standard deviations for proportion of fixations made to the primary emotion ROIs (i.e., eye region and mouth) and the other ROI.

A)

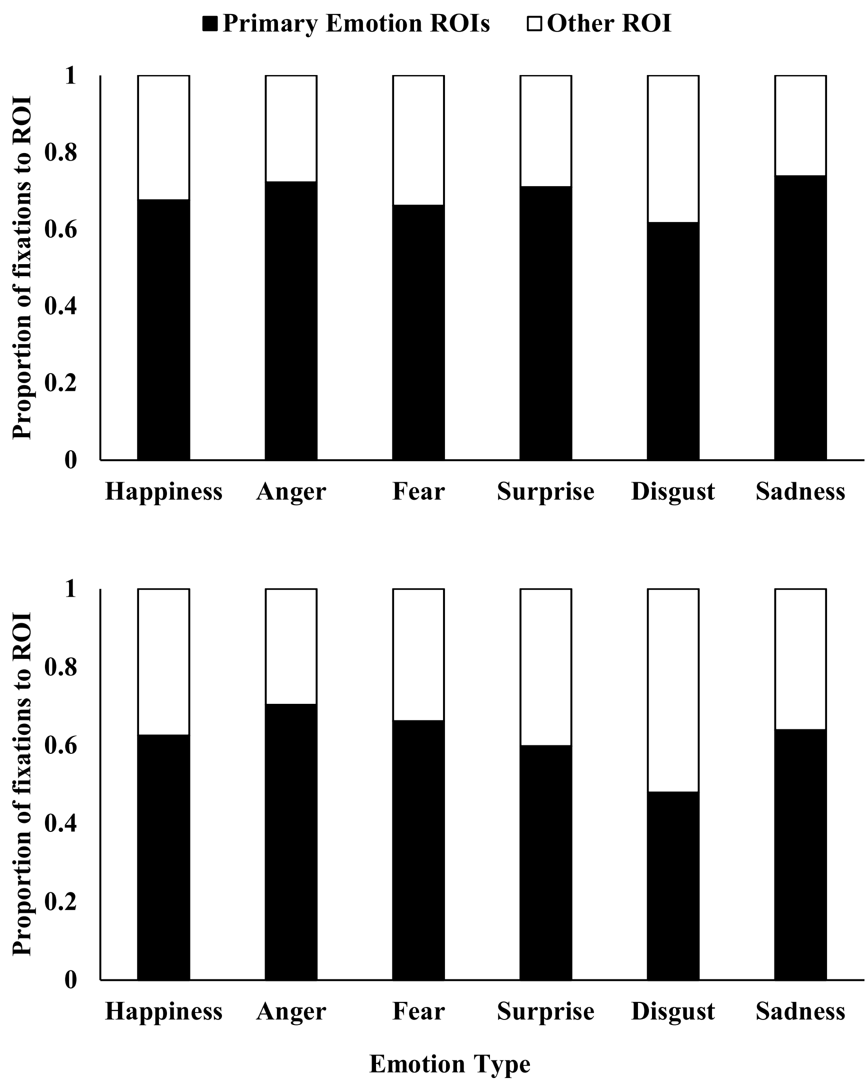

Figure 4.2. Proportion of fixations to primary emotion ROIs and other ROI for adolescents with CI (A) and TH adolescents (B). The x-axis shows emotion type and the y-axis shows proportion of fixations. The black bars represent fixations to the primary emotion ROIs (i.e., eye region and mouth) and the white bars reflect fixations to the other ROI. Proportion of fixations to the primary emotion ROIs differed significantly between CI and TH groups for expressions of surprise, disgust, and sadness.

4.3.2 Average fixation duration to primary emotion ROIs

We conducted a 2 (Group) x 6 (Emotion type) repeated measures ANOVA with average fixation duration (msec) as the dependent variable and participant group (CI vs. TH) and emotion type as the independent variables. Results for average fixation duration to the primary emotion ROIs were similar to the findings for proportion of fixations. Table 4.2 displays the means and standard deviations for average fixation duration to the primary emotion ROIs, including eye region and mouth, and the other ROI for each emotion type. A repeated measures ANOVA revealed a significant main effect of participant group, $F\ (1, 52) = 7.63$, $p = .008$, $\eta_p{}^2 = .13$, power = .77, indicating that the amount of time spent fixating on the primary emotion ROIs differed between the CI group and TH group. This effect size was moderate-to-large and participant group explained 13% of the total variance in fixation duration to the primary emotion ROIs. Adolescents with CI spent, on average, 880.83 msec (*SD* = 94.05; Eyes: *M* = 602.54 msec, *SD* = 111.74; Mouth: *M* = 278.30 msec, *SD* = 53.03) per trial fixating on the primary emotion ROIs, while the TH group spent an average of 730.27 msec (*SD* = 98.55; Eyes: *M* = 526.60 msec, *SD* = 122.90; Mouth: *M* = 203.68 msec, *SD* = 54.54) fixating to these regions per trial. The analysis also revealed a significant effect of emotion type on average fixation duration to the primary emotion ROIs, $F\ (4.24, 220.31) = 28.58$, $p < .001$, $\eta_p{}^2 = .36$, power = 1.00, indicating that average fixation duration differed by emotion type and that emotion type explained more than 35% of total variance in fixation duration outcomes (i.e., large effect size).

The interaction effect between participant group and emotion type was significant, $F\ (4.24, 220.31) = 2.58$, $p = .036$, $\eta_p{}^2 = .05$, power = .74, but the effect size was small suggesting that the interaction explained 5% of total variance. Analyses of simple main effects showed that adolescents with CIs fixated, on average, significantly longer on the primary emotion regions than adolescents with TH for sadness, F (1, 52) = 11.17, p = .002, $\eta_p{}^2$ = .18, power = .72, surprise, F (1, 52) = 9.89, p = .003, $\eta_p{}^2$ = .16, power = .65, and disgust, F (1, 52) = 8.49, p = .005, $\eta_p{}^2$ = .14, power = .57. Like the results observed for proportion of fixations, the effect sizes for sadness, surprise, and disgust were large and participant group explained 14–18% of the total variance in fixation duration for these three emotions. Alternatively, the simple main effects of participant group did not reach significance for happiness, F (1, 52) = 3.91, p = .053, $\eta_p{}^2$ = .07, power = .23, anger, F (1, 52) = 2.15, p = .149, $\eta_p{}^2$ = .04, power = .11, or fear, F (1, 52) = 2.35, p = .132, $\eta_p{}^2$ = .04, power = .12. The effect sizes for these three emotions were small to moderate, indicating that participant group accounted for 7% and 4% of total variance in fixation duration for happiness, anger, and fear, respectively.

Table 4.2. Average fixation duration (msec) made by adolescents with CI and adolescents with TH to ROIs for each emotion type.

