Navigating the world of emotions: Social Information processing in children with and without hearing loss

Tsou, Y.

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YUNG-TING TSOU

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Navigating the World of Emotions

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Promotores
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CHAPTER 1

General Introduction

"The boy sees that the girl is laughing, therefore he also feels happy."

Can we safely assume that this conclusion is correct? It may be true in some situations, yet it can be rejected when the girl is laughing *at* the boy. Apparently, when one tries to understand one's own or others' emotions, the social context has to be taken into account.

When seeing this given situation, what would people do to infer the boy's feeling? According to the Social Information Processing (SIP) model (Crick & Dodge, 1994; see Box 1), one of the first steps would be collecting relevant cues. What are the boy and the girl's facial expressions? What are their body postures and actions? Then, the observer can integrate these cues to formulate an interpretation, and this interpretation would help decide how to respond to the situation.

However, which cues are relevant and how they should be integrated depend on one's experiences in past social interactions, i.e., the "database" in the SIP model (Box 1). Children who have been deaf or hard of hearing (DHH) since early childhood therefore could establish and update their databases with experiences different from their typically-hearing (TH) peers. To what extent does being DHH affect children's responses to social situations is the topic of the current thesis.

HEARING LOSS AND SOCIAL INFORMATION PROCESSING

Living in a dominantly hearing environment, DHH children miss out on a variety of information relevant for learning emotions and social rules when their attention is not directed to their source (Calderon & Greenberg, 2012). Even when they have focused the attention on the source, DHH children might still recruit only a fragment of information in situations with multiple talkers or background noises (Leibold et al., 2013). Moreover, the interactions between DHH children and their families have already been different since birth. Over 90% of the DHH children are born to hearing families (Mitchell & Karchmer, 2004), and parents with typical hearing often face difficulties attracting attention or communicating with a child with hearing loss (Harris & Chasin, 2005; Loots et al., 2005; Spencer et al., 1992; Traci & Koester, 2010; Vaccari & Marschark, 1997; Waxman & Spencer, 1997). This often results in a more directive and protective parenting style, with less turn-taking and shorter utterances in conversations, and less usage of mental-state language, compared to TH parents with TH children (Dirks et al., 2020; Morgan et al., 2014; Pinquart, 2013). Thus, DHH children may afford less opportunities to explore their environment, make mistakes and solve problems, or learn the causes and consequences of social situations (Calderon & Greenberg, 2012).

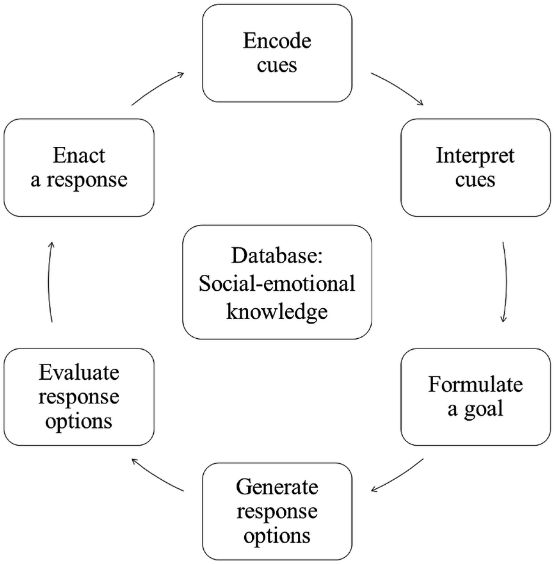

Figure 1. The Social Information Processing (SIP) model. For simplicity, the steps are illustrated sequentially. Yet, the steps could be in parallel and with numerous feedback loops (for more details, see Crick & Dodge, 1994; Dodge, 1991; Lemerise & Arsenio, 2000).

Although many DHH children are now with a hearing aid (HA) or a cochlear implant (CI) that significantly improves their hearing ability, they still experience the challenges mentioned above. Before these children receive a CI or a HA, they have limited auditory and language input. The fact that they do not gain sufficient access to the auditory social environment during the first year(s) of life has marked negative effect on their social-emotional knowledge and functioning (Mancini et al., 2016; Sundqvist et al., 2014), and psychological adjustment (Theunissen et al., 2014). After these children receive a HA or a CI, the auditory devices do not restore hearing to the full extent. The limitations of HAs and CIs cause difficulties for the users to hear the subtle differences in speech that are perceptible to TH listeners, such as different lexical tones, intonations, and emotional prosodies, or when there are background noises or multiple speakers (Leibold et al., 2013; Loizou & Poroy, 2001; See et al., 2013; Zeng, 2002). Parents and other family members can easily overestimate the hearing ability of a child with a CI or a HA, leaving their difficulties with learning social-emotional knowledge unnoticed (Marschark et al., 2012; Weisel et al., 2007).

Given the atypical experiences with social interactions since early childhood, DHH children are likely to establish and update their database for SIP with inputs distinctive from their TH peers. This could in turn guide them towards aberrant SIP patterns. Considering the higher prevalence of maladaptive social behaviors observed in DHH children, as compared to TH children (Chao et al., 2015; Dammeyer, 2009; Fellinger et al., 2008; Hoffman et al., 2016; Netten et al., 2015; Van Eldik et al., 2004; for a review, see Bigler et al., 2019, Stevenson et al., 2015, and Theunissen et al., 2014), it is of rehabilitative importance to investigate how DHH children process emotional information and react to social situations.

BOX 1. The Social Information Processing (SIP) Model

The SIP model denotes six successive, interdependent steps for processing social information (Crick & Dodge, 1994). How the social information is processed in these steps explains individual differences in behavioral responses to social situations. This well-documented and influential approach has been further extended to integrate emotional processes (De Castro et al., 2005; Lemerise & Arsenio, 2000). The integrated model proposes that, in the first step, people encode emotional information by focusing their attention on relevant cues in the social situation. Second, people interpret the emotion according to the cues encoded. In the next steps, people formulate the goal that they want to achieve in the situation, generate options of responses to the situation, and assess these options to make a decision. Finally, people enact the most positively evaluated response (see Figure 1; also see Lemerise & Arsenio, 2000 for more details about the SIP model integrated with emotional processes).

At each step, people are guided by the "database" they develop that consists of memories, experiences, and knowledge about emotions and social rules. This database allows people to know which cues are relevant, how to integrate and interpret the cues, and what the more socially favorable way is to respond to the situation. Atypical social-emotional learning experiences thus could lead to characteristic SIP patterns and maladaptive responses to social situations. Supporting the theory, empirical research on autistic children and children with intellectual disability showed that these children focused more on negative emotional information during the encoding stage and evaluated assertive response options less positively than their typically developing peers (Embregts & Van Nieuwenhuijzen, 2009). Likewise, children with conduct problems gave more hostile interpretations to non-hostile cues and generated more aggressive responses (De Castro et al., 2005; Horsley et al., 2010).

THIS THESIS

Aims

In the current thesis, the overall aim was to examine how DHH children respond to emotions in a social context. This aim was achieved by investigating three emotional processes, i.e., emotion understanding, empathic responding, and emotion expression/production, in the framework of the SIP theory.

Specifically, we first focused on the initial two steps of the SIP model, i.e., encoding and interpretation of emotional cues, to investigate the underlying patterns when DHH and TH children understand emotional information in others' facial expressions and in social situations.

Second, we examined the three emotional processes involved in the responses to emotions, and to what extent these emotional processes are related to psychosocial functioning in DHH and TH children.

Understanding Emotions in Faces and in Social Situations by DHH children

Human facial expressions are important cues in daily life. Yet, correct identification of facial emotional expressions is not enough for a child to interact with the social environment. They still need to be able to extract such information from a social context where an overwhelming amount of information is present, and interpret the emotions according to the social context in order to properly evaluate the situation they are in (Crick & Dodge, 1994; Lemerise & Arsenio, 2000).

The advanced eye-tracking and pupillometry technologies developed in recent years are useful tools for examining the encoding stage of emotion understanding because it measures where people are actually looking at and how they react physiologically (see Box 2). While to the best of our knowledge no studies have examined DHH children's physiological responses to emotional stimuli, a small number of studies showed that DHH individuals' experiences with hearing loss may lead to a different gaze pattern when understanding emotions in faces. Letourneau and Mitchell (2011) reported that American TH adults focused on the eye region when looking at emotional faces, while DHH adults distributed their gazes evenly on eyes and mouth, thus exhibiting longer mouth-looking time than TH adults. Watanabe and colleagues (2011) found a focus on the nose region in Japanese TH adults, whereas DHH adults looked longer at the eyes than the nose. Yet, contrary to the previous two studies on adults, Wang and colleagues (2017) found that DHH and TH children (aged 3 to 7 years) did not differ in gaze patterns on positive and neutral facial expressions, except for the condition with verbal cues. When facial expressions were accompanied by verbal cues, DHH children looked shorter at the upper half of the face than TH children. To the best of our knowledge, this study is also the only one that investigated gaze patterns to emotional faces in DHH children. These findings seem to indicate a tendency in TH individuals to look at a core feature when recognizing emotions in faces (i.e., the eyes or the nose, possibly related to the cultural background). The patterns in DHH individuals was less clear (see Box 3 for an introduction on visual attention in DHH individuals).

As to the interpretation of emotional faces, some researchers hypothesized that DHH children may be more sensitive to facial expressions (Ludlow et al., 2010) because neuroimaging studies showed a reorganization of the functional links between cortical regions specialized for visual and auditory processing in DHH individuals (Rouger et al., 2012; Stropahl et al., 2015). However, this hypothesis is not fully supported by previous studies. When preschool DHH children were asked to sort facial emotions or label faces with emotions, they were less accurate than their TH peers (Wang et al., 2011, 2016; Wiefferink et al., 2013). Yet, in school-aged children, emotion-matching skills were comparable between DHH and TH children (Hosie et al., 1998; Ziv et al., 2013). This may indicate that school-aged DHH children would catch up with their TH peers, at least in terms of matching the emotional faces

To the best of our knowledge, there is only one study available examining DHH individuals' encoding and interpretation of emotional cues in dynamic social situations (Torres et al., 2016). This study also applied the SIP model, and found that DHH participants encoded less relevant cues and made more misinterpretations than TH participants. Other studies focused on the stage of interpretation and used static stimuli, such as drawings or photos. In these studies, DHH children were also found to more often misinterpret the emotions triggered in social situations than their TH peers. While most TH children are able to attribute basic emotions to a social situation when they are 4 years old (Rieffe et al., 2005), DHH children aged 2.5 to 8 years show lower performance than age-matched TH peers (Gray et al., 2007; Wiefferink et al., 2013). One study pointed out that 5- to 7-year-old DHH children who used spoken language as primary communication mode performed similarly as their TH peers, whereas those used sign language were less accurate in

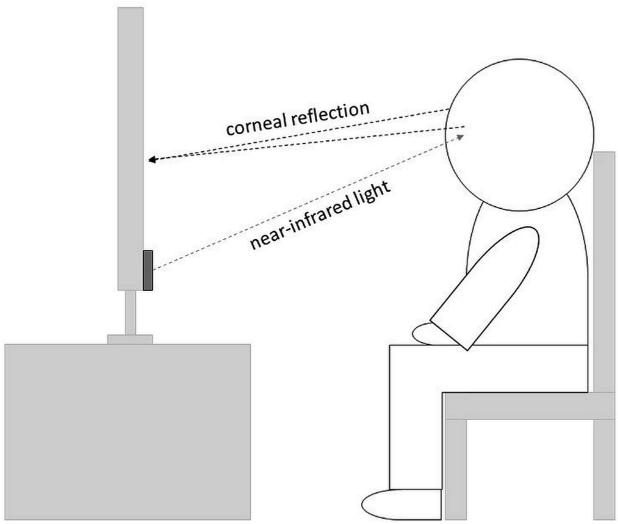

Figure 2. Lab setting for eye-tracking experiments in the current thesis (Chapter **2** and **3**). Participant sat 65 cm in front of a computer screen where an eye tracker was mounted. An experimenter sat next to the participant and controlled the experiments.

understanding emotions in a situational context, which was most likely due to limited social access in their educational setting where the staff were not all proficient in sign language (Ziv et al., 2013).

BOX 2. How Eye Tracking Works

Eye tracking is a sensor technology that measures eye movements, which allows a computer to know where an individual is looking, for how long the individual is looking at a particular location, and in what sequence the individual look at different spots in the visual field. Moreover, it provides pupillometry, a measure of the size of the pupils, which can be used as an indication of cognitive load or physiological arousal (Bradley et al., 2008).

An eye tracker consists of projectors, cameras, and advanced algorithms. The projectors emit invisible near-infrared light onto the eyes. High-definition cameras then record the direction of the light reflected off the cornea of the eyes. This corneal reflection techniques enables the position of the eyes, the gaze points, and the diameters of pupils to be calculated by a series of machine learning, image processing, and mathematical algorithms. Depending on the sampling rate of the eye tracker, the eye gazes and pupil diameter are captured multiple times a second (Tobii Pro, n.d.).

There are different types of eye trackers, such that are screen-based (mounted below computer screens) or wearable (as glasses or headset). Eye tracking allows eye movement to be measured in an unobtrusive manner and provides objective and quantifiable data.

Empathic Responses in the Social Context by DHH children

Empathy is a multifaceted capacity that enables people to feel others' emotions, and to affectively and appropriately respond to those emotions (Hoffman, 1990; Rieffe et al., 2010). According to the SIP model that integrates emotional processes (Lemerise & Arsenio, 2000), empathy allows people to shift their attention to others' emotional displays during the encoding stage, and empathic actions such as providing comfort or help are evaluated in the stage where different response options are assessed. Empathy is therefore an essential capacity for daily social participation as it guides our navigation of the social environment and stimulates prosocial responses (De Waal, 2010).

To date, little is known about DHH children's empathic skills. One study using teacher reports showed that the overall empathy levels in DHH children (aged 4 to 12 years) were lower than in their TH peers (Peterson, 2016). In studies that investigated separate empathic skills, the results were mixed. DHH and TH children did not differ in levels of affective empathy (Dirks et al., 2017; Netten, Rieffe, Theunissen, Soede, Dirks, Briaire, et al., 2015). Yet, parents of DHH children and DHH adolescents themselves reported fewer prosocial actions (Dirks et al., 2017; Netten, Rieffe, Theunissen, Soede, Dirks, Briaire, et al., 2015),

BOX 3. Visual Attention in DHH Individuals

There is a widely held myth that hearing loss would lead to enhanced visual ability. Empirical evidence shows that changes in the visual sensory domain following congenital hearing loss are actually rather specific. To date, the only behavioral difference between DHH and TH individuals that is replicable across studies is in the spatial distribution of visual attention. DHH individuals are faster and more accurate to detect an object or a motion in the peripheral visual field than TH individuals (e.g., Armstrong et al., 2002; Bavelier et al., 2000; Bosworth & Dobkins, 2002; Lore & Song, 1991; Neville et al., 1983; Neville & Lawson, 1987; Parasnis & Samar, 1985; Proksch & Bavelier, 2002). Likewise, DHH individuals are also more easily distracted by an irrelevant distractor in the periphery when they are asked to focus on a central target. By contrast, TH individuals find distractors presented centrally more distracting than peripheral distractors (Proksch & Bavelier, 2002).

The findings indicate that DHH individuals direct greater visual attention to the periphery, while TH individuals primarily attend to the center of the visual field. Possibly, congenital hearing loss leads to a preferred allocation of visual attention over the whole visual field to obtain more information, as a compensatory mechanism for the lack of auditory input (Dye et al., 2008; Letourneau & Mitchell, 2011; Proksch & Bavelier, 2002). Imagine that you are crossing the street without any auditory input from the environment, distributing visual attention to the peripheral locations to check the approaching cars appears to be a smart strategy for keeping yourself safe.

Importantly, such a change in visual spatial attention is chiefly driven by congenital hearing loss, rather than the use of sign language. When DHH signers and TH signers (i.e., TH individuals born to Deaf families) are compared, only the DHH signers exhibit greater attention to the peripheral visual field (Bavelier et al., 2001; Fine et al., 2005; Neville & Lawson, 1987b; Proksch & Bavelier, 2002). For a review on this topic, see Bavelier and colleagues (2006) and Dye and colleagues (2008).

whereas during an observational task DHH participants more often directed their attention to the person experiencing an emotion than TH participants (Ketelaar et al., 2013; Netten, Rieffe, Theunissen, Soede, Dirks, Briaire, et al., 2015).

Expressions of Own Emotions in the Social Context by DHH children

Emotion expressions are often part of people's enactment of responses to social situations. Expressing emotions helps people send specific information to their interaction partner(s) in regard to what is important to them and the goal they want to achieve in a social situation (Lemerise & Arsenio, 2000; Levenson, 1999). When a person reacts to a social situation with anger, he/she signals to the other(s) that there is a problem in the situation to be dealt with, or their relationship might be negatively affected. However, emotion expressions have to be guided by social rules, i.e., the display rules. Expressions of emotions, whether negative or positive, that are considered too frequent, intense, or prolonged by interaction partners could be harmful to social relationships (Liew et al., 2004; Rothbart et al., 2001; Sallquist et al., 2009; Wiefferink et al., 2012).

According to a small body of literature, DHH children (aged 1.5-5 years) were rated by their parents to express more frequent and more intense negative emotions than TH children, while the expression of positive emotions did not differ between DHH and TH children (Wiefferink et al., 2012). In emotion-provoking situations, DHH children's negative emotion expression remained intense after using a coping strategy (e.g., problem solving or avoidance) as compared to TH children (aged 9.5-13 years; Rieffe, 2012). Also, DHH children explained the causes of their anger less constructively than their TH peers, who expressed anger to communicate the discomfort the interaction partner caused (Rieffe & Meerum Terwogt, 2006). DHH children may express emotions in a less strategic manner to maintain or strengthen their relationships with others (Rieffe & Meerum Terwogt, 2006; Wiefferink et al., 2012).

Association between Responses to Emotions and Psychosocial Functioning

Being DHH during childhood is often reported to affect children's social functioning, leading to peer problems and psychopathological symptoms (Chao et al., 2015; Dammeyer, 2009; Fellinger et al., 2008; Hoffman et al., 2016; Netten, Rieffe, Theunissen, Soede, Dirks, Korver, et al., 2015; Van Eldik et al., 2004). A recent longitudinal study reported that children with a CI showed consistent lower levels of social competence, including lower adaptability and social interaction skills, than their TH peers four to eight years after implantation (chronological age 5 to 14 years; Hoffman et al., 2016). Also, the prevalence rates of internalizing and externalizing behaviors in DHH children are 4 to 14 percentage points higher than the rates in TH children (Fellinger et al., 2008; Stevenson et al., 2015; Van Eldik et al., 2004). Notably, the difficulties are not necessarily related to DHH children's auditory performance. Factors such as degree of hearing loss, age at amplification, unilateral/bilateral amplification, and receptive vocabulary were often found unrelated to social functioning in preschool and school-aged children (Dammeyer, 2009; Fellinger et al., 2008; Laugen et al., 2016; Netten, Rieffe, Theunissen, Soede, Dirks, Korver, et al., 2015; Stevenson et al., 2011).

Based on the SIP model, social behaviors are closely relate to how people respond to emotions. This is indeed what has been observed in typical development. For example, adaptive empathic responses to other people's emotions are consistently linked to better peer relationships (Eisenberg et al., 2010; Zhou et al., 2002) and fewer behavioral difficulties, such as internalizing behaviors like depression and anxiety (e.g., Smith, 2015; Tully & Donohue, 2017), and externalizing behaviors like aggression and conduct problems (e.g., Mayberry & Espelage, 2007; Pursell et al., 2008). When children are able to properly express their emotions towards others, share others' emotions, and know how to provide help or comfort, they can more skillfully engage in social interactions, thus establishing better social relationships (such as better-quality friendship; Denham et al., 1990; Zhou et al., 2002) and tending to do less harm to other people (Lovett & Sheffield, 2007; Rieffe & Meerum Terwogt, 2006).

Yet, to what extent are these findings applicable to children who are DHH? To our knowledge, only two studies have examined the relation between responses to emotions and social functioning in DHH children. Ketelaar and colleagues (2013) reported that higher levels of overall empathy was related to higher levels of social competence in DHH and TH children alike (aged 1-6 years). Yet, a positive correlation between emotion understanding and social competence was observed only in DHH children, but not in TH children, indicating the importance of understanding others' emotions in DHH children's social life. Wiefferink and colleagues (2012) showed that excessive expression of negative emotions was related to more externalizing behaviors in both DHH and TH children (aged 1-6 years). However, while TH children who expressed more positive emotions were regarded as more socially competent by their parents, such a relation was not found in DHH children. This might reflect that TH children expressed positive emotions more strategically than DHH children to maintain or strengthen their relationships with others (Rieffe & Meerum Terwogt, 2006; Wiefferink et al., 2012). Though limited in number, these studies show the possibility that DHH children respond to emotions differently, thus further hindering their social participation.

DHH CHILDREN IN TAIWAN AND IN THE NETHERLANDS

The majority of the aforementioned studies were done on children from the Western societies. Given that different language systems and cultures could affect how emotions are processed (e.g., Liu et al., 2015; Masuda et al., 2008; Ogarkova et al., 2009; Tanaka et al., 2010), studies done in the Western world may not be fully applicable to the other parts of the world. A small body of literature has shown that Western and East Asian people use different gaze patterns for encoding emotional faces: Eastern Asian viewers looked at the eye region for a longer time than Western viewers (Jack et al., 2009, 2012). Westerners and East Asians also differed in the interpretation of emotion category. For example, when interpreting angry faces posed by Japanese actors, Japanese subjects attributed more disgust, while American subjects attributed more sadness (Dailey et al., 2010). Moreover, East Asian children and adolescents were found to experience higher levels of personal emotional arousal than Western counterparts when witnessing other people's emotional displays (Cassels et al., 2010; Trommsdorff, 1995). To understand the generalizability of the current knowledge on emotional development, more studies on the non-Western samples are absolutely needed.

The current thesis includes DHH and TH children from Taiwan and from the Netherlands for different studies, aiming to increase the external validity of existing knowledge on DHH children's psychosocial development. Below information is provided in regard to culture, language, and support offered to DHH children in Taiwan and in the Netherlands.

Culture and Language

According to Hofstede's individualism-collectivism dimension, Taiwan is more collectivistic, while the Netherlands is more individualistic (Hofstede, 1984; Hofstede & Bond, 1984). Collectivistic-oriented cultures focus on the needs and goals of an individual's social group. The "I" is part of the "we," and people are encouraged to live up to the expectations and standards of the social group (Markus & Kitayama, 2014; Singelis, 1994; Wong & Tsai, 2007). Individualistic-oriented cultures focus on the needs and goals of the individuals themselves (Markus & Kitayama, 2014; Singelis, 1994), and thus promote self-responsibility, autonomy, and uniqueness of each individual (Oyserman et al., 2002; Realo et al., 2002).

Taiwanese Mandarin is the most widely used language in Taiwan. It is a variety of Mandarin Chinese and a tonal language. Different tones, i.e., pitches, distinguish the lexical meaning of a syllable. For example, *ma* with a high level tone means "mother," whereas *ma* with a falling tone means "scold." Taiwan also has its separate sign language, the Taiwanese Sign Language, which was developed from the Japanese Sign Language. Dutch is the language spoken by the majority of the people in the Netherlands. It is a West Germanic, non-tonal language. There is also a separate Dutch Sign Language in the Netherlands: Nederlandse Gebarentaal (NGT).

Prevalence of Hearing Loss and National Newborn Hearing Screening

Taiwan has 23.5 million inhabitants, of which around 120,000 have a disability related to hearing. Annually, about 200,000 babies are born (National Statistics Taiwan, n.d.). Approximately 700 of these newborns per annum are with a hearing loss (0.37%; Chen et al., 2015). As to the Netherlands, there are 17.1 million inhabitants. About 18,000 babies are born per annum (Statistics Netherlands, 2019), and among them about 300 newborns are with a hearing loss (0.17%; Van der Ploeg et al., 2015).

The national newborn hearing screening program started from year 2012 in Taiwan, and from year 2006 in the Netherlands. This program allows the hearing of newborns to be checked within 24 to 60 hours (Taiwan) or 4 to 7 days (the Netherlands) after birth, enabling early identification and treatment of hearing loss. As a result, in recent years more children are able to receive intervention at a younger age. Before the national newborn hearing screening program was launched, hearing loss in children was usually diagnosed after their first birthday. Therefore, the earlier start of the program allows the majority of DHH children in the Netherlands to receive a CI before the age of two years, while many DHH children in Taiwan receive implantation at a relatively older age (specific data unknown).

Intervention and Rehabilitation

When infants in Taiwan and in the Netherlands do not pass the newborn hearing screening after two rounds of tests, they are referred to a hospital or an audiological center for diagnosis. A team of medical doctors, audiologists, speech therapists, psychologists, and social workers does a series of examinations and provides support. After children are diagnosed with a hearing loss, they are introduced to suitable treatments, such as a HA trial or pre-CI tests.

In Taiwan, the costs of HAs are partially subsidized by the government when the degree of hearing loss is above 55 dB HL. All children under 18 years old who have bilateral severe-to-profound hearing loss and cannot benefit from HAs (e.g., hearing threshold surpasses 110 dB HL or the HA makes no improvement after three months) are eligible to receive a CI with the expenses covered by the national health insurance. Bilateral cochlear implantation is less common, most likely because only the first implant can be insured. Some hospitals initiate financial support projects for the second implant for children. In the Netherlands, the costs of HAs can be insured when the degree of hearing loss is above 35 dB HL. For children under 18 years old who are assessed by the CI team and deemed eligible for CIs, the first and the second CI can both be fully reimbursed by the insurer.

As to the rehabilitation in Taiwan, several foundations offer comprehensive aural-verbal rehabilitation programs for DHH children. These rehabilitation programs aim to help children listen and hear so as to communicate through spoken language. The most common programs involve a DHH child, a parent, and a teacher. The teacher stimulates children's hearing and verbal responses with a variety of activities and demonstrates to the parent what they can do at home. Other programs also include activities such as storytelling, music, and art that involve a group of DHH children.

In the Netherlands, sign-supported Dutch is encouraged in family interactions and used in rehabilitation programs from the start of intervention. A family-centered approach is adopted in rehabilitation programs. Such programs often include home visits by a family counselor, courses for parents and family members, and group treatments that involve a group of DHH children, a speech therapist, and two pedagogical counselors (one of them is also DHH). Regular sessions are provided to parents to watch the group treatments so they can learn the signs associated with a particular theme.

Education

Under the *Special Education Act*, children in Taiwan are placed in mainstream schools whenever possible. To address the needs of children with a disability, mainstream schools have three options to provide support: an external teacher for periodical extra guidance, a "resource room" in the school for regular extra guidance, and a special education class for placing students with special needs together. More than 70% of the DHH children go to regular classes without extra guidance, and about 15% receive one of the three extra support options (Special Education Transmit Net Taiwan, n.d.). Children who are not suitable for mainstream schools are placed in special education schools. These children take up about 12% among all preschool DHH children, and 6% among all school-aged DHH children.

In the Netherlands, the placement of DHH children is in accordance to the *Dutch Appropriate Education Act* of 2014. Schools have a "duty of care" to make adjustments to ensure that each child's needs can be addressed in mainstream education, or to offer alternatives (to another mainstream school or to a school providing special education). Beside basic support, schools need to adapt their teaching and, when needed, provide extra supervision and individual development plans. Children who are not possible to attend mainstream schools receive special education. About 0.5% of all primary school children go to special education schools for the DHH each year (Dienst Uitvoering Onderwijs, 2018; Onderwijs in Cijfers, 2019).

OUTLINE OF CHAPTERS

Applying the SIP model, this thesis examines the role of social-emotional learning, as a result of hearing status (DHH or TH), in children's responses to emotions in a social context. The first half of the thesis (Chapter 2 and 3) focusses on the encoding and interpretation patterns, i.e., the initial two steps of the SIP model, when children understand emotions in faces and in social situations. In the second half (Chapter 4 and 5), the focus is on the level and development of children's responses to emotions, as well as the association between these responses and psychosocial functioning.

In **Chapter 2**, we test how three- to ten-year-old DHH and TH children understand others' facial expressions of emotions. Using eye-tracking and pupillometry, we measure how these children scan the faces and their physiological arousal when they encode the emotions in faces, and later check how they interpret the emotions they observe. In **Chapter 3**, we further test how DHH and TH children understand emotions in dynamic, prototypical social situations. Again, we measure these children's eye movement to examine how the emotional cues in the dynamic social scenes are encoded, and ask for their interpretation of the emotion triggered by the social interaction. In **Chapter 4**, we examine how responses to emotions (emotion understanding, empathy, and emotion expression) are related to DHH and TH children's social competence and externalizing behaviors. In **Chapter 5**, we investigate the developmental trajectory of empathy in preschool DHH and TH children, and its association with early symptoms of psychopathology, using a longitudinal four-wave design. Finally, in **Chapter 6**, we summarize key findings, discuss implications for interventions, and suggest directions for future research.

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CHAPTER 2

Reading Emotional Faces in Deaf and Hard-of-Hearing and Typically Hearing Children

Tsou, Y. T., Li, B., Kret, M. E., Da Costa, I. S., & Rieffe, C.

Reading emotional faces in deaf and
hard-of-hearing and typically hearing children

In press; Emotion

ABSTRACT

Reading emotions from other people's facial expressions is an important skill that guides social interactions. With limited auditory input and atypical emotion socialization, deaf and hard-of-hearing (DHH) children may develop atypical processing patterns when reading emotional faces. The current study aimed at understanding whether and how DHH and typically-hearing (TH) children differed at three emotion processing levels: gaze patterns, physiological arousal, and interpretation. Fifty-five DHH children and 72 TH children completed an emotional face matching task in which they were presented with happy, angry, fearful, and emotionally-neutral faces. During the task participants' eye gazes and pupil diameter were measured by an eye-tracking device. The DHH and TH children both paid most attention to the eye region when reading emotional faces. Yet, a contrast between happy faces and non-happy faces was observed in physiological arousal and interpretation tendency in the DHH children only: Non-happy facial expressions were more arousing and were confused more often than happy expressions, which may reflect the DHH children being less experienced in processing non-happy expressions due to limited access to the social environment. The results highlighted the importance of looking into the qualitative differences between typical and atypical development.

INTRODUCTION

Human facial expressions are important cues in daily life for interpreting the social environment and provide guidance during social interactions. This skill of "reading" or processing expressions of emotions in faces involves extracting, integrating, and interpreting information from facial features (Adolphs, 2002). This is achieved by children through the process of emotion socialization, when they interact with others, communicate their needs, observe social situations, or overhear conversations (Rieffe et al., 2015; Saarni, 1999). However, these daily practices are less accessible to deaf and hard-of-hearing (DHH) children. The limited access to the social environment could hamper their development in other areas, and in turn further hinder their social participation. It is therefore important to examine how children process emotion expressions in faces during childhood, so that support may be provided early in life when needed. In this study we addressed this issue and focused on DHH and typical hearing (TH) children's ability to process other people's facial emotion expressions at visual, physiological, and interpretation levels.

Many DHH children nowadays receive a hearing device, such as a hearing aid (HA) or a cochlear implant (CI). These technologies significantly improve their auditory performance and speech perception (Waltzman, 2006). Nevertheless, it is worth noting that hearing devices still have their limitations, such as a narrower hearing range and a lower ability to discriminate pitch information, which prevents users from perceiving subtle variations in daily conversations, especially in the presence of background noises or multiple speakers (Bacon et al., 1998). Consequently, both before and after intervention, despite access to a hearing device, DHH children still have limited access to their social environment. This reduced access grants them fewer opportunities for emotion socialization, i.e., to learn emotion skills in their social context by participating in or observing social interactions, as compared to their TH peers (e.g., Calderon & Greenberg, 2011; Rieffe et al., 2015).

This more difficult access to the social world impacts children's emotion socialization in different ways, including their ability to read people's facial emotion expressions. Previous studies showed more difficulties with matching different facial emotion expressions in DHH children compared to their TH peers at or before the age of 5 years (Wang et al., 2011, 2016; Wiefferink et al., 2013). Yet, studies on older children showed comparable emotion-matching skills in DHH and TH children (Hosie et al., 1998; Ziv et al., 2013), indicating that school-aged DHH children may catch up with their TH peers, at least regarding the mean level of accuracy.

To date, studies on reading facial emotion expressions in DHH children focused solely on the accuracy to recognize expressions. However, processing other people's facial emotions occurs at multiple levels in a parallel and coordinated manner, involving more aspects than the interpretation accuracy alone (Scherer, 2000). All these levels of processing can be informative. First, at the visual level, an observer fixates gazes on different facial features to extract information (Lundqvist & Ohman, 2005). Second, at the physiological level, the observer experiences physiological arousal as an automatic aspect of the emotion-reading process. This enables them to immediately act upon an emotion-evoking situation (Frijda, 1986). Third, at the cognitive level, the observer interprets the observed facial expression by relating it to an emotion category as per past experiences (McClure, 2000).

Gaze Patterns in DHH Children

Eye movements reveal how an individual scans and extracts information from the visual field. This is modulated by both top-down (goal-driven) and bottom-up (stimulus-driven) processes of attention (Liversedge & Findlay, 2000). In typical development, signals with high relevance (goal-driven) and/or high salience (stimulus-driven) are fixated for longer than other sources of information. For example, emotional faces are looked at for longer than neutral faces (Bradley et al., 2011); and eyes attract more attention than other facial regions (Schurgin et al., 2014). However, "relevance" and "saliency" are relational, depending on a person's prior experiences. Previous research has shown that with age, typically-developing children direct more attention towards the eye region than the mouth region (Meaux et al., 2014) and towards the inner features (i.e., eyes, nose, and mouth) than the other areas on emotional faces (Hunnius et al., 2011; Naruse et al., 2013). Although infants exhibit an innate preference for human faces (Slater & Quinn, 2001), their allocation of fixations over the inner features on the faces appears to develop with their increasing experiences in recognizing facial expressions (Hunnius et al., 2011).