		Emotion Type					
		Happiness	**Anger**	**Fear**	**Surprise**	**Disgust**	**Sadness**
	Regions of Interest	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
CI (*n* = 32)	**Primary Emotion**	**847.19 (176.94)**	**890.74 (206.55)**	**837.75 (226.12)**	**886.82 (204.86)**	**771.12 (245.04)**	**1051.33 (171.27)**
	Eyes	534.57 (212.29)	703.67 (226.20)	584.25 (248.82)	548.54 (234.78)	474.50 (225.90)	769.70 (250.28)
	Mouth	312.62 (189.76)	187.07 (155.38)	253.50 (182.60)	338.28 (230.61)	296.67 (202.29)	281.63 (170.32)
	Other	**366.20 (163.26)**	**328.94 (145.53)**	**375.18 (169.96)**	**319.50 (124.85)**	**440.60 (197.03)**	**311.06 (131.54)**
TH (*n* = 22)	**Primary Emotion**	**740.45 (218.57)**	**795.77 (269.05)**	**738.89 (243.00)**	**689.31 (255.68)**	**564.61 (271.05)**	**852.61 (266.17)**
	Eyes	481.08 (219.62)	686.25 (277.43)	507.18 (234.27)	444.89 (260.42)	377.22 (243.66)	662.95 (246.85)
	Mouth	259.37 (166.72)	109.53 (110.53)	231.72 (181.63)	244.42 (171.77)	187.39 (176.82)	189.66 (149.48)
	Other	**404.14 (168.24)**	**337.40 (215.12)**	**381.51 (202.02)**	**410.30 (214.54)**	**536.89 (247.20)**	**387.74 (187.04)**

Note. CI = Cochlear implant; TH = Typical hearing.

4.3.3 Location of first fixations within the primary emotion region

For each emotion type, the ratio of observed to expected frequencies of first fixations to the mouth or eye ROI were calculated for each participant group. The total number of initial fixations within these primary emotion ROIs for each emotion type (range: 203—212) is shown in the left column of Table 4.2. The diagonal of each emotion type table represents the first fixation predictions that adolescents with CI would show more initial fixations to the mouth and adolescents with TH would fixate earlier to the eye region. Ten of our predictions were proven correct (i.e., happiness, anger, fear, surprise, sadness, disgust) and none of the values outside of our predictions were above-chance. Ratio results for surprise indicate that the observed frequency of first fixations to the eyes and mouth for each group were no different from the expected frequencies.

For each column, chi square analysis was conducted to compare observed first fixation frequencies of adolescents with CI and TH adolescents to each of the primary emotion ROIs to the expected frequencies (see Table 4.2). Patterns of first fixations to the mouth ROI reached statistical significance for expressions of fear (p = .035) and disgust (p = .012). The difference between the observed and expected frequencies of first fixations to mouth ROI were not sufficient for a significant chi square for happiness (p = .297), anger (p = .384), surprise (p = 1.00), or sadness (p = .630). Likewise, differences between predicted and chance frequency for first fixations to the eye region did not reach statistical significance for any emotion type.

Table 4.3. Ratio of observed to expected occurrences of first fixations to ROIs (i.e., eye region, mouth) within the primary emotion regions of facial expressions by adolescents with CI and adolescents with TH.

Emotion type	Participant Group	Region of Interest	
		Mouth	Eyes
Happiness			
N = 211	CI	**1.10**	.95
	TH	.85	**1.08**
	Significance	---	---
Anger			
N = 208	CI	**1.12**	.98
	TH	.82	**1.04**
	Significance	---	---
Fear			
N = 205	CI	**1.23**	.91
	TH	.66	**1.13**
	Significance	*	---
Surprise			
N = 211	CI	**1.00**	1.00
	TH	1.00	**1.00**
	Significance	---	---
Sadness			
N = 212	CI	**1.05**	.98
	TH	.93	**1.03**
	Significance	---	---
Disgust			
N = 203	CI	**1.23**	.87
	TH	.62	**1.21**
	Significance	*	---

Note. *$p < .05$; CI = Cochlear Implant; TH = Typical Hearing.

4.3.4 Time course of facial emotion processing

The mean proportion of adolescents with CI and adolescents with TH fixating on either the eye region, mouth, or other ROIs was calculated at each 100-msec time window within the 1500-msec presentation of facial expression photographs (Figure 4.3). This exploratory, qualitative analysis revealed differences in fixation patterns between participant group and emotion type.

Initial switch to primary emotion ROI. There was a rapid decrease in participants fixating on other ROI following onset of the facial expression photograph and an increase in fixations toward the eye region and mouth, features commonly associated with emotion recognition. A majority of adolescents in both groups switched from fixating on other ROI to one of the feature regions around 400 msec into the trial, regardless of emotion type. The switch to eye region and/or mouth ROI observed across participants around the same time after trial onset reflects facial emotion processing.

Fixations to mouth ROI. Visual inspection of the time course plots of adolescents with CI revealed a distinct pattern of increased proportion of participants fixating on the mouth ROI beginning around 500 msec. This increase, or "bump," in fixations to the mouth by adolescents in the CI group varied in size but was observed across all six emotions. Time course plots for happiness, anger, fear, and disgust indicate that the proportion of adolescents with CI interested in the mouth increased between 500 to 900 msec. For expressions of sadness and surprise, this trend continued with a greater proportion of adolescents with CI fixating to the mouth than to the other ROI for the remainder of the image presentation. A secondary increase in proportion of CI users fixating on the mouth over the other ROI occurred for photographs of anger and fear around 1100 msec.

The adolescents with TH did not demonstrate the same visual attention pattern to the mouth. Increases in the proportion of participants with TH fixating on mouth, if any, were smaller than those observed in the CI group and began later around 600 or 700 msec. Overall, adolescents with CIs demonstrated a distinct preference for mouth over the other ROI across emotions and over the eye region on expressions of happiness and surprise. The proportion of participants with TH fixating on the mouth and other ROIs remained similar across the presentation of facial expressions.

Ending on the eye region. One final clear fixation pattern that emerged from the time course plots was the predominant focus on the eye region at the end of stimulus presentation. The majority of adolescents in both the CI and TH groups returned to fixating largely on the eye region after 1000 msec. This increase in attention to the eyes is observed across participants from CI and TH groups for all expressions except disgust. Proportion of adolescents with TH fixated on the eye region compared to the other ROI was similar when visually processing photographs of disgusted facial expressions.

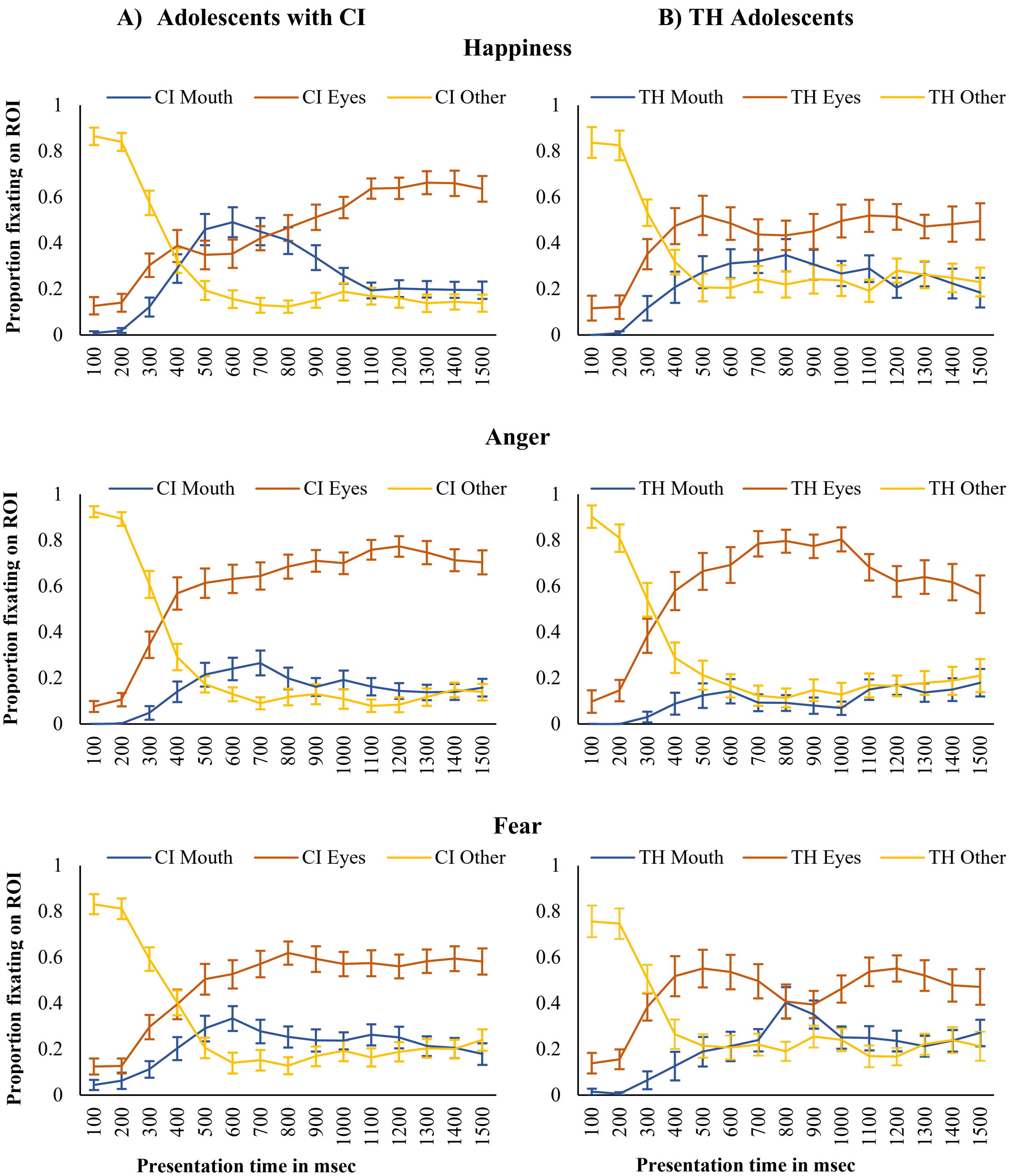

Figure 4.3. Time course of participants fixating on mouth, eye region, and other ROIs during presentation of the six emotion types with adolescents with CI (A) and TH controls (B). Error bars represent SEM at each 100-msec bin. The x-axis shows the presentation time of the static photograph (1500 msec) and the y-axis shows the proportion of participants in the CI or TH

group fixating on the ROI. The blue line shows results for the mouth ROI, the orange line for the eye region, and the yellow line for the other ROI.

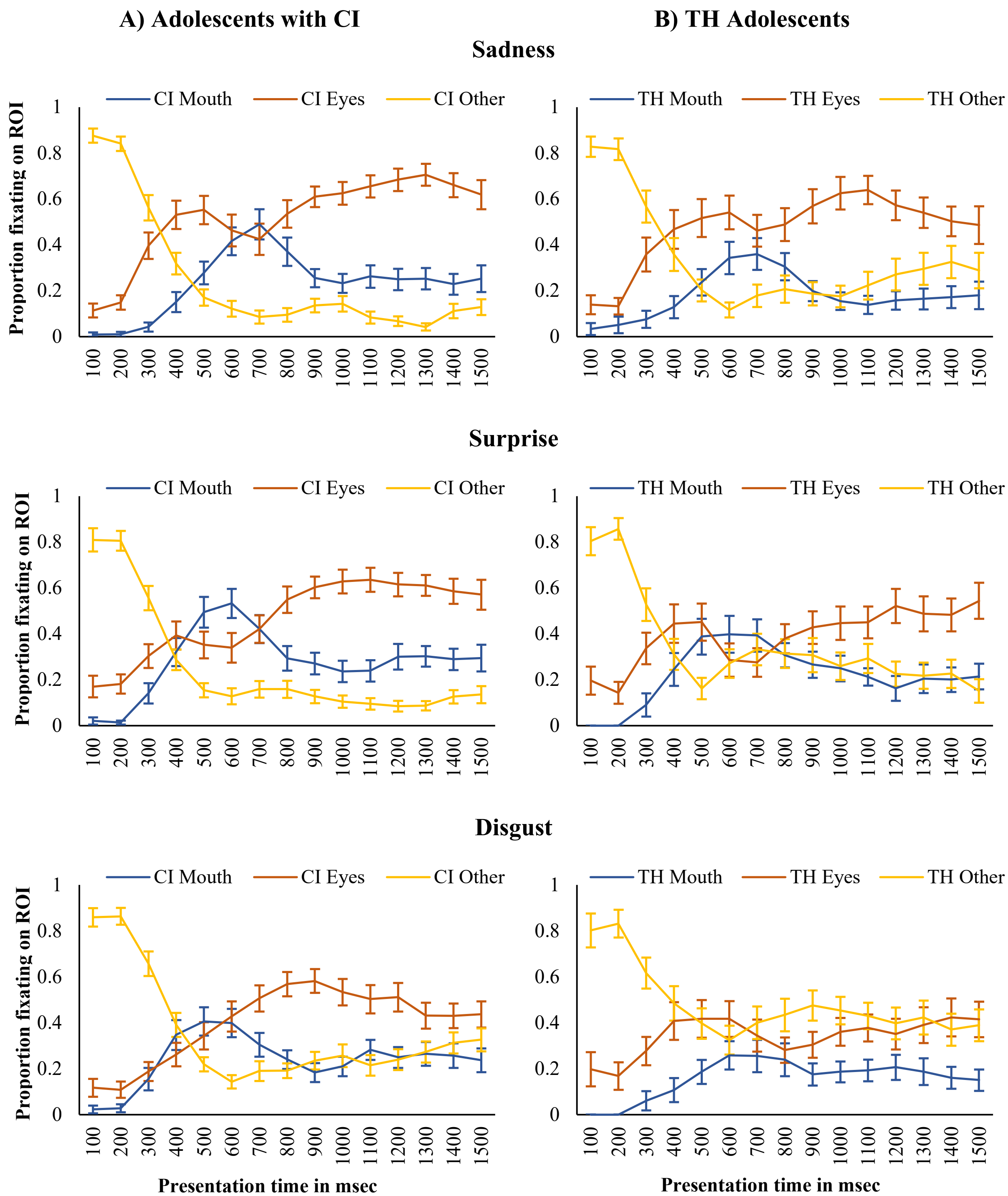

Figure 4.3 contd. Time course of participants fixating on mouth, eye region, and other ROIs during presentation of the six emotion types with adolescents with CI (A) and TH controls (B).