Given an atypical hearing experience, DHH individuals may navigate the world in a way that differs from TH individuals to extract relevant information from faces. This was indeed what was found in the literature, despite the small body of studies. Letourneau and Mitchell (2011) found that American TH adults focused on the eye region when looking at emotional faces, while Deaf adults distributed their gazes more evenly on eyes and mouth, thus showing longer mouth-looking time than TH adults. Watanabe and colleagues (2011) reported a main focus on the nose region in Japanese TH adults, whereas Deaf adults fixated longer on the eyes than the nose. These findings show that TH individuals tend to fixate on a core feature, which was the eye region in a Western population (Letourneau & Mitchell, 2011), and the nose region in an Eastern-Asian population (see Watanabe et al., 2011 for a cultural explanation of the tendency).

However, the patterns shown by DHH individuals was less clear from these two studies. A possible explanation for the reported patterns is that DHH individuals may tend to distribute their gazes to a greater area, thus showing longer fixations outside the core feature. This speculation is based on many previous studies that found DHH individuals to attend more to the peripheral visual field than TH individuals when detecting a shape on the screen (Bavelier et al., 2001; Proksch & Bavelier, 2002). Possibly, congenital deafness leads to a preferred allocation of visual attention over the whole visual field to obtain more information, as a compensatory mechanism for the lack of auditory input (Dye et al., 2008; Letourneau & Mitchell, 2011; Proksch & Bavelier, 2002).

It is worth mentioning that the studies above are all about DHH adults. To the best of our knowledge, only one study examined DHH children's visual attention towards emotional faces. Wang and colleagues (2017) found that DHH and TH children (aged 3 to 7 years) did not differ in gaze patterns on positive and neutral facial expressions, except for the condition with auditory cues. In this condition, DHH children looked shorter at the upper half of the face than TH children. These findings suggested that DHH children may perform differently from DHH adults during visual presentation of emotional faces. More data from children are needed in order to verify if this different gaze pattern for reading emotional faces emerges already in childhood.

Physiological Arousal in DHH Children

Physiological responses that cause pupil dilation, sweating, and an increased heart rate in the observer are part of the process of reading other people's emotions (Bradley et al., 2008). This physiological arousal enables an observer to act immediately upon an emotion-provoking situation. In the recent decade, increasing research has been carried out examining pupillary responses to emotional stimuli in adults (e.g., Bradley et al., 2008; Laeng et al., 2013; Partala & Surakka, 2003) and children (e.g., Geangu et al., 2011; Jessen et al., 2016) because its noninvasive nature makes it a suitable measure for emotional arousal in various populations. A greater magnitude of pupil dilation reflects higher arousal (Bradley et al., 2008).

It has been consistently found that pupils dilate in response to both negative and positive emotional stimuli in adults (Bradley et al., 2008; Partala & Surakka, 2003) and 6- to 12-month-old infants (Geangu et al., 2011). Moreover, in the studies that specifically used isolated emotional faces as stimuli, adults showed a greater pupil dilation towards negative facial expressions than positive ones (Laeng et al., 2013), while 7-month old infants demonstrated a reversed pattern (Jessen et al., 2016). This implies a possible developmental change that young children may experience greater arousal when facial expressions are most familiar and relevant in their daily social life (Campos et al., 2000; Jessen et al., 2016), whereas adults may develop a greater sensitivity to threatening signals which prepares them for a fight or flight (Kret & De Gelder, 2013; Laeng et al., 2013).

Yet, the development of physiological reactivity may be affected by difficult parent-child interaction in early childhood. For example, children (aged 8 to 14 years) with a depressed mother were more strongly aroused by sad faces, while children with an anxious mother were more strongly aroused by angry faces, when compared to children whose mothers were not depressed or anxious, respectively (Burkhouse et al., 2014). Adolescents (aged 15 to 22 years) who thought their parents to be less socially supportive or communicatively skilled were more likely to exhibit higher arousal when talking about stressful events related to their parents (Afifi et al., 2011). The higher arousal indicates higher sensitivity or more effort when handling negative emotions. Another study reported a reduced arousal level towards positive and negative emotion words in 18-year-old college students with depressed parents, reflecting decreased engagement in emotion-laden contexts (Bistricky et al., 2014).

DHH children experience similar difficulties in parent-child interaction. Over 90% of the DHH children are born to TH parents (Mitchell & Karchmer, 2004) and parent-child communication is often less effective in families with DHH children (Calderon & Greenberg, 2011). However, it remains unexplored how DHH individuals physiologically respond to emotional information. To our knowledge, only two studies have investigated DHH children's emotional arousal using parent- or self-reports (Dirks et al., 2017; Netten et al., 2015). The studies indicated that DHH toddlers and adolescents did not differ from their TH peers in the parent- or self-rated levels of emotional contagion, i.e., the affective component of empathy that triggers personal arousal upon the witness of another person's emotion (Decety & Jackson, 2004; Hoffman, 1987). Nevertheless, these outcomes did not necessarily reflect physiological responses.

Interpretation Tendency in DHH Children

The ability to understand the meaning of facial expressions is not innate. It requires an emotion socialization process in which children learn and practice the skill to relate a facial expression to their experiences. Children need to be exposed to social interactions to gain the experiences (Gordon, 1989; Rieffe et al., 2015). The quality and quantity of social interactions during the early years of life could thus affect how a person appraises a facial expression. That is, the interpretation of emotions is not definite but experiential. This view is supported by developmental research on the interpretation of emotion categories in TH children. Studies showed that TH children start with a valence-based interpretation of emotional faces (i.e., feeling good vs. feeling bad) and gradually develop the ability to differentiate same-valence facial expressions as discrete emotion categories (see Widen, 2013, for a review). As a result, young children are more likely to confuse between same-valence emotional faces (e.g., angry and fearful faces) than between opposite-valence emotional faces (e.g., happy and angry faces), whether verbal responses are required or not.

What DHH individuals "see" on an emotional face is a topic rarely analyzed. To our knowledge, Hosie et al. (1998) is the only study that reported the confusion pattern DHH children (aged 5-12.5 years) exhibited when recognizing emotional faces, which was similar to their TH peers: the younger children (5-8 years), whether DHH or TH, more often confused between the emotional faces within the negative valence, while the older children (8.5-12.5 years) mainly had difficulties with faces showing disgust. However, the picture emerges here is unclear because of the age difference between the younger DHH and TH children (M_{DHH} = 6.6 years, SD = 1.3 vs. M_{TH} = 5.3 years, SD = 0.3).

In addition, prior studies that reported accuracy results also inform us DHH children's interpretation tendency. Using a matching task, Wiefferink et al. (2013) and Wang et al. (2016) found that DHH children (aged 2.5-7 years) had more difficulties differentiating between opposite-valence faces (e.g., happy and sad) and between same-valence faces (e.g., angry and sad) than their TH peers. When asked to point at an angry, fearful, happy, or neutral face among other faces, DHH children (2.5-7 years) more often chose an emotion expression not asked by the experimenter than their TH peers (Wang et al., 2011; Wang et al., 2016; Wiefferink et al., 2013). Moreover, DHH and TH children seem to differ in the emotion category they recognized best/worst. For example, Wiefferink et al. (2013) indicated that TH children were best at recognizing happy faces, yet DHH children (aged 2.5 to 5 years) performed similarly on all types of emotion expressions. Wang et al. (2011) showed that DHH children (aged 4 to 6.5 years) often chose an emotional face when asked for a neutral face, compromising their score on the neutral category, while TH children performed similarly on all expressions.

Taken together, these studies suggest that DHH and TH children may demonstrate different interpretation tendencies at least until middle childhood. More empirical evidence is needed to confirm the patterns DHH children exhibit when interpreting emotional faces.

The Present Study

DHH children have a different experience of emotion socialization due to hearing and communication difficulties that hinder their participation in social interactions. Past studies have shown that such an atypical childhood experience could influence the way DHH individuals respond to emotional signals, but studies on the underlying mechanisms and evidences from children are lacking, leaving a gap in the literature. Therefore, in this study we aimed to understand how DHH and TH children read other people's facial emotion expressions, considering three levels of facial emotion processing: gaze pattern, physiological arousal, and interpretation. We included children aged 3 to 10 years, since this is a period in which typically-developing children gradually learn and master the skill to identify different emotion categories (Durand et al., 2007).

First, we examined DHH and TH children's gaze patterns while they were looking at emotional faces. We hypothesized that TH children would focus mostly on the core features (i.e., eyes or nose), while DHH children would tend to scan the entire face more evenly, thus looking longer at the mouth. We expected this pattern across the different emotion categories.

Second, we investigated the physiological arousal elicited by the observation of emotional faces through changes in pupil diameter. To the best of our knowledge, no research has been conducted to directly measure DHH individuals' physiological arousal towards emotional faces. Therefore, we based our hypothesis on the physiological arousal patterns found in children who had difficult emotion socialization in early childhood like

DHH children (Afifi et al., 2011; Bistricky et al., 2014; Burkhouse et al., 2014). We expected a different pattern in physiological arousal, thus a different magnitude of pupil dilation, in the DHH group than in the TH group. We did not hypothesize on the direction of the difference given that hyper- and hypo-arousal were both observed in children with difficult emotion socialization experiences.

Third, we analyzed the interpretation children gave to the facial expressions to assess their interpretation accuracy and the tendency for recognizing faces as a certain emotion. Given the previous findings that school-aged DHH and TH children had comparable performances (Hosie et al., 1998; Ziv et al., 2013), we expected that DHH and TH children would identify facial expressions of basic emotions at a similar level of accuracy. Yet, we did not develop specific hypotheses for interpretation tendencies and group differences in these tendencies due to the lack of support.

Given that the present study aimed at understanding the underlying patterns DHH and TH children showed at the three processing levels, it is important that we considered not only the emotion categories predefined by the study but also the actual perceived emotion categories, which provides insight into how children actually "read" the faces (Russell & Steinberg, 1994; Wagner, 1993). Therefore, all three levels of emotion processing were analyzed twice: once based on the predefined emotion category of the stimuli (i.e., the category intended by the design of the study), and once based on the interpreted emotion category (i.e., the emotion that the participant identified).

METHODS

Participants

A total of 127 children in Taiwan aged between 3 and 10 years old participated in this study, including 55 DHH children (M_{age} = 6.45, SD_{age} = 2.10) and 72 TH children (M_{age} = 6.03, SD_{age} = 1.77). Children with additional disabilities were excluded from recruitment. Those who could not use oral language for communication were also excluded to narrow our focus on hearing status. All children and their parents were Asian. See Table 1 for participant characteristics.

Among the DHH children, five children wore HAs, and the other 50 children were implanted with a CI. All the DHH children had congenital or prelingual hearing loss. They received intervention (HA or CI) before 2.5 years of age and had used the hearing device for a minimum duration of 7 months. As Table 1 shows, the DHH and TH children did not differ regarding their age, $t(125) = -1.22$, $p = .223$, gender distribution, $\chi^2(1, N = 127) = .70$, $p = .473$, nonverbal intelligence, $t(120) = 1.77$, $p = .079$, or parental educational level, $t(118) = 1.45$, $p = .150$. Nonverbal intelligence was measured by two subscales of the Wechsler Preschool and Primary Scale of Intelligence Revised Edition (Block Design and

Matrix subscales for children aged 3-5 years; Wechsler, 1989) or the Wechsler Intelligence Scale for Children Third Edition (Block Design and Picture Arrangement subscales for children aged 6-10 years; Wechsler, 1991).

This study was part of a research project that also includes other variables to examine social-emotional functioning in children with (a)typical development. Participants received a small gift (e.g., crayons) after finishing the experiments. All informed consent forms were signed by the primary caregivers on behalf of the child participants and by participants older than 7 years before the test procedures. The study protocol and informed consent form were approved by The Psychology Ethics Committee of Leiden University and Chang-Gung Memorial Hospital Ethics Committee for Human Studies.

Based on Wiefferink et al. (2013), a difference between DHH and TH children in their ability to discriminate basic emotions could be observed with a small-to-medium effect size ($d = .4$). Therefore, we estimated with a power analysis that a minimum sample size of 82 was required to be able to detect a group difference with an alpha of 0.05 and a power of 0.90.[1] A total of 153 children were approached. After excluding children who did not finish at least 50% of the tasks that were part of the current study ($n = 8$), children who had additional disorders or low/high nonverbal intelligence (2 *SD* lower/higher or indicated by the teacher/responsible clinician; $n = 17$), and a child who accidentally took the test twice, the final sample included 127 children. The included ($n = 127$) and excluded ($n = 26$) samples did not differ in age, $t(151) = .62$, $p = .537$, gender distribution, $\chi^2(1, N = 153) = 2.40$, $p = .136$, and nonverbal intelligence, $t(142) = .08$, $p = .937$. Yet, the parents of the excluded sample had lower educational level than the parents of the included sample, $t(141) = 2.42$, $p = .017$.

Materials and Procedure

Three levels of emotion processing were investigated, including gaze patterns, physiological arousal, and interpretation. The specific measurements at these levels are specified below. Children conducted an emotional match-to-sample task (Figure 1) in a quiet room at a cochlear implant center or at the participant's school, while their gazes and pupil size were being recorded by a Tobii X3-120 eye tracker (Tobii Technology, Sweden). A light meter was put in front of the computer screen and in front of the participant's eyes to control for the illumination in the test environment. They were seated 65 cm away from the eye tracker mounted below a computer screen with a resolution of 1024 x 768 pixels. A 5-point calibration was conducted prior to each experiment. All participants were tested by the same experimenter, who received training on using the eye tracker before data collection.

1. Note that originally we planned to use a mixed model ANOVA when estimating the sample size a priori and later changed to multilevel modeling considering the two-level structure of the data.

Table 1. Characteristics of the participants.

Characteristic	DHH	TH
N	55	72
Age, years, mean (*SD*)	6.45 (2.10)	6.03 (1.77)
Gender, *n* (%)		
Male	27 (49%)	30 (42%)
Female	28 (51%)	42 (58%)
Nonverbal intelligence, mean (*SD*)[a]	9.49 (2.71)	10.35 (2.57)
Parental education level, mean (*SD*)[b]	3.32 (1.04)	3.59 (0.96)
Type of hearing device, *n* (%)		
Cochlear implant	50 (92%)	
Hearing aid	5 (8%)	
Degree of hearing loss, *n* (%)		
Mild	2 (4%)	
Moderate	2 (4%)	
Severe to profound	51 (92%)	
Age at intervention, years, mean (*SD*)	2.54 (1.32)	
Duration of using hearing device, years, mean (*SD*)	3.91 (1.91)	

Note: DHH = deaf and hard of hearing; TH = typically hearing.
[a]For nonverbal intelligence, age-corrected norm scores are presented. The grand population mean is 10 and the standard deviation is 3.
[b]Parental education level: 1 = no/primary education; 2 = lower general secondary education; 3 = higher general secondary education; 4 = college/university.

Emotional Match-to-Sample Task

Stimulus materials included angry, fearful, happy, and emotionally-neutral faces. There were 52 trials in total, counterbalanced by emotion category and face gender. All the faces were Asian, shown in a frontal view with direct gaze. A trial started with the presentation of a single facial expression, after which four faces of a different person were presented, one of which showing the same expression as before (Figure 1). Children were asked to choose the face expressing the same emotion as the one they saw at the start of the trial. Four practice trials were given prior to the start of the experiment. Only the children who understood the practice trials continued doing the testing trials.

Stimuli

Adobe Photoshop was used to standardize the photos so that all photos were grey scaled and in a vertical elliptical shape. Hair and impurities on the skin (e.g., moles, scars, and pocks) were removed. The average luminance in each photo was calculated and adjusted to the mean. The sample pictures were each resized to 480 x 672 pixels, and those used for

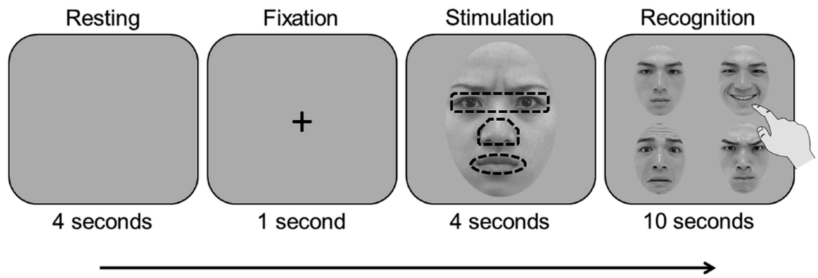

Figure 1. An example trial sequence. The dashed lines on the face in the stimulation phase denote the three areas of interest (AOIs) used in the analyses, which were not presented to the participants during the experiment. The face images shown here were downloaded with the owner's permission for using the face images of these two models in scientific publications from http://bml.ym.edu.tw/tfeid/modules/wfdownloads/.

recognition to 270 x 378 pixels. The faces were placed against a grey background which had the same mean luminance as the faces. Tobii Studio 3.4.8 was used for stimulus presentation. The face images (*n* = 620) were obtained from validated face databases upon the owners' approval (Chen et al., 2013; Chen & Yen, 2007; Lee et al., 2013; Ma et al., 2015; Meuwissen et al., 2017; Park et al., 2011; Tottenham et al., 2002; Tottenham et al., 2009) and were randomly divided into four sets. Fifty-four typically-developing Asian adults (40 female, 13 male, 1 unreported) were given one of the sets and rated the faces regarding emotion category and intensity. The faces that were recognized above 70% correct were included in the experiment. Among the selected faces, those with the highest accuracy rate (M = 95.15%, SD = 6.71) and highest intensity (M = 6.20, SD = 1.09, on a scale from 0 to 10) were chosen as sample stimuli, while the others were used in the recognition phase.

Gaze Patterns

Gaze patterns were analyzed when participants watched the sample stimuli. The gaze patterns towards specific facial features were measured by calculating the ratio of total fixation duration within a predefined area of interest (AOI) against total fixation duration on the entire screen. Three AOIs were predefined: eyes, nose, and mouth (Figure 1). In addition, to examine the visual attention towards the faces, we calculated the ratio of total fixation duration on the entire face against the entire screen. The first 200 ms of each stimulation phase was discarded from calculation to reduce the lingering effect of the fixation cross (Kret et al., 2013).

Physiological Arousal

The magnitude of arousal was measured by calculating the changes in pupil diameter from the baseline during the stimulation phase. Averaged pupil size during the final 500 ms of the fixation-cross presentation was used as the baseline for each trial. The first 2 seconds of the stimulation phase were discarded from analyses to avoid the influence from the picture-onset decrease in pupil size (Bradley et al., 2008). The signals during the last 2 seconds of the stimulation phase were down-sampled to 100-ms timeslots for analysis. PhysioData Toolbox v0.2.2 (Sjak-Shie, 2019) was used to preprocess the raw pupil data. Following the guidelines suggested by Kret and Sjak-Shie (2019), we filtered out trial outliers (pupil size outside the feasible range, i.e., smaller than 1.5 mm or larger than 9 mm; pupil size that changed more than 2 standard deviations of the dilation speeds of all pupil diameter samples in-between two adjacent data points), removed eye blinks, and interpolated gaps smaller than 250 ms.

Interpretation Accuracy and Tendency

The answers the participants provided during the recognition phase were used for evaluating interpretation accuracy and tendency. Accuracy was regarded as the extent to which participants' answers agreed with the predefined emotion category. We used the unbiased hit rates (*Hu* scores) as an indicator of accuracy (Wagner, 1993). The *Hu* scores incorporated answers agreeing and disagreeing with the predefined category, allowing appropriate evaluation of accuracy especially in the cases that children constantly chose the same option throughout the trials. A simplified calculation example is given here: If there are two stimulus categories and two answer options in a forced-choice task (e.g., angry and neutral), the *Hu* score for the angry category is computed by the formula $A/(A+B)*A/(A+C)$, where A is the number of angry stimuli recognized as angry, B is the number of angry stimuli interpreted as neutral, and C is the number of neutral stimuli interpreted as angry. The *Hu* values range between 0 and 1.

Further, we calculated the frequency that a certain type of answers was given to explore interpretation tendency. Using the same example above, we divided B by the total number of angry trials to obtain the frequency of angry faces misinterpreted as neutral.

Eye-Tracking Data Processing

Via corneal reflection techniques, the Tobii X3-120 eye tracker recorded the position of participant's eyes and their diameter at a sampling rate of 120 Hz. Tobii Studio 3.2.1 was utilized to process the data and the Tobii I-VT fixation filter was applied. AOIs were predefined on the software using its Dynamic AOI tool by drawing freeform shapes. Only the samples where both eyes were detected by the eye tracker (i.e., validation code was "0" for both eyes) were included in analyses.

Statistical Analyses

Statistical analyses were carried out using SPSS 25.0 (IBM Corp., Armonk, NY). Children with a CI and children with an HA were analyzed together as a group because leaving out children with an HA (n = 5) from the analyses did not change the direction of the results or the size of the effects (see Supplementary Materials S2.1 for the results after children with an HA were excluded). Group characteristics were compared using independent t-tests. Considering the wide age range in our participants, we added age as a covariate in all analyses. All independent variables were centered. Level of significance was set at $p < .05$.

Gaze Patterns

Two generalized linear mixed models were used to analyze the gaze data considering the two-level data structure: trials (level 1) nested in participants (level 2). A final model was derived via a standard model selection procedure where nonsignificant factors were removed one by one from the full model, starting with higher-order interactions. Factors with a trend towards significance may still be included in the final model if removing them resulted in a worse model fit. A better model fit was indicated by a lower -2 log likelihood. A random intercept was included in both models. First, the fixation ratios within each of the AOIs were modeled to understand the gaze patterns towards specific facial features. Fixed effects included Age, Group (2: DHH, TH), Emotion (4: angry, fearful, happy, neutral), AOI (3: eyes, nose, and mouth), and interactions between Group and Emotion/AOI. Second, the fixation ratios within the entire face were modeled to examine participants' visual attention to the faces. Fixed effects include Age, Group, Emotion, and the interaction of Group x Emotion. Additionally, we developed extra models to analyze the fixation ratios based on the interpreted emotion categories (i.e., the emotion the participant identified). Here we excluded Emotion from the fixed effects and replaced it by Interpretation (4: interpreted as angry, fearful, happy, or neutral). Where post-hoc analyses were needed to interpret results, we repeated the models with the reference category changed (e.g., from neutral to happy emotion), or ran separate models in each group to confirm within-group effects (for such analyses, significance level was adjusted by the number of models, i.e., set at $p < \alpha/2 = .025$).

Physiological Arousal

A generalized linear mixed model was developed to analyze the pupil data. A time factor at which the pupil diameter was sampled was added to the model of pupil diameter. Thus, the model had a nesting structure defined by repeated measures: time (level 1) nested in trials (level 2) nested in participants (level 3). To control for auto-correlation, a First Order Autoregressive (AR1) covariance structure was included at level 1 (i.e., time). A final model was derived following the same standard model selection procedure described previously. A random intercept was included. Fixed effects included Age, Group, Emotion, and the interaction of Group x Emotion. Linear, quadratic, and cubic terms were also added to model the changes in pupil size over time. An extra model for analyzing pupil size based on the interpreted emotion categories was developed, where Emotion was replaced by Interpretation as a fixed effect. Post-hoc analyses were conducted by repeating the models with the reference category changed, or by fitting separate models in each group (significance level set at $p < .025$).

Interpretation Accuracy and Tendency

Hu scores and frequency of misinterpretation were respectively analyzed by a multivariate analysis of variance. The *Hu* scores were analyzed with a 2 (Group) x 4 (Emotion) analysis of variance. When analyzing the frequency of misinterpretation, a 2 (Group) x 4 (Misinterpretation: misinterpreted as anger, fear, happiness, or neutral emotion) analysis of variance was conducted. To follow up significant within-group effects, pairwise *t*-tests with Bonferroni correction were applied by dividing α by the number of comparisons between the four emotion categories. Thus, adjusted significance level was set at $p < \alpha/6 = .008$. In both multivariate analyses Age was included as a covariate. Given that the DHH and TH groups did not differ in their mean age, it is legitimate to add Age as a covariate to analyses of variance to reduce the noise variance and improve the relationship between Group and the dependent variables (Miller & Chapman, 2001). For exploratory purposes, we additionally used four 2 (Group) x 3 (Misinterpretation: e.g., anger misinterpreted as fear, happiness, or neutral emotion) multivariate analyses of variance to examine how each predefined emotion category was confused with the other emotion categories. More details and results of these exploratory analyses can be found in Supplementary Materials S2.2.

Effect Size

For generalized linear mixed models, we report standardized effect sizes (δ) calculated using the formula provided by Raudenbush and Liu (2000), which is an extension to Cohen (1988) approach suitable for a multilevel design. Raudenbush and Liu (2000) suggested that a δ of .20, .50, and .80 respectively indicates a small, medium, and large effect size. For multivariate analyses of variance, we used partial eta squared () for effect size comparison with .01, .06, and .14 being respectively viewed as a small, medium, and large effect size (Cohen, 1988).

Missing Data

Of one DHH child and three TH children, eye tracker data could not be acquired due to device failure. Nonverbal intelligence scores were missing from four DHH children and one TH child. Five parents of the DHH children and two parents of the TH children did not report their educational level. Little's MCAR test (Little, 1988) showed that the data were missing completely at random, $\chi^2 = 3997.08$, $df = 3990$, $p = .465$.

RESULTS

Gaze Patterns

First, we analyzed the gaze data within each AOI as a function of the *predefined* emotion categories. We found main effects of Emotion, $F(3, 15177) = 2.70$, $p = .044$, and AOI, $F(2, 15177) = 2678.50$, $p < .001$ (Table 2 and Figure 2A). All children looked longer at the AOIs in fearful faces than the other emotional faces, $b = .01$, $t = 2.04$, $p = .042$, 95% *CI* [.00, .02], $\delta = .05$, and longer at the eyes than the mouth, $b = .27$, t = 55.45, $p < .001$, 95% *CI* [.26, .28], $\delta = 1.08$, which was looked at longer than the nose, $b = -.07$, $t = -13.65$, $p < .001$, 95% *CI* [-.08, -.06], $\delta = .27$. No effects related to Age or Group were observed.

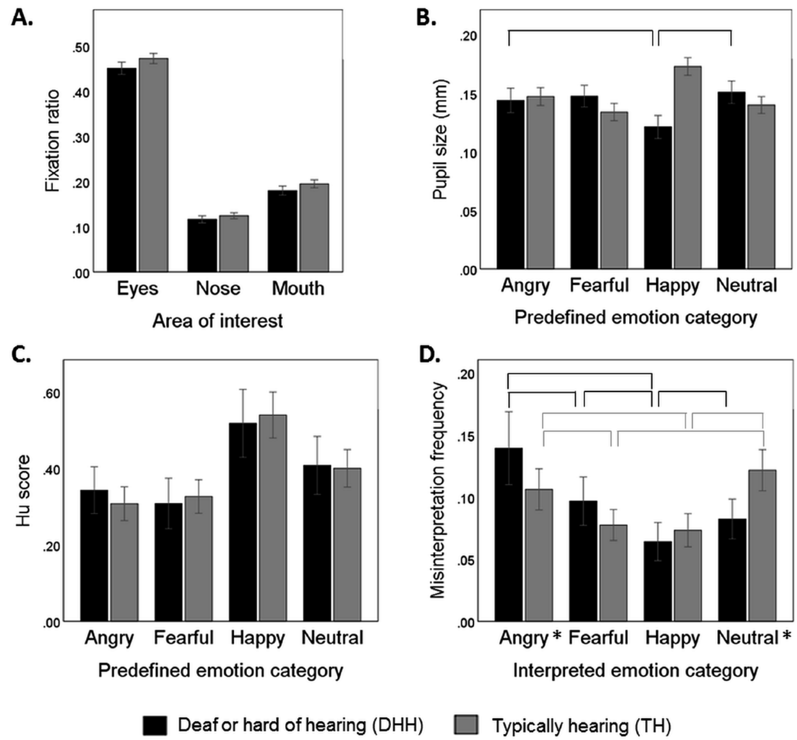

Figure 2. Graphic representations of the interaction effects with group membership. When reading emotional faces, (A) all children, DHH and TH, looked longer at eyes than at nose and mouth; (B) DHH children were less aroused by happy faces than by angry and neutral faces, while TH children were similarly aroused by all faces; (C) all children, DHH and TH, performed better on happy faces than on angry, fearful, and neutral faces; (D) DHH children more often misinterpreted a face as non-happy than as happy, while TH children more often misinterpreted a face as angry or neutral than as fearful or happy. The error bars represent 95% confidence interval. The black lines represent significant differences between emotion categories within the DHH group. The grey lines represent significant differences between emotion categories within the TH group. *significant between-group difference ($p < .05$).

Second, we modeled the gaze data within the entire face as a function of the *predefined* emotion categories. We found a main effect of Emotion, $F(3, 5057) = 3.84$, $p = .009$ (Table 2). In all children, angry and fearful faces were looked at longer than neutral faces, i.e., the reference category (angry: $b = .012$, $t = 2.67$, $p = .008$, 95% CI [.003, .02], $\delta = .10$; fearful: $b = .014$, $t = 3.16$, $p = .002$, 95% CI [.01, .02], $\delta = .12$), while happy faces were looked at equally as neutral faces. No effects related to Age or Group were observed.

In order to rule out group differences in gaze behavior on the basis of how the children *interpreted* the emotions, we replaced the factor Emotion with Interpretation and ran the two above models again. As in the first model, the third model showed a main effect of AOI, $F(2, 15180) = 2677.59$, $p < .001$ (Table 2). Fourth, when investigating the fixation ratios within the entire face, none of the effects reached significance (Table 2). No effects related to Age, Group, or Interpretation were observed.

Physiological Arousal

Analyzing the pupil data based on the *predefined* emotion category, we found an interaction of Group x Emotion, $F(3, 55074) = 3.28$, $p = .020$ (Table 2 and Figure 2B). To interpret this interaction, we first repeated the model with each predefined emotion category as the reference category. In all these repeated models, the main effect of Group was not observed, indicating that the DHH group did not differ from the TH group in their arousal towards the referenced emotions. Next, we conducted separate models in each group to confirm the within-group effect of Emotion (significance level set at $p < \alpha/2 = .025$). Respectively using each predefined emotion category as the reference, we found that the DHH children were more aroused by angry and neutral faces than by happy faces (anger faces: $b = .07$, $t = 2.63$, $p = .009$, 95% CI [.02, .11], $\delta = .17$; neutral faces: $b = .06$, $t = 2.33$, $p = .020$, 95% CI [.01, .11], $\delta = .15$), and there was no difference between fearful and happy faces, nor between the three non-happy emotions. The TH children were similarly aroused by the four types of faces (see Supplementary Materials S2.3 for these post-hoc analyses). No other effects involving Age, Group, and Emotion were observed. Moreover, when the pupil data were analyzed based on the *interpreted* emotion categories, none of the fixed effects were significant (Table 2).

Interpretation Accuracy and Tendency

Using the unbiased *Hu* scores as the dependent variable, we found a main effect of Emotion, $F(3, 372) = 64.42$, $p < .001$, = .34 (Figure 2C). No effects involving Group were observed. Pairwise comparisons showed that all children recognized happy faces better than neutral faces, $t(125) = 8.32$, $p < .001$, 95% CI [.10, .16], which were interpreted better than angry and fearful faces, ts > 5.11, ps < .001. No difference was found between angry and fearful faces, $t(126) = .28$, $p = .784$, 95% CI [-.03, .04]. An older Age was related to a higher *Hu* score, $F(1, 123) = 67.99$, $b = .005$, $p < .001$, 95% CI [.004, .007], = .36.

Table 2. Fixed and random effects in the generalized linear mixed models of gaze patterns and physiological arousal.

	Fixation ratios within AOIs				**Fixation ratios within entire faces**				**Physiological arousal (pupil dilation)**			
	Predefined category		**Interpreted category**		**Predefined category**		**Interpreted category**		**Predefined category**		**Interpreted category**	
Fixed/random effect	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI
Intercept	.18	[.17, .20]	.19	[.18, .20]	.96	[.96, .97]	.97	[.97, .98]	.13	[.09, .17]	.14	[.11, .16]
Age	ns		*ns*		*ns*		*ns*		ns		*ns*	
Group	ns		*ns*		*ns*		*ns*		.03 (.08)	[-.03, .09]	*ns*	
Category(AN)	-.00 (.02)	[-.02, .01]	*ns*		**.01** (.10)	[.003, .02]	*ns*		.01 (.03)	[-.03, .05]	*ns*	
Category(FE)	**.01** (.05)	[.00, .02]	*ns*		**.01** (.12)	[.005, .02]	*ns*		-.01 (.04)	[-.06, .03]	*ns*	
Category(HA)	.01 (.02)	[-.01, .02]	*ns*		.01 (.08)	[.000, .02]	*ns*		.03 (.08)	[-.01, .07]	*ns*	
AOI(Eyes)	**.27** (1.08)	[.26, .28]	**.27** (1.08)	[.26, .28]	--		--		--		--	
AOI(Nose)	**-.07** (.27)	[-.08, -.06]	**-.07** (.27)	[-.08, -.06]	--		--		--		--	
Category(AN) x Group	*ns*		*ns*		*ns*		*ns*		-.00 (.01)	[-.07, .06]	*ns*	
Category(FE) x Group	*ns*		*ns*		*ns*		*ns*		-.02 (.04)	[-.08, .05]	*ns*	
Category(HA) x Group	*ns*		*ns*		*ns*		*ns*		**-.09** (.23)	[-.15, -.02]	*ns*	
AOI x Group	*ns*		*ns*		--		--		--		--	
Variance(Intercept)	.002	[.002, .003]	.002	[.002, .003]	.001	[.001, .001]	.001	[.001, .001]	**.014**	[.01, .02]	**.014**	[.01, .02]
Residual	.062	[.060, .063]	.062	[.060, .063]	.013	[.012, .013]	.013	[.012, .013]	**.132**	[.13, .14]	**.133**	[.13, .14]
N included	15183		15183		5061		5061		55082		55082	

Note: Group was coded as -1 = DHH, 1 = TH (reference). Category (i.e., predefined/interpreted emotion category) was coded as -2 = anger (AN), -1 = fear (FE), 1 = happiness (HA), 2 = neutral emotion (reference). Area of interest (AOI) was coded as -1 = eyes, 0 = nose, 1 = mouth (reference). An "*ns*" indicates that the variable was removed from the final model due to insignificance. A "--" indicates that the variable was not included in the full model. Significant values ($p < 0.05$) are bolded. Coef = unstandardized coefficient; CI = confidence interval. δ = standardized effect size, calculated by dividing fixed coefficient by the square root of the sum of Level 1 (residual) and Level 2 (intercept) variances (formula suggested by Raudenbush and Liu, 2000). *N* included = number of cases included in the analysis.

2

Next, the frequency of misinterpretation was used as the dependent variable to examine which emotion category was most frequently chosen when it was not the target. We found a main effect of Misinterpretation, $F(3, 372) = 15.62$, $p < .001$, = .11, and an interaction of Group x Misinterpretation, $F(3, 372) = 7.77$, $p < .001$, = .06 (Figure 2D). Post-hoc pairwise comparisons showed that the DHH children more often chose an angry face than the TH children, $t(125) = 2.08$, $p = .039$, 95% *CI* [.001, .07], while the TH children more often chose a neutral face than the DHH children, $t(124) = -3.32$, $p = .001$, 95% *CI* [-.06, -.02]. Also, the DHH children more often chose angry faces than fearful faces, $t(54) = 2.86$, $p = .006$, 95% *CI* [.01, .07], which were chosen similarly often as neutral faces, $t(54) = 1.29$, $p = .204$, 95% *CI* [-.01, .04], but more often than happy faces, $t(54) = 3.50$, $p = .001$, 95% *CI* [.01, .05]. The TH children more often chose angry and neutral faces over fearful and happy faces, $ts > 3.14$, $p < .003$, while there was no difference between fearful and happy faces, $t(71) = .57$, $p = .569$, 95% *CI* [-.01, .02]. An older Age was related to a lower frequency of misinterpretation, $F(1, 123) = 42.84$, $b = -.001$, $p < .001$, 95% *CI* [-.001, -.001], = .26.

DISCUSSION

Children learn to process emotions when they participate in or observe others during social interactions, and this skill in turn becomes one of the fundamental elements in their interactions with others. It is therefore crucial to study emotion processing in children who have less access to the social world, such as DHH children, to understand the effect of atypical emotion socialization on the development of this skill. The present study examined how 3- to 10-year-old DHH and TH children read static emotional faces at three underlying processing levels: gaze patterns, physiological arousal, and interpretation. We found that the DHH and TH children developed a similar level of accuracy in reading faces expressing basic emotions and showed a similar gaze pattern that focused more on the eyes and less on nose and mouth. Yet, dissimilarities were also found between the two groups at physiological and interpretation levels. While the TH children found all facial expressions similarly arousing and more often incorrectly chose angry or neutral faces over fearful and happy faces, the DHH children were more strongly aroused by angry and neutral faces than by happy faces, and more often incorrectly chose non-happy (angry, fearful, and neutral) faces over happy faces. Below we will discuss these outcomes and their implications.

The hypothesis of different gaze patterns towards facial features between DHH and TH children was not supported by our findings. This outcome may be related to the context in which facial cues are used by DHH individuals. In the studies by Letourneau and Mitchell (2011) and Watanabe and colleagues (2011), Deaf adults, who used sign language as their main mode of communication, distributed their gazes to a greater area of the emotional faces than TH adults, which seems relevant when using sign language. In the study by Wang et al. (2017), children were tested with and without verbal cues, and DHH children looked shorter at the upper part of the emotional faces than their TH peers, but only in the condition with verbal cues. Very likely, DHH children still partly rely on lipreading as their hearing is not on the level of their TH peers despite a CI or HA. Taken together, these past studies show differential attention on facial features between DHH and TH individuals, when (verbal or sign) language is involved. However, in the current study, all stimuli were presented only visually and none of the children used sign language. In such a context, the facial areas that are most relevant to emotion recognition, i.e., the eyes in our case, attracted more attention of DHH and TH children. Our finding, together with the previous studies on DHH participants, suggests that DHH individuals use facial cues adaptively according to the situation.

Despite the similar level of accuracy and similar gaze pattern towards facial features in the DHH and TH children, the DHH children exhibited a contrast between happy and non-happy facial expressions in physiological arousal and interpretation tendency that was not observed in the TH children. These findings are partly expected, although we based our hypotheses on studies that involved other clinical groups than the one we tested (Afifi et al., 2011; Bistricky et al., 2014; Burkhouse et al., 2014). Similar to those studies, our results show that children with atypical emotion socialization experiences may exhibit characteristic arousal and interpretation patterns when processing emotions. There could be two potential explanations for this happy vs. non-happy contrast in DHH children. First, the contrast may be considered threat sensitivity: DHH children may be more vigilant towards stimuli they consider negative and threatening in order to be prepared for a "fight or flight" (Field & Lester, 2010; Kret & De Gelder, 2013; Laeng et al., 2013). However, this hypothesis was not fully supported by our results. If the threat-sensitive state were what we observed in the DHH children, the DHH children were supposed to show higher arousal towards negative emotions than the TH children, and group differences should have been more pronounced when the *interpreted* emotion category was taken into the analysis, which were not the case in the current study.

The second "familiarity" hypothesis may be a more possible explanation: DHH children may be less familiar with non-positive emotions because of an (over-)protective environment provided by their parents (Calderon & Greenberg, 2011; Holmbeck et al., 2002). Given the hardship DHH children experienced in their childhood due to medical examinations, surgery, and rehabilitation, their parents are often reported to show overprotection (Calderon & Greenberg, 2011; Pinquart, 2013). A highly protective family setting, along with limited access to the social environment, could result in reduced exposure to emotions that are not positive, which requires more cognitive resources to process. In this study, the DHH children were more physiological aroused by angry and neutral faces than by happy faces, while no differences were found between angry/fearful faces and neutral faces; also, the DHH children more often incorrectly chose an angry, fearful, or neutral faces over happy faces. These results together suggested that the DHH children may devote more effort to process the emotional faces less familiar to them yet still experience more confusion between these faces. This may have implications for rehabilitative trainings as the exposure to different emotions appears to be of importance.

Limitations and Future Directions

This current study had the strength of investigating underlying processing mechanisms of emotion recognition in DHH children. This topic was hardly studied in the past. It was partly because DHH children who had better spoken language or milder hearing loss were often considered to have better social adjustment, and thus more focus was on the hearing and language factors rather than socioemotional development. However, during the past decade an increasing number of studies has shown that children with a CI or HA still exhibited difficulties in developing various social-emotional skills despite their stable hearing and language abilities (Netten et al., 2015; Rieffe et al., 2018). This suggests that limited access to the social environment could hinder social learning, and that more studies are needed to understand its impact. The advanced eye-tracking technology developed in recent years also made it possible to measure young children's eye movement and pupil size in a reliable and unobtrusive manner. Therefore, the current study took a step forwards by examining the mechanisms involved in emotion recognition. Our findings underline the importance of emotion socialization, which could be associated with atypical physiological and cognitive processing of emotions. However, several limitations of this study should be taken into account when interpreting the results.

First, this study had a cross-sectional design and included a wide age range. Although we controlled for age in all analyses, further investigations are needed in order to better account for the following two findings. The first one is in regard to the age effect found only in children's interpretation but not in their gaze pattern and physiological arousal. This indicates that the gaze/arousal patterns observed in the present study might already be observed during toddlerhood, which remain relatively stable across time at least until 10 years of age. The finding that children improve their interpretation with age may imply that they become more and more proficient in using the processing patterns they developed. Yet, no conclusion may be drawn without longitudinal data. The second finding that cannot be well explained by the current design is the relation between gaze/arousal patterns and interpretation tendency. Given a lack of experimental manipulation on the timeline, we could not conclude on the potential (causal) link between these parallel processing levels. However, past studies have shown both top-down and bottom-up influences: Attention and physiological arousal contribute to the appraisal of emotional signals (Gray et al., 2007; White et al., 2011), whereas a pre-existing interpretation tendency may affect arousal pattern (Joormann et al., 2015) and direct attention towards cues inconsistent with expectation (Horsley et al., 2010).

Second, in this study we ran separate analyses using *predefined* and *interpreted* emotion categories as independent variables respectively, and found an interaction for group and emotion categories predicting physiological arousal only when we included the *predefined* categories, but not the *interpreted* categories. When we analyzed the *predefined* categories, we considered the responses elicited by viewing the emotional expressions (without necessarily consciously interpreting them). When the *interpreted* categories were included in the analyses, participants' decision-making process was also taken into account. Previous studies have shown that people may react to an emotional expression differently depending on whether they interpret it as a threat. For example, socially anxious people may regard smiles as threatening and thus show stronger physiological responses than non-anxious individuals towards these stimuli (e.g., Garner et al., 2011). Therefore, conducting the analyses with *predefined* and *interpreted* emotion categories may help us disentangle the viewing process from the decision-making process that were involved in our study. Yet, given the exploratory nature of such analyses and the lack of previous literature, we can only provide speculative explanations to any discrepancy observed between the two analyses. Our finding that the group interaction in physiological arousal was only observed for *predefined* emotion categories might suggest that the group difference lay in the viewing process, rather than in the decision-making process. Perhaps, the presentation of angry and neutral expressions caused more confusion, and thus higher levels of arousal, in the DHH children than happy expressions because DHH children have likely had less experience with these expressions of emotion. Moreover, different brain mechanisms might be involved. For people to *interpret* the emotional expressions of others, the recruitment of social brain areas informing decision-making brain areas is required. For viewing the emotional expressions, the process relies largely on the lower-level subcortical networks (Adolphs, 2002, 2006). Perhaps, DHH children's cortical network was over-active when viewing emotional faces because they needed to put more effort into identifying the emotions, which overshadowed the lower-level subcortical effects (see Kret et al., 2011, for a similarly over-activated cortical network in an adult population with social inhibition). Although viewing and interpreting emotions were obviously not completely independent, they did capture slightly different variance across the two populations. This discrepancy might reflect group differences in the underlying mechanisms, which requires further investigations using multidimensional measures.

Third, some limitations regarding the stimuli used in the current study need to be considered. We examined only static faces showing highly expressive basic emotions posed by actors/actresses. In real life, emotion processing usually involves subtle, spontaneous expressions and more complex, or even mixed, emotions, which are expressed through different modalities (e.g., face, voice, and body) and need to be evaluated together with the social context (Scherer, 2000). To increase ecological validity, more dimensions could be considered in future studies. For this reason, the current finding that DHH and TH children showed similar levels of accuracy and gaze patterns should be interpreted with caution. When the emotion to be processed involves more dimensions, children may experience more difficulties. Very likely, the unfamiliarity towards non-happy signals that we observed in the processing of basic emotions may also be found in DHH children's understanding of more complex emotional events.

Moreover, the current study used only adult faces as stimuli. Although in adults an own-age advantage has been found in face processing (see Rhodes & Anastasi, 2012 for a review), developmental studies showed that children (aged 3 to 16 years) better recognized adult faces than child faces, possibly because they have accumulated more experiences interacting with adults since birth, and adult faces carry more relevant, determinant information for, e.g., rewards and punishment (Hoehl et al., 2010; Macchi Cassia et al., 2012; Marusak et al., 2013). Considering together with the fact that validated face sets with Asian child faces are very limitedly available, we included only adult faces in this study. Yet, we also suggest future studies to use peer faces, given the neural responses induced by adult and child faces were found to be different in recent studies (Hoehl et al., 2010; Marusak et al., 2013). It is therefore crucial that validated face sets including non-Western child faces can be developed.

Fourth, some considerations are also required regarding the background of participants. DHH refers to a very heterogeneous population. Yet, the majority of the DHH children in this study had a CI, meaning that most of them had severe-to-profound hearing loss (i.e., hearing threshold > 70 dB HL). Currently, we could only conclude that excluding the children with HAs did not change the results. Future studies may take into account the heterogeneity in the DHH population to further increase our knowledge on the association between auditory input and emotion socialization. In addition, Taiwanese children were recruited in the current study. Prior studies have shown that Western and East Asian people use different gaze patterns for reading emotional faces: Eastern Asian viewers fixated at the eye region for a longer time than Western viewers (Jack et al., 2009, 2012). This may also explain why our study found both DHH and TH groups to focus on the eye region, which appears to be an important cue for emotion recognition in East Asians. Likewise, Westerners and East Asians differed in the interpretation of emotion category (e.g., Dailey et al., 2010) and in how physiological arousal was moderated (e.g., Chentsova-Dutton et al., 2010). Therefore, future studies are needed to understand the generalizability of the results in this study.

Importantly, the ability to recognize emotion expressions is often found to predict internalizing and externalizing behaviors, such as depression, anxiety, hyperactivity, and aggression (Chronaki et al., 2015; Trentacosta & Fine, 2010). Past research did show a higher prevalence (about twofold) of these psychopathological symptoms in DHH children than in TH children (Stevenson et al., 2015). Family support, parent-child interaction, and communicative skills were found to be important factors contributing to fewer internalizing and externalizing behaviors (Theunissen et al., 2015; Van Eldik et al., 2004), whereas the degree of hearing loss and mode of communication were not (Dammeyer, 2010; Fellinger et al., 2008). The results in general support the view that limited access to social environment, rather than the deafness itself, is a barrier that hinders the development of children's social competence. Here, our findings on the underlying processing of emotional information provide a new perspective that may help improve the knowledge on the causes underlying the emotional-behavioral difficulties in DHH children. Future research is required to investigate this link by including measures for psychopathological symptoms, such as depression and aggression, and interpersonal relations, such as peer acceptance and rejection.

CONCLUSIONS

To conclude, the current study calls for the need to look beyond accuracy and into the possible qualitative differences between children with typical and atypical emotion socialization experiences. The DHH and TH children in this study did not differ in their accuracy and gaze patterns when recognizing facial emotions, yet the two groups of children differed in physiological arousal patterns and interpretation tendencies when processing non-positive emotions in faces. Such differences reflect that the DHH children may devote more effort to processing the emotional faces less familiar to them. The results highlight the benefit of measuring accuracy along with other dimensions that help us gain a deeper insight into children's behaviors. Moreover, our findings underlie the importance of social access for DHH children to acquire sufficient emotional knowledge. Importantly, what we found in DHH children may also be relevant to other clinical groups who experience similar difficulties in social interactions, such as children with Developmental Language Disorder (DLD) and children with Autism Spectrum Disorder (ASD). These children, though not the majority, take up about 9% of world's pediatric population (1.5% for DHH; 7% for DLD; 0.6% for ASD; Norbury et al., 2016; Tomblin et al., 1997; WHO, 2018, 2019). Atypical outcomes found in these children are not necessarily impairments but signals that indicate different learning experiences and the need for a more accessible social environment for easier acquisition of social-emotional knowledge.

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CHAPTER 3

Hearing Status Affects Children's Emotion Understanding In Dynamic Social Situations: An Eye-Tracking Study

Tsou, Y.T., Li, B., Kret, M.E., Frijns, J.H.M., & Rieffe, C.

Hearing status affects children's emotion understanding in dynamic social situations: An eye-tracking study

In press; Ear and Hearing

ABSTRACT

Objectives

For children to understand the emotional behavior of others, the first two steps involve emotion encoding and emotion interpreting, according to the Social Information Processing (SIP) model by Crick and Dodge (1994). Access to daily social interactions is prerequisite to a child acquiring these skills, and barriers to communication such as hearing loss impede this access. Therefore, it could be challenging for children with hearing loss to develop these two skills. The current study aimed to understand the effect of prelingual hearing loss on children's emotion understanding, by examining how they encode and interpret nonverbal emotional cues in dynamic social situations.

Design

Sixty deaf or hard-of-hearing (DHH) children and 71 typically-hearing (TH) children (3-10 years old, mean age 6.2 years, 54% girls) watched videos of prototypical social interactions between a target person and an interaction partner. At the end of each video, the target person did not face the camera, rendering their facial expressions out of view to participants. Afterwards, participants were asked to interpret the emotion they thought the target person felt at the end of the video. As participants watched the videos, their encoding patterns were examined by an eye tracker, which measured the amount of time participants spent looking at the target person's head and body and at the interaction partner's head and body. These regions were preselected for analyses because they had been found to provide cues for interpreting people's emotions and intentions.

Results

When encoding emotional cues, both the DHH and TH children spent more time looking at the head of the target person and at the head of the interaction partner than they spent looking at the body or actions of either person. Yet, compared to the TH children, the DHH children looked at the target person's head for a shorter time (b = -.03, p = .030), and at the target person's body (b = .04, p = .006) and at the interaction partner's head (b = .03, p = .048) for a longer time. The DHH children were also less accurate when interpreting emotions than their TH peers (b = -.13, p = .005), and their lower scores were associated with their distinctive encoding pattern.

Conclusions

Our findings suggest that children with limited auditory access to the social environment tend to collect visually observable information to compensate for ambiguous emotional cues in social situations. These children may have developed this strategy to support their daily communication. Yet, to fully benefit from such a strategy, these children may need extra support for gaining better social-emotional knowledge.

INTRODUCTION

Understanding others' emotions during social interactions is an essential skill that is closely related to social competence and adjustment (De Castro et al., 2005). Importantly, this skill is learned within the context of daily social interactions in a process called emotion socialization. This process starts in the first days of life (Saarni, 1999). Experiencing a lower quantity and quality of social interaction with meaningful others during early childhood can negatively affect children's development of emotion understanding, which in turn hinders their social participation (e.g., Deneault & Ricard, 2013; Klein et al., 2018). This can create a vicious cycle. For many children who are deaf or hard of hearing (DHH) and who rely not on sign language but on spoken communication in a predominantly hearing world, this vicious cycle can become a daily reality. Yet despite increasing research on this population, DHH children's understanding of emotional cues in dynamic social situations has hardly been studied. To narrow this gap, this study investigated how DHH and typically hearing (TH) children, respectively, encode and interpret nonverbal emotional cues in dynamic social situations. We examined these two aspects of emotion understanding because they are the first steps toward responding adaptively to social situations, as proposed in the Social Information Processing (SIP) model (Crick & Dodge, 1994).

The Social Information Processing (SIP) Model

The SIP model is a well-documented approach for understanding individual differences in behavioral responses to social situations, where emotional processes have been well integrated (Crick & Dodge, 1994; De Castro et al., 2005; Lemerise & Arsenio, 2000). The SIP model proposes that people enter a social situation where they then rely on past experiences and process social information in six successive, interdependent steps. First, people *encode* emotional information by focusing their attention on relevant cues. Second, people *interpret* emotional information according to the cues that are encoded. In the later steps, people formulate goals that they want to achieve in the situation, generate response alternatives to the situation, and evaluate these alternatives to make a decision. Finally, people enact the most favorable response. Empirical research has shown that children with atypical development, where autism or intellectual disability (Embregts & Van Nieuwenhuijzen, 2009) or behavioral problems (De Castro et al., 2005) are involved, exhibit characteristic patterns in some SIP steps. These characteristic patterns may in part explain their maladaptive responses to social situations. However, little is known regarding the DHH population.

Hearing Status and Emotion Understanding in Social Situations

Emotion understanding cannot develop without access to the social context in which emotions occur (Crick & Dodge, 1994; Rieffe et al., 2015). In a social environment that features spoken communication, DHH children do not access the social world in the same way as their TH peers. This might negatively affect their emotion understanding. During the first years of life, parent-child interactions have already been shown to be different. TH parents with DHH children use more commands, shorter utterances, less mental-state language, and less turn-taking during conversation, compared to TH parents with TH children (Dirks et al., 2020; Morgan et al., 2014). DHH children also miss many cues from the environment when their attention is not directed to the source of the cue (Calderon & Greenberg, 2011). Moreover, even when attention is directed to the source, DHH children might still recruit only partial information, for example due to background noise (Leibold et al., 2013).

To the best of our knowledge, there is only one study to date on DHH individuals' emotion understanding in naturalistic, dynamic social situations, and the study also applied the SIP model (Torres et al., 2016). Torres and colleagues (2016) interviewed DHH and TH participants (13 to 21 years old) who had watched videos depicting dynamic social interactions. They found the two groups to differ in all SIP steps: compared to TH participants, DHH participants encoded less relevant cues as defined by the study; made more misinterpretations (i.e., interpreting non-hostile situations as hostile or vice versa); formulated more goals that were either aggressive or not effective (e.g., crying); and generated, decided upon, and enacted more aggressive or ineffective responses. Similarly, in studies that used static stimulus materials (e.g., drawings or photos) and examined children's interpretation of emotions in social situations, more misinterpretations were reported in DHH children than in TH children (2.5 to 8 years old; Gray et al., 2007; Wiefferink et al., 2013). Based on the SIP model, it is reasonable to suspect that DHH participants' difficulties could result from a different encoding pattern that occurs during the first processing step. However, this relation was not examined by Torres and colleagues (2016).

In any real-life social situation, a considerable amount of information is available. In theory, the encoding stage works as a filter through which people collect the most relevant emotional cues for subsequent processing. Empirical evidence from studies on typical development has shown that the head region of others is an important cue to which people most often direct their attention, when processing social situations. It provides a rich source of information that allows for inferences about other people's attention, intentions, and feelings (Birmingham et al., 2009; End & Gamer, 2017). In fact, soon after birth, infants are already more responsive to face patterns than to non-face patterns (Slater & Quinn, 2001; Farroni et al., 2005). They also show longer sustained attention to faces than to non-face patterns when a distractor appeared (Ahtola et al., 2014; Pyykkö et al., 2019), and continued to improve their ability to detect faces or heads among other objects during the first year of life (Frank et al., 2014; Reynolds & Roth, 2018). Even when facial expressions cannot be seen clearly, the head region remains important because its angle (e.g., bowed or raised), orientation, and movement provide information about the emotions and attention of other people (Hess et al., 2015; Main et al., 2010). While cues such as body posture and actions also carry emotional value needed for adequate emotion understanding (Dael et al., 2012), children and adults alike still look at heads for a longer period of time than at other cues, when asked to recognize emotions in dynamic social situations (Nelson & Mondloch, 2018).

Yet to date, no research has examined how DHH individuals visually encode emotions in social scenes. Such investigations could be particularly relevant to the DHH population because DHH individuals may collect visual cues in a way that is different from TH individuals, to support daily communication. For example, empirical evidence has shown that DHH adults allocate their visual attention over a wider area in a scene than TH adults when searching for an object, as a strategy to compensate for limited auditory input (e.g., Proksch & Bavelier, 2002; Sladen et al., 2005). Similarly, when DHH adults were required to recognize emotions from isolated faces, they distributed their attention equally to the eye and mouth regions, whereas TH adults focused on the eyes (Letourneau & Mitchell, 2011). This tendency to allocate visual resources over a wider area may mean that DHH individuals give more weight to body cues than to the head itself, when processing social interactions between people (Rollman & Harrison, 1996).

The Present Study

In this study, we wanted to build on the study by Torres and colleagues (2016). Our first aim was to investigate more closely how DHH children encoded emotional cues in dynamic social situations by using eye-tracking technology. By checking children's gaze patterns, we aimed to understand how long DHH and TH children attended to different nonverbal emotional cues that we preselected. These cues included the head, the body, and actions. Considering the importance of heads (End & Gamer, 2017; Nelson & Mondloch, 2018), we expected DHH and TH children to show a stronger focus on heads than on the other cues. Yet, given the finding by Torres and colleagues (2016) that DHH participants encoded less relevant cues than TH participants, we expected the total time spent looking at the preselected emotional cues to be shorter in DHH children than in TH children. We did not make specific hypotheses as to which emotional cues would be viewed for a shorter duration, due to a lack of evidence.

Second, we examined how DHH and TH children interpreted emotions in social situations. Based on Torres and colleagues (2016), we expected that DHH children would interpret the situations with the emotion predicted by the study less often than TH children. Thus, DHH children were expected to be less accurate than their TH peers when identifying and labeling the emotion triggered in social situations.

Third, for exploratory purposes, we examined how DHH and TH children's encoding patterns were associated with their interpretation of emotions in dynamic social situations.

Previously, this relation has only been studied in children with aggressive or antisocial behaviors who were found to encode less relevant emotional cues, followed by a less thorough exploration of their social environment (Horsley et al., 2010; Troop-Gordon et al., 2018). Due to the lack of previous studies on the DHH population, we explored this association without making specific hypotheses.

Fourth, we expected to find an age effect. We predicted that in both DHH and TH children, an increase in age would be associated with an increase in time spent looking at the preselected emotional cues and in interpretation accuracy.

METHODS

Participants

Sixty DHH and 71 TH children in Taiwan of ages 3-10 years old participated in this study. Inclusion criteria for DHH children were mild-to-profound congenital or prelingual bilateral hearing loss; use of hearing aids or cochlear implants; use of spoken language as the primary communication mode; and ages between three and ten years old. Inclusion criteria for TH children were typical bilateral hearing (as reported by parents); use of spoken language as the primary communication mode; and age between three and ten years old. Children with additional disabilities and diagnoses other than hearing loss were excluded from recruitment (e.g., autism, language disorder, or attention deficit hyperactivity disorder, according to parent or teacher report). The two groups did not differ in demographic characteristics (see Table 1).

We approached 153 children in total. For this study, we excluded children who did not finish 50% of the trials (n = 4), children who had additional disorders or low/high nonverbal intelligence (2 *SD* lower/higher or indicated by teacher/clinician; n = 17), and a child who was tested twice by mistake. The excluded sample did not differ from the included sample in age, gender distribution, and nonverbal intelligence, but had lower parental educational level, $t(141) = 2.31$, $p = .022$. See Supplementary Materials S3.1 for details about sample size justification.

This study was part of a research project that examines social-emotional functioning in children with typical and atypical development. Permission for the study was granted by The Psychology Ethics Committee of Leiden University and Chang-Gung Memorial Hospital Ethics Committee for Human Studies. All parents provided written informed consent. Children between three and ten years old were recruited for this project because previous studies have shown that the period from preschool to middle childhood is crucial for children's development and mastery of skills for understanding the categories and causes of basic emotions expressed by other people (e.g., Durand et al., 2007; Kolb et al., 1992; Rieffe et al., 2005). In addition, recruitment was conducted through a cochlear implant

Table 1. Characteristics of the participants.

Characteristic	DHH	TH	p value
N	60	71	
Age, years (SD)	6.32 (2.08)	6.07 (1.75)	$t(129) = -0.74$, $p = .458$
Girls, n (%)	30 (50%)	41 (58%)	$\chi^2(1, N=131) = 0.79$, $p = .375$
Nonverbal intelligence (SD)[a]	9.51 (2.67)	10.31 (2.61)	$t(121) = 1.66$, $p = .099$
Parental education level (SD)[b]	3.31 (1.03)	3.58 (.96)	$t(121) = 1.47$, $p = .143$
Age at amplification, years (SD)	2.51 (1.29)		
Duration of amplification, years (SD)	3.81 (1.87)		
Degree of hearing loss, n (%)			
Mild (26-40 dB)	2 (3%)		
Moderate (41-60 dB)	2 (3%)		
Severe (60-80 dB)	1 (2%)		
Profound (> 80 dB)	55 (92%)		
Type of amplification, n (%)			
Unilateral cochlear implant	40 (67%)		
Bilateral cochlear implants	15 (25%)		
Hearing aid only	5 (8%)		
Etiology, n (%)			
Congenital	29 (48%)		
Inner ear anomaly	14 (23%)		
Waardenburg syndrome	1 (2%)		
Auditory neuropathy	2 (3%)		
Unknown	14 (23%)		
Type of education, n (%)			
Regular schools	57 (95%)		
Special schools	3 (5%)		

Note: DHH = deaf and hard-of-hearing; TH = typically hearing.
[a]For nonverbal intelligence, age-corrected norm scores are presented. The grand population mean is 10 and the standard deviation is 3. Children aged 3 to 5 years old were tested with Block Design and Matrix subscales of the Wechsler Preschool and Primary Scale of Intelligence Revised Edition (Wechsler, 1989). Children aged 6 to 10 years were tested with Block Design and Picture Arrangement subscales of the Wechsler Intelligence Scale for Children Third Edition (Wechsler, 1991). These tests were used because the experimenter had access to them and had received training to administer these versions.
[b]Parental education level: 1 = no/primary education; 2 = lower general secondary education; 3 = higher general secondary education; 4 = college/university.

center, and the majority of the DHH children we recruited had profound hearing loss and one cochlear implant. However, we did examine the effects of age and different degrees of hearing loss by including age as a covariate in all analyses, and by checking how results differed when analyses were conducted separately for children with a cochlear implant instead of for the entire DHH group.

Materials and Procedure

Emotion Understanding Task

The task was designed for this study. Children conducted the task in a quiet room at a cochlear implant center or at participants' schools. Tobii X3-120 eye tracker (Tobii Technology, Sweden) was placed 65 cm away from children's eyes and mounted below a computer screen. After a centrally presented fixation cross (1000 *ms*), children watched eight videos (10-15 seconds) showing prototypical social situations where either a positive emotion (happiness, excitement, or pleasant surprise) or a negative emotion (anger, sadness, or fear) was triggered in a target person by an interaction partner. After each video, the participant was presented with six different still photographs of the face of the target person, each expressing a different emotion. The child was then asked to give a nonverbal response (by pointing to the face showing the emotion that the child thought the target person would express, at the end of each video) and a verbal response (by labelling the emotion).

Before the experiment, a 5-point calibration was conducted, and then children completed two practice trials. The structure of these practice trials was similar to the testing trials, but with pictures that allowed for step-by-step instruction. All children gave nonverbal and verbal answers within the expected valence in the practice trials, so they all continued to the testing trials.

Stimuli

All videos were silent, displayed at a size of 640 x 480 pixels and centrally presented on a computer screen of 1024 x 768 pixels. The videos started with a contextual scene: A target person showed an initial emotional state on the face, and an interaction partner entered. Next, in a key-action scene, the partner carried out an emotion-eliciting action on the target person. In the key-action scene, the target person was viewed from the side by the camera, so that about three quarters of the face was not visible. A red arrow pointing to the target person was presented at the end of each video, to ensure that the child understood which person was the target person.

Each video had a counterpart that showed a parallel contextual scene and key-action scene that ended in an opposite emotional valence. For example, one video showed a man with a broken leg walking with sticks and a woman passing by (the contextual scene), and then the woman laughing at the man (the key-action scene). Its counterpart video showed the same contextual scene, but it ended with the woman giving a cake to the man. The counterpart videos were put into two different sets of tests and watched by different children, who were randomly assigned to one of the sets.

We only considered the key-action scene in our analyses because this was where the emotion was triggered in the target person. The key-action scenes were 5-9 seconds long (mean = 6838.13 ms, SD = 1038.84 ms). See Supplementary Materials S3.2 for more details about stimuli and video validation.

Encoding of Emotional Cues

We preselected four areas of interest (AOIs), corresponding with four emotional cues: target person's head, target person's body, partner's head, and partner's action (e.g., an arm engaged in the action of pushing or pointing at someone; see Figure 1 for an example). Children's eye movements were measured by the eye tracker at a sampling rate of 120 *Hz* using corneal reflection techniques, and processed by Tobii Studio 3.2.1. Using a Dynamic AOI tool provided by the software, we predefined AOIs by drawing freeform shapes, frame by frame. Tobii I-VT fixation filter was applied to define fixations. Only the sampling points where both eyes were detected by the eye tracker were included in later calculations. The total fixation duration within each AOI was the sum of the duration times for all fixations within an AOI. Fixation ratios were calculated by dividing total fixation durations within each AOI by the total fixation duration within the entire screen. Moreover, we calculated the fixation ratio within the video frame to examine attention to the videos.

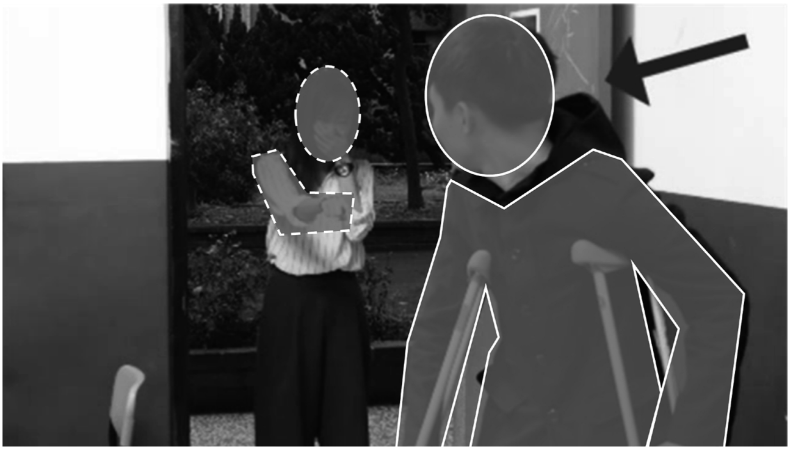

Figure 1. An example last scene of video presentation. The areas within the white lines denote the four areas of interest used in the analyses (solid lines denoting the target person; dashed lines denoting the interaction partner). The white lines were not presented to the participants during the experiment.

Interpretation of Emotions

Children's ability to interpret an emotion nonverbally (by pointing at an emotion) and verbally (by labelling an emotion) was scored on a 3-point scale: 2 = the emotion intended by the study; 1 = other emotions within the valence intended by the study; 0 = not within the valence intended by the study. For example, in a video predicted to trigger anger (e.g., someone falls from a bike and is laughed at by a passer-by), a score of 2 was given to children who stated anger or its synonyms (e.g., rage); a score of 1 for answers that fell within the negative valence (e.g., sad/depressed, fearful/scared, unhappy, upset); and a score of 0 for any positive emotions or answers that referred to actions rather than emotions (e.g., crying, shouting).

Note that people's responses towards an emotion-evoking situation are affected by their action tendencies, which reflect the goal they aim to achieve in that particular situation. In turn, this action tendency defines which emotion is expressed (Frijda, 1986; Rieffe et al., 2005). Yet, the same emotion-evoking situation can evoke different action tendencies in different children. Consequently, individual differences towards the same emotion-evoking situation are possible, which can result in different emotion expressions. In the example situation given above, a person can feel angry because of the passer-by's socially inappropriate behavior; or, a person may feel sad because he/she thinks his/her riding skill is poor. Therefore, different emotions within the same valence (positive or negative) can be a correct or appropriate emotional response towards the same emotion-evoking situation. However, some emotions are considered more prototypical, i.e., in line with common knowledge and expectations, such as feeling angry when your bike is stolen (focusing on the aggressor) or sad when your cat died (focusing on the loss).