Error bars represent SEM at each 100-msec bin. The x-axis shows the presentation time of the static photograph (1500 msec) and the y-axis shows the proportion of participants in the CI or TH group fixating on the ROI. The blue line shows results for the mouth ROI, the orange line for the eye region, and the yellow line for the other ROI.

4.4 Discussion

The aim of this exploratory study was to examine visual processing of facial expressions by adolescents with CIs and adolescents with TH using an emotion recognition task. We used static photographs of full-intensity expressions of happiness, anger, sadness, fear, surprise, and disgust similar to the stimuli used in previous emotion recognition research with CI users (Hopyan-Misakyan et al., 2009; Wang et al., 2011; Wang et al., 2016; Warner-Czyz et al., 2019; Wiefferink et al., 2013). Comparable response patterns were obtained between CI and TH groups on this task in our previous study (Warner-Czyz et al., 2019), but these outcome measures provided limited information about potential subtle processing differences in how adolescents with CI and adolescents with TH process emotion cues in real-time. Therefore, we employed eye tracking methods to examine emotion-mediated visual attention to diagnostic facial features (i.e., eyes, mouth, etc.).

Across emotion types, adolescents with CIs and adolescents with TH fixated longer on the eye region of the face than on the mouth or other ROI. The majority of adolescents from both groups demonstrated a similar initial shift in attention from the other ROI to the eye region around 400 msec after stimulus onset. This pattern was observed across emotion types for the CI and TH groups. Adolescents with CI and adolescents with TH also showed similar patterns of fixation at the conclusion of stimulus presentation. Most adolescents fixated on the eye region from 1000 msec through the end of the trial, regardless of emotion type. Our results align with previous research indicating that fixations to primary emotion regions are essential for recognition of intense emotions (i.e., 100% of an expression) (Adolphs, 2002; Ekman & Friesen, 1978).

Eye tracking also revealed that adolescents with CI and adolescents with TH differ in their visual attention patterns when processing emotion cues in real-time. When regions of the face were clustered by primary emotion regions (i.e., eyes and mouth) versus the other ROI, adolescent CI users showed increased visual attention to the primary emotion regions. Compared to the CI group, adolescents with TH directed significantly fewer fixations to the primary emotion ROIs for expressions of sadness, surprise, and disgust. There were also group differences in first fixations within the primary emotion regions. First fixations were defined as the first landing of the eye within either of the primary emotion regions: the eyes or the mouth. In line with our predicted fixation pattern for each group, adolescents with CI consistently looked more at the mouth than the eyes upon entering the primary emotion region of the face. The adolescents with TH showed the opposite fixation pattern and made more first fixation to the eye region.

Time course plots likewise revealed group differences in the processing of visual emotion cues in real-time. The proportion of adolescent CI users fixating on the mouth increased from 500 msec to 900 msec (i.e., happiness, anger, fear, disgust) or through the end of the stimulus presentation time (i.e., sadness, surprise). Adolescents with TH showed a different pattern of visual attention that did not involve a “bump” in attention to the mouth. Compared to the CI group, increases in the proportion of TH group fixating on the mouth were smaller and occurred later into the trial (i.e., 700 msec). For all emotions, the majority of participants with TH fixated on the eye region with little differentiation between the mouth and other ROI. Overall, these results suggest that adolescents with CI and adolescents with TH differ in visual processing of the mouth during facial expression recognition.

Compared to peers with TH, adolescents with CIs focus more visual attention to areas associated with emotion cues (i.e., primary emotion regions) and spend less time exploring areas of the face outside of these regions (i.e., other ROI) for expressions of sadness, surprise, and disgust. Results for adolescents with TH align with previous research examining visual attention during emotion recognition in adults with TH. Individuals with TH look longer at the upper lip, nose, and areas outside of the primary emotion regions for disgusted faces (Schurgin et al., 2014). Emotion cues of sadness and surprise may not be extracted by viewing any one single facial feature and are likely processed through a more holistic strategy (Smith et al., 2005).

Adolescents with CI and adolescents with TH showed different visual attention patterns to the face when processing facial expressions. Both groups began trials with an initial switch from other ROI to the eye region and ended the trial fixating predominately on the eye region. However, compared to adolescents with TH, a greater proportion of adolescent CI users allocated their attention to the mouth in the middle of the trial beginning around 500 msec. The timing of this change in visual attention coincides with critical periods of emotional image processing (i.e., P300 and Late Positive Potential) based on previous ERP studies of individuals with TH (Cuthbert et al., 2000; Sabatinelli et al., 2007). Allocating attention away from the eyes during this time period may negatively impact the perception and interpretation of emotion. Additionally, the transmission of complex sensory signals that assist with dynamic emotion recognition occurs during this time period (Jack et al., 2014). The differences between the CI and

TH groups in the temporal component of visual emotion processing may underlie group differences in emotion recognition of subtle emotions (i.e., 80% of an expression) (Evans et al., 2020) and, possibly impact social interaction with peers.

The visual attention pattern of the CI group when processing emotion is similar to that observed in children with HL and children with TH during speechreading (Worster et al., 2018). Both groups showed a social-tuning pattern when processing visual speech that began with attention on the eye region, followed by a shift to the mouth during speech, and ended with a return to the eyes. These findings indicate that visual attention to the face by adolescents with HL and peers with TH is influenced by an awareness that social information is expressed largely through the eyes (Beaudry et al., 2014; Schurgin et al., 2014). These results also suggest that adolescents with CI use a similar social-tuning pattern of visual attention to process static facial expressions that children with HL and TH use for speechreading. Adolescents with CI who rely on speechreading to communicate during social interactions more than adolescents with TH (Kyle et al., 2013). The adolescent CI users included in this study communicate primarily with auditory-based modes of communication, which may involve some reliance on speechreading during speech perception. Overall, our study shows that auditory experience and use of compensatory speech perception strategies (i.e., speechreading) may affect visual perception of social cues from the face independent of the presence of spoken language.