ANALYSIS AND RESULTS

Because the data had a two-level structure of trials (level 1) nested in participants (level 2), we used generalized linear mixed models (GLMMs) for analyses. The fixed factors included in each model are specified below, and all models included a random intercept for each participant. Centering was used on all independent variables. Age was added as a covariate in all models. Following a standard model selection procedure, non-significant factors were removed one by one from the full model, starting with higher-order interactions, to derive a final model. Factors with a trend towards significance could stay in the final model if removing them worsened model fit. A lower -2 log likelihood indicates a better model fit. Normal probability plots were used to inspect the normality of the residuals. The residuals of the fixation ratios within the AOIs and of the interpretation scores were close to a normal distribution, while the residuals of the fixation ratios within the video frame were not (data were negatively skewed). Therefore, GLMMs with a normal distribution were used to model the fixation ratios within the AOIs and the interpretation scores. The fixation ratios within the video frame were modeled with a GLMM where a binomial distribution (link function = logit) was selected. Level of significance was set at $p < 0.05$. Standardized effect sizes (δ) were calculated based on Raudenbush and Liu (2000). The authors extended Cohen's approach to fit multilevel research, and suggested effect sizes of .20, .50, and .80 to be small, medium, and large, respectively. Statistical analyses were carried out using SPSS 23.0 (IBM Corp., Armonk, NY), except for the GLMM with a binomial distribution, which was conducted using the *glmmTMB* package in R version 3.6.3.

Complete models are specified in Tables 2 and Supplemental Digital Content 3 (Tables). We also conducted analyses with the children with a cochlear implant separately ($n = 55$), instead of with the entire DHH group. However, the directions of the results did not change. We report the results where children with a cochlear implant and children with a hearing aid were analyzed as one group. See Supplemental Digital Content 4 (Text and Table) for separate analyses on the children with a cochlear implant. In addition, Supplemental Digital Content 5 (Table) shows the correlations between study variables and hearing-related variables within the DHH group.

Missing Data

Non-verbal intelligence scores were missing for eight children (7 DHH, 1 TH). Eight parents (6 DHH, 2 TH) did not provide information about their own educational level. Six children (3 DHH, 3 TH) did not have eye-tracking data due to device failure. Little's MCAR test (Little, 1988) showed that the data were missing completely at random, $\chi2 = 597.98$, $df = 726$, $p = 1.00$.

Encoding

First, we checked the fixation ratios within the video frame. Fixed effects included Age, Group (2: DHH, TH), Valence (2: Positive, Negative), and Group x Valence. Since no effects related to Group were observed, we verified that the two groups paid similar attention to the videos (i.e., 97% of the screen time. See Supplemental Digital Content 3). Age was observed to have an effect: An increase in Age was associated with an increase in the fixation ratio within the video frame, $b = .04$, $p = .001$. Finally, an effect for Valence was found, $b = -.46$, $p = .003$. Videos that featured positive emotions were looked at for a longer time than videos that featured negative emotions. The interaction of Group x Valence was not observed.

Second, we modelled the fixation ratio within the AOIs. Fixed effects included Age, Group, Valence, AOI (4: Target Head, Target Body, Partner Head, Partner Action), and interactions with Group. We observed an effect for Group, which indicated a group difference in the reference category, i.e., the Target Head: Compared to the TH children, the DHH children spent less time looking at a Target Head, $b = -.025$, $p = .030$ (Table 2 and Figure 2a). We also found interactions for Group x Target Body and for Group x Partner Head. Compared to the TH children, the DHH children spent more time looking at a Target Body, $b = .04$, $p = .006$, and at Partner Head, $b = .029$, $p = .048$. The two groups generally showed the same pattern: participants looked at the Partner Head for a longer time than the Target Head, and participants looked at the Target Head for a longer time than the Target Body and Partner Action (Figure 2a). An effect for Age was observed: An increase in Age was associated with an increase in the fixation ratio within the AOIs in the videos, $b = .001$, $p < .001$. There was no effect for Valence. See Supplemental Digital Content 3 for more details about the exact duration children spent looking at the screen versus off the screen and at each AOI.

Interpretation

A model was developed for nonverbal and verbal interpretation. Fixed effects included Age, Group, Valence, Task (2: nonverbal, verbal), Group x Valence, Group x Task, and Group x Valence x Task. An effect for Group was observed: The DHH children scored lower than the TH children in both nonverbal and verbal tasks, $b = -.13$, $p = .005$ (Table 2 and Figure 2b). An effect for Task indicated that both groups of children performed better on

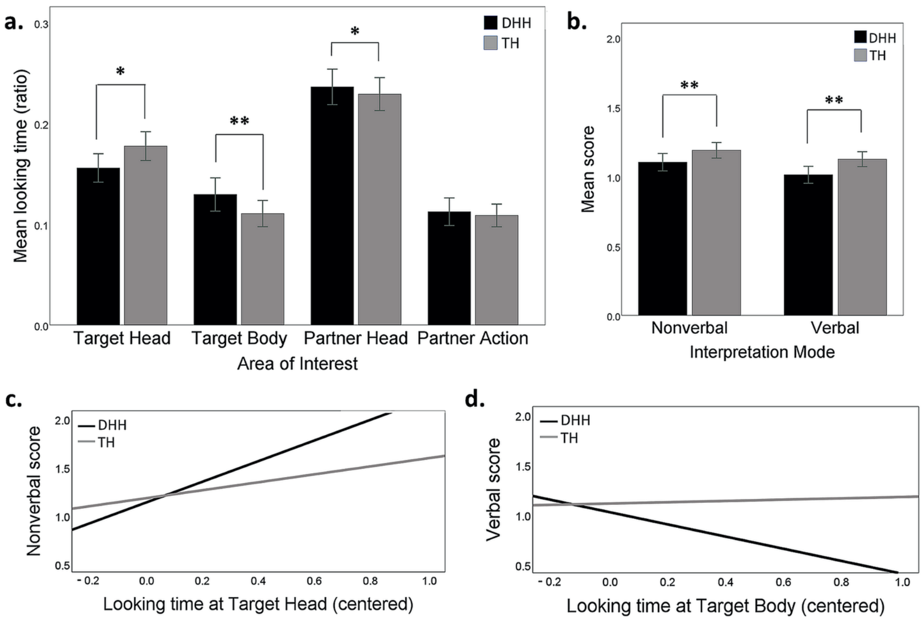

Figure 2. Group differences during the emotion understanding task. (a) DHH children (in black) looked for a shorter time at the target person's head, and for a longer time at target person's body and trigger person's head, than TH children. (b) DHH children were less accurate (on a scale from 0 to 2) than TH children when nonverbally and verbally interpreted the emotion in the situations. (c) A larger increase in nonverbal interpretation scores with longer looking times at target person's head was observed in DHH children than in TH children. (d) A decrease in verbal interpretation scores with longer looking times at target person's body was observed in DHH children, but not in TH children. DHH children were represented with black bars/lines; TH children were represented with grey bars/lines. The error bars indicate 95% confidence interval. *p < .05; **p < .01.

nonverbal interpretation than on verbal interpretation, $b = .08$, $p = .005$. Finally, there was an effect for Age: An increase in Age was associated with an increase in interpretation scores, $b = .01$, $p < .001$. No other effects were observed.

Table 2. Fixed and random effects in the generalized linear mixed models.

	Fixation ratio within AOIs		**Interpretation**		**Effect of encoding**			
					Nonverbal		**Verbal**	
Fixed and random effect	*b* (δ)	95% CI	*b* (δ)	95% CI	*b* (δ)	95% CI	*b* (δ)	95% CI
Intercept	.18	[.16, .19]	1.13	[1.06, 1.20]	1.18	[1.11, 1.25]	1.11	[1.05, 1.18]
Age	**.00 (.01)**	[.00, .00]	**.01 (.01)**	[.01, .01]	**.01 (.02)**	[.01, .01]	**.01 (.02)**	[.01, .01]
Group	**-.03 (.16)**	[-.05, -.00]	**-.13 (.20)**	[-.22, -.04]	-.06 (.09)	[-.17, .04]	**-.11 (.18)**	[-.21, -.01]
Valence	*ns*		*ns*		*ns*		*ns*	
Task	--		**.08 (.12)**	[.02, .13]	--		--	
Group x Valence	*ns*		*ns*		*ns*		*ns*	
Group x Valence x Task	--		*ns*		--		--	
Target Head	*ref*		--		.14 (.22)	[-.20, .48]	**.37 (.61)**	[.10, .64]
Target Body	**-.07 (.44)**	[-.09, -.05]	--		**-.32 (.50)**	[-.61, -.03]	.05 (.08)	[-.32, .42]
Partner Head	**.05 (.31)**	[.03, .07]	--		**-.27 (.41)**	[-.51, -.02]	*ns*	
Partner Action	**-.07 (.44)**	[-.09, -.05]	--		*ns*		**-.35 (.58)**	[-.65, -.06]
Group x Target Head	*ref*		--		**.61 (.94)**	[.06, 1.15]	*ns*	
Group x Target Body	**.04 (.25)**	[.01, .07]	--		*ns*		**-.54 (.89)**	[-1.05, -.03]
Group x Partner Head	**.03 (.18)**	[.00, .06]	--		*ns*		*ns*	
Group x Partner Action	.03 (.18)	[-.00, .05]	--		*ns*		*ns*	
Variance - Intercept	.00	[.00, .00]	.03	[.02, .06]	.03	[.02, .06]	.02	[.01, .05]
Residual	.03	[.02, .03]	.41	[.37, .45]	.39	[.35, .43]	.35	[.31, .38]

Note: Group was coded as -1 = DHH, 1 = TH. Valence was coded as -1 = negative, 1 = positive. Task was coded as -1 = nonverbal interpretation, 1 = verbal interpretation. AOI was coded as -2 = interaction partner's head, -1 = interaction partner's action, 1 = target person's body, 2 = target person's head. The last category was used as the reference ("*ref*"). An "*ns*" indicates that the variable was removed from the final model due to insignificance. A "--" indicates that the variable was not included in the full model. Significant fixed effects ($p < 0.05$) are bolded. CI = confidence interval. δ = standardized effect size, calculated by dividing fixed coefficient by the square root of the sum of Level 1 (residual) and Level 2 (intercept) variances (formula suggested by Raudenbush and Liu, 2000).

Effect of Encoding on Interpretation

In the exploratory analysis, we developed two models respectively for nonverbal and verbal interpretation. Fixed effects included Age, Group, Valence, and looking times at Target Head, Target Body, Partner Head, and Partner Action, as well as their interactions with Group.

For nonverbal interpretation, we observed an interaction for Target Head x Group, $b = .61$, $p = .029$ (Table 2). The increase in nonverbal scores associated with longer looking times for the Target Head was greater in the DHH children than in the TH children (Figure 2c). It was also observed that lower nonverbal scores were associated with longer looking times for the Target Body, $b = -.32$, $p = .029$, and for the Partner Head, $b = -.27$, $p = .033$, in both groups.

For verbal interpretation, we observed an interaction for Target Body x Group, $b = -.54$, $p = .037$ (Table 2). Longer looking times at the Target Body were associated with a decrease in verbal scores in the DHH children, but we found no effect for the TH children (Figure 2d). Moreover, in both groups, the verbal scores increased with longer looking times at the Target Head, $b = .37$, $p = .006$, but with shorter looking times at the Partner Action, $b = -.35$, $p = .018$.

DISCUSSION

In this study, we examined the initial two steps of the SIP model, i.e., encoding and interpretation, to investigate how DHH and TH children understood nonverbal emotional cues in dynamic social situations, where an interaction partner elicited an emotion in a target person. Our results showed characteristic patterns at both SIP steps in the DHH children. While the DHH and TH children both paid more attention to the heads of the target person and the partner than to their bodies or actions when encoding emotional cues, the DHH children spent less time looking at target person's head, and more time looking at target person's body and at partner's head, than the TH children. When interpreting emotions, the DHH children scored lower than their TH peers, and their lower scores were associated with their distinctive encoding pattern of spending less time looking at the target person's head and more time looking at the target person's body. With age, children attended to the relevant emotional cues preselected by this study longer and interpreted situations with the emotion intended by the study more often. The implications of these outcomes will be discussed below.

Outcomes showed that the DHH children diverted their attention from the target person's head to the target person's body and partner's head, whereas their TH peers exhibited a clear focus on the heads of the two protagonists. Note that the facial information of the target persons was not visible in our videos as the target persons were not facing the camera. Despite the missing facial expressions, the TH children collected information mainly from the heads. This tendency is congruent with past studies that indicated a preference among typically developing individuals for attending to heads over other body regions (End & Gamer, 2017; Nelson & Mondloch, 2018).

Although the DHH children also exhibited a preference for looking at heads, the head region seems to have been less informative to them than to the TH children when the facial information was missing. It is worth noting that in real life, the head region carries not only visual cues but auditory cues. While TH individuals do not need specific facial information, such as lip movements, to fully understand speech in real-time, this may be the case for DHH individuals (Letourneau and Mitchell, 2011; Schreitmüller et al., 2018; Tye-Murray et al., 2014; Wang et al. 2017; Worster et al., 2018). This stronger dependence on facial information during daily communication may explain why the DHH children found the head region less informative when facial cues were missing. We speculate that the DHH children reduced their attention to the target person's head, thus increasing their attention to the cues that could give more information about the situation (i.e., the target person's body, which informs emotions, e.g., moving forward in anger and backward in fear; where the emotion is directed to; and physical conditions such as falling), or about the intention of the interaction partner (i.e., the emotion expressed by the partner, whose face was shown). Taken together, these outcomes suggest that DHH children try to make use of more explicit, visually observable cues to compensate for the ambiguous information (Kret & De Gelder, 2013; Kret et al., 2017). As the saying goes, "Let the evidence speak for itself". DHH children may use this visual cue-based strategy to minimize misinterpretations or fill in the blanks during their daily social interactions and observations, given that they lack full auditory access to the social world around them that their TH peers have (Rieffe & Terwogt, 2000; Rieffe et al., 2003).

In line with the SIP framework, this encoding pattern of diverting attention from ambiguous to explicit cues was associated with the DHH children's interpretation of emotions in social situations. Indeed, a target person's body can provide essential information, when the situation results in a clear physical condition such as falling down. However, it could also be misleading, when more ambiguous physical outcomes are to be observed, such as being laughed at. Without adequate social-emotional knowledge, an encoding pattern that depends on explicit cues only may lead to misinterpretations. We did observe small effect sizes for group differences when analyzing emotion encoding and emotion interpreting separately. However, large effect sizes were observed when we analyzed the effect of encoding on interpretation. This suggests that an encoding strategy that is not supported by adequate social-emotional knowledge could potentially lead to serious misinterpretations. Such findings may carry important rehabilitative implications. As the SIP model proposes that children constantly refer to their past experiences when processing social information at different steps (Crick & Dodge, 1994), providing children with an accessible social environment to allow for easier acquisition of social-emotional knowledge may be essential for supporting DHH children's emotion understanding.

Limitations and Future Directions

Through the use of eye tracking technology, this study is among the first to show that DHH and TH children encoded nonverbal emotional cues differently in a dynamic social situation, and that furthermore, these patterns were linked to their interpretations of these situations. However, some limitations must be considered.

First, in this study we included only basic emotions and prototypical situations, and recruited children three to ten years old. Also, out of consideration for the complexity of our models and for the likelihood that participants' response toward a certain situation might be affected by their past experiences (Frijda, 1986; Rieffe et al., 2005), we examined the valence of emotions rather than discrete emotional categories. The relatively easy task and older age might explain the small effect sizes for the group differences observed in the encoding stage and in the interpretation stage. However, it should be noted that difficulties in emotion understanding could be even more evident when complex emotional categories and novel situations are involved.

Second, in the current study we did not include any auditory signals in our video stimuli. However, in daily life people usually process emotional information through multiple channels. According to previous studies that examined how DHH children looked at the eyes, nose, and mouth when looking at faces, DHH children only increased their attention to the mouth region when presented with a face along with auditory linguistic information (Wang et al. 2017; Worster et al., 2018). This indicates that DHH children could encode cues differently in the presence of auditory information. Further investigations are needed in order to establish whether such an adaptation can be observed when DHH children encode emotions in dynamic social situations that include auditory information.

Third, the heterogeneity of the DHH population is an aspect that we did not tackle. Instead, we included a group of DHH children where the majority had profound hearing loss and used CIs. All had TH parents and used spoken language. Our results showed that hearing loss could affect emotion understanding, despite partially restored hearing and spoken language mode. Yet, future studies are needed in order to confirm whether this pattern also emerges in DHH individuals with other hearing, family, or language backgrounds. Moreover, given that the SIP model centers around children's past experiences and social-emotional knowledge, examining the SIP patterns in DHH children with different backgrounds would provide further insight into the model. This may include DHH children in their early years prior to amplification, and DHH children with DHH parents, who may receive more nonverbal language input from their parents than DHH children with TH parents (e.g., Loots et al., 2005).

Finally, we suggest that future studies take into account DHH children's visual cue-based compensatory mechanism when interpreting the social interaction patterns of these children. On the one hand, DHH children may use this strategy to maximize their understanding of what is happening in a situation and to facilitate their communication with others. On the other hand, DHH children may easily misunderstand a situation when they do not have adequate social-emotional knowledge to guide their visual processing. Moreover, such a mechanism may underlie not only the interpretation of emotions, but other areas that require social-emotional knowledge. For example, DHH children were reported to show fewer prosocial behaviors (e.g., helping and sharing) than their TH peers (Eichengreen et al., 2019; Netten et al., 2015). This may suggest that DHH children face difficulties approaching other people in social situations or that they do so in a different manner, which could further affect their peer relationships (Rieffe et al., 2018). More studies are needed to understand the relation between visual processing and how DHH children actually approach social situations.

CONCLUSIONS

This study showed that DHH children diverted their attention away from ambiguous information to more explicit, visually observable cues when processing emotions in social situations. This visual cue-based tendency is likely a strategy to minimize misunderstanding in their daily communication. However, DHH children might not have adequate knowledge about causes of emotions and social rules to support such a strategy. This, in turn, may lead to misinterpretation of emotions in social situations. Our findings underscore the need to provide extra support to DHH children. Such support could include more explicit discussion about and instruction on mental states, and providing an environment where these children can more easily follow what is happening around them, such as one that features the use of a frequency modulation (FM) system and acoustic paneling in classrooms. Moreover, professionals and parents may need to consider the possibility that children with hearing loss may employ unique compensatory visual encoding patterns for understanding social situations. By taking the information processing patterns of these children into account, more appropriate support may be provided to these children.

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CHAPTER 4

Functions of Emotions in the Social Context in Deaf and Hard-of-Hearing Children and Typically Hearing Children

Tsou, Y.T., Li, B., Eichengreen, A., Frijns, J.H.M., & Rieffe, C.

Functions of emotions in the social context in deaf and hard-of-hearing children and typically hearing children

In revision

ABSTRACT

Deaf and hard-of-hearing (DHH) children are known for their difficulties in social participation. However, the factors underlying such difficulties have been limitedly studied. Therefore, this study aimed to understand the role of emotional functioning in DHH children's social life. For this purpose, this study investigated three aspects of emotional functioning (emotion recognition, empathy, and emotion expression), and their relations with two aspects of social functioning (social competence and externalizing behaviors) in DHH children and in their typically hearing (TH) peers. Fifty-five DHH children and 74 TH children aged three to ten years participated in this study (*M*age = 6.04 years, *SD* = 1.94). Parents filled out questionnaires regarding their child's emotion recognition, empathy, expression of positive and negative emotions, social competence, and externalizing behaviors. Data related to DHH children's hearing level were also collected. Results showed that the levels of emotional and social functioning were similar in DHH and TH children. In both groups, higher levels of empathy were associated with higher levels of social competence and fewer externalizing behaviors. Higher levels of negative emotion expression were associated with lower level of social competence in the two groups, but with more externalizing behaviors in DHH children only. Emotion recognition and positive emotion expression were unrelated to social functioning, whether in DHH or TH children. Moreover, hearing-related factors did not correlate with any of the emotional and social functioning measures in DHH children. The findings suggest that DHH children may not have an adequate knowledge for expressing negative emotions in a socially appropriate manner, despite the long-term use of hearing devices.

INTRODUCTION

Social interaction involves a dynamic, reciprocal process of stimulation and response between individuals, during which emotions work as oil for engines that facilitate the process (Frijda & Mesquita, 1998; Levenson, 1999; Payton et al., 2000). How people respond to others' emotions thus have profound influence on their communication and relationship with others. This link between affective responses and their effects on interpersonal relationships is learned by children gradually through overhearing, observing, and participating in social interactions (Saarni, 1999). Disruptions in learning this link through social interactions could result in disruptions in social functioning (e.g., Deneault & Ricard, 2013; Eisenberg et al., 1995; Klein et al., 2018; Wilson et al., 2013), which involves the skills and behaviors with which children initiate and maintain their relationships with other people (Arnold et al., 2012; Eisenberg et al., 2000; Gresham & Elliott, 1987; Wiefferink et al., 2012). Being deaf or hard of hearing (DHH) during early childhood is likely to cause such disruptions, and problems with social functioning are often observed in DHH children who live in a predominantly hearing environment (e.g., Chao et al., 2015; Dammeyer, 2009; Fellinger et al., 2008; Hoffman et al., 2016; Van Eldik et al., 2004). However, little is known regarding the extent to which DHH children's social functioning is associated with their emotional responses. In the current study, we aimed to narrow this gap by investigating three aspects of emotional functioning involved in social interactions (emotion recognition, empathy, and emotion expression) in DHH children and in their peers with typical hearing (TH), and how these aspects are related to their social functioning.

Recognizing others' emotions allows people to collect the information required for subsequent decisions on responses to social situations. Failing to correctly recognize others' emotion could lead to maladaptive responses to the situation (Crick & Dodge, 1994; Lemerise & Arsenio, 2000), such that observed in children with aggressive behavior who tended to interpret others' emotional expressions as hostile (De Castro et al., 2005). In regard to DHH children's ability to recognize emotions, mixed findings have been reported. In preschool years, DHH children showed difficulties matching and labeling different facial expressions of emotions, as compared to their peers with TH (Most & Michaelis, 2012; Y. Wang et al., 2011, 2016; Wiefferink et al., 2013), yet parents' ratings on DHH children's emotion recognition were on par with those on children with TH (Ketelaar et al., 2013). In studies that included school-aged children, DHH children either showed comparable performances or experienced more difficulties than their peers with TH in facial emotion recognition tasks (Dyck et al., 2004; Hosie et al., 1998; H. Wang et al., 2019; Ludlow et al., 2010; Ziv et al., 2013). The discrepancies might be attributed to the context in which children were evaluated: parent reports (Ketelaar et al., 2013) gave a more positive picture than experimental tasks (Most & Michaelis, 2012; Y. Wang et al., 2011, 2016; Wiefferink et al., 2013), while paper-based experimental stimuli (Hosie et al., 1998; Ziv et al., 2013) produced more positive results than computer-based stimuli (Dyck et al., 2004; H. Wang et al., 2019; Ludlow et al., 2010). Moreover, DHH children's ability to recognize others' basic emotions was found to associate with their social competence, while this relation was not observed in children with TH (aged 1-6 years; Ketelaar et al., 2013). Possibly, preschool DHH children depend on their understanding of basic emotions to decide how they should behave in a social context, while their peers with TH may have developed other skills to assist this process, such as the understanding of more complex emotions and of others' desires and beliefs (Izard et al., 1999; Wellman et al., 2001). One study further indicated that DHH youths (aged 13-21 years) misinterpreted the emotions in social situations more often than their peers with TH and subsequently responded with more aggressive behaviors or crying (Torres et al., 2016).

Showing concerns for other people's emotions — a capacity known as empathy — helps create social bonding. Empathy allows people to feel what others are feeling, understand others' emotion, and respond to the emotion with proper affects and actions such as comforting, helping, and sharing (Hoffman, 1990; Rieffe et al., 2010). As a result, people with higher levels of empathy have better peer relationships (Eisenberg et al., 2010; Zhou et al., 2002) and do less harm to other people (Mayberry & Espelage, 2007; Pursell et al., 2008). According to parent reports, similar levels of empathy were found in children with and without hearing loss during preschool years (aged 1-6 years; Ketelaar et al., 2013, 2017). Yet in the stages where peer interactions become increasingly important, DHH children (aged 4-14 years) were rated lower on empathy by their teachers than children with TH (Peterson, 2016). No evidence has shown that the association between empathy and social functioning is different between children with and with hearing loss (Ketelaar et al., 2013).

Expressing emotions helps people to send specific information to their interaction partners (Levenson, 1999). It shows the other(s) not only what is important to the individual, but also what the sender wants to achieve within the relationship. When a person approaches a friend with anger, they are signaling to the friend that there is an issue which needs to be solved or it might negatively affect their relationship. Yet, frequent or prolonged expression of negative emotions is harmful to social participation, and may even be considered symptoms of psychopathology (Liew et al., 2004; Sallquist et al., 2009; Wiefferink et al., 2012). Contrarily, more expressions of positive emotions are in general linked to higher levels of social competence (Hayden et al., 2006; Lengua, 2003; Pesonen et al., 2008; Wiefferink et al., 2012), although excessive expressions of positive emotions may also associate with hyperactivity and impulsivity (Rothbart et al., 2001).

While the expression of positive emotions does not differ between children with and without hearing loss (aged 1.5-5 years), parents of DHH children reported more frequent and more intense negative emotion expression than parents of children with TH (Wiefferink et al., 2012). Rieffe (2012) further showed that in emotion-provoking situations, the intensity of DHH children's negative emotion expression did not decrease as much as children with TH (aged 9.5-13 years) after using a coping strategy (e.g., problem solving or avoidance). DHH children also more often expressed their anger without constructively explaining the causes, as compared to their peers with TH, who used anger to communicate to the other person who caused the discomfort (Rieffe & Meerum Terwogt, 2006). Moreover, although the excessive expression of negative emotions is related to more externalizing behaviors in children with and without hearing loss alike, only in children with TH are more positive emotion expressions associated with higher levels of social competence (Wiefferink et al., 2012). These group differences in how emotion expression functions in social interactions reflects that DHH children may express emotions in a less strategic manner to maintain or strengthen their relationships with others (Rieffe & Meerum Terwogt, 2006; Wiefferink et al., 2012).

Investigations on the relations between emotional and social functioning could be of particular rehabilitative relevance to DHH children. As early as preschool years, difficulties in social functioning have been reported in this population, including more aggressive behaviors, more peer problems, and lower adaptability, as compared to children with TH (Chao et al., 2015; Dammeyer, 2010; Fellinger et al., 2008; Hoffman et al., 2016; Netten et al., 2015; Van Eldik et al., 2004; see Bigler et al., 2019 and Stevenson et al., 2015 for a review). Yet, in some studies that focused on DHH preschoolers with a cochlear implant (aged 1-5 years), comparable levels of social functioning were observed (Ketelaar et al., 2013, 2015; Netten et al., 2018). This may suggest the benefit of early diagnosis and support (as a result of newborn hearing screening), whereas also shows the possibility that social problems are more noticeable when DHH children enter school age. Notably, the hearing loss alone may not explain the between-group differences. Factors such as degree of hearing loss, age at intervention of hearing loss, and language ability were sometimes found unrelated to emotional and social functioning in preschool and school-aged children (Chao et al., 2015; Dammeyer, 2010; Fellinger et al., 2008; Ketelaar et al., 2013, 2017; Laugen et al., 2016; Netten et al., 2015; Stevenson et al., 2011; Wiefferink et al., 2012, 2013).

Present Study

To successfully navigate the social world, knowing how to respond to others' emotions are necessary skills. Given the difficult social participation often experienced by DHH children, understanding how emotions function in young DHH children's daily social life could help us provide support at the earliest possible stage. While a small number of studies has provided us valuable information in this regard, those studies focused on a single aspect of emotional or social functioning. The current study aimed to build on previous studies on this topic by investigating the relation between three aspects of emotional functioning (emotion recognition, empathy, and emotion expression) and two aspects of social functioning (social competence and externalizing behaviors) in children with and without hearing loss. We recruited three- to ten-year-old children because this is the period when typically-developing children gradually understand basic and complex emotions, and link these emotions to social contexts (Durand et al., 2007; Harris, 2008). Where possible, we made our hypotheses based on studies that included a similar age range as the current study.

The first aim of this study was to examine the levels of emotional functioning (i.e., emotion recognition, empathy, and emotion expression) and of social functioning (i.e., social competence and externalizing behaviors) in children with and without hearing loss. Regarding emotional functioning, we expected lower levels of emotion recognition and empathy in DHH children than in children with TH (Peterson, 2016; Wang et al., 2019). Also, we expected DHH children to show more negative emotion expression than their peers with TH, while no difference was expected for positive emotion expression (Wiefferink et al., 2012). In regard to social functioning, we expected lower levels of social competence and more externalizing behaviors in DHH children than in children with TH.

Secondly, we aimed to understand how emotions function in social interactions in children with and without hearing loss. Therefore, we investigated to what extent emotional functioning is associated with social functioning, and the moderating role of DHH group membership. We expected these relations to be in line with previous findings. That is, in both groups, higher levels of empathy and lower levels of negative emotion expression were expected to associate with higher levels of social competence (Wiefferink et al., 2012; Ketelaar et al., 2013). Yet, as Wiefferink and colleagues (2012) reported, we expected a positive association between positive emotion expression and social competence only in children with TH, but unrelated in DHH children because DHH children might express their emotions less strategically. Also, we expected a positive association between emotion recognition and social competence only in DHH children, but unrelated in children with TH, because DHH children may depend more on their ability to recognize others' emotions during social interactions (Ketelaar et al., 2013). In regard to externalizing behaviors, we hypothesized lower levels of emotion recognition and empathy, and higher levels of negative emotion expression, to associate with more externalizing behaviors, in the two groups alike (Ketelaar et al., 2013; Wiefferink et al., 2012). We did not expect a relation between positive emotion expression and externalizing behaviors. These hypotheses are visually illustrated in Figure 1.

Finally, we aimed to understand to what extent each measure for emotional and social functioning is related to hearing-related factors within the DHH group. We expected hearing-related factors, including age at intervention (a cochlear implant or a hearing aid), duration of using the hearing device, type of amplification, and speech perception, to be unrelated to the levels of emotional and social functioning.

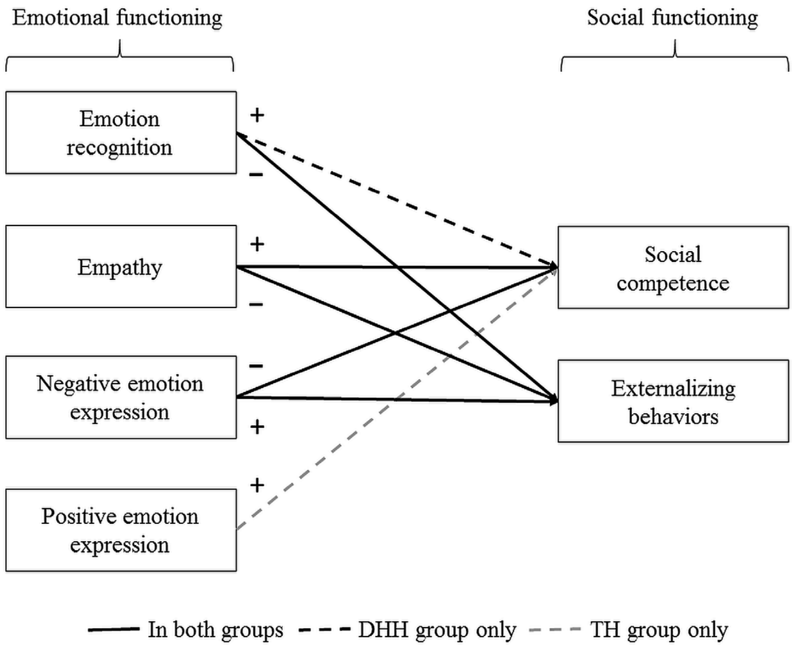

Figure 1. Visual illustration of the hypotheses on the relations between emotional functioning and social functioning. Black solid lines represent relations expected to be present in the two groups. Black dotted lines represent relations expected to be present only in deaf or hard-of-hearing (DHH) children. Grey dotted lines represent relations expected to be present only in children with typical hearing (TH).

METHODS

Participants

A total of 129 children aged three to ten years from Taiwan were included in the current study. Fifty-five children were DHH (M_{age} = 6.24 years, *SD* = 2.11) and wore a cochlear implant (*n* = 50) or a hearing aid (*n* = 5). The other 74 children were with TH (M_{age} = 5.90 years, *SD* = 1.80). None of the children had additional disabilities or diagnoses. All of the children used spoken language as the primary communication mode and attended mainstream schools. See Table 1 for participant characteristics.

The two groups did not differ in terms of age, $t(127) = -.97$, $p = .333$, gender distribution, $\chi^2(1, N = 129) = .94$, $p = .333$, nonverbal intelligence, $t(760) = 1.66$, $p = .098$, parental education level, $t(403) = 1.90$, $p = .059$, and net household income, $t(67) = .34$, $p = .733$.[1] Nonverbal intelligence scores were obtained by averaging the age-corrected

1 The *t*-statistics presented here was based on the multiply imputed dataset, due to missing data in some variables. See the Statistical Analysis section for more details.

standardized scores from Block Design and Matrix subscales of the Wechsler Preschool and Primary Scale of Intelligence Revised Edition (WPPSI-R, for children aged 3-5 years; Wechsler, 1989) or from Block Design and Picture Arrangement subscales of the Wechsler Intelligence Scale for Children Third Edition (WISC-III, for children aged 6-10 year; Wechsler, 1991).

Table 1. Participant characteristics.

	DHH	TH
N	55	74
Age, years, mean (*SD*)	6.24 (2.11)	5.90 (1.80)
Gender, female *n* (%)	28 (51%)	44 (59%)
Nonverbal intelligence[a], mean (*SD*)	9.63 (2.63)	10.46 (2.69)
Parent education level[b], mean (*SD*)	3.53 (0.71)	3.76 (0.62)
Net household income[c], mean (*SD*)	2.44 (1.12)	2.49 (1.03)
Age at intervention, years, mean (*SD*)	2.50 (1.31)	-
Duration of amplification, years, mean (*SD*)	3.74 (1.87)	-
Type of amplification, *n* (%)		
Hearing aid only	5 (9%)	-
Unilateral cochlear implant	35 (64%)	-
Bilateral cochlear implants	15 (27%)	-
Speech perception, percentage correct, mean (*SD*)		
Monosyllabic words	88.90 (11.40)	-
Everyday sentences	86.91 (18.89)	-

Note: DHH = deaf and hard of hearing; TH = typical hearing.
[a]For nonverbal intelligence, age-corrected norm scores are presented. The grand population mean is 10 and the standard deviation is 3.
[b]Parental education level: 1 = no/primary education; 2 = lower general secondary education; 3 = higher general secondary education; 4 = college/university.
[c]Net household income: 1 = less than €15,000; 2 = €15,000 – €30,000; 3 = €30,000 – €45,000; 4 = €45,000 – €60,000; 5 = more than €60,000.

This study was part of a larger-scale research project in which other variables were included to examine different aspects of social-emotional functioning in children with (a) typical development. Guardians of the child participants and children older than seven years signed the informed consent forms before the test procedures. The study protocol and informed consent form were approved by The Psychology Ethics Committee of Leiden University and Chang-Gung Memorial Hospital Ethics Committee for Human Studies.

A total of 153 children were approached for this project. After excluding children whose parents did not return the questionnaires (*n* = 9), who had additional problems or nonverbal intelligence two standard deviations below or above the mean (n = 14; according to WISC-III/WPPSI-R or indicated by teachers/responsible doctors), and who was accidentally given the questionnaires twice (n = 1), a final sample included 129 children. No differences in age, $t(151) = 1.89$, $p = .058$, and nonverbal intelligence, $t(83) = -1.25$, $p = .216$, were observed between the included and excluded samples. Yet, the children excluded from this study had a larger proportion of boys, $\chi^2(1, N = 153) = 4.10$, $p = .043$, lower parental educational level, $t(51) = -3.55$, $p = .001$, and lower net household income, $t(195) = -2.17$, $p = .031$, than the children included in the study.[1]

Materials

Emotional Functioning

Emotion Recognition. The Emotion Acknowledgment subscale (6 items) from the *Emotion Expression Questionnaire* (*EEQ*; 35 items) was used to examine how well children understand the emotions expressed by their parents (e.g., "does your child understand when you are angry?"; Rieffe et al., 2010). Parents rated on a 5-point scale (1 = (almost) never; 5 = (almost) always). The internal consistency was good (Table 2). See Supplementary Materials S4.1 for the items in each parent report.

Empathy. We used age-appropriate measures for empathy. For preschool children (aged 3-5 years), the *Empathy Questionnaire* (*EmQue*, 19 items) was used (Rieffe et al., 2010). Parents rated on a 3-point scale (0 = never; 2 = often) in regard to their children's empathic responses to other people's emotional displays, such as "when another child is upset, my child needs to be comforted too," "when another child is angry, my child stops his own play to watch," and "when another child starts to cry, my child tries to comfort him/her."

For school-aged children (aged 6-10 years), the *Empathy Questionnaire for Children and Adolescents* (*EmQue-CA*, 18 items) was administered (Overgaauw et al., 2017). The *EmQue-CA* was originally a self-report and was adapted into a parent report for this study by replacing "I" with "my child." On a 3-point scale (0 = no; 2 = often), parents rated on items such as "when a friend is upset, my child feels upset too," "my child understands that a friend is ashamed when he/she has done something wrong," and "if a friend is sad, my child likes to comfort him."

The internal consistencies were good for both questionnaires (Table 2). *EmQue* and *EmQue-CA* did not differ in their correlations with other measures in this study (see Supplementary Materials S4.2). Also, no difference was found between the number distribution of DHH and TH children who were rated on *EmQue* and was comparable to the distribution of DHH and TH children those rated on *EmQue-CA*, $\chi^2(1, N = 129) = .01$, $p = .919$. Therefore, the total scores from the two questionnaires were combined into one variable for later analyses.

Negative and Positive Emotion Expression. We used the Negative Emotion Expression subscale (8 items) and Positive Emotion Expression subscale (6 items) from the *EEQ* (Rieffe et al., 2010). On a 5-point scale, parents scored the frequency, intensity, and duration of their child's expressions of negative emotions, including anger and sadness, and positive emotions, including happiness and joy, as well as the extent to which the child can calm down from the emotional episode. Example items are "how often does your child show anger?" (1 = (almost) never; 5 = (almost) always) and "is your child easy to calm down when angry?" (1 = very easy; 5 = very difficult). The internal consistencies were good for both subscales (Table 2).

Table 2. Psychometric properties and mean scores (standard deviations) of the measures

	N items	Scale	Cronbach's α (*n* sample)	Mean (SD)		*t* value[a]	*p* value[ab]
				DHH	TH		
Emotion recognition	6	1-5	.84 (127)	3.71 (.66)	3.61 (.74)	-.84	.202
Empathy (all children)	--	0-2	--	1.21 (.29)	1.25 (.34)	.65	.257
Empathy (3-5 years)	19	0-2	.78 (63)	1.07 (.25)	1.07 (.28)	-.02	.493
Empathy (6-10 years)	18	0-2	.85 (60)	1.35 (.27)	1.42 (.29)	.98	.165
Negative emotion expression	8	1-5	.80 (128)	2.38 (.56)	2.43 (.54)	.50	.308
Positive emotion expression	6	1-5	.73 (128)	3.65 (.63)	3.63 (.54)	-.26	.399
Social competence	8	0-2	.69 (125)	1.47 (.36)	1.52 (.30)	.72	.235
Externalizing problems	9	0-2	.73 (126)	.71 (.38)	.62 (.30)	-1.52	.065

Note: DHH = deaf and hard of hearing; TH = typically hearing.
[a] Pooled results after multiple imputations.
[b] One-tailed.

Social Functioning

The *Strengths and Difficulties Questionnaire* (*SDQ*; 25 items) is a widely-used instrument for measuring children's social functioning (Goodman, 1997). Parents rated each statement on a 3-point scale (0 = not true; 2 = certainly true). In the current study, we examined two aspects of social functioning: externalizing behaviors and social competence. Externalizing behaviors (9 items) were assessed by the combination of the subscales Hyperactivity (5 items; e.g., "restless, overactive, cannot stay still for long") and Conduct Problems (4 items; e.g., "often fights with other children or bullies them"). One item from the original Conduct Problems subscale was removed because it conceptually overlapped with the measure for negative emotion expression ("often has temper tantrums or hot tempers").

To assess social competence (8 items), we combined the subscales Prosocial (4 items; e.g., "shares readily with other children (treats, toys, pencils etc.)") and Peer Relation (4 items; e.g., "has at least one good friend"; items denoting peer problems were reversely scored). One item from the original Prosocial subscale was removed because it conceptually overlapped with the measures for empathy ("helpful if someone is hurt, upset or feeling ill"). One item from the original Peer Relation was removed because it had a negative correlation with the other items in the merged social competence scale and thus reduced internal consistency ("gets on better with adults than with other children"). The internal consistencies for the two aspects of social functioning were adequate (Table 2).

Translation Procedures

The Traditional Chinese version of the *SDQ* is readily available (available at http://sdqinfo.org). The Traditional Chinese version *EEQ*, *EmQue*, and *EmQue-CA* were adapted from the original English questionnaires for the purpose of this study, following a standard back-translation procedure. A bilingual translator translated the Traditional Chinese versions back to English, and the back-translation was compared to the original version. Language inconsistencies were modified after discussion within the research team.

Hearing-Related Information

Information about DHH children's hearing history, including age at intervention (cochlear implant or hearing aid), duration of using the hearing device, and type of amplification, was collected from parents or medical records.

The scores for speech perception assessed during children's most recent visit to a speech pathology and audiology center were obtained from their medical records. The assessments included a sentence test and a monosyllabic word test. In a quiet room, an audiologist read out a series of sentences or words with her mouth covered, and children were asked to repeat the sentences/words. The sentence tests were developed by Lin et al. (unpublished materials) based on the Central Institute for the Deaf (CID) Everyday Sentence test (Silverman & Hirsh, 1955). It includes 15 easy sentences, each with one to seven key words frequently used in daily communication, such as "book" and "car"; and 20 difficult sentences, each with one to ten key words less frequently used in daily communication, such as "examine" and "dormitory." The monosyllabic word test includes 25 monosyllabic words that are phonetically balanced (Wang & Su, 1979). The percentage of correctly repeated (key) words was calculated and used in the analyses.

Procedures

The children were recruited in Taiwan through a speech pathology and audiology center (the DHH children) and kindergartens/primary schools (the TH children). Parents filled out the questionnaires at the center or at the child's school. Meanwhile, an experimenter administered the nonverbal intelligence tasks (WPPSI-R or WISC-III) to the child in a quiet room. All measures were conducted by the same experimenter, who received training before data collection. Background information, such as parental education level and household income, was collected from parents.

Statistical Analysis

Statistical analyses were carried out using SPSS 25.0 (IBM Corp., Armonk, NY). To address our first research question, levels of emotional functioning (negative emotion expression, positive emotion expression, emotion recognition, and empathy) and social functioning (social competence and externalizing behaviors) were compared between DHH and TH children using independent t-tests. To better understand the effect of age, we also ran the tests separately for children in different age groups (3 to 4 years old; 5 to 6 years old; 7 to 10 years old).

Our second research question was tested using hierarchical regression analyses in which the moderating role of group membership in the contribution of emotional functioning to social functioning was examined. In the first step, we entered age, gender (0 = male, 1= female), group (0 = TH, 1 = DHH), and the four variables for emotional functioning. In the second step, we added the two-way interactions of group with each of the four emotional functioning variables. Continuous independent variables were centered.

When addressing the first two research questions, we conducted the analyses with and without the five children who did not use cochlear implants. Excluding the children without cochlear implants did not change the results (see Supplementary Materials S4.3). Therefore, we included all DHH children in our analyses and report the results accordingly.

Finally, using partial correlation analyses controlling for age, we checked within the DHH group whether the emotional and social functioning variables were related to hearing-related factors. Included factors were age at intervention, duration of using the hearing device, number of cochlear implants (0 = only hearing aids; 1 = unilateral implantation; 2 = bilateral implantation), and word and sentence perception scores. For these correlations, Bonferroni correction was applied to adjust the significance level according to the number of hearing-related factors: $p < \alpha/5 = .01$.

Missing Values and Multiple Imputations

Due to time constraints, nonverbal intelligence tasks were not administered in five children (4 DHH, 1 TH), and only one of the two nonverbal intelligence tasks was conducted in 24 children (14 DHH, 10 TH). Parental educational levels and net household income were not available for nine (6 DHH, 3 TH) and 22 (16 DHH, 6 TH) children, respectively. In each questionnaire, parents of DHH children ($n = 3$) missed one or two items. Also, speech perception scores were only available for 42 DHH children. Little's MCAR test showed that the data were missing completely at random (ps > .148 for the samples rated on *EmQue*/*EmQue-CA* and for the DHH sample). Missing data could lead to biased interpretation and a loss of power given that most statistical methods apply complete case analysis (Donders et al., 2006; Netten et al., 2017) Therefore, we used multiple imputations (MI), a technique that fills in missing data points based on the characteristics of participants and the relations in the dataset with other participants (Azur et al., 2011; Schafer & Graham, 2002; Van Buuren, 2012). The missing values described above were estimated along with age, gender, group membership, and social/emotional functioning scores. Ten imputations were performed (Sterne et al., 2009). Pooled results are reported for all the analyses. The *F* tests for regression model fits (i.e., pooled ΔR^2) on the multiply imputed data were conducted according to the approach and the SPSS macro (*MI-MUL2*) provided by Van Ginkel, 2010, 2019).

RESULTS

Group Differences

According to parent reports, the children with and without hearing loss had similar levels on all emotional and social functioning measures, *t*s < 1.52, one tailed *p*s > .128 (Table 2). To understand if the absence of group differences was related to age, we divided the children into three age groups (see Supplementary Materials S4.4). No differences between DHH children and children with TH were noted in each age group.

Relations between Emotional and Social Functioning

Table 3 shows the results of hierarchical regression models. Correlations between the study variables are reported in Supplementary Materials S4.5. In the analysis on social competence, lower levels of negative emotion expression, $b = -.18$, $p < .001$, 95% *CI* [-.28, -.08], and higher levels of empathy, $b = .28$, $p = .009$, 95% *CI* [.07, .48], contributed to higher levels of social competence. Adding interactions of group with emotional functioning variables did not improve the model fit, $\Delta R^2 = .04$, $F(4, 115.04) = 1.83$, $p = .129$. This suggests that the relations between social competence and each of the emotional functioning measures were not moderated by group. No other effects were observed.

In the analysis on externalizing behaviors, adding group interaction terms in the second step improved the model fit, $\Delta R^2 = .07$, $F(4, 114.95) = 3.03$, $p = .020$. Group membership fully moderated the relations between negative emotion expression and externalizing behaviors: Higher levels of negative emotion expression were associated with more externalizing behaviors only in the DHH group, $b = .32$, $p = .002$, 95% *CI* [0.12, 0.51], but not in the group with TH, $b = .06$, $p = .428$, 95% *CI* [-0.08, 0.19] (see Figure 2). Yet, in both groups, lower levels of empathy contributed to more externalizing behaviors, $b = -.50$, $p < .001$, 95% *CI* [-0.76, -0.25]. No other effects were observed.

Table 3. Hierarchical regression analyses for emotional functioning measures on social functioning (pooled results after multiple imputations)

	Social competence			Externalizing behaviors		
	b	*p*	*95% CI*	*b*	*p*	*95% CI*
Step 1	$R^2 = .25^{**}$			$R^2 = .25^{**}$		
Age	<.001	.798	[-.003, .002]	.001	.322	[-.001, .004]
Gender	.01	.866	[-.10, .11]	.04	.523	[-.07, .14]
Group	-.04	.404	[-.15, .06]	.09	.105	[-.02, .20]
Emotion recognition	.05	.235	[-.03, .14]	-.01	.793	[-.10, .08]
Empathy	.28	.009	[.07, .48]	-.31	.005	[-.52, -.09]
Negative emotion expression	-.18	<.001	[-.28, -.08]	.22	<.001	[.12, .32]
Positive emotion expression	.01	.815	[-.08, .10]	.01	.771	[-.08, .11]
Step 2	$\Delta R^2 = .04$			$\Delta R^2 = .07^{*}$		
Age				.002	.165	[-.001, .004]
Gender				.04	.444	[-.06, .15]
Group				-.56	.233	[-1.47, .36]
Emotion recognition				.04	.477	[-.07, .15]
Empathy				-.50	<.001	[-.76, -.25]
Negative emotion expression				.06	.428	[-.08, .19]
Positive emotion expression				.04	.524	[-.09, .17]
Group x Emotion recognition				-.08	.349	[-.26, .09]
Group x Empathy				.33	.099	[-.06, .71]
Group x Negative emotion expression				.32	.002	[.12, .51]
Group x Positive emotion expression				-.06	.542	[-.24, .13]

Note: Gender was coded as 0 = male, 1 = female. Group was coded as 0 = typically hearing, 1 = deaf and hard of hearing. 95% CI: 95% confidence interval. $^{*}p < .05$; $^{**}p < .001$ for the change in R^2.

Table 4. Partial correlations between hearing-related factors and emotional-social functioning measures in DHH children, controlling for age (pooled results after multiple imputations)

	Age at intervention	Duration of amplification	No. cochlear implants	Word perception	Sentence perception
Emotion recognition	.18	-.18	-.28	-.01	.06
Empathy	.04	-.04	.05	.26	.02
Negative emotion expression	-.12	.12	.30	.21	-.19
Positive emotion expression	.04	-.04	.03	-.05	-.07
Social competence	.15	-.15	-.11	.18	.25
Externalizing behaviors	-.24	.24	.09	-.10	-.15

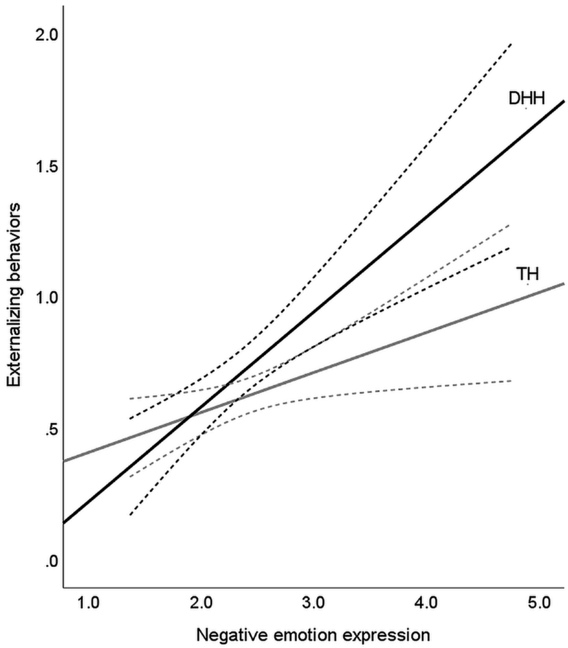

Figure 2. Group status moderates the effects of negative emotion expression on externalizing behaviour. Deaf and hard-of-hearing (DHH) children are represented in black; children with typical hearing (TH) are represented in grey. The dotted lines represent 95% confidence interval.

Relations with Hearing-Related Factors

Table 4 shows the correlations between emotional and social functioning variables and hearing-related factors in DHH children, while age was controlled for. None of the correlations reached significance.

DISCUSSION

Emotions serve important interactional functions in daily social life. Recognizing the emotions of others and reacting empathically to them allow people to collect necessary information for evaluating possible response options and to establish closer relationships with others. The expression of emotions allows people to send specific information about one's attitude, intention, and feelings to interaction partners. The current study examined the relations between emotional and social functioning, in order to deepen our understanding on how emotions function in DHH children's social life. The levels of emotional and social functioning were similar in DHH children and their peers with TH.

In both groups, higher levels of empathy were related to higher levels of social competence and fewer externalizing behaviors. Higher levels of negative emotion expression were associated with lower level of social competence in both groups, but with more externalizing behaviors in DHH children only. Positive emotion expression and emotion recognition were unrelated to social functioning, whether in DHH children or in children with TH. Also, hearing-related factors did not correlate with any of the emotional and social functioning measures. Below, the implications of these findings will be discussed.

Previous studies showed mixed results regarding skills for emotional functioning in DHH children. In our sample, we found DHH children to be on par with their peers with TH. A possible explanation for the absence of group differences is the early detection of hearing loss and the educational system in Taiwan. More than half (n = 33; 60%) of the DHH children in this study received newborn hearing screening (launched in 2012) within their first days after birth. Thus, families with these DHH children were aware of the hearing loss and received systematic support very early. This is congruent with some studies that also included DHH children with early detection and a cochlear implant in the Netherlands (Ketelaar et al., 2013, 2017; Netten et al., 2018). Also, mainstream schools provide periodical or regular extra support to DHH children and other children with special needs. These children often start with a tailor-made curriculum that helps them adapt to the pace of the mainstream schools (Special Education Transmit Net Taiwan, n.d.).

Alternatively, the setting where children were evaluated might have contributed to these positive outcomes. Comparable results between DHH children and children with TH were reported in several other studies that also asked parents to rate the levels of emotional functioning (Ketelaar et al., 2013, 2017; Dirks et al., 2017). However, group differences were often found when DHH children's emotional functioning was assessed outside the familial setting. For example, a study asked teachers to rate children's overall empathic responses and found lower levels of empathy in DHH children (Peterson, 2016). Studies that measured emotion recognition in a controlled, experimental setting also noted differences between children with and without hearing loss in their ability to match and label facial emotions (Wang et al., 2011, 2016, 2019; Wiefferink et al., 2013). The discrepant findings suggest that DHH children may still face emotional functioning challenges outside the family circle, or that parent overrate their DHH child's functioning.

Notably, when we linked emotional functioning to the social context, a group difference emerged. Excessive expressions of negative emotions were associated with more externalizing behaviors in DHH children only. This shows that DHH children's social functioning might be particularly dependent on their expression of negative emotions. Past studies reported that DHH children expressed their negative emotions less strategically than children with TH (e.g., without constructively explaining the cause to interaction partners; Rieffe & Meerum Terwogt, 2006). They also had more difficulties calming themselves down by diverting their attention away from the negative stimuli, or by using other coping strategies (Rieffe, 2012; Wiefferink et al., 2012). The more effortful process for controlling negative emotions is likely a result of their lack of familiarity with display rules or coping options towards different social situations. Such kinds of knowledge are primarily learned during social interactions, to which DHH children have a limited access (Morris et al., 2007; Saarni, 1999; Thompson, 1994). Moreover, parental overprotection and linguistic over-simplification are often observed between DHH children and their parents with TH (Calderon & Greenberg, 2012; Pinquart, 2013; Vaccari & Marschark, 1997). These leave DHH children with fewer opportunities for learning skills by trial and error, and fewer explanations from parents for more abstract concepts, such as mental states (Dirks et al., 2020; Moeller & Schick, 2006; Morgan et al., 2014). In turn DHH children may learn less how to express emotions verbally and constructively. Thus, although on average DHH children expressed negative emotions as much as their peers with TH, they may find negative emotions harder to moderate or to explain, when the emotional arousal they experience is high, or when the social situations are novel to them, which further affects their social behaviors. This outcome also implies that when DHH children can effectively display or regulate their negative emotions, the externalizing problems in these children could decrease to a more notable extent than in children with TH. Note that in this study none of the skills for emotional and social functioning correlated with hearing-related factors. In other words, this potential difficulty for negative emotions might not simply "disappear" when DHH children have more listening experience or perceive speech better. They may need specific considerations from parents and professionals/teachers for gaining more social interactions and mental-state talks.

The cultural background could be another factor that played a role. In this study, children from Taiwan were recruited. Previous cross-cultural studies showed that East Asian youths experienced higher levels of personal emotional arousal than Western counterparts when seeing other people's emotional displays (Cassels et al., 2010; Trommsdorff, 1995). As a result, East Asian DHH children may have to invest an even larger amount of effort to moderate their emotion expressions in a socially favorable manner. Also, cross-cultural studies found that intense expressions of positive emotions were valued more in Western, individualistic cultures than in East Asian, collectivistic cultures (Eisenberg et al., 2001; Heine et al., 1999; Kitayama et al., 2000; Tsai et al., 2002, 2006). Such a tendency was reflected in studies on Western individuals with TH that showed a positive relation between positive emotion expression and social competence (e.g., Wiefferink et al., 2012; Hayden et al., 2006; Lengua, 2003; Pesonen et al., 2008). However, in this study positive emotion expressions did not contribute to social competence in children with and without hearing loss, possibly because East Asians tend to balance positive emotion expressions in order to "fit in" to a collectivistic culture (Heine et al., 1999; Tsai et al., 2006).

Importantly, we found that higher levels of empathy were associated with higher levels of social competence and fewer externalizing behaviors, in both groups. Children who are able to feel what others are feeling and understand what causes others' emotions, may also be more able to establish bonding with their peers, and to know whether their behaviors would cause harm to others (Eisenberg et al., 2010; Mayberry & Espelage, 2007; Pursell et al., 2008; Zhou et al., 2002). This finding thus could be relevant to interventions: Programs that improve children's empathic responses may help both DHH children and children with TH show more adaptive social behaviors.

Limitations and Future Directions

This study examined the relations between emotional and social functioning in DHH children. By investigating three aspects of emotional functioning involved in responding to others' emotions, we gained a clearer understanding of the challenges DHH children have in daily social interactions. Nevertheless, some limitations must be considered when interpreting our results.

First, this study was cross-sectional. Therefore, no causal relations could be drawn from our results. We also could not conclude whether the outcomes would be stable across time, although we did not observe an effect of age in the current study. Future investigations are needed to examine the developmental trajectories and longitudinal associations between emotional and social functioning in DHH children. It should be noted that problems with emotional and social functioning might become more pressing for DHH children in adolescence, when they spend more time with peers, engage in peer activities that require higher levels of verbal sharing and social attunement (Hartup, 1993; Rose & Asher, 1999), and are in more difficult acoustic conditions (e.g., larger classes and more group conversations; Punch & Hyde, 2011; Rieffe et al., 2018).

Second, the emotional functioning measures in this study examined children's responses to basic emotions. Yet, real-life social situations often involve complex emotions, or mixed emotions. Previous studies have shown that DHH adolescents reported shame and guilt less often in social situations that elicited moral emotions (Broekhof et al., 2018), and reported fewer emotions in stories that were designed to trigger more than one emotion (Rieffe, 2012), compared to their peers with TH. For this reason, we still need further studies to understand how DHH children respond to more complex emotions, and how such an ability is related to social functioning.

Third, only parent reports were used in this study. To increase the possibility that parents answered accurately and thus to minimize common method biases, we provided clear instructions before each questionnaire, and ensured unambiguity in sentence content and structure by asking a team of native researchers to check the translated questionnaires (see Podsakoff et al., 2012, for suggestions on procedural remedies for common method biases). Also, Evans (1985) and Siemsen et al. (2009) demonstrated that common method biases do not account for the effects observed in studies designed to test interaction effects. The moderating effect of hearing status found in the current study thus was not at risk to be biased. Nevertheless, future studies are suggested to include multiple methods, such as observations and in vivo experiments, to increase ecological validity.

Fourth, the background characteristics of the DHH children should be considered. In this study, DHH children used spoken language as the primary communication mode. Also, the majority of the DHH children had profound hearing loss and a cochlear implant, and attended mainstream (pre)schools. Although we checked hearing-related factors and no effects were observed, future studies are suggested to address the heterogeneity in the DHH population. For example, a study reported that DHH adolescents in special education were unique in how they regulated emotions (Rieffe et al., 2018). Their use of approach strategies (e.g., problem-solving; seeking social support) was related to negative friendship features, possibly because they approached in a blunt manner, while in mainstreamed DHH adolescents and in their peers with TH the use of approach strategies was related to positive friendship features. Thus, studies that consider different hearing, language, and/or educational backgrounds are warranted as these factors might affect how emotions are expressed.

Finally, future studies are suggested to assess if the cultural values affect DHH children's emotional and social functioning. This study was the first to examine the relations between emotional and social functioning in East Asian DHH children. It increases the external validity of the current knowledge about DHH children's psychosocial development that has been largely built on Western samples. Notably, our results regarding the expression of emotions and its link to social functioning were not consistent with previous research on Western samples. Past studies have shown that individualistic-oriented cultures promote personal uniqueness, while collectivistic-oriented cultures value group harmony (Markus & Kitayama, 2014; Singelis, 1994), and the cultural values influence how emotions are expressed and valued (e.g., Trommsdorff, 1995; Tsai et al., 2006). Although out of the scope of the current study, a cross-cultural design is needed for further research to understand the extent to which these cultural values affect the inclusion of DHH children in their social environment and their socialization experiences.

CONCLUSIONS

Differences between DHH children and children with TH were hardly observed in the current study. DHH children recognized the basic emotions displayed by other people, empathically responded to those emotions, and expressed positive and negative emotions as much as their peers with TH. Also, higher levels of empathy were associated with higher levels of social competence and fewer externalizing behaviors in both groups. Only one group difference was found: More negative emotion expressions were related to more externalizing behaviors in DHH children only. DHH children may express their negative emotions less strategically or regulate those emotions less efficiently, possibly because they were unfamiliar with the display rules or coping options towards different social situations. They may also experience more difficulties explaining their negative emotions verbally due to a more limited access to linguistic discourses about emotions. It is noteworthy that none of the emotional and social functioning measures in this study were correlated with hearing-related factors. Despite the long-term use of hearing devices and a fairly good ability to perceive speech, producing emotional responses in social interactions could still be an effortful task for some DHH children. Our findings call for closer investigations into the functioning of emotions in DHH children's daily social life, and underscore the need to provide more social interaction opportunities to DHH children for learning the knowledge required for efficient regulation and effective expression of emotions. Moreover, intervention programs that facilitate mental-state talks between DHH children and their meaningful others, especially on the experience of negative emotions, could be beneficial.

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CHAPTER 5

The Developmental Trajectory of Empathy and Its Association with Early Symptoms of Psychopathology in Children with and without Hearing Loss

Tsou, Y.T., Li, B., Wiefferink, C.H., Frijns, J.H.M., & Rieffe, C.

The developmental trajectory of empathy and its association with early symptoms of psychopathology in children with and without hearing loss

In revision

ABSTRACT

Empathy enables people to share, understand, and show concern for others' emotions. However, this capacity may be more difficult to acquire for children with hearing loss, due to limited social access, and the effect of hearing on empathic maturation has been unexplored. This four-wave longitudinal study investigated the development of empathy in children with and without hearing loss, and how this development is associated with early symptoms of psychopathology. Seventy-one children with hearing loss and cochlear implants (CI), and 272 typically-hearing (TH) children, participated (aged 1-5 years at Time 1). Parents rated their children's empathic skills (affective empathy, attention to others' emotions, prosocial actions, and emotion acknowledgment) and psychopathological symptoms (internalizing and externalizing behaviors). Children with CI and TH children were rated similarly on most of the empathic skills. Yet, fewer prosocial actions were reported in children with CI than in TH children. In both groups, affective empathy decreased with age, while prosocial actions and emotion acknowledgment increased with age and stabilized when children entered primary schools. Attention to emotions increased with age in children with CI, yet remained stable in TH children. Moreover, higher levels of affective empathy, lower levels of emotion acknowledgment, and a larger increase in attention to emotions over time were associated with more psychopathological symptoms in both groups. These findings highlight the importance of social access from which children with CI can learn to process others' emotions more adaptively. Notably, interventions for psychopathology that tackle empathic responses may be beneficial for both groups, alike.

INTRODUCTION

Empathy is the capacity to share and understand other people's emotions, and to affectively and appropriately respond to those emotions (Hoffman, 1990; Rieffe et al., 2010). This capacity is essential for successfully navigating daily social life, given its role as the "social glue" in stimulating social belongingness (De Waal, 2009). Higher levels of empathy are associated with better social competence and fewer symptoms of internalizing and externalizing problems (e.g., Mayberry & Espelage, 2007; Pursell et al., 2008; Smith, 2015; Tully & Donohue, 2017). Yet despite its importance in children's psychosocial wellbeing, very little is known about the development of such capacity in children with a cochlear implant (CI), who are at risk for experiencing difficulties in social participation during early childhood as a result of hearing loss (Calderon & Greenberg, 2012; Rieffe et al., 2015). The current four-wave study attempted to discover how empathy develops in children with a CI, and how this development is associated with early symptoms of psychopathology across the preschool years, by using a longitudinal design for the first time.

For the maturation of empathy, four skills are involved during the preschool years. According to Hoffman (1990), empathy starts with an affective mirroring of other people's emotions during the first days of life. This affective component of empathy triggers emotional arousal in the person witnessing an emotional display, allowing that individual to feel what others are feeling (Hatfield et al., 1993; Hoffman, 1990). A newborn tends to experience an overwhelming level of personal emotional arousal when witnessing someone in distress because they are not yet able to differentiate between themselves and another person. However from the age of one year on, children become more aware of other people's emotional displays, and experience a lower level of personal arousal (Hoffman, 1990; Rieffe et al., 2010). This enables a child to shift their attention away from their own arousal to the person who is experiencing the emotion. Paying attention to other people is the starting point for understanding how others feel. As a child's responses to others' emotions increase, they may start to show concern for other people through prosocial actions, for example by comforting, helping, or sharing (Hoffman, 1990; Rieffe et al., 2010). An early form of such prosocial actions can be observed even in two-year-old children (Zahn-Waxler et al., 1992). Moreover, being able to acknowledge other people's emotions is a prerequisite for understanding the causes of those feelings. This skill starts developing as early as four months old, but it is not mastered until middle childhood (Durand et al., 2007; Montague & Walker-Andrews, 2001).

For young children with hearing loss living in a predominantly hearing social environment, the acquisition of these empathic skills is not easy. Children need social exposure and participation to master these skills for attending to and understanding others' emotions, and for reacting appropriately to them (Rieffe et al., 2015). However, children with hearing loss in a predominantly hearing world are given fewer chances to observe or participate in social interactions, due to communicative difficulties. They also miss out on a variety of information relevant for learning the meaning of emotions, such as the sound of other crying babies, emotion expressions displayed behind them, and conversations not directed to them. Such information represents sources of incidental learning, or unplanned, unintended, and unprompted learning (Kelly, 2012). Incidental learning is important for the acquisition of social-emotional skills (Moeller, 2007).

Even within their family, children with hearing loss face challenges in dyadic interactions from birth because over 90% of them are born to hearing families (Mitchell & Karchmer, 2004), and parents with typical hearing often know less well how to attract attention or communicate with a child with hearing loss (Calderon & Greenberg, 2012). This often results in a more directive and protective parenting style, with less turn-taking and shorter utterances in conversations, and less usage of mental-state language (Dirks et al., 2020; Morgan et al., 2014; Pinquart, 2013). Although CIs significantly improve many deaf children's hearing and speech performance (Waltzman, 2006), these children still receive limited auditory input both before and after implantation, due to the congenital hearing loss, and the technological limitations of the hearing devices (Bacon et al., 1998). Moreover, parents and other family members can easily overestimate the hearing ability of a child with a CI.

To date, our knowledge regarding empathic maturation in the population with hearing loss is scarce. In a study that measured overall empathy levels using teacher reports, children with hearing loss aged 4 to 12 years were rated lower than their typically hearing (TH) peers (Peterson, 2016). When empathic skills were investigated separately, the results were mixed. Children with or without hearing loss did not differ in levels of affective empathy (Dirks et al., 2017; Netten et al., 2015). Yet, parent reports and self-reports indicated that children with hearing loss showed fewer prosocial actions (Dirks et al., 2017; Netten et al., 2015) while looking more often at the person experiencing an emotion than TH children during an observational task (Netten et al., 2015). Preschoolers with a CI also exhibited difficulties in acknowledging others' emotion expressions (H.Wang et al., 2019; Y.Wang et al., 2016).