The ability to perceive socially and emotionally relevant cues from facial expressions is necessary for successful social interaction and communication (Pelphrey et al., 2003). Inefficient perception of mental state and well-being of self and others can delay development of social competence, affecting confidence in social skills, sense of self, and the ability to form and maintain relationships with peers (Bal et al., 2010). Children and adolescents with HL report experiencing significantly more peer problems and higher rates of peer victimization than children and adolescents with TH (Kouwenberg et al., 2012; Moeller, 2007; Warner-Czyz et al., 2018; Wiefferink et al., 2012). Pediatric CI users also demonstrate difficulty with empathy and emotion regulation – two aspects of social cognition that stem from accurate perception and interpretation of emotion information (Adolphs, 2010; Hosie et al., 2000; Rieffe & Terwogt, 2006). The differences in visual perception of emotion between adolescents with CIs and adolescents with TH could inform our understanding what underlies the social and emotional difficulties observed in pediatric CI users.

4.4.1 Study strengths and limitations

This exploratory study adds to the literature by examining the effects of early-onset HL on visual perception of emotion in adolescents with CI. Use of eye tracking to assess visual processing of static facial expressions allowed for the detection of qualitative differences between adolescents with CI and adolescents with TH. Additionally, this is the first study to examine real-time emotion processing in pediatric CI users.

The sample included in this study allows for the examination of the effects of delayed and degraded auditory access on visual processing of faces by adolescents with CI compared to adolescents with TH. Additionally, all of the CI users in our study utilized spoken language to communicate, which eliminated some variability (i.e., communication mode) observed in studies with individuals with HL. It is important to note that the sample size was relatively small (n = 54) for examining differences between groups and the interaction effects should be interpreted with caution. Future studies should endeavor to include a large sample to decrease variability in outcomes.

A second limitation of this study is this study used static visual cues to assess visual attention to the face during emotion recognition. Static images have been used in the majority of emotion recognition research with children and adolescents with HL to date. However, real-time processing of faces during social interactions involves movements of facial musculature, additional auditory input, environmental distractions, and other complex aspects of communication. Previous studies have shown that children with CI can identify emotion from static photographs but show less success when interpreting emotion from audio recordings of spoken sentences (Hopyan-Misakyan et al., 2009). As such, future studies should aim to assess visual attention of CI users with tasks of increased demands such as dynamic or audiovisual emotion recognition.

4.5 Conclusion

This exploratory study contributed to current knowledge of facial expression recognition and processing by comparing visual attention to the face by adolescents with CI and adolescents with TH using eye-tracking analysis. Our approach allowed for the examination of subtle differences in visual processing of facial expressions between groups and extended assessment beyond behavioral measures of accuracy. The adolescents with CI allocated more attention to diagnostic features of the face that are important for emotion (i.e., eyes, mouth) than adolescents with TH. CI users may have developed a visual processing strategy that differs from that observed in TH and deaf peers to compensate for delayed and continually degraded auditory signals. However, the differences in visual attention pattern may impede processing of multisensory cues in social situations with increased task demands and could negatively influence more complex, advanced social cognitive skills (i.e., theory of mind).

4.6 References

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CHAPTER 5

OVERALL CONCLUSIONS

This manuscript dissertation investigated the impact of pediatric HL and use of a CI on the perception of visual cues in and recognition of emotion from facial expressions. These two processes play a key role in social cognition and, in turn, can affect the success of social communication with peers by adolescent CI users. This series of studies used behavioral and eye tracking data to examine how prelingual hearing loss influences visual processing of the face and affects emotion recognition in adolescents with CI and adolescents with TH. Overall, the two groups performed similarly when interpreting full-intensity (i.e., 100% of expression) emotions. However, recognition of subtle (i.e., less than 100% of expression) emotions may be affected by differences in the visual attention strategies employed by pediatric CI users.

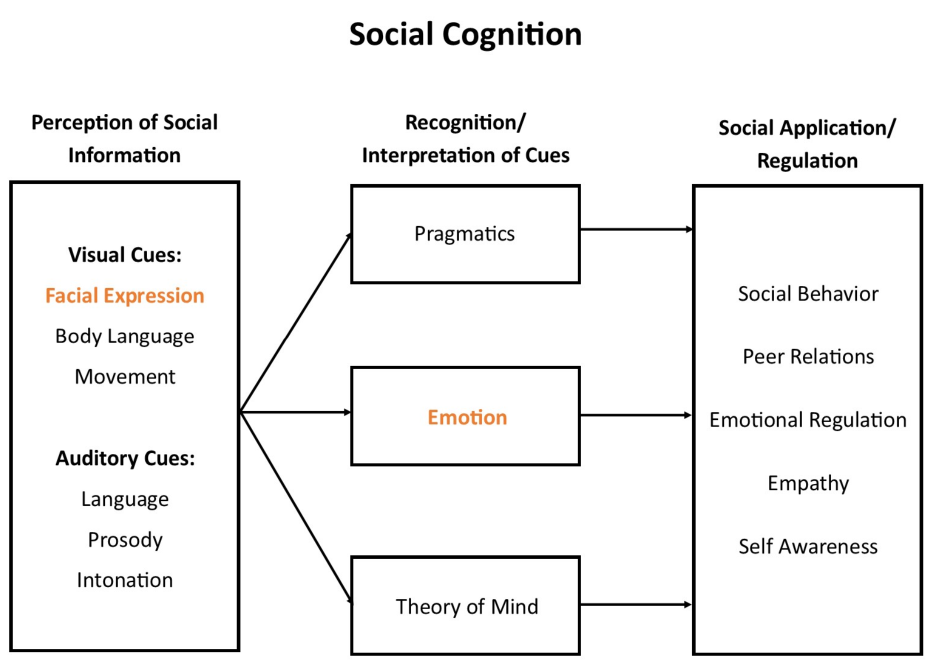

Figure 5.1. Different levels of social cognition processing adapted from Adolphs (2010) and McDonald (2013). Social cognition is a multi-level process that involves (1) the perception of social stimuli from various visual and auditory inputs, (2) the interpretation and recognition of

the mental states, emotions, beliefs, and behavior of ourselves and others, and (3) the application of this knowledge to guide and regulate social interaction. The labels in orange represent the aspects of social cognition examined in the series of studies included in this dissertation.

5.1 Common themes

5.1.1 Similar recognition of full-intensity expressions by adolescents with CI and adolescents with TH

Previous research suggests young children with CI exhibit poorer recognition of full-intensity facial expressions than children with TH (Most & Michaelis, 2012; Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013). However, the gap based on auditory status diminishes with increased chronologic age such that CI users achieve outcomes similar to peers with TH by adolescence (Hopyan-Misakayan et al., 2009; Most & Aviner, 2009; Ziv et al., 2013). This series of studies indicates that adolescents with CI and adolescents with TH interpret full-intensity facial expressions similarly whether the face is depicted in a static photograph (Study 1) or a dynamic morphing video clip (Study 2). Adolescents with CI did not significantly differ from peers with TH in the choices that they made when identifying expressions, independent of whether those responses met adult emotion recognition standards. Likewise, adolescents in both groups demonstrated comparable error patterns and consistently misidentified the target emotion as an expression of similar positive or negative valence, independent of stimulus motion (Study 2).