A longitudinal account of empathy is highly relevant to our knowledge of social-emotional development, as empathy is consistently found to play a protective role in typical development. For example, a higher level of empathy is associated with fewer internalizing symptoms, such as depression and anxiety (e.g., Smith, 2015; Tully & Donohue, 2017), and with fewer externalizing behaviors, such as aggression and conduct problems (e.g., Mayberry & Espelage, 2007; Pursell et al., 2008). According to two longitudinal studies in typically developing preschool children, this negative association between empathy (measured as an overall response) and behavioral difficulties is stable from preschool to early primary school years (Hastings et al., 2000; Zhou et al., 2002), suggesting that empathy is effective in reducing behavioral problems. When children can share emotions, understand others' perspectives, and are motivated to provide help or comfort, they establish better social support (such as better-quality friendship; Denham et al., 1990; Zhou et al., 2002) and do less harm to other people (Lovett & Sheffield, 2007; Rieffe & Terwogt, 2006).

Whether the protective effect of empathy on psychopathology can also be extended to the population with hearing loss remains an unexplored topic. Considering that the prevalence rates of internalizing and externalizing behaviors in deaf and hard-of-hearing children are 4 to 14 percentage points higher than the rates in TH children (e.g., Fellinger et al., 2008; Theunissen et al., 2014; Van Eldik et al., 2004), further investigations on the role of empathy in the development of children with hearing loss may carry important rehabilitative implications.

The Present Study

In this four-wave study, we focused on the preschool years because it is a crucial period for learning various social and emotional skills, and thus an important window for understanding early difficulties in social-emotional functioning experienced by children with a CI (Pahl & Barrett, 2007). With a longitudinal design, we could determine whether these children showed an early delay and remained low over time, or experienced elevated difficulties with increasing age due to limited input from the social environment.

Our first goal was to examine the levels and developmental trajectories of four empathic skills (affective empathy, attention to others' emotions, prosocial actions, and acknowledgment of others' emotions) in 1- to 5-year-old children with a CI and TH children by measuring these skills at four time points with a 12-month interval. Regarding the overall levels of empathic skills, we expected children with a CI to score similarly on affective empathy, higher on attention to emotions, and lower on prosocial actions and emotion acknowledgment than their TH peers (Dirks et al., 2017; Netten et al., 2015; H. Wang et al., 2019; Y.Wang et al., 2016). Regarding the developmental trajectories of these skills, we made hypotheses for TH children based on the theory proposed by Hoffman (1990). We expected an increase with age in attention to others' emotions, prosocial actions, and emotion acknowledgment in preschool TH children. We also expected a decrease in the level of affective empathy with age as TH children become better at attending to other people's emotions rather than their own arousal. As to children with a CI, we did not make directional hypotheses because to our knowledge, no longitudinal research on empathy had been undertaken in individuals with hearing loss.

Our second goal was to examine the longitudinal effects of empathic skills on early symptoms of psychopathology (i.e., internalizing and externalizing behaviors) in children with a CI and TH children. Based on the longitudinal studies on children with typical development (Hastings et al., 2000; Zhou et al., 2002), we expected all empathic skills to have a negative association with internalizing/externalizing behaviors in TH children. We did not make specific hypotheses for each empathic skill and for children with a CI given the lack of longitudinal studies on separate empathic skills and on children with hearing loss.

METHODS

Participants and Procedure

A total of 343 children participated in this study (Table 1). Of these, 71 children had a CI, and the other 272 children were TH. They were between 1 and 5 years old at Time 1 (M = 3.16, SD = 1.14). The children with a CI were recruited through hospitals and family counseling services in the Netherlands and the Dutch-speaking areas of Belgium. The TH children were recruited through day-care centers and primary schools in the Netherlands. None of the children had additional disabilities. The children with a CI were diagnosed with congenital or prelingual severe-to-profound bilateral hearing loss, and received at least one CI (37 children received bilateral implantation). All of the children with a CI entered a tailored rehabilitation program following implantation for aural-verbal training, technical support for the device, and specialized playgroups.

Parents were asked to fill out questionnaires on social-emotional development at four time points. The average duration of the time intervals was 13.14 (SD = 3.08), 11.97 (SD = 1.22), and 11.97 (SD = 1.07) months between Time 1 and Time 2, Time 2 and Time 3, and Time 3 and Time 4, respectively. Other information, such as household income, parent's educational level, age at implantation, and hearing history, was acquired from parents and/or medical records. Besides, children's fine motor development at Time 1 was used as an indicator of their cognitive development, given the difficulty to obtain reliable IQ scores in children as young as one year and the close link between fine motor skills and cognitive skills, such as executive functioning (Roebers et al., 2014) and reasoning (Martzog et al., 2019; Pitchford et al., 2016). The fine motor scale (30 items) of the standardized Dutch-version *Child Development Inventory* (*CDI*) was used (Ireton & Glascoe, 1995). Parents rated on all 30 items whether their children showed a certain fine motor skill (0 = no; 1 = yes). As Table 1 shows, at Time 1 the children with a CI did not differ from the TH children in their age, t = 1.42, p = .155, gender distribution, χ^2 = 2.35, p = .126, fine motor development, t = 1.19, p = .235, parental education level, t = -.10, p = .924, or net household income, t = 1.28, p = .216.

The study protocol was approved by the Medical Ethics Committee of the Leiden University Medical Center. Informed consent forms were signed by the parents of all children. This study is part of a large-scale longitudinal project on the social-emotional development of children with communicative difficulties, including children with a CI, children with Autism Spectrum Disorder, and children with Developmental Language Disorder (Broekhof et al., 2015; Ketelaar et al., 2010, 2013, 2015, 2017; Li et al., 2020; Netten et al., 2018; Rieffe & Wiefferink, 2017; Wiefferink et al., 2012, 2013). Part of the data on empathy (Time 1) and on psychopathology (Time 1 to 3) in children with a CI and TH children was previously reported by Ketelaar and colleagues (2013, 2017) and Netten and colleagues (2018), respectively.

Table 1. Participant characteristics.

	CI	TH
Number of children at Time 1	71	272
Gender, female, n (%)	28 (39%)	135 (50%)
Age at Time 1, years, mean (SD)	3.21 (1.22)	3.25 (1.13)
Fine motor development[a], mean (SD)	19.95 (6.92)	20.83 (6.51)
Parental education[b], mean (SD)	3.51 (.69)	3.46 (.77)
Net household income[c], mean (SD)	3.63 (1.15)	3.91 (.99)
Age at implantation, years, mean (SD)	1.37 (.73)	
Duration of using CI at Time 1, years, mean (SD)	1.54 (1.07)	
Type of amplification		
Unilateral cochlear implantation	14 (20%)	
Bimodal fitting	16 (23%)	
Bilateral cochlear implantation	37 (52%)	
Unknown	4 (5%)	
Preferred mode of communication		
Spoken language only, n (%)	19 (27%)	
Sign-supported Dutch, n (%)	34 (48%)	
Dutch sign language, n (%)	7 (10%)	
Combination of communication modes, n (%)	8 (11%)	
Unknown	3 (4%)	

Note. CI: cochlear implant. TH: typically hearing.
[a] Scores ranged between 0 and 30.
[b] Parental education level: 1 = no/primary education; 2 = lower general secondary education; 3 = higher general secondary education; 4 = college/university.
[c] Net household income: 1 = less than €15,000; 2 = €15,000 – €30,000; 3 = €30,000 – €45,000; 4 = €45,000 – €60,000; 5 = more than €60,000.

MATERIALS

Parent Reports

The *Empathy Questionnaire* was designed to measure young children's empathic behaviors in daily life (Rieffe et al., 2010). It was rated by parents to indicate the extent to which each item reflected their child's behaviors during the past two months (0 = never; 1 = sometimes; 2 = often), and it includes three subscales: affective empathy (6 items; e.g., "When another child cries, my child gets upset too"), attention to emotions (7 items; e.g., "When another child is angry, my child stops his own play to watch"), and prosocial actions (6 items; e.g., "When another child starts to cry, my child tries to comfort him/her"). Internal consistency was adequate across time for affective empathy ($66 \leq \alpha \leq .78$), attention to emotions ($72 \leq$

α ≤ .82), and prosocial actions (.66 ≤ α ≤ .76; see Table 2 for the internal consistency for all measures per time point).

The emotion acknowledgment subscale of the *Emotion Expression Questionnaire* was used to measure children's ability to acknowledge their parents' emotions (Rieffe et al., 2010). Parents rated on a 5-point scale (1 = almost never; 5 = almost always) the extent to which their children could understand their emotions (6 items; e.g., "Does your child understand when you are angry?"). Internal consistency was good across time (.70 ≤ α ≤ .78).

The *Early Childhood Inventory-4* (ECI-4) is a questionnaire rated by parents on a 4-point scale (0 = never; 3 = very often), according to the frequency of psychopathological symptoms in their children (Sprafkin et al., 2002). It is a widely used tool for assessing Diagnostic and Statistical Manual of Mental Disorders (4th ed.; DSM-IV) symptoms. We used the subscales for major depressive disorder (6 items) and anxiety disorder (14 items, including generalized anxiety disorder, separation anxiety disorder, and social anxiety disorder), to indicate the level of internalizing behaviors. For measuring the level of externalizing behaviors, we used the subscales for peer conflict (10 items), oppositional defiant disorder (8 items), and conduct disorder (10 items). The scores of each subscale were summed to calculate final scores for internalizing/externalizing behaviors, where a higher score reflected more symptoms of psychopathology. Internal consistency was good across time for internalizing behaviors (.78 ≤ α ≤ .88), and for externalizing behaviors (.87 ≤ α ≤ .92).

ANALYSIS AND RESULTS

Statistical analyses were performed using SPSS version 25 (SPSS Inc., Chicago, IL, USA). Graphs were made in R version 3.6.3 (*Ggplot2* package). Considering the two-level structure in our data, i.e., time points (level 1) nested within participants (level 2), we used linear mixed models (LMMs) to analyze the longitudinal data. LMMs allow the dependency within the data to be accounted for. A predictor variable was regarded as having a significant contribution to the model when its 95% confidence interval (95% CI) did not include the value zero.

Missing Values and Multiple Imputation

At Time 1, missing scores were found on *Empathy Questionnaire* (0 CI, 4 TH), *Emotion Expression Questionnaire* (0 CI, 2 TH), *ECI-4* (4 CI, 16 TH), fine motor development (16 CI, 27 TH), parental education level (18 CI, 38 TH), and net household income (31 CI, 95 TH). The Little's MCAR test showed that data were missing at random, $\chi^2 = 20955$, $df = 21054$, $p = .684$. To handle the missing data at Time 1, we used multiple imputations (MI). The MI technique fills in missing data according to participant characteristics and relations

Table 2. Psychometric properties and total scores of study variables at each time point

	No. items	Scale	Cronbach's alpha	Mean (SE)[a]		
				CI	TH	t value[a]
Time 1						
Affective empathy	6	0-2	.69	2.59 (.28)	2.24 (.12)	-1.30
Attention to emotions	7	0-2	.72	9.32 (.33)	9.70 (.16)	1.08
Prosocial actions	6	0-2	.76	4.45 (.31)	5.05 (.16)	1.73
Emotion acknowledgment	6	1-5	.76	22.65 (.41)	22.88 (.21)	.50
Internalizing behaviors	20	0-3	.78	2.78 (.39)	2.87 (.19)	.21
Externalizing behaviors	28	0-3	.87	8.13 (.75)	7.74 (.32)	-.52
Time 2						
Affective empathy	6	0-2	.78	2.36 (.32)	2.43 (.23)	.18
Attention to emotions	7	0-2	.75	10.05 (.37)	9.91 (.26)	-.30
Prosocial actions	6	0-2	.71	5.55 (.37)	5.92 (.23)	.86
Emotion acknowledgment	6	1-5	.70	23.71 (.50)	24.18 (.30)	.83
Internalizing behaviors	20	0-3	.80	3.22 (.49)	3.39 (.39)	.27
Externalizing behaviors	28	0-3	.89	9.48 (.96)	7.58 (.60)	-1.73
Time 3						
Affective empathy	6	0-2	.66	2.3 (.30)	2.04 (.20)	-.74
Attention to emotions	7	0-2	.74	9.91 (.39)	9.59 (.27)	-.66
Prosocial actions	6	0-2	.71	5.88 (.33)	6.69 (.23)	1.99*
Emotion acknowledgment	6	1-5	.78	24.04 (.52)	24.32 (.34)	.47
Internalizing behaviors	20	0-3	.81	3.39 (.63)	3.33 (.37)	-.10
Externalizing behaviors	28	0-3	.87	8.66 (.86)	7.59 (.56)	-1.08
Time 4						
Affective empathy	6	0-2	.74	2.02 (.43)	1.82 (.21)	-.46
Attention to emotions	7	0-2	.82	10.65 (.48)	9.84 (.35)	-1.28
Prosocial actions	6	0-2	.66	5.93 (.41)	6.90 (.26)	2.02*
Emotion acknowledgment	6	1-5	.72	24.45 (.54)	24.28 (.36)	-.26
Internalizing behaviors	20	0-3	.88	4.93 (1.18)	4.49 (.62)	-.03
Externalizing behaviors	28	0-3	.92	10.50 (1.58)	7.86 (.78)	-1.68

Note. CI: children with a cochlear implant. TH: typically-hearing children. * $p < .05$ between children with a CI and TH children.
[a] Pooled results after multiple imputations.

observed in the data with other participants (Azur et al., 2011; Schafer & Graham, 2002; van Ginkel et al., 2019), thus increasing statistical power and reducing biases caused by missing data (Donders et al., 2006; Netten et al., 2017). The following variables were included for the estimation of missing values: age, gender, hearing status, fine motor development, parental education level, net household income, and outcomes on the three parent reports. Ten imputations were performed (Sterne et al., 2009), and pooled results are reported.

Only missing data at Time 1 were imputed because LMMs can handle missing follow-up data points of a participant (Twisk et al., 2013). Therefore, participants who had missing data at Time 2, 3, or 4 were still included in the analyses. Missing data were found at Time 2 (25 CI and 166 TH children), Time 3 (30 CI and 180 TH children), and Time 4 (44 CI and 204 TH children). For 38 children with a CI (54%) and 92 TH children (34%), data were available for at least three time points. Children with and without missing data points did not differ in age at Time 1, t = -1.26, p = .208, gender distribution, χ^2 = 1.29, p = .256, fine motor development, t = -.99, p = .324, and parental education level, t = -1.16, p = .247. Yet children who participated in all waves had higher net household income than those with missing data points, t = -2.59, p = .010.

Descriptive Statistics

Table 2 shows the total scores and standard deviations for the variables per group at each time point and the independent t-statistics for group comparison. Based on parent reports, the children with a CI exhibited fewer prosocial actions than their TH peers at Time 3, t = 1.99, p = .047, and Time 4, t = 2.02, p = .044. No other group differences were found. See Supplementary Materials S5.1 and S5.2 for correlations between study variables and graphic representations of individual variations at the four time points.

Levels and Developmental Trajectories of Empathic Skills

Via a formal model-fitting procedure of LMM, increasingly more complex models were fitted to the data. By using the total score of each empathic skill, respectively, as the dependent variable, we started by fitting an unconditional means model which included only a fixed and random intercept as a baseline. Then, we included age (centered) to the model and examined two trends of change: linear and quadratic. A random-slope effect for age and a fixed effect for gender (0 = boys; 1 = girls) were added to the best age model, which did not improve the model fits and thus are not reported here. Finally, group membership (0 = TH; 1 = CI) and its interaction with age were added, to examine if there were group differences in the overall level of each empathic skill and its developmental course. The -2 log likelihood (-2*LL*) values were used to compare between the model fits (the stacking procedure suggested by Wood and colleagues (2008) was used to obtained the -2*LL* values after multiple imputations). The likelihood ratio test was conducted to test whether the deviance in the -2*LL* values was significant. Preferred models should have significantly lower -2*LL* values. Best-fitting models are reported in Table 3.

Affective empathy and attention to others' emotions were both best explained by a linear age-model (Figure 1a and 1b). Affective empathy decreased with age, b = -.01, 95%

Table 3. Regression weights [95% CI] for explaining the developmental trajectories of empathic skills.

Parameter	Affective empathy	Attention to others' emotions	Prosocial actions	Emotion acknowledgment
Age linear	-.01 [-.02, -.01]	-.01 [-.02, .01]	.06 [.05, .07]	.04 [.02, .05]
Age quadratic	-	-	-.001 [-.001, -.0003]	-.001 [-.001, -.0003]
Group	-	.15 [-.48, .77]	-.55 [-1.06, -.03]	
Group x Age	-	.03 [.01, .05]	-.01 [-.03, .004]	

Note. Group was coded as 0 = typically hearing, 1 = cochlear implant. Significant effects are bolded.

CI [-.02, -.01], and no group differences appeared. Attention to others' emotions remained stable over time in TH children, b = .01, 95% *CI* [-.02, .01], but increased with age in children with a CI as indicated by an interaction of group with age, b = -.03, 95% *CI* [.01, .05]. No other group effects were observed.

Prosocial actions and emotion acknowledgment were both best explained by a quadratic age-model. This indicates that prosocial actions and emotion acknowledgment increased with age and stabilized around the time when children entered primary schools (Figure 1c and 1d). Yet, parents reported that children with a CI showed fewer prosocial actions than their TH peers across time, b = -.55, 95% *CI* [-1.06, -.03]. For emotion acknowledgment, there were no group differences.

Longitudinal Effect of Empathy on Internalizing/Externalizing Behaviors

To investigate both between- and within-person effects of empathic skills on the development of internalizing/externalizing behaviors across time, we first calculated a mean score (between persons) and a change score (within persons), for each empathic skill. The mean score is represented by the overall mean score of the four measurement points per participant (i.e., a participant's average level across time points). It was added to the model to examine how the development of psychopathological symptoms could be explained by the differences between participants in the level of a given empathic skill. The change scores indicate the deviations around this mean score (i.e., Time 1 – mean; Time 2 – mean; Time 3 – mean; Time 4 – mean), and were used to examine whether the development of psychopathological symptoms could be explained by within-person changes in the level of an empathic skill over time (Singer & Willett, 2003).

By using the frequency of internalizing and externalizing behaviors, respectively, as the dependent variable, we started with fitting a model with three control variables: age, gender, and group membership. In the next model, all the empathic skills (mean and change scores) were fitted to the model to check their unique contributions to internalizing/externalizing behaviors. Subsequently, we added the interaction terms between group and one of the empathic skills (mean and change scores), one skill at a time, to examine whether

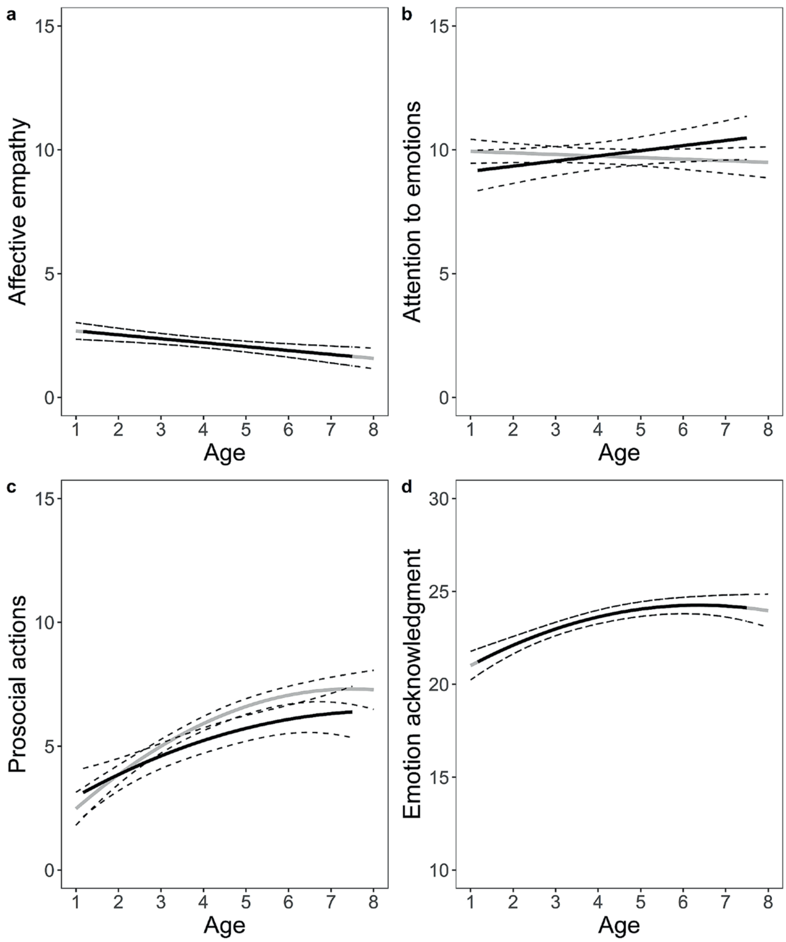

Figure 1. Longitudinal graphic representation of the predicted values based on the optimal fitting model for **1a.** affective empathy; **1b.** attention to others' emotions; **1c.** prosocial actions; **1d.** emotion acknowledgment. Lines for children with a cochlear implant are displayed in black, and lines for typically-hearing children are displayed in grey. Dotted lines represents 95% confidence interval.

the effect of the skill differed between groups. The interaction terms would be included in the final model if adding them significantly improved the model fit. Table 4 shows the best-fitting models for internalizing and externalizing behaviors.

In the model for internalizing behaviors, we observed effects of affective empathy (mean score), b = .63, 95% *CI* [.44, .82], affective empathy (change score), b = .23, 95% *CI* [.05, .41], and attention to others' emotions (change score), b = .19, 95% *CI* [.03, .35]. This indicates that children with a higher mean level of affective empathy, and children with a larger increase in their affective empathy and attention to emotions over time, showed an

Table 4. Regression weights [95% CI] of empathic skills (mean and change scores) for predicting internalizing/externalizing behaviors.

Parameter		Internalizing	Externalizing
Age		**.06 [.04, .07]**	**.04 [.02, .06]**
Gender		.42 [-.21, 1.06]	-1.07 [-2.17, .02]
Group		-.26 [-1.01, .48]	.44 [-.83, 1.71]
Affective empathy	Mean	**.63 [.44, .82]**	**.35 [.02, .67]**
	Change	**.23 [.05, .41]**	.19 [-.10, .48]
Attention to emotions	Mean	.07 [-.08, .22]	.15 [-.10, .41]
	Change	**.19 [.03, .35]**	-.09 [-.34, .16]
Prosocial actions	Mean	-.16 [-.32, .004]	-.01 [-.29, .27]
	Change	-.06 [-.22, .09]	.06 [-.19, .30]
Emotion acknowledgment	Mean	-.11 [-.22, .0003]	**-.21 [-.40, -.01]**
	Change	-.05 [-.17, .07]	-.12 [-.31, .08]

Note. Gender was coded as 0 = boys, 1 = girls. Group was coded as 0 = typically hearing, 1 = cochlear implant. Significant effects are bolded.

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increase in internalizing behaviors. The addition of group interaction terms did not further improve the model fits. This suggests that the effects of the empathic skills in the two groups had similar strengths across time.

In the model for externalizing behaviors, we observed effects of affective empathy (mean score), $b = .35$, 95% *CI* [.02, .67], and emotion acknowledgment (mean score), $b = -.21$, 95% *CI* [-.40, -.01]. This suggests that children with higher mean level of affective empathy and a lower mean level of emotion acknowledgment showed an increase in externalizing behaviors. Adding group interaction terms did not improve the model fits, suggesting similar strength for empathic effects in the two groups across time.

DISCUSSION

Current knowledge about children's development regarding empathy is largely based on studies of children with typical development. This four-wave study is among the first to longitudinally investigate the development of empathy and its effects on early symptoms of psychopathology in children with a CI and children with typical hearing. Notably, differences between the groups were not often observed. This suggests that the empathy development of children with a CI was broadly on par with their TH peers. When parents reported on their child's level of affective empathy, no group differences appeared. In both groups, affective empathy decreased with age, and higher levels of affective empathy were related to more psychopathological (i.e., internalizing and externalizing) symptoms.

The overall level of attention to others' emotions were not different between the groups, whereas the trajectories of the two groups differed: A stable trend in TH children but an increasing trend in children with a CI were observed over time. In the two groups alike, children who became increasingly attentive to others' emotions over time were more likely to develop internalizing behaviors. Prosocial actions were more often reported in TH children than in children with a CI. Over time, an increase in prosocial actions was observed in both groups, which stabilized after children entered primary schools. Yet this trend was unrelated to the development of psychopathology. The level of emotion acknowledgment did not differ between the groups. Like prosocial actions, emotion acknowledgment increased with age and became stable at the beginning of school age in both groups. Higher levels of this skill contributed to a decrease in externalizing symptoms. Below, we will discuss the implications of these findings in greater detail.

Affective Empathy

Children with a CI and their TH peers were similar in the levels and developmental trajectories of affective empathy. In line with the theory proposed by Hoffman (1990), affective empathy declined with age in both groups of this study. Considering that affective empathy – also called emotion contagion (Hatfield et al., 1993) – is a basic building block of empathy, this result is not surprising. Affective empathy involves a primitive arousal mode, which is thought to be present at birth and prewired in the mirror neuron system in the brain (Decety & Jackson, 2004; Eisenberg et al., 2006; Engen & Singer, 2013). When the level of such arousal is too high, children tend to focus on the emotional reaction triggered in themselves and to alleviate their own arousal, rather than turning their attention to the person actually experiencing the emotion (Eisenberg et al., 2006; Hoffman, 1990). With an improved self-other differentiation, children experience a more moderate level of personal arousal. The decreasing trend we found in the current study appears to follow this developmental trajectory, driven by the need to keep a moderate level of personal arousal – thus able to react adaptively while sharing others' emotions.

For this reason, children in this study who instead retained higher levels of affective empathy, or showed an increase in the levels of affective empathy over time, were at greater risk of developing psychopathological symptoms, including both internalizing and externalizing symptoms. These children experienced a higher level of personal arousal when witnessing others' emotions, which could lead to self-oriented responses to the emotions and prevent them from responding adaptively to the situation (Eisenberg et al., 2006; Rieffe et al., 2010). An inward processing of emotions, also when triggered by others' affective states, and incompetent reactions to the external world, are characteristic of internalizing and externalizing behaviors.

Attention to Others' Emotions

In the current study, the level of attention to others' emotion remained stable in TH children, but increased in children with a CI over time. According to Hoffman (1990), children start to direct more attention to others' emotions from the age of one year. At this age, children know better that what others are feeling is different from their own affective state, thus they can observe others' emotional displays without experiencing too much personal arousal. In our study, children at the first measurement had a mean age of three years. The stable trend we found in TH children suggests that from the age around three years TH children become more skilled with grasping emotional information and the processing is more automatic to them. Thus, attention beyond sufficient level is unnecessary for TH children.

This result showed that, like affective empathy, attention to emotions may not be the more the better. While directing attention to others helps a person understand others' emotions, paying too much attention to others' emotional displays may leave the person with little mental energy to channel to other things in the surroundings or to evaluating a proper response. Following the same line of reasoning, the increasing level of attention to others' emotions we observed in children with a CI may reflect elevated vigilance or sensitivity to emotions (Pérez-Edgar et al., 2010). Alternatively, children may recruit increasingly more attentional resources because they find emotional events become more challenging to process (Wild et al., 2012). Whichever is the case, increased attention over time may reflect that children experience more effortful processing of others' emotions with age.

This group difference in the developmental trend of attention could be alarming, because our results also showed that children who became increasingly attentive to others' emotions over time were more likely to develop internalizing symptoms. The more effortful processing of others' emotions could lead to more difficult coping with negative emotions observed in other people for these children. Although in this study we did not find children with a CI to develop more internalizing behaviors than their TH peers during the preschool years, the increasing levels of attention to emotions observed in children with a CI highlight the need to study these children's empathic maturation and psychopathological symptoms at later stages of life. Moreover, it should be noted that only the change scores of attention to emotions, but not the mean scores, contributed to the development of internalizing behaviors in our analysis. This indicates that changes in attention level is a signal that children are facing difficulties processing others' emotions and may need support.

Prosocial Actions and Emotion Acknowledgment

Prosocial actions and emotion acknowledgment both increased with age and stabilized when the two groups of children entered primary schools. Unlike affective empathy and attention to others' emotions, which may involve only "sit and watch," prosocial actions and emotion acknowledgment require proactive responses and understanding of emotions and social rules. Our results suggest that children keep developing these skills throughout preschool years until around the beginning of school age, when they start to recognize others' basic emotions and show the intention to comfort or help other people in a more stable manner.

However, despite the similar developmental trajectories, children with a CI were rated lower on prosocial actions than their TH peers. Such a group difference may be best explained by children with a CI's limited incidental learning (Netten et al., 2015) and Theory of Mind (ToM) ability (Ketelaar et al., 2012). To react prosocially to others' emotions, children have to know why the other person is experiencing an emotion, and how to benefit the person in a socially appropriate way. This requires ToM, i.e., the ability to understand, explain, and predict other people's mental states, which guides children's (emotional) behaviors (Goldman, 2012; Wellman & Liu, 2004). Yet, such an ability could only be obtained within a social context where children learn the why and how through observing, overhearing, and participating in social interactions (Rieffe et al., 2015; Saarni, 1999). As described earlier, children with a CI experience a lower quantity and quality of social interactions in the predominantly hearing social environment. Many opportunities for learning prosocial actions are thus missed during early childhood.

While the development of prosocial actions was unrelated to psychopathological symptoms, higher levels of emotion acknowledgment were associated with fewer externalizing behaviors, in the two groups alike. When children improve the ability to acknowledge others' emotions, they may better theorize other people's states of mind and more appropriately interpret the situation they are in (Brüne, 2005; Cassidy et al., 2003; Lane et al., 2010). A more thorough evaluation of social situations may thus help children react to the external world in a more adaptive manner. However, it should be noted that children with a CI are known for their ToM problems (Ketelaar et al., 2012; Peterson, 2016; Peterson & Siegal, 2000). When these children are required to theorize more complex mental states in others beyond the basic emotions examined in this study, emotion acknowledgment might start to be challenging. This again underscores the importance of giving children with a CI an accessible social environment because the social context is required for learning emotional knowledge.

Limitations and Future Research

The current study has the strength of examining different empathic skills in children with a CI and TH children using a four-wave longitudinal design. It is among the first to investigate empathy development in children with hearing loss, and to show that maladaptive empathic responses could be a risk factor for children with typical and atypical development alike, when they are studied over time. Our outcomes stress the idea that each empathic skill may be related differently to behavior, and therefore needs to be examined separately.

However, some considerations are needed when interpreting the results. First, further investigations will be necessary to understand how much the current outcomes can be generalized to other groups of children with hearing loss, such as those with mild-to-moderate or unilateral hearing loss. Deaf and hard-of-hearing children represent a highly heterogeneous group, and children with a CI are usually the ones that receive more intensive rehabilitative training, and have better auditory and language performance.

Second, it should be noted that we used only parent reports. Past studies have shown that parent-child agreement on children's emotional competence and psychopathology is lower when the child has clinical conditions than when the child is typically developing (Barbosa et al., 2002; Johnson et al., 2009), and the self-reported level of internalizing behaviors is often higher than parent-reported level (Anmyr et al., 2012; Hope et al., 1999). Therefore, collecting data from different methods, such as real-life playground observations or in vivo experiments, is suggested for future research to increase ecological validity.

Third, the questionnaires used in the current study were designed for young children. This means that only empathic skills that involve basic emotions and simple social interactions were considered. Therefore, the stabilizing developmental trends and small group differences found in this study should be interpreted with caution. Further studies are needed to understand how children with a CI develop to show empathy to more complex emotions (e.g., embarrassment and shame) and social situations (e.g., what to do when others are having arguments).

CONCLUSIONS

The present four-wave study paints a largely positive picture of young children with a CI. These preschool children with a CI and their TH peers in general had similar levels of empathic skills and developed these skills with similar trajectories. However, parents reported that children with a CI were increasingly more attentive to others' emotions over time and carried out fewer prosocial actions across time, compared to TH children. Children with a CI may need more opportunities for social access to learn to process others' emotions less effortfully and react to other people more prosocially.

Moreover, the effects of empathic skills on early symptoms of psychopathology were similar in the two groups of children. This indicates that intervention programs for psychopathology that tackle children's empathic responses could be beneficial for children with a CI and TH children, alike. On one hand, children who show a strong affective response and become increasingly attentive to other people's emotional displays may need extra support to develop more adaptive behaviors. Such an intervention may be particularly relevant to children with a CI, given their increasing level of attention to emotions during preschool years. On the other hand, training children to acknowledge other people's emotions may help them understand emotional situations better, thus decreasing externalizing symptoms.

Taken together, this study demonstrated the necessity that children with a CI are provided with more opportunities to acquire emotional knowledge in daily social life. This may be achieved by making social interactions more accessible to these children through, for example, multiple communication means (e.g., verbal language supported by sign language) and a more inclusive environment where these children's needs are addressed. Including the emotional domain in rehabilitation programs for children with a CI is also suggested.

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CHAPTER 6

General Discussion

When interacting with other people, it is essential to understand what our interaction partners are feeling, and to respond with appropriate affect to their emotions. Such skills are closely related to social belongingness (De Waal, 2010), social competence, and adjustment (De Castro et al., 2005). According to the Social Information Processing (SIP) model (Crick & Dodge, 1994), people enter each social situation with a database of social-emotional knowledge that is acquired through past social interaction experiences. People constantly refer to and update this database during social encounters, and this process guides their responses to any given situation and facilitates future interactions (see Box 1 in **Chapter 1**).

In a social environment composed mostly of people with typical hearing, children who are deaf or hard of hearing (DHH) update this database of social-emotional knowledge with experiences that are very different from their typically hearing (TH) peers. They miss out on crucial information in daily social encounters, and often receive shorter and more directive communication from their parents, as compared to TH children (Dirks et al., 2020; Leibold et al., 2013; Morgan et al., 2014). As a result, many DHH children experience lower quantity and quality of social interactions, which further limits their acquisition of knowledge about emotions and social rules.

Unfortunately, to date little is known regarding the difficulties these children face in daily social life, because the social-emotional development of DHH children remains an underexplored topic. Yet we do know that, even after several years of using hearing technology, DHH children face lower levels of social competence and higher rates of prevalence for behavioral difficulties than TH children (Fellinger et al., 2008; Hoffman et al., 2016; Van Eldik et al., 2004). Obtaining better knowledge about the factors underlying DHH children's known social and emotional difficulties will allow us to develop more effective supports.

In the current thesis, we approached this issue by examining DHH children's responses to other people's emotions in a social context. Based on the SIP model (Crick & Dodge, 1994), we attempted to gain better knowledge on how DHH children encode, interpret, and react to others' emotions. These are the steps one would take when engaging in a social encounter. Moreover, we examined how such skills are related to children's psychosocial functioning. We hypothesized that the limited access to social learning experienced by DHH children could lead to an atypical acquisition of social-emotional knowledge, and that emotions could therefore function differently in these children during social encounters. To test this hypothesis, we used a variety of measures that included eye tracking, pupillometry, behavioral tasks, parent reports, and longitudinal follow-up.

In this chapter, we summarize and integrate the main findings of this thesis, explore practical implications, discuss strengths and weakness of the studies, and suggest directions for future research.

MAIN OUTCOMES

The first aim of this thesis was to examine the two initial steps of the SIP model (encoding, and the interpretation of emotional cues) in order to investigate the underlying patterns for understanding emotional information in DHH and TH children.

Using eye tracking and pupillometry along with computerized tasks, we examined whether and how DHH and TH children differed in the encoding and interpretation of emotional cues, when trying to understand others' facial expressions (**Chapter 2**) and others' emotions triggered in dynamic social situations (**Chapter 3**). In two separate tasks, children aged three to ten years old were presented with still images of faces displaying basic emotions (anger, fear, happiness, and neutral emotions), and watched videos of prototypical social interactions between a target person and an emotion-triggering interaction partner. During the encoding phase, participants' eye gaze and pupil diameter were measured by an eye-tracking device. Then, participants were asked to interpret the emotion expressed in the faces and triggered by the social situations. (Physiological arousal, assessed in terms of pupil dilation, was not included in the analysis of the social situations, due to difficulties in reliably controlling for luminance in dynamic videos).

It is known that DHH individuals, despite a cochlear implant (CI) or hearing aid (HA), rely partly on lipreading and pay more attention to the mouth region when they are presented with language information, as their hearing is not on the same level as their TH peers (Letourneau & Mitchell, 2011; Schreitmüller et al., 2018; Tye-Murray et al., 2014; Wang et al., 2017; Worster et al., 2018). Yet regarding gaze patterns when encoding still emotional faces (**Chapter 2**), our results showed that the DHH and TH children both paid more attention to the eye region than to the nose and mouth regions. Taking this outcome in to consideration, together with the findings of prior studies , it is likely that DHH individuals show more attention to the mouth area only when auditory linguistic information or sign language is involved. In this first study of ours, children only needed to visually recognize emotions from isolated, still faces where no spoken or sign language was used. In such a context, the facial areas most relevant to emotion recognition (i.e., the eyes) attracted more attention in both DHH and TH children.

In real life, however, people collect information not only from faces but from multiple sources, such as body postures, gestures, and the social context. In **Chapter 3**, we aimed to understand how our findings on isolated facial expressions of emotion translated to more naturalistic scenarios. Our results showed that differential gaze patterns could be observed when DHH and TH children were required to encode emotional cues in dynamic social situations, which involves processing a large volume of cues, movements, and social interactions, as compared to simply looking at isolated faces. In such a context, the DHH children looked at a target person's head for a shorter duration, and at a target person's body and at a partner's head for a longer duration than the TH children. I.e., the head region appears to have been less informative to the DHH children when facial information was missing (note that the target persons were not facing the camera) as compared to their TH peers, who exhibited a clear focus on the heads of the two protagonists. In a real-life setting, the head region carries not only visual cues but also auditory and speech cues. As previously mentioned, DHH individuals may have a stronger dependence on facial information, such as lip movements, to better understand what is going on in the environment. The head region could thus become less informative for them when facial cues are unavailable. Therefore, the DHH children may reduce their attention to the target person's head, and increase their attention to cues where they could obtain more information.

Moreover, when examining the encoding of emotional faces, we also measured children's physiological arousal through pupillometry (**Chapter 2**). The DHH children were more strongly aroused (i.e., showing a greater magnitude of pupil dilation) by angry and neutral faces than by happy faces, whereas the TH children found all facial expressions similarly arousing. This contrast between happy versus non-happy faces also seemed to be reflected in the DHH children's tendency to make misinterpretations. When presented with faces displaying different emotions to match with the emotion expressed in the stimulus face, the DHH children more often incorrectly chose non-happy (angry, fearful, and neutral) faces over happy faces, while the TH children more often incorrectly chose angry or neutral faces over fearful and happy faces. This happy vs. non-happy contrast may have reflected less experience in processing non-happy facial expressions for the DHH children (see **Chapter 2** for a more detailed discussion on this explanation). These children may be exposed to such emotions less often, due to a protective family setting and limited access to the social environment (Calderon & Greenberg, 2012; Pinquart, 2013). DHH children may thus be devoting more cognitive effort to processing emotional faces that are less familiar to them, while still experiencing more confusion about the meaning of these faces.

Similarly, we observed that DHH children appeared to be less experienced in interpreting emotions in dynamic, prototypical social situations (**Chapter 3**). The DHH children scored lower than their TH peers when interpreting emotions in social situations, and their lower scores were associated with their distinctive encoding pattern of diverting attention away from ambiguous emotional cues to explicit cues. Again, children need social-emotional knowledge (i.e., the "database" in the SIP model) in order to interpret social situations properly. Our findings suggest that DHH children may need support to gain better knowledge about social situations. Otherwise, an encoding pattern that is overly reliant on explicit cues could easily lead to misinterpretations of social situations by DHH children.

A final note is that we did not find group differences in interpretation accuracy of emotional faces (**Chapter 2**), although the DHH and TH children showed different tendencies when making errors. This highlights the importance of looking beyond accuracy and into the qualitative differences between typical and atypical development.

The second aim of the thesis was to examine the emotional processes involved in responding to others' emotions, and to what extent these processes were related to overall psychosocial functioning in DHH and TH children.

We pursued this aim by examining two different samples. In a cross-sectional study on three- to ten-year-old Taiwanese children (**Chapter 4**), we investigated how three emotional processes involved in emotional responding (emotion understanding, empathy, and emotion expression) were associated with social competence and externalizing behaviors. In another four-wave longitudinal study on one- to five-year-old Dutch children (**Chapter 5**), we narrowed our focus to empathy, and studied it in greater depth. Using a longitudinal design, we examined the development of three components of empathy (affective empathy, attention to others' emotions, and prosocial actions) and a closely related skill (emotion understanding), and their relations with early symptoms of psychopathology (internalizing and externalizing behaviors).

In both studies (which involved two different samples), DHH and TH children performed similarly on emotion understanding, according to their parents. The parent report measures asked parents to rate to what extent their children recognized and understood the parents' basic emotions, such as anger, sadness, fear, and happiness. Moreover, DHH and TH children developed this skill with a similar trajectory over the preschool years, where levels of emotion understanding increased with age and stabilized when children entered primary schools in both groups (**Chapter 5**). This showed that preschool and school-aged DHH children's development of basic emotion understanding was on par with their TH peers. Such an ability is essential to social functioning, as we found that higher levels of emotion understanding predicted fewer externalizing behaviors in preschool DHH and TH children, alike (**Chapter 5**). The ability to understand others' emotions may help children better evaluate social situations and react more adaptively to the external world.

Regarding empathy, overall empathic responding was also similar in three- to ten-year-old DHH and TH children (**Chapter 4**). Yet, when we looked into the development of different components of empathy, we also found dissimilarities between the groups (**Chapter 5**). On the one hand, levels of affective empathy were comparable, and declined with age in the two groups. This trend followed the theory of Hoffman (1990) that young children often experience more overwhelming levels of emotional arousal than older ones upon witnessing others' emotions, because they are still immature in self-other differentiation. Yet on the other hand, attention to others' emotions remained stable over time in TH children, but increased with age in DHH children. Also, DHH children were rated lower on prosocial actions than their TH peers across time, despite similar developmental trajectories for prosocial actions in the two groups. These outcomes suggest that DHH children invested increasing attentional resources to processing others' emotions as they grew up, possibly because they found emotional events more and more difficult to process. However, paying attention does not warrant that children know how to respond appropriately: these DHH children did not respond with prosocial actions (such as comforting or helping) as much as their TH peers.

Importantly, empathy was related to psychosocial functioning in a similar manner in DHH and TH children. When we examined overall empathy responding in three- to ten-year-old children through a cross-sectional design (**Chapter 4**), we found that higher levels of empathy were associated with higher levels of social competence and lower levels of externalizing behaviors in both groups, alike. Yet, further investigation on separate components of empathy showed that preschool children who retained higher levels of affective empathy across time were at greater risk for developing both internalizing and externalizing symptoms (**Chapter 5**). Also, preschoolers who became increasingly attentive to others' emotions over time were more likely to develop internalizing behaviors (**Chapter 5**).

Finally, in regard to emotion expression, we found that DHH and TH children were similarly expressive of positive and negative emotions. While the expressions of positive emotions were not related to social functioning in the two groups (see **Chapter 4** for a cultural explanation for this), excessive expression of negative emotions was linked to lower levels of social competence in both groups, and to more externalizing behaviors in DHH children only. This latter outcome could be explained by DHH children expressing their negative emotions less strategically, or regulating their negative emotions through a more effortful process, due to a lack of familiarity with display rules or coping options towards different social situations (Bradley & Corwyn, 2008; Eisenberg et al., 2009; Oldehinkel et al., 2007). Thus, when emotional arousal was high, they may have experienced more difficulties moderating their expressions of negative emotions, which further affected their social participation.

GENERAL DISCUSSION

Similarities and Dissimilarities Between DHH and TH Children

The studies in the current thesis paint a fairly positive picture about DHH children's emotion development. In spite of using different samples, group differences between DHH and TH children were barely observable in levels of performance, when we looked at emotional skills that did not necessarily involve the understanding of social rules, such as facial emotion recognition and affective empathy. However, when we tested the skills that required the children to possess adequate knowledge about social interactions, such as attributing emotions to social situations or responding to others' emotions with prosocial actions, we did find that DHH children scored or were rated lower than their TH peers.

A strength of this thesis is that it allowed us to look beyond performance levels and into possible qualitative differences. This gave us a new perspective for evaluating the similarities and dissimilarities that resulted from hearing status. When encoding emotions of other people, DHH children tended to make use of visually observable, explicit cues, which could be the eyes on faces, or the body postures of the interaction partners when facial information was missing. They were also more physiologically aroused when encoding non-happy emotions (such as angry and neutral faces) than when encoding happiness, most likely because non-happy expressions were more cognitively demanding to them. These patterns were not observed in their TH peers, who exhibited a clear focus on the most emotionally relevant cues (i.e., eyes on the faces and heads in social situations) and who devoted a similar amount of cognitive effort into processing all facial expressions of basic emotions. Moreover, we observed a positive association between expressions of negative emotions and externalizing behaviors in DHH children, but not in TH children. This indicates that DHH children may have expressed their negative emotions in a less socially desirable manner, even though they expressed negative emotions as much as their TH peers. These results about the underlying patterns showed that although DHH and TH children reached the same performance level, they may have achieved that in different ways.

Adapted, Compensatory Strategy for Encoding Emotional Cues by DHH Children

Similar to what has been found in vision and brain research, indicating compensatory mechanisms in the absence of auditory input, such as greater sensitivity to the peripheral visual field (e.g., Proksch & Bavelier, 2002; also see Box 3 in **Chapter 1**) and increased activation of the brain areas for visual attention and multisensory information integration (Bavelier et al., 2001), the current thesis found that DHH children used an adapted, compensatory strategy to visually encode social-emotional information.

In **Chapter 2**, we saw that DHH and TH children did not differ in gaze patterns when encoding static emotional faces: both groups looked at the eyes for a longer period of time than at the other facial features. In this task, children were aware that their job was to look at emotional faces and to select the emotion the face was expressing, from among several options. It was clear to them from the beginning, when they did the practice trials, that the task included isolated faces, and did not involve auditory signals or verbal responses. In such a context, it appeared that both DHH and TH children put their focus on the cues that provided the most information for emotion recognition: the eyes. Although we did not include a condition with auditory signals in this thesis, the claim that DHH children adapt their gaze patterns according to the situation is supported by a previous study that measures eye movements in visual-only and audiovisual conditions (Wang et al., 2017). The study showed that DHH children only exhibited an attentional preference for the mouth region when emotional faces were accompanied by auditory signals.

An adaptation was also observed in our task in which children were presented with dynamic social situations with missing facial information (**Chapter 3**). The findings helped us gain further insight into the strategy DHH children tended to use. In this task, children needed to infer the emotion felt by the target person whose face was not visible, according to the interaction between this target person and his or her interaction partner. Outcomes showed that the DHH children diverted their attention from the target person's head to the target person's body, and to the partner's head (whose facial expressions were visible). Thus, for the DHH children, the head region appeared to be less informative when facial information was unavailable. This is most likely because these children are used to depending on facial information (e.g., lip movement) to fully understand what is going on in social situations. Therefore, in the absence of facial information from the target person, and for the purpose of inferring his or her emotions, the DHH children showed a tendency to reduce attention to the ambiguous information (i.e., the target person's head) and increase attention to cues that could provide visually observable information. The body postures can provide cues about emotions (e.g., moving forward in anger, backward in fear), about where emotion is directed to, and about physical conditions (e.g., falling), thus providing useful information about the situation (Dael et al., 2012; Kret &De Gelder, 2013; Van Den Stock et al., 2007). The head region of an interaction partner can inform the emotion expressed by the partner and his or her intention (End & Gamer, 2017; Horstmann, 2003).

Our outcomes in **Chapters 2 and 3** showed that the DHH children tended to make use of explicit, visually observable cues that gave them most information about the situation (Kret & De Gelder, 2013; Kret et al., 2017). This explanation seems to apply to both the encoding of emotional faces and the encoding of social situations. The DHH children focused on the eyes to recognize emotions when faces were presented to them visually, with no auditory information; and, as previous studies found, they shifted their attention to the mouth when required to encode auditory verbal cues. When encountering social situations involving ambiguous emotional information, they directed their attention to visually observable cues in order to compensate for any ambiguity. In contrast, the TH children seemed to exhibit a clear focus on the most emotionally or socially relevant information, such as the eyes on faces, or heads of people in social situations, even when facial features were not available.

In everyday social life, an overwhelming amount of information is available, and attentional resources are limited. While TH children often allocate their attention to the most relevant features, such a strategy might not fit DHH children because much of the information they receive, though relevant, is partial. Therefore, DHH children may develop this visual cue-based strategy of "letting the evidence speak for itself" to minimize misinterpretations during their daily social interactions and observations (Rieffe et al., 2003; Rieffe & Meerum Terwogt, 2000).

It is noteworthy that our finding about compensatory strategies for recruiting emotional and social information through alternate visual means may be extended to other clinical groups. For example, adults with high levels of social anxiety were found to divert their attention from faces to hands when recognizing emotions, while those low in social anxiety showed a clear focus on faces, even when facial features were blurred (Kret et al., 2017). A meta-analysis study also reported that autistic individuals spent less time looking at faces and more time looking at the body than non-autistic individuals, when viewing social scenes (Chita-Tegmark, 2016). Our findings, when taken together with these studies on other clinical groups, underscore the importance of using stimulus materials that are as naturalistic as possible, and of considering the possibility of alternate viewing patterns, when interpreting social attention in clinical groups.

Limited Social-Emotional Knowledge

Several outcomes in this thesis suggest that DHH children may need extra support in order to increase their knowledge about emotions and social rules. First, DHH children showed more confusion when interpreting non-positive emotion categories (e.g., anger, fear, and neutral faces) than happy faces (**Chapter 2**). They also recruited more cognitive-attentional resources when processing others' emotions: they demonstrated a greater magnitude of pupil dilation in response to angry and neutral faces than to happy faces in **Chapter 2**, and showed an increasing trend in attention to others' emotions over the preschool years in **Chapter 5**. This happy vs. non-happy contrast and increased attention towards emotions very likely reflected DHH children's unfamiliarity with processing certain emotions, as a result of a protective family setting and limited access to the social environment.

Second, we found that DHH children's performance on interpreting emotions in social situations was associated with their visual encoding pattern (**Chapter 3**): more time spent looking at the target person's body was related to lower interpretation accuracy. This outcome showed that DHH children did not have adequate knowledge about social rules to support their visual cue-based encoding strategy, and that this easily led to misinterpretation. Although body postures indeed provide useful information when the situation results in a clear physical condition such as being pushed down to the ground, this cue may be misleading when the physical outcomes are ambiguous, such as being laughed at. In such a situation, children need adequate knowledge about social norms and causes of emotions in order to make proper interpretations.

Third, we observed a positive association between negative emotion expression and externalizing behaviors only in DHH children, and not in TH children (**Chapter 4**). This indicates that DHH children knew less well how to express their negative emotions in a socially appropriate way. This could be explained by either a lack of skills for efficiently regulating their negative emotions, or by limited knowledge about display rules, or both. Whichever is the case, results suggest the need for DHH children to learn how to efficiently cope with negative emotions in different social situations, and to learn about social rules and alternatives for expressing those emotions.

Fourth, our longitudinal study showed fewer prosocial actions taken by preschool DHH children, as compared to TH children (**Chapter 5**). To take prosocial actions, children need to have knowledge about the causes of emotions, and about socially appropriate behavior. When children do not have adequate knowledge in this regard, carrying out prosocial actions could be a challenging and stressful task because they do not know what to do, and if they have done something, they do not know whether what they are doing is right or wrong. As a result, they may prefer to sit and watch, before they are sure what to do. Note that DHH children did not differ from TH children in affective empathy and recognition of their parents' basic emotions, and they even became increasingly attentive to others' emotions over time. These outcomes indicated that DHH children did feel, attend to, and recognize other people's emotions. A similar outcome was also reported in a study on autistic preadolescents, where autistic youngsters displayed no differences in their looking or smiling behavior, but engaged in spontaneous helping behavior less often than their non-autistic peers (O'Connor et al., 2019).

To summarize, DHH children are well aware of other people's emotions. However, more effort is required of them in order to process these emotions, and these children are not familiar with the social rules and various causes of emotions behind social interactions. Such social-emotional knowledge (i.e., the "database" in the SIP model; see Box 1 in **Chapter 1**) is acquired within the context of daily social interactions (Saarni, 1999), primarily in the form of incidental learning, i.e., unplanned, unintended, and unprompted learning (Kelly, 2012). From the very first days of life, children constantly learn from their social environment by overhearing, observing, and participating in social interactions. For example, a child learns about an affect-event link and socially desirable behavior when overhearing a sibling being complimented by their parent for helping pick up a pen. DHH children miss such learning opportunities on a daily basis. This can negatively affect their acquisition of emotional skills and social rules, and further hinder their social participation, creating a vicious cycle.

Practical Implications

DHH children who receive intervention (such as a CI or HA) at an early age are often thought to have better social adjustment because their hearing is improved in the aided condition, and so they are able to use spoken language as the primary communication mode in daily life. However, a growing body of literature has shown that this picture is not entirely true. Children with a CI or HA still experience challenges with developing various social and emotional skills, despite stable hearing and language abilities (Netten et al., 2015; Rieffe et al., 2018). In this thesis, we showed that the limited knowledge about emotions and social rules in their personal SIP database could be an underlying factor that affects DHH children's social-emotional skills. To equip them with improved social-emotional knowledge in their databases, increasing DHH children's exposure to social interactions will be fundamental, because the social context is indispensable for acquiring such knowledge. This aim can be pursued through three approaches.

The first approach is to increase auditory access through technological support. Current CIs and HAs have been improved over the past decades in the way they deliver different auditory cues and suppress background noise, to help users accurately perceive environmental and speech sounds. Assistive hearing technologies (such as the personal frequency modulation or FM system that collect speech sounds directly from a speaker through a microphone and transmit the signals to a CI or HA) also allow DHH children to hear a particular speaker (e.g., their teacher) better in a noisy environment (e.g., classrooms). New options are also being developed, aiming to further improve listening experiences and reduce listening effort. For example, artificial intelligence is being applied to CIs with algorithms that can flexibly extract a particular speaker's voice among other distracting sounds (Goehring et al., 2019). For children with bilateral CIs, or for those who use a CI in one ear and a HA in the other, such new techniques also allow better coordination between the two ears, thus improving their ability to locate sounds. The accessibility of these hearing technologies should be on the agenda of policymakers.

The second approach involves informing and training professionals and parents. The findings in this thesis revealed specific areas that can be incorporated into rehabilitation programs and parent-child interaction. DHH children were found to be less familiar with non-positive emotions (**Chapter 2**), and more easily misled by the body postures (e.g., falling or standstill) in social situations (**Chapter 3**). They also expressed negative emotions in a less socially favorable manner (**Chapter 4**), and carried out fewer prosocial actions (**Chapter 5**) than their TH peers. Moreover, showing empathy to other people was related to better social functioning in both groups (**Chapter 4**). These all indicate the need to teach DHH children about different types of emotional events and social rules, about the links between emotions and events, and about different alternatives for responding to social situations, for example through storytelling or through having discussions when children are watching cartoons. This could help DHH children respond to others' emotions with less cognitive and attentional effort (**Chapter 2 and 5**). In addition, a better ability to understand others' emotions further reduces the possibility of developing externalizing behaviors (**Chapter 5**).

The two former approaches are centered around the child. It should be noted, however, that the DHH children who participated in this research do not have disabilities other than their hearing loss. The only barrier for these children in gaining social-emotional knowledge to the level that hearing children develop such knowledge is in the limited social access caused by the hearing loss. To date there is no technology that can fully restore hearing, and sounds must pass through the environment in order to reach those technologies, no matter how advanced they are. However, since DHH children cannot control their environment, one could argue that the environment must adapt to the needs of DHH children, in order to maximize their social participation and development by providing these children with opportunities equal to those of their TH peers.

Therefore, the third approach involving the environment warrants particular consideration: People surrounding DHH children may need to adapt to use multiple communication means. This could include sign-supported verbal language, making sure their faces are always clearly visible to the person with hearing loss, and other strategies. DHH children's attention also needs to be taken into account by interaction partners, because information can be acquired more easily when attention is directed to the sources of information. Moreover, sometimes minor adjustments to the physical environment can yield major impact. For example, tables and chairs with rubber feet and acoustic paneling can reduce classroom background noise. Playtime is easier for DHH children in playgrounds placed in a quiet area, e.g., away from football games, and where playground equipment is built with materials and structures that absorb sounds or produce less echoes (Barrett et al., 2015; Crandell & Smaldino, 2000). The nature of toys and play materials can also affect how children are included or excluded during play. Promising new research in this area with so-called "loose parts play" (where placing new, loose objects on the playground for children to explore) shows that these kinds of changes to the environment enhance social interaction and inclusion (Gibson et al., 2017, 2018; Heravi et al., 2018). Such considerations for the environment would not only benefit DHH children, but also increase inclusiveness for all children.

Considerations and Future Directions

This thesis raised issues that require further consideration. First, further investigations will be necessary in order to understand how much of current outcomes can be generalized to other groups of children with hearing loss, such as those with mild-to-moderate or unilateral hearing loss. The majority of the DHH children in this thesis had a CI, used spoken language as the primary communication mode, and attended mainstream schools. To better understand the effect of social-emotional learning in the context of hearing loss in general, future studies are suggested in order to account for the heterogeneity of the DHH population.

Second, in this thesis we focused on the emotional development of DHH and TH children without emphasizing much about their cultural background. We included samples from Western and East Asian cultures for different studies with an aim to increase the external validity of existing knowledge on DHH children's emotional development. However, it is undeniable that culture plays an important role in social-emotional development. As described in **Chapter 1**, Taiwan has a more collectivistic-oriented culture, while the Netherlands has a more individualistic-oriented culture. Such a difference in cultural values could affect how people respond in a social context. For example, Western, individualistic cultures evaluate intense expressions of positive emotions more positively than East Asian, collectivistic cultures (Kitayama et al., 2000; Tsai et al., 2002, 2006). To what extent do these cultural values (e.g., the desire for standing out vs. fitting in) affect DHH children's psychosocial functioning is a topic worthy of further investigation.

Third, following the previous point, we also did not emphasize the language background of our participants, and we focused on the visual aspects of emotional functioning. In daily life, we perceive emotions through multiple channels, and language input is an important source for learning emotions. Taiwanese Mandarin is a tonal language that differentiates lexical meanings through different pitches. Pitches, however, are particularly difficult to perceive for many users of CIs because the device has a limited spectral resolution (i.e., ability to differentiate frequencies; Luo et al., 2007). This limitation also makes it hard for children with a CI to perceive emotional prosodies, i.e., the variations in pitch that denote emotional content. Therefore, when asked to recognize the emotion of a musical excerpt, TH children primarily use spectral cues (i.e., pitches) from the melody, while children with a CI use temporal cues (i.e., the tempo of the musical excerpt; Hopyan et al., 2016). Interestingly, children with a CI who are native users of tonal language seem to develop greater sensitivity to pitches than do their non-tonal language peers (Deroche et al., 2019). To what extent this tonal-language benefit may extend to the perception of emotional prosody could be a topic for future research.

Fourth, the current thesis focused on basic emotions. Due to limitations in current knowledge on the topics we investigated, focusing on the basic emotions allowed us to understand the baselines. However our results indicate that future studies need to keep on examining the skills that require knowledge about the causes of others' emotions and about social rules. In real life, others' emotional expressions are usually spontaneous and subtle, and involve more complex or even mixed emotions. Mixed emotions could be more difficult for DHH children to understand because they need more knowledge to encode and interpret the situations that trigger such emotions (Rieffe, 2012). Also, a study showed that DHH adolescents reported shame and guilt less often than their TH peers, in social situations that provoked moral emotions (Broekhof et al., 2018).

Lastly, in the previous section we discussed the practical implications of our findings. More studies on interventions are needed. Which approach is most effective for stimulating social participation by DHH children, and in recruiting meaningful social-emotional learning? How can we best promote discussions between parents and children on abstract concepts such as emotions, thoughts, and intentions? What can schools and families do to adapt their teaching and environment to DHH children's needs? Recent studies have shown that activities like loose parts play could increase cooperation between peers (Gibson et al., 2017), and that mothers and teachers referred more to mental states during wordless storytelling than during storybook reading (Ziv et al., 2013, 2015). More studies are needed, to understand which interventions are applicable to children with hearing loss, and to other children who also face barriers to communication.

CONCLUSIONS

The current thesis aimed to unravel whether hearing status affects how children encode, interpret, and react to others' emotions, and whether their responses to emotions are associated with psychosocial functioning. Our results showed that DHH children were largely on par with their TH peers in emotional development, and similar relations were observed in the two groups between their responses to emotions and psychosocial functioning. Yet, DHH children still faced difficulties when they had to interpret or react to an emotion with adequate knowledge about social rules and about different categories and causes of emotions. Moreover, DHH children used a visual cue-based encoding strategy to compensate for ambiguous or unavailable information in social situations, and recruited more cognitive resources to process unfamiliar emotional expressions. This underscores the need to look into possible qualitative differences between typical and atypical development. Although DHH and TH children may perform similarly on many emotional tasks, they do not necessarily achieve that with the same underlying processing mechanism, and their difficulties may still be exposed in certain kinds of situations.

This thesis highlights the importance of a more inclusive, accessible environment, where children — all children — can easily participate in social interactions and therefore acquire the social-emotional knowledge necessary for facilitating future interactions. When DHH children and other children who face barriers to communication are given as many opportunities for meaningful social interaction as typically developing children, they will have the opportunity to acquire commensurate knowledge naturally during the process. This goal can be pursued by adapting the physical and social environment, such as improving the acoustics of the built environment, providing suitable play materials that encourage cooperation, and supporting verbal communication with nonverbal cues. To increase inclusiveness, we should also reconsider the meaning of differences observed in children. As this thesis shows, the differences at stake relate to adaptive strategies for supporting daily life, or signals that indicate the need to increase knowledge in a certain social or emotional domain.

Hopefully, this thesis will inspire other like-minded researchers. We envision more studies to further our understanding of children's challenges and potential for successfully navigating their social world.

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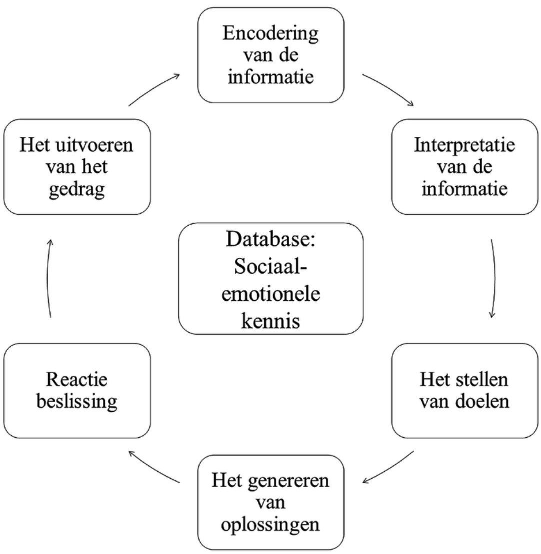
CHAPTER 7

Nederlandse Samenvatting

HET SOCIALE INFORMATIEVERWERKINGSMODEL
(SOCIAL INFORMATION PROCESSING, SIP-MODEL)

Het SIP-model duidt zes opeenvolgende, onderling afhankelijke stappen aan voor het verwerken van sociale informatie (Crick & Dodge, 1994). Hoe de sociale informatie in deze stappen wordt verwerkt, verklaart individuele verschillen in gedragsmatige reacties in sociale situaties. Deze goed gedocumenteerde en invloedrijke benadering is verder uitgebreid om emotionele processen te integreren (De Castro et al., 2005; Lemerise & Arsenio, 2000). Het geïntegreerde model stelt voor dat mensen in de eerste stap emotionele informatie *encoderen* door hun aandacht te richten op relevante signalen in de sociale situatie. In de tweede stap *interpreteren* mensen de emotie volgens de geëncodeerde signalen. In de volgende stappen formuleren mensen het *doel* dat ze in de situatie willen bereiken, genereren ze *opties* om op de situatie te reageren en beoordelen ze deze opties om een *beslissing* te nemen. Ten slotte *voeren* mensen de meest positief geëvalueerde reactie *uit* (zie Figuur 1). Bij elke stap worden mensen geleid door de 'database' die ze zelf ontwikkelen, die bestaat uit herinneringen, ervaringen en kennis over emoties en sociale regels. Deze database stelt mensen in staat om te weten welke signalen relevant zijn, hoe ze de signalen kunnen integreren en interpreteren, en wat het sociaal gunstigst is om op de situatie te reageren.



Figuur 1. Crick en Dodge's model van sociale informatieverwerking (het SIP-model).

GEHOORVERLIES EN SOCIALE INFORMATIEVERWERKING

In een sociale omgeving die voornamelijk bestaat uit horende mensen werken dove of slechthorende (DSH) kinderen aan deze database van sociaal-emotionele kennis bij met ervaringen die heel anders zijn dan hun horende leeftijdsgenoten. Ze missen cruciale informatie in dagelijkse sociale ontmoetingen en krijgen vaak kortere en meer directieve communicatie van hun ouders in vergelijking met horende kinderen (Dirks et al., 2020; Leibold et al., 2013; Morgan et al., 2014). Als gevolg hiervan ervaren veel DSH-kinderen een lagere kwantiteit en kwaliteit van sociale interacties, wat hun verwerving van kennis over emoties en sociale regels verder beperkt.

Gezien de atypische ervaringen met sociale interacties sinds de vroege kinderjaren, is het waarschijnlijk dat DSH-kinderen hun database voor SIP zullen opzetten en bijwerken met inputs die verschillen van hun horende leeftijdsgenoten. Dit zou hen op hun beurt kunnen leiden naar afwijkende SIP-patronen. Gezien de hogere prevalentie van onaangepast sociaal gedrag dat wordt waargenomen bij DSH-kinderen in vergelijking met horende kinderen (Bigler et al., 2019; Dammeyer, 2009; Fellinger et al., 2008; Hoffman et al., 2016; Netten et al., 2015; Stevenson et al., 2015; Theunissen et al., 2014; Van Eldik et al., 2003), is het van rehabilitatief belang om te onderzoeken hoe DSH-kinderen emotionele informatie verwerken en reageren op sociale situaties.

DOELEN VAN DIT PROEFSCHRIFT

In dit proefschrift hebben we de reacties van DSH-kinderen op de emoties van andere mensen in een sociale context onderzocht op basis van het SIP-model (Crick & Dodge, 1994). Bovendien hebben we onderzocht hoe dergelijke vaardigheden verband houden met het psychosociaal functioneren van kinderen. We hebben verondersteld dat de beperkte toegang tot sociaal leren die DSH-kinderen ervaren zou kunnen leiden tot een atypische verwerving van sociaal-emotionele kennis, en dat emoties daarom bij deze kinderen anders zouden kunnen functioneren tijdens sociale ontmoetingen. Om deze veronderstelling te testen, hebben we een verscheidenheid aan maatregelen gebruikt, onder andere het volgen van de oogbeweging, pupillometrie, gedragstaken, ouderrapporten en longitudinale opvolging.