Study 2 also showed that both CI and TH groups achieved higher overall emotion recognition when shown dynamic video clips rather than static photographs. Movement of facial muscles is thought to provide an advantage for the recognition of facial expressions — especially for individuals with HL who rely more heavily on visual cues for social and linguistic information (Corina et al., 2009; Jones et al., 2017). Moreover, full-intensity dynamic expressions may afford a more ecologically valid measure than static photographs for recognition of certain emotions (e.g., happiness, anger, disgust, fear) for adolescents with CI and adolescents with TH.

Combined with results from previous studies, these findings support a stabilization of emotion recognition abilities with maturation. Emotions expressed at full-intensity involve dramatic movements of facial features, making them easier to recognize (Montagne et al., 2007). This amount of facial movement allowed equivalent interpretation of emotions by the adolescents with and without HL. However, expression of emotion during social communication does not always involve intense emotions; rather, real-world interactions more frequently include quick, subtle expressions (Jones et al., 2017; Sato & Yoshikawa, 2004). Thus, tasks that assess recognition of full-intensity expressions are likely not representative of the abilities necessary for successful social interactions.

5.1.2 Differences in emotion recognition by adolescents with CI and adolescents with TH

This series of studies contributes to the broader literature by measuring emotion recognition of expressions that varied in emotion intensity (Study 2). Blocking the videos into three levels of emotion intensity (i.e., 60%, 80%, and 100% of the dynamic morphing video clip) allowed for the examination of whether the amount of emotion information needed to recognize emotions differed between adolescents with CI and adolescents with TH. Findings from Study 2 indicated that participants in the CI and TH groups attained similar choice patterns for the highest (100%) and lowest (60%) levels of emotion intensity. As indicated in the previous section, full-intensity (100%) facial expressions provide an adequate and perhaps redundant amount of emotion information for successful recognition but may not reflect the amount of emotion intensity typically expressed during conversations with peers (Jones et al., 2017; Sato & Yoshikawa, 2004). Recognition of low intensity emotions (e.g., 60% and 80% intensity) requires the perception of subtle facial movements and continues to develop into adulthood in individuals with TH (Gao & Maurer, 2010; Herba et al., 2006).

Quantitative differences emerged between the CI and TH groups with limited access to emotion information in the lower intensity conditions. Neither group performed well on the 60% emotion intensity task, suggesting that 60% of an emotion expression does not provide sufficient info to illuminate subtle differences in emotion recognition between CI users and peers with TH. Differences in interpretation of expressions emerged in the 80% condition, suggesting a difference in trajectory of emotion recognition between adolescents with CI and adolescents with TH. Adolescents with TH gleaned an adequate amount of information about emotions from facial movements expressed with 80% condition to achieve a significantly improved level of emotion recognition. In contrast, adolescents with CI did not show a significant difference in emotion recognition between the 60% and 80% intensity conditions. Rather, the CI group required incrementally more facial movement to demonstrate a significant improvement in emotion recognition (i.e., 80% to 100% emotion intensity). The group difference in percent choice to target emotions suggests that adolescents with CI may interpret the visual emotion information in more subtle facial expressions differently than adolescents with TH.

Although the two groups perform comparably with both low intensity (i.e., 60%) and full-intensity (i.e., 100%) expressions, they differ with intermediate levels of emotion information (i.e., 80% emotion intensity). The poorer performance by CI users with less information about emotions in the intermediate condition (i.e., 80% intensity) could relate to the peer problems often reported by this group, as evidenced by research showing a link between emotion comprehension and development of social competence from childhood through adolescence in individuals with TH (Custrini & Feldman, 1989; Denham, 1998). Thus, misinterpretation of subtle facial expressions by adolescents with CI could complicate social communication with others and may serve as an underlying contributor to social difficulties reported by children and adolescents with CIs.

5.1.3 Visual perception of emotion differs between CI and TH groups

Adolescents with CIs identify intense emotions similar to peers with TH but differ from adolescents with TH on interpretation of subtle emotions (Study 1 and 2). Previous studies show that visual fixation patterns to the face influence recognition of subtle facial expressions (i.e., less than 100% emotion intensity), but not recognition of high intensity emotions (Vaidya et al., 2014). Study 3 is the first to use eye tracking and time course analysis to examine quantitative and qualitative differences in visual attention to static photographs of faces between adolescents with CIs and adolescents with TH.

Fixations to primary emotion regions such as the eyes and mouth are critical for recognizing both intense (i.e., 100% of expression) and subtle expressions (i.e., less than 100% emotion intensity) (Adolphs, 2002; Ekman & Friesen, 1978). Visual attention to the primary emotion regions of the face (i.e., eyes and mouth) differed between the CI and TH groups. Compared to adolescents with TH, adolescents with CIs fixated more attention on the primary emotion regions for static expressions of sadness, surprise, and disgust. Adolescents with CIs made more first fixations within the primary emotion regions to the mouth, while adolescents with TH made more first fixations to the eye region for the majority of emotions. Across emotions, both groups fixated longer on the eyes than the mouth or other ROI. Previous studies have shown a correlation between increased attention to the eyes and improved emotion recognition in individuals with TH (Beaudry et al., 2014; Schurgin et al., 2014).

Time course analysis, used to examine the temporal aspects of visual attention, provided further evidence of a difference in visual perception of facial expressions between the CI and TH groups. A majority of adolescents in both groups showed an initial switch from other ROI to fixating on a primary emotion region (i.e., eyes or mouth) at the beginning of each trial and fixating on the eye region at the end of each trial. However, for each emotion type, a greater proportion of adolescents with CIs fixated on the mouth beginning 500 msec into the stimulus presentation - a pattern that differs from the adolescents with TH. The timing of this deviation in visual attention patterns between groups coincides with the critical period of emotional image processing based on previous ERP studies (i.e., P300 and Late Positive Potential) (Cuthbert et al., 2000; Sabatinelli et al., 2007). Additionally, studies investigating facial expression temporal dynamics show that the transmission of complex signals that assist with the classification of basic emotions occurs around this time period (Jack et al., 2014). Differences in visual attention to the eyes and mouth during this critical period during emotion recognition could underlie differences in emotion recognition abilities for adolescents with CI compared to adolescents with TH.

The differences observed between the visual attention patterns of adolescents with CI and adolescents with TH could result from differences in auditory experiences. Children with hearing loss rely more on visual, nonverbal cues from the face for speechreading during social communication to compensate for a degraded auditory input (Ambert-Dahan et al., 2017; Worster et al., 2018). Daily use of communication modes that involve speechreading could create a tendency to look at the mouth for visual cues when processing the face, thereby disrupting visual attention to emotion information expressed in other facial regions (i.e., eyes). The ability to perceive socially and emotionally relevant cues from facial expressions is necessary for successful social interaction and communication (Pelphrey et al., 2003). Differences in visual processing of subtle and fleeting facial cues during social interactions could impact social communication abilities and disrupt social cognitive processes.

5.2 Social and emotional implications

This series of studies examined the effect of auditory status on visual perception and recognition of emotion to identify potential underlying causes of social deficits in adolescents with CI. Perception and recognition of facial expressions form two key aspects of a multi-level social cognitive process that influences social and emotional competence (see Figure 5.1). Inefficient perception of multisensory cues or poor/inaccurate interpretations of social cues can negatively affect a person's ability to guide their social behavior and develop strong peer relationships (Adolphs, 2001; Hess et al., 1999). Difficulties perceiving the emotional state of others can lead to poor self-awareness, lower levels of empathy, and insufficient social skills for communicating with others (Denham et al., 1990; Pons et al., 2004).

Studies examining social well-being in children and adolescents with HL shows that they struggle with social dynamics and peer relations. For instance, adolescents with HL report experiencing significantly more peer problems, lower peer acceptance, and higher rates of peer victimization compared to adolescents with TH (Kouwenberg et al., 2012; Moeller, 2007;

Warner-Czyz et al., 2018; Wiefferink et al., 2012). Difficulties with peer relationships could occur due to poorer perception or interpretation/recognition of the social cues provided by peers during interactions (see Figure 1). Children with HL also struggle with social skills that largely depend on emotion perception and recognition abilities. Children with HL show poorer understanding of complex concepts of mixed emotions (Mancini et al., 2016) and utilize less effective emotion regulation strategies (Rieffe, 2012). Compared to peers with TH, children with HL exhibit difficulty with empathy as they are less inclined to conceal their emotions to protect the feelings of others (Hosie, Russel, Gray, et al., 2000) and do not expect their peers to demonstrate empathy (Rieffe & Terwogt, 2006).

Based on what is known about social cognition processes, it is possible that poor emotion perception and recognition play a role in the social difficulties experienced by children and adolescents with HL. Children and adolescents with HL have trouble perceiving auditory cues (e.g., language, prosody) commonly used to express emotion and show poorer spoken emotion recognition than peers with TH (Chatterjee et al., 2015, Luo et al., 2007). As such, effective and efficient perception of visual cues is of the utmost importance for successful social and emotional communication by adolescents with CI. Results from Study 3 indicated that adolescents with CI show a different visual attention pattern during facial expression processing compared to adolescents with TH. Increased fixations to the primary emotion regions of the face and the mouth may interfere with the perception of visual emotion information expressed outside of the eyes and mouth (i.e., nose/central face region). Differences in visual attention to the face could affect CI users' abilities to perceive social and emotional information in the timely and efficient manner necessary for successful social interactions with peers. Additionally, this series of studies concluded that adolescents with CIs misinterpret subtle facial expressions of emotion more frequently than adolescents with TH. Social communication is a complex and demanding task that requires multisensory perception of several cues. Poorer emotion recognition of subtle expressions may make judgements of others emotional state difficult for adolescents with CIs.

5.3 Clinical implications

The social cognitive processes (i.e., perception, recognition/interpretation, regulation/communication) develop from experience over time. The development of emotion perception and recognition in children with CI may be delayed due to limited exposure to opportunities to verbally communicate with others about feelings and poorer quality interactions with parents and peers (Ludlow et al., 2010; Moeller & Schick, 2006; Morgan et al., 2014; Rieffe et al., 2015). Early clinical intervention should focus on emphasizing the importance of explicit discussion of thoughts and feelings, thinking out loud to increase emotional intelligence, and other aspects of social cognition. Parents should be encouraged to provide the opportunity for their child to observe or be involved in social interactions.

This series of studies highlighted differences in emotion perception and recognition between adolescents with CIs and adolescents with TH. Differences in recognition and visual processing of various emotions were moderately explained by participant group (CI vs. TH). However, the effect of group was larger for visual attention outcomes (i.e., proportion of fixations, fixation duration), indicating that use of a CI may influence the processing of facial expressions. For CI users who communicate using spoken language, visual attention to the face may be split between processing social-emotional information and speech perception. Additionally, the effect of participant group on emotion recognition outcomes was larger when dynamic facial expressions were more subtle (i.e., 80% emotion intensity), suggesting that the impact of CI use is more apparent when less emotion information is available.

This knowledge should be used to guide clinical intervention strategies to focus more on CI users' awareness of the importance of eye contact during social interactions. Eye contact plays an important role in the perception of emotion and is often used to find cues expressing the mental state of others (Kleinke, 1986). Clinicians are effective in increasing vocabulary size and improving understanding of syntax, but less attention is given to pragmatic skills. Clinical intervention should also aim to assist children and adolescents with CI to develop visual processing strategies that balance attention to the mouth for speechreading and social eye contact. Greater focus on the social-emotional development and well-being of children and adolescents with CI could lead to better development of emotion recognition and social cognition.

5.4 Future directions

Future studies should aim to expand our understanding of emotion perception in more real-life contexts. Eye tracking data from the dynamic emotion recognition task (Study 2) will be used in future studies to illuminate whether adolescents with CI and adolescents with TH differ in visual attention to subtle (i.e., less than 100% emotion intensity) facial expressions (Study 3). Studies on emotion recognition in CI users should incorporate auditory and auditory-visual stimuli to investigate the perception of multisensory emotion cues during increased task demands.

5.5 Conclusion

This manuscript-style dissertation utilized behavioral measures and exploratory eye-tracking analyses to understand emotion perception and recognition in adolescents with CIs. These three studies compared adolescent CI users' outcomes to adolescents with TH to examine the effect of early auditory deprivation on the development of emotion recognition abilities. Results indicated that adolescents with CI and adolescents with TH interpret full-intensity expressions similarly. Compared to adolescents with TH, adolescents with CI visually process facial expressions differently and struggle with recognition of subtle, more life-like facial expressions. This dissertation suggests that differences in emotion perception and recognition could underlie the social and emotional difficulties observed and reported in adolescents with CI. Early clinical focus on visual perception of faces during social interactions may be beneficial in shaping and improving the social and emotional communication abilities of adolescents with CIs. Clinical intervention strategies should be modified to include a greater focus on social cognitive processes such as emotion recognition and theory of mind.

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Wiefferink, C., Rieffe, C., Ketelaar, L., De Raeve, L., & Frijns, J. (2013). Emotion understanding in deaf children with a cochlear implant. *Journal of Deaf Studies and Deaf Education, 18*(2), 175-186.

Worster, E., Pimperton, H., Ralph-Lewis, A., Monroy, L., Hulme, C., & MacSweeney, M. (2018). Eye Movements During Visual Speech Perception in Deaf and Hearing Children. *Language Learning*, *68*(Suppl 1), 159–179.

Ziv, M., Most, T., & Cohen, S. (2013). Understanding emotion and false beliefs among hearing children versus deaf children. *Journal of Deaf Studies and Deaf Education, 18*(2), 161-174.

BIOGRAPHICAL SKETCH

Delaney Evans was born in Dallas, Texas. She attended The University of Texas at Dallas, earning a Bachelor of Science in Speech-Language Pathology and Audiology in 2013. She continued to pursue a master's degree at The University of Texas at Dallas and earned a Master of Science in Applied Cognition and Neuroscience in 2019. Her research interests explore social and emotional development in children and adolescents with cochlear implants. Specifically, her interests lie in examining social cognition processes (e.g., emotion recognition, theory of mind) to better understand how prelingual hearing loss affects social communication abilities in this population.

CURRICULUM VITAE

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EDUCATION

Doctor of Philosophy, Candidate, The University of Texas at Dallas, Richardson, Texas,
Communication Sciences and Disorders
Advisors: Andrea Warner-Czyz & Julia Evans

Master of Science, 2019, The University of Texas at Dallas, Richardson, Texas,
Applied Cognition and Neuroscience

Bachelor of Science, 2013, The University of Texas at Dallas, Richardson, Texas,
Speech – Language Pathology & Audiology

PUBLICATIONS

Refereed Journal Articles

1. Warner-Czyz, Andrea D., **Evans, Delaney**, Turkstra, Lyn, Scheppele, Meredith, Song, Chen, & Evans, Julia L. (2019). Effect of auditory status on visual emotion recognition in adolescents. *Cochlear Implants International, 20*(3), 127-137. doi: 10.1080/14670100.2019.1573952

Manuscripts in Preparation

1. **Evans, Delaney L.**, Ahmadi, Reihaneh, Warner-Czyz, Andrea D., Turkstra, Lyn, & Evans, Julia L. (in preparation). Theory of mind development in children and adolescents with cochlear implants – A scoping review.
2. **Evans, Delaney L.,** Warner-Czyz, Andrea D., Turkstra, Lyn, Scheppele, Meredith, & Evans, Julia L., (in preparation). The role of stimulus motion and emotion intensity in facial emotion recognition by adolescent cochlear implant users.
3. **Evans, Delaney L.**, Warner-Czyz, Andrea D., Turkstra, Lyn, Scheppele, Meredith, & Evans, Julia L. (in preparation). Visual processing of static facial expressions by adolescents with cochlear implants.

HONORS AND SCHOLARSHIPS

2014: American Speech-Language-Hearing Association (ASHA) Audiology Research Travel Award (ARTA) to attend the ASHA convention in Orlando Florida (November 20-22, 2014)

PRESENTATIONS AT PROFESSIONAL MEETINGS

Invited talks

1. **Evans, Delaney.** (2020) Effect of auditory status on visual processing of facial affect cues in adolescents. Oral presentation at the North Texas Cochlear Implant Symposium, Dallas, Texas. April 3.

Oral presentations

1. **Evans, Delaney,** Warner-Czyz, Andrea D., Turkstra, Lyn, Scheppele, Meredith, Evans, Julia L. (2020) Effect of auditory status on visual processing of static affect cues in adolescents. Oral presentation at the ACI Alliance CI2020 International: 16th International Conference on Cochlear Implants and Other Implantable Technologies, Orlando, Florida. March 18-21. (Abstract accepted).
2. Warner-Czyz, Andrea D., Evans, Julia L., Turkstra, Lyn, **Evans, Delaney**, Scheppele, Meredith, & Suen, Abigail. (2019) Effect of auditory status on visual processing of emotion cues in adolescents. Oral presentation at the ACI Alliance CI2019 Pediatrics: 16th Symposium on Cochlear Implants in Children, Hollywood, Florida. June 10-13.
3. Warner-Czyz, Andrea D., Evans, Julia L., Turkstra, Lyn, Scheppele, Meredith, Song, Chen, & **Evans, Delaney**. (2018). Effect of auditory status on recognition of facial expressions in adolescents. Oral presentation at the North Texas Cochlear Implant Symposium, Dallas, Texas. May 4.
4. Warner-Czyz, Andrea D., Evans, Julia L., Turkstra, Lyn, Scheppele, Meredith, Song, Chen, & **Evans, Delaney**. (2018). Recognition of facial expressions by adolescents with cochlear implants and typical hearing. Oral presentation at the ACI Alliance: Emerging Issues in Cochlear Implantation, Washington D.C. March 7-10.

Poster presentations

1. Warner-Czyz, Andrea D., Evans, Julia L., Turkstra, Lyn, Scheppele, Meredith, & **Evans, Delaney**. (2017). Visual perception of emotions by adolescents with cochlear implants and adolescents with normal hearing. Presented at the Symposium on Research in Child Language Disorders, Madison, Wisconsin. June 8-10.

2. Tchen, Stephanie, Palumbo, Devin, Mattice, Evan, **Welch, Delaney**, & Cokely, Carol. (2015). Audiologist and patient awareness and knowledge of assistive listening devices

(ALDs) in entertainment venues. Presented at AudiologyNOW!, the annual convention of the American Academy of Audiology, San Antonio, Texas. March 25-28.

3. Wiseman, Kathryn B., **Welch, Delaney**, Warner-Czyz, Andrea D., and Tobey, Emily A. (2014). Effect of early cochlear implantation on reading and writing skills in children. Presented at the American Speech-Language Hearing Association Convention, Orlando, Florida. November 20-22.
4. **Welch, Delaney**, Tobey, Emily, & Warner-Czyz, Andrea. (2013). A meta-analysis of expressive language in children with cochlear implants. Presented at the Texas Undergraduate Research Day at the Capitol, Austin, Texas. April 26.

Departmental talks

1. **Evans, Delaney**. (2019). Visual emotion processing of adolescents with and without cochlear implants. Presented at Friday Seminars in Speech, Language, and Hearing (FLASH) at the Callier Center for Communication Disorders, Dallas, Texas. May 3.

RESEARCH EXPERIENCE

2015-present: Graduate research assistant, Children and Infant Listening Laboratory (CHILL), The University of Texas at Dallas, under the direction of Andrea Warner-Czyz

2013-2015: Graduate research assistant, Dallas Cochlear Implant Program laboratory, The University of Texas at Dallas, under the direction of Emily Tobey (2010-2014) and Andrea Warner-Czyz (2014-present)

TEACHING

Teaching assistant – Graduate courses

Seminar in Cochlear Implants and Technology for Persons with Hearing Impairments (Fall 2020)

Pediatric Audiology (Spring 2020)

Research in Audiology (Fall 2016)

Articulation Disorders (Summer 2016)

Teaching assistant – Undergraduate courses

Audiology (Fall 2019)

Communication Sciences (Spring 2017, Spring 2019)

Anatomy and Physiology of Speech and Hearing (Spring 2015, Spring 2018, Summer 2018, Fall 2018)

Articulation Disorders (Spring 2016)

Guest lecturer

Anatomy and Physiology of Speech and Hearing
Topic: *Anatomy and Physiology of Hearing*

Seminar on Cochlear Implants
Topic: *Special Considerations in Cochlear Implant Users: Cognitive Function*

Communication Sciences
Topics: *Integrating Speech Production & Perception*

Research in Audiology
Topics: *Evidence Based Practice*