Specifiek was het eerste doel van dit proefschrift om de eerste twee stappen van het SIP-model (encodering en de interpretatie van emotionele signalen) te onderzoeken en de onderliggende patronen na te gaan met het oog op het begrijpen van emotionele informatie bij DSH- en horende kinderen. Met behulp van het volgen van de oogbeweging en pupillometrie samen met geautomatiseerde taken onderzochten we of en hoe DSH- en horende kinderen verschilden in het encoderen en in de interpretatie van emotionele signalen wanneer ze probeerden de gezichtsuitdrukkingen van anderen (**hoofdstuk 2**) en de emoties van anderen die werden uitgelokt in dynamische sociale situaties (**hoofdstuk 3**) te begrijpen. In twee afzonderlijke taken kregen kinderen van drie tot tien jaar oud stilstaande beelden van gezichten met basis moties (woede, angst, geluk en neutrale emoties) voorgeschoteld en bekeken ze video's van prototypische sociale interacties tussen een doelpersoon en een emotie-uitlokkende interactiepartner. Tijdens de encoderingsfase werden de blik van de deelnemers en de pupildiameter gemeten door een oogvolgapparaat. Vervolgens werden de deelnemers gevraagd om de emotie te interpreteren die in de gezichten tot uiting kwam en werd uitgelokt door de sociale situaties.

Het tweede doel van het proefschrift was om de emotionele processen te onderzoeken die betrokken zijn bij het reageren op de emoties van anderen, en in hoeverre deze processen verband hielden met het algemeen psychosociaal functioneren bij DSH- en horende kinderen. We hebben dit doel nagestreefd door twee verschillende monsters te onderzoeken. In een dwarsdoorsnede studie bij drie- tot tienjarige Taiwanese kinderen (**hoofdstuk 4**), onderzochten we hoe de drie emotionele processen die betrokken zijn bij emotioneel reageren (emotiebegrip, empathie en emotie-expressie) verband hielden met sociale competentie en externaliserend gedrag. In een ander longitudinaal onderzoek met vier golven bij één- tot vijfjarige Nederlandse kinderen (**hoofdstuk 5**) versmalden we onze focus tot empathie en bestudeerden we het dieper. Met behulp van een longitudinaal ontwerp onderzochten we de ontwikkeling van drie componenten van empathie (affectieve empathie, aandacht voor de emoties van anderen en prosociale acties) en een nauw verwante vaardigheid (emotiebegrip), en hun verband met vroege symptomen van psychopathologie (internaliserend en externaliserend gedrag).

OVEREENKOMSTEN EN VERSCHILLEN TUSSEN DSH- EN HORENDE KINDEREN

De onderzoeken in het huidige proefschrift schetsen een redelijk positief beeld over de emotionele ontwikkeling van DSH-kinderen. Ondanks het gebruik van verschillende steekproeven waren groepsverschillen tussen DSH- en horende kinderen nauwelijks waarneembaar in prestatieniveaus, wanneer we naar de emotionele vaardigheden keken waarvoor begrip van sociale regels niet noodzakelijk is, zoals de herkenning van gezichtsemoties en affectieve empathie. Toen we de vaardigheden testten waarvoor de kinderen voldoende kennis moesten hebben over sociale interacties, zoals emoties toeschrijven aan sociale situaties of reageren op de emoties van anderen met prosociale acties, ontdekten we echter dat DSH-kinderen minder scoorden of lager beoordeeld werden dan hun horende leeftijdgenoten.

Een sterk punt van dit proefschrift is dat het ons in staat stelde om verder te kijken dan prestatieniveaus en toch naar mogelijke kwalitatieve verschillen te kijken. Dit gaf ons een nieuw perspectief voor het evalueren van de overeenkomsten en ongelijkheden die het gevolg waren van de gehoorstatus. Bij het encoderen van emoties van andere mensen hadden DSH-kinderen de neiging gebruik te maken van visueel waarneembare, expliciete signalen, zoals de ogen op gezichten of de lichaamshoudingen van de interactiepartners wanneer gezichtsinformatie ontbrak. Ze waren ook fysiologisch meer opgewonden bij het encoderen van niet-gelukkige emoties (zoals boze en neutrale gezichten) dan bij het encoderen van geluk, hoogstwaarschijnlijk omdat niet-gelukkige uitdrukkingen cognitief veeleisender voor hen waren. Deze patronen werden niet waargenomen bij hun horende leeftijdsgenoten, die een duidelijke focus toonden op de meest emotioneel relevante signalen (d.w.z. ogen op de gezichten en hoofden in sociale situaties) en die een vergelijkbare hoeveelheid cognitieve inspanning besteedden aan het verwerken van alle gezichtsuitdrukkingen van basisemoties. Bovendien zagen we een positieve associatie tussen uitingen van negatieve emoties en externaliserende gedragingen bij DSH-kinderen, maar niet bij horende kinderen. Dit geeft aan dat DSH-kinderen hun negatieve emoties mogelijk op een minder sociaal wenselijke manier hebben geuit, hoewel ze net zoveel negatieve emoties uitten als hun horende leeftijdsgenoten. Deze resultaten over de onderliggende patronen toonden aan dat hoewel DSH- en horende kinderen hetzelfde prestatieniveau bereikten, hebben ze het op verschillende manieren bereikt.

AANGEPASTE, COMPENSERENDE STRATEGIE VOOR HET ENCODEREN VAN EMOTIONELE SIGNALEN DOOR DSH-KINDEREN

Vergelijkbaar met wat is gevonden in visie- en hersenonderzoek, wat wijst op compensatiemechanismen bij de afwezigheid van auditieve input, zoals grotere gevoeligheid voor het perifere gezichtsveld (bijv. Proksch & Bavelier, 2002) en verhoogde activering van de hersengebieden voor visuele aandacht en multisensorische informatie-integratie (Bavelier et al., 2001), ontdekte het huidige proefschrift dat DSH-kinderen een aangepaste, compenserende strategie gebruikten om sociaal-emotionele informatie visueel te encoderen.

In **hoofdstuk 2** zagen we dat DSH- en horende kinderen niet verschilden in blikpatronen bij het encoderen van statische emotionele gezichten: beide groepen keken langer naar de ogen dan naar de andere gelaatstrekken. Bij deze taak waren kinderen zich ervan bewust dat het hun taak was om naar emotionele gezichten te kijken en de emotie te selecteren die het gezicht uitdrukte, uit verschillende opties. Het was voor hen vanaf het begin, toen ze de oefenproeven deden, duidelijk dat de taak geïsoleerde gezichten omvatte en geen auditieve signalen of verbale reacties inhield. In een dergelijke context bleek dat zowel DSH- als horende kinderen hun aandacht vestigden op de signalen die de meeste informatie verschaften voor emotieherkenning: de ogen. Hoewel we in dit proefschrift geen omstandigheden met auditieve signalen hebben opgenomen, wordt de bewering dat DSH-kinderen hun blikpatronen aanpassen aan de situatie ondersteund door een eerdere studie die oogbewegingen meet in alleen-visuele en audiovisuele omstandigheden (Wang et al., 2017). De studie toonde aan dat DSH-kinderen alleen een aandachtsvoorkeur voor de mond en het perifere gebied daarvan vertoonden wanneer emotionele gezichten vergezeld door auditieve signalen onder ogen te zien zijn.

Er werd ook een aanpassing waargenomen in onze taak waarbij kinderen dynamische sociale situaties voorgeschoteld kregen met ontbrekende gezichtsinformatie (**hoofdstuk 3**). De bevindingen hielpen ons meer inzicht te krijgen in de strategie die DSH-kinderen neigden te gebruiken. Bij deze taak moesten kinderen de emotie concluderen die gevoeld werd door de doelpersoon wiens gezicht niet zichtbaar was, op basis van de interactie tussen deze doelpersoon en zijn of haar interactiepartner. De resultaten toonden aan dat de DSH-kinderen hun aandacht afleidden van het hoofd van de doelpersoon en richtten op het lichaam van de doelpersoon en het hoofd van de partner (wiens gezichtsuitdrukkingen zichtbaar waren). Dus voor de DSH-kinderen leken het hoofd en het perifere gebied ervan minder informatief wanneer de gezichtsinformatie niet beschikbaar was. Dit komt hoogstwaarschijnlijk omdat deze kinderen gewend zijn om afhankelijk te zijn van gezichtsinformatie (bijv. lipbeweging) om volledig te begrijpen wat er aan de hand is in sociale situaties. Daarom vertoonden de DSH-kinderen, bij gebrek aan gezichtsinformatie van de doelpersoon, en met het doel zijn of haar emoties af te leiden, de neiging om de aandacht te verminderen naar de dubbelzinnige informatie (d.w.z. het hoofd van de doelpersoon) en de aandacht voor signalen te vergroten, die visueel waarneembare informatie zou kunnen opleveren. De lichaamshoudingen kunnen aanwijzingen geven over emoties (bijv. toename van woede, afname van angst), over waar emotie naar toe is gericht en over fysieke omstandigheden (bijv. vallen), en zo nuttige informatie over de situatie opleveren (Dael et al., 2012; Kret & De Gelder, 2013; Van Den Stock et al., 2007). Het hoofd en het perifere gebied van een interactiepartner kan de emotie die door de partner wordt uitgedrukt en zijn of haar intentie overdragen (End & Gamer, 2017; Horstmann, 2003).

Onze uitkomsten in de **hoofdstukken 2 en 3** toonden aan dat de DSH-kinderen de neiging hadden gebruik te maken van expliciete, visueel waarneembare signalen die hen de meeste informatie over de situatie gaven (Kret & De Gelder, 2013; Kret et al., 2017). Deze verklaring lijkt van toepassing op zowel het encoderen van emotionele gezichten als het encoderen van sociale situaties. De DSH-kinderen concentreerden zich op de ogen om emoties te herkennen wanneer hun gezichten visueel werden gepresenteerd, zonder auditieve informatie; en, zoals uit eerdere studies bleek, verlegden ze hun aandacht naar de mond wanneer dat nodig was om auditieve verbale signalen te encoderen. Bij het tegenkomen van sociale situaties met dubbelzinnige emotionele informatie, richtten ze hun aandacht op visueel waarneembare signalen om eventuele dubbelzinnigheid te compenseren.

Daarentegen leken de horende kinderen een duidelijke focus te vertonen op de meest emotioneel of sociaal relevante informatie, zoals de ogen op gezichten of hoofden van mensen in sociale situaties, zelfs als gezichtskenmerken niet beschikbaar waren.

In het dagelijkse sociale leven is een overweldigende hoeveelheid informatie beschikbaar en zijn de aandachtsmiddelen beperkt. Hoewel horende kinderen hun aandacht vaak besteden aan de meest relevante kenmerken, past een dergelijke strategie misschien niet bij DSH-kinderen omdat veel van de informatie die ze ontvangen, hoewel relevant, onvolledig is. Daarom kunnen DSH-kinderen deze visuele signaal-gebaseerde strategie ontwikkelen om 'het bewijs voor zichzelf te laten spreken' om verkeerde interpretaties tijdens hun dagelijkse sociale interacties en observaties te minimaliseren (Rieffe et al., 2003; Rieffe & Meerum Terwogt, 2000).

BEPERKTE SOCIAAL-EMOTIONELE KENNIS

Verschillende uitkomsten in dit proefschrift suggereren dat DSH-kinderen mogelijk extra ondersteuning nodig hebben om hun kennis over emoties en sociale regels te vergroten. Ten eerste vertoonden DSH-kinderen meer verwarring bij het interpreteren van niet-positieve emotiecategorieën (bijv. woede, angst en neutrale gezichten) dan blije gezichtsuitdrukkingen (**hoofdstuk 2**). Ze rekruteerden ook meer cognitieve aandachtsbronnen bij het verwerken van de emoties van anderen: ze lieten een grotere omvang van pupilverwijding zien als reactie op boze en neutrale gezichten dan op blije gezichten in **hoofdstuk 2**, en toonden een opwaartse trend in aandacht voor de emoties van anderen gedurende de hele periode van voorschoolse jaren in **hoofdstuk 5**. Dit gelukkige versus niet-gelukkige contrast en de toegenomen aandacht voor emoties weerspiegelden zeer waarschijnlijk de onbekendheid van DSH-kinderen met het verwerken van bepaalde emoties, als gevolg van een beschermende gezinssituatie en beperkte toegang tot de sociale omgeving.

Ten tweede ontdekten we dat de prestaties van DSH-kinderen bij het interpreteren van emoties in sociale situaties verband hielden met hun visuele encoderingspatroon (**hoofdstuk 3**): meer tijd besteed aan het kijken naar het lichaam van de doelpersoon was verwant aan een lagere interpretatienauwkeurigheid. Deze uitkomst toonde aan dat DSH-kinderen niet voldoende kennis hadden over sociale regels om hun visuele signaal-gebaseerde encoderingsstrategie te ondersteunen, en dat dit gemakkelijk leidde tot verkeerde interpretatie. Hoewel lichaamshoudingen inderdaad nuttige informatie opleveren wanneer de situatie resulteert in een duidelijke fysieke conditie, zoals op de grond gedrukt worden, kan dit signaal misleidend zijn wanneer de fysieke uitkomsten dubbelzinnig zijn, zoals uitgelachen worden. In een dergelijke situatie hebben kinderen voldoende kennis nodig over sociale normen en oorzaken van emoties om de juiste interpretaties te kunnen geven.

Ten derde zagen we een positief verband tussen negatieve emotie-expressie en externaliserend gedrag alleen bij DSH-kinderen, en niet bij horende kinderen (**hoofdstuk 4**). Dit geeft aan dat DSH-kinderen minder goed wisten hoe ze hun negatieve emoties op een sociaal gepaste manier moesten uiten. Dit kan worden verklaard door ofwel een gebrek aan vaardigheden om hun negatieve emoties efficiënt te reguleren, ofwel beperkte kennis over expressieregels, of toch beide. Welke het geval ook is suggereren de resultaten dat DSH-kinderen moeten leren hoe ze efficiënt kunnen omgaan met negatieve emoties in verschillende sociale situaties, en om te leren over sociale regels en alternatieven om die emoties te uiten.

Ten vierde liet onze longitudinale studie zien dat er minder prosociale acties werden ondernomen door voorschoolse DSH-kinderen in vergelijking met horende kinderen (**hoofdstuk 5**). Om prosociale acties te ondernemen moeten kinderen kennis hebben over de oorzaken van emoties en over sociaal passend gedrag. Als kinderen niet over voldoende kennis op dit gebied beschikken, kan het uitvoeren van prosociale acties een uitdagende en stressvolle taak zijn, omdat ze niet weten wat ze moeten doen, en als ze iets hebben gedaan, weten ze niet of wat ze doen juist of verkeerd is. Als gevolg hiervan willen ze misschien liever zitten en kijken totdat ze zeker weten wat ze moeten doen. Houd er rekening mee dat DSH-kinderen niet verschilden van horende kinderen in affectieve empathie en herkenning van de basisemoties van hun ouders, en dat ze in de loop van de tijd zelfs steeds meer attent werden op de emoties van anderen. Deze uitkomsten gaven aan dat DSH-kinderen de emoties van andere mensen voelden, er aandacht aan schonken en ze herkenden. Een vergelijkbaar resultaat werd ook gerapporteerd in een onderzoek onder autistische preadolescenten, waar autistische jongeren geen verschillen vertoonden in hun kijk- of lachgedrag, maar minder vaak spontaan hulpgedrag vertoonden dan hun niet-autistische leeftijdsgenoten (O'Connor et al., 2019).

Kortom: DSH-kinderen zijn zich goed bewust van de emoties van andere mensen. Er is echter meer inspanning nodig om deze emoties te verwerken, en deze kinderen zijn niet bekend met de sociale regels en verschillende oorzaken van emoties achter sociale interacties. Dergelijke sociaal-emotionele kennis (d.w.z. de 'database' in het SIP-model) wordt verworven binnen de context van dagelijkse sociale interacties (Saarni, 1999), voornamelijk in de vorm van incidenteel leren, d.w.z. ongepland, onbedoeld en ongevraagd leren (Kelly, 2012). Vanaf de eerste levensdagen leren kinderen voortdurend van hun sociale omgeving door af te luisteren, te observeren en deel te nemen aan sociale interacties. Een kind leert bijvoorbeeld over een gevoel-gebeurtenis verband en sociaal wenselijk gedrag wanneer het hoort dat een broer of zus wordt gecomplimenteerd door de ouder voor het helpen bij het oppakken van een pen. Dagelijks missen DSH-kinderen dergelijke leermogelijkheden. Dit kan hun verwerving van emotionele vaardigheden en sociale regels negatief beïnvloeden en hun sociale participatie verder belemmeren, waardoor een vicieuze cirkel ontstaat.

CONCLUSIES EN PRAKTISCHE IMPLICATIES

Het huidige proefschrift was bedoeld om te ontrafelen of de gehoorstatus van invloed is op hoe kinderen de emoties van anderen encoderen, interpreteren en erop reageren, en of hun reacties op emoties verband houden met psychosociaal functioneren. Onze resultaten toonden aan dat DSH-kinderen grotendeels vergelijkbaar waren met hun horende leeftijdsgenoten wat betreft emotionele ontwikkeling, en vergelijkbare relaties werden waargenomen in de twee groepen tussen hun reacties op emoties en psychosociaal functioneren. Toch hadden DSH-kinderen nog steeds problemen wanneer ze een emotie moesten interpreteren of erop moesten reageren met voldoende kennis over sociale regels en over verschillende categorieën en oorzaken van emoties. Bovendien gebruikten DSH-kinderen een visuele signaal-gebaseerde encoderingsstrategie om dubbelzinnige of onbeschikbare informatie in sociale situaties te compenseren, en rekruteerden ze meer cognitieve middelen om onbekende emotionele uitingen te verwerken. Dit onderstreept de noodzaak om te kijken naar mogelijke kwalitatieve verschillen tussen typische en atypische ontwikkeling. Hoewel DSH- en horende kinderen op dezelfde manier kunnen presteren bij veel emotionele taken, bereiken ze dat niet noodzakelijkerwijs met hetzelfde onderliggende verwerkingsmechanisme, en hun problemen kunnen nog steeds worden blootgelegd in bepaalde soorten situaties.

Dit proefschrift toont het beland aan van een meer inclusieve, toegankelijke omgeving, waar kinderen - alle kinderen - gemakkelijk kunnen deelnemen aan sociale interacties en als volgt de sociaal-emotionele kennis kunnen verwerven die nodig is om toekomstige interacties te vergemakkelijken. Wanneer DSH-kinderen en andere kinderen die met communicatiebelemmeringen evenveel kansen krijgen voor zinvolle sociale interactie als typisch ontwikkelende kinderen, zullen ze de gelegenheid hebben om tijdens het proces op natuurlijke wijze evenredige kennis te verwerven. Dit doel kan worden nagestreefd door aanpassingen aan de fysieke en sociale omgeving, zoals het verbeteren van de akoestiek van de gebouwde omgeving, het bieden van geschikt speelmateriaal dat samenwerking stimuleert en het ondersteunen van verbale communicatie met non-verbale signalen. Om inclusiviteit te vergroten moeten we ook de betekenis van de waargenomen verschillen bij kinderen heroverwegen. Zoals dit proefschrift laat zien hebben de verschillen die op het spel staan betrekking op adaptieve strategieën ter ondersteuning van het dagelijks leven, of signalen die erop wijzen dat kennis in een bepaald sociaal of emotioneel domein moet worden vergroot.

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APPENDICES

Supplementary Materials
Acknowledgments
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SUPPLEMENTARY MATERIALS CHAPTER 2

S2.1. Analyses Excluding Children with a Hearing Aid

Table S2.1.1. Fixed and random effects in the generalized linear mixed models of gaze patterns and physiological arousal, after excluding children with only a hearing aid (n = 5).

	Fixation ratios within AOIs				Fixation ratios within entire faces				Physiological arousal (pupil dilation)			
	Predefined category		Interpreted category		Predefined category		Interpreted category		Predefined category		Interpreted category	
Fixed/random effect	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI	Coef (δ)	95% CI
Intercept	**.18**	[.17, .20]	**.19**	[.18, .20]	**.96**	[.95, .97]	**.97**	[.97, .98]	**.13**	[.09, .17]	**.14**	[.12, .17]
Age	*ns*		*ns*		*ns*		*ns*		*ns*		*ns*	
Group	*ns*		*ns*		*ns*		*ns*		.03 (.08)	[-.03, .10]	*ns*	
Category(AN)	-.00 (.01)	[-.01, .01]	*ns*		**.01** (.10)	[.00, .02]	*ns*		.01 (.03)	[-.03, .05]	*ns*	
Category(FE)	**.01** (.05)	[.00, .02]	*ns*		**.02** (.13)	[.01, .02]	*ns*		-.01 (.04)	[-.06, .03]	*ns*	
Category(HA)	.01 (.02)	[-.01, .02]	*ns*		**.01** (.08)	[.00, .02]	*ns*		.03 (.08)	[-.01, .07]	*ns*	
AOI(Eyes)	**.27** (1.08)	[.26, .28]	**.27** (1.08)	[.26, .28]	--		--		--		--	
AOI(Nose)	**-.07** (.27)	[-.08, -.06]	**-.07** (.27)	[-.08, -.06]	--		--		--		--	
Category(AN) x Group	*ns*		*ns*		*ns*		*ns*		-.00 (.01)	[-.06, .07]	*ns*	
Category(FE) x Group	*ns*		*ns*		*ns*		*ns*		-.02 (.04)	[-.08, .05]	*ns*	
Category(HA) x Group	*ns*		*ns*		*ns*		*ns*		**-.08** (.21)	[-.15, -.02]	*ns*	
AOI x Group	*ns*		*ns*		--		--		--		--	
Variance(Intercept)	.002	[.002, .003]	.002	[.002, .003]	.001	[.001, .001]	.001	[.001, .001]	**.015**	[.01, .02]	**.014**	[.01, .02]
Residual	.061	[.060, .063]	.062	[.060, .063]	.013	[.012, .013]	.013	[.012, .013]	**.131**	[.13, .14]	**.132**	[.13, .14]
N included	14727		14727		4909		4909		50925		53405	

Note: Group was coded as -1 = DHH, 1 = TH (reference). Category (i.e., predefined/interpreted emotion category) was coded as -2 = anger (AN), -1 = fear (FE), 1 = happiness (HA), 2 = neutral emotion (reference). Area of interest (AOI) was coded as -1 = eyes, 0 = nose, 1 = mouth (reference). An "*ns*" indicates that the variable was removed from the final model due to insignificance. A "—" indicates that the variable was not included in the full model. Significant values ($p < 0.05$) are bolded. Coef = unstandardized coefficient; CI = confidence interval. Δ = standardized effect size, calculated by dividing fixed coefficient by the square root of the sum of Level 1 (residual) and Level 2 (intercept) variances (formula suggested by Raudenbush and Liu, 2000). *N* included = number of cases included in the analysis.

Table S2.1.2. Results of multivariate analyses of variance on accuracy Hu scores and misinterpretation tendencies, after excluding children with only a hearing aid.

Effect	Accuracy	Misinterpretation
Group	$F(1, 123) = .80, \eta_p^2 = .01$	$F(1, 123) = .56, \eta_p^2 = .004$
Category	$F(3, 372) = 64.42^{***}, \eta_p^2 = .34$	$F(3, 372) = 15.62^{***}, \eta_p^2 = .11$
Category x Group	$F(3, 372) = 1.09, \eta_p^2 = .01$	$F(3, 372) = 7.77^{***}, \eta_p^2 = .06$
Post-hoc results	HA > NE > AN = FE (*t*s > 5.11, *p*s < .001 for the differences)	*Between-group* AN: DHH > TH ($t = 2.08^*$) FE: DHH = TH ($t = 1.73$) HA: DHH = TH ($t = -.90$) NE: DHH < TH ($t = -3.32^{**}$) *Within-group* DHH: AN > FE = NE > HA (*t*s > 2.86, *p*s < .007 for the differences) TH: AN = NE > FE = HA (*t*s > 3.14, *p*s < .003 for the differences)

Note: DHH = deaf and hard of hearing. TH = typically hearing. AN = angry. FE = fearful. HA = happy. NE = neutral. $^*p < .05$; $^{**}p < .01$; $^{***}p < .001$.

S2.2. Exploratory Analyses on Confusion Patterns between Predefined Emotion Categories

For exploratory purposes, we used four 2 (Group: DHH, TH) x 3 (Misinterpretation: e.g., anger misinterpreted as fear, happiness, or neutral emotion) multivariate analyses of variance to examine how each predefined emotion category was confused with the other emotion categories. Age was included as a covariate. Given the number of analyses we ran, which increased the chance of Type I errors, we adjusted the significance level of all exploratory analyses to $p < \alpha/4 = 0.0125$. See Table S1 for percentages of misinterpretations in the two groups.

When angry faces were presented, we observed a main effect of Misinterpretation, $F(2, 248) = 26.74$, $p < .001$, = .18, and an interaction of Group x Misinterpretation, $F(2, 248) = 10.61$, $p < .001$, = .08. Pairwise comparisons showed that the TH children more often misinterpreted angry faces as neutral than the DHH children, $t(124) = -3.82$, $p < .001$. Moreover, the DHH children more often misinterpreted angry faces as fearful or neutral than as happy, ts > 3.16, ps < .004. The TH children more often mistook angry faces as neutral faces than as fearful faces, $t(71) = 4.49$, $p < .001$, which were mistaken more often than happy faces, $t(71) = 3.01$, $p = .004$.

When fearful faces were presented, we observed a main effect of Misinterpretation, $F(2, 248) = 23.61$, $p < .001$, = .16. Post-hoc tests showed that fearful faces were more often recognized as being angry than as being happy or neutral, ts > 4.40, ps < .001.

When happy faces were presented, we did not observed any effects involved Group and Misinterpretation.

When neutral faces were presented, we found main effects of Group, $F(1, 124) = 7.83$, $p = .006$, = .06, and Misinterpretation, $F(2, 250) = 10.62$, $p < .001$, = .08. We also observed an interaction of Group x Misinterpretation, $F(2, 250) = 4.56$, $p = .011$, = .04. Post-hoc t-tests showed that the DHH children more often misinterpreted neutral faces as angry than the TH children, $t(125) = 2.61$, $p = .010$. Also, the DHH children more often mistook neutral faces as expressing anger than as expressing fear or happiness, ts > 3.07, ps < .004. The TH children did not show a particular pattern for misinterpreting neutral faces.

Taken together, the results of the exploratory analyses indicated that the TH children showed a tendency to interpret angry faces as neutral, while the DHH children showed more confusion between angry, fearful, and neutral faces.

Finally, the misinterpretation of fearful, happy, and neutral faces decreased with Age (for fearful faces: $F(1, 123) = 62.63$, $b = -.002$, $p < .001$, 95% CI [-.002, -.001], = .34; for happy faces: $F(1, 123) = 30.75$, $b = -.002$, $p < .001$, 95% CI [-.002, -.001], = .20; for neutral faces: $F(1, 124) = 50.33$, $b = -.002$, $p < .001$, 95% CI [-.003, -.001], = .29). The misinterpretation of angry faces remained stable across Age.

Table S2.2.1. Confusion matrices of the DHH and TH children. The numbers indicate percentages.

	DHH				TH				Difference DHH - TH			
	Interpreted Category				Interpreted Category				Interpreted Category			
Predefined Category	A	F	H	N	A	F	H	N	A	F	H	N
Anger	58	19	8	15	52	14	9	25	6	5	-1	-10
Fear	28	48	12	12	22	49	12	17	6	-1	0	-5
Happy	14	12	65	9	10	9	72	9	4	3	-7	0
Neutral	21	12	10	57	13	10	11	66	8	2	-1	-9

S2.3. Post-Hoc Analyses on Physiological Arousal

Table S2.3.1. Fixed and random effects in the generalized linear mixed models of physiological arousal, using each predefined emotion category as the reference category to examine between-group differences.

	Between-group differences					
	Angry as reference		**Fearful as reference**		**Happy as reference**	
Fixed/random effect	*Coef*	95% *CI*	*Coef*	95% *CI*	*Coef*	95% *CI*
Intercept	**.14**	[.10, .18]	.12	[.08, .16]	.16	[.12, .20]
Age	*ns*		*ns*		*ns*	
Group	.03	[-.04, .09]	.01	[-.05, .08]	-.06	[-.12, .004]
Angry	*ref*		.03	[-.02, .07]	-.02	[-.06, .02]
Fearful	-.03	[-.07, .02]	*ref*		**-.04**	[-.09, -.002]
Happy	.02	[-.02, .06]	**.04**	[.002, .09]	ref	
Neutral	-.01	[-.05, .03]	.01	[-.03, .06]	-.03	[-.07, .01]
Angry x Group	*ref*		.01	[-.05, .08]	**.09**	[.02, .15]
Fearful x Group	-.01	[-.08, .05]	*ref*		**.07**	[.01, .14]
Happy x Group	**-.09**	[-.15, -.02]	**-.07**	[-.14, -.01]	*ref*	
Neutral x Group	-.002	[-.06, .07]	.02	[-.05, .08]	**.09**	[.02, .15]
Variance(Intercept)	.01	[.01, .02]	.01	[.01, .02]	.01	[.01, .02]
Residual	.13	[.13, .14]	.13	[.13, .14]	.13	[.13, .14]

Note: Group was coded as -1 = DHH, 1 = TH (reference). An "*ns*" indicates that the variable was removed from the final model due to insignificance. Significant values ($p < 0.05$) are bolded. *Coef* = unstandardized coefficient; *CI* = confidence interval.

Table S2.3.2. Fixed and random effects in the generalized linear mixed models of physiological arousal within the DHH group, using each predefined emotion category as the reference category to examine differences between predefined emotion categories within the DHH children.

	Within-group differences: DHH group							
	Angry as reference		**Fearful as reference**		**Happy as reference**		**Neutral as reference**	
Fixed/random effect	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*
Intercept	.17	[.12, .21]	.13	[.08, .18]	.10	[.06, .15]	.16	[.11, .21]
Age	ns		ns		ns		ns	
Angry	ref		.04	[-.01, .09]	.07	[.02, .11]	.01	[-.04, .06]
Fearful	-.04	[-.09, .01]	ref		.03	[-.02, .08]	-.03	[-.08, .02]
Happy	-.07	[-.11, -.02]	-.03	[-.08, .02]	ref		-.06	[-.11, -.01]
Neutral	-.01	[-.06, .04]	.03	[-.02, .08]	.06	[.01, .11]	ref	
Variance(Intercept)	.01	[.01, .02]	.01	[.01, .02]	.01	[.01, .02]	.01	[.01, .02]
Residual	.14	[.13, .15]	.14	[.13, .15]	.14	[.13, .15]	.14	[.13, .15]

Note: An "*ns*" indicates that the variable was removed from the final model due to insignificance. Significant values ($p < 0.025$) are bolded. *Coef* = unstandardized coefficient; *CI* = confidence interval.

Table S2.3.3. Fixed and random effects in the generalized linear mixed models of physiological arousal within the TH group, using each predefined emotion category as the reference category to examine differences between predefined emotion categories within the TH children.

	Within-group differences: TH group							
	Angry as reference		**Fearful as reference**		**Happy as reference**		**Neutral as reference**	
Fixed/random effect	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*	Coef	95% *CI*
Intercept	**.14**	[.10, .18]	**.12**	[.07, .16]	**.16**	[.12, .20]	**.13**	[.09, .17]
Age	*ns*		*ns*		*ns*		*ns*	
Angry	*ref*		.03	[-.02, .07]	-.02	[-.06, .02]	.01	[-.03, .05]
Fearful	-.03	[-.07, .02]	ref		-.04	[-.09, -.003]	-.02	[-.06, .03]
Happy	.02	[-.02, .06]	.04	[.003, .09]	*ref*		.03	[-.01, .07]
Neutral	-.01	[-.05, .03]	.02	[-.03, .06]	-.03	[-.07, .01]	*ref*	
Variance(Intercept)	.02	[.01, .03]	.02	[.01, .03]	.02	[.01, .03]	.02	[.01, .03]
Residual	.13	[.12, .14]	.13	[.12, .14]	.13	[.12, .14]	.13	[.12, .14]

Note: An "*ns*" indicates that the variable was removed from the final model due to insignificance. Significant values ($p < 0.025$) are bolded. *Coef* = unstandardized coefficient; *CI* = confidence interval.

SUPPLEMENTARY MATERIALS CHAPTER 3

S3.1. Sample Size Justification

The sample size for the research project was estimated a priori with a power analysis. Previous studies indicated that a difference in emotion understanding between DHH and TH children could be observed with small-to-medium effect sizes (Torres et al., 2016; Wiefferink et al., 2013). Thus, a minimum sample size of 82 was required to detect a group difference (d = .4; α = .05; power = .90). Note that we planned to use mixed model ANOVAs when estimating sample size a priori and later changed to multilevel models considering the two-level structure in the data.

S3.2. Stimuli

Video Validation

Before the study started, the emotion triggered in the videos were rated by 17 typically developing adults. The consent rate was above 82% for 15 of the 16 videos (M = 90.86%, SD = 6.27). Yet, one video had a low consent rate (58.82%) because some raters mistook the surprised face among the response options as fearful. This face image was replaced by a retaken photo.

Table S3.2.1. Overview of videos. There were two sets of videos, and children were randomly assigned to one of the sets. The first sentence describes the contextual scene. The second sentence (bolded) describes the key-action scene (i.e., the scene included in the analyses).

Trial	Set A	Set B
1§	A woman is crying and a man approaches. **The man gives her a flower.***	A man is enjoying himself (slightly shaking body with a tempo) and a woman approaches. **The woman gives him a well wrapped gift.**
2§	A woman is hurt and a man approaches. **The man does not help her.**	A man is enjoying himself (smoking) and a woman approaches. **The woman shows that he is forbidden to be here.***
3	A woman is happily checking smartphone and another woman approaches. **The second woman gives her a high five.**	A woman is happily checking smartphone and another woman approaches. **The second woman pushes her away with elbow while walking by.***
4	A man is sitting in a cafeteria, looking hungry, and a woman approaches with a pizza. **The woman refuses to share the pizza with him.**	A man is sitting in a cafeteria, looking hungry, and a woman approaches with a pizza. **The woman shares the pizza with him.***
5	A woman is waving with a smile and crossing a road. **A man on the other side of the road pushes her down to the ground.***	A woman is waving with a smile and crossing a road. **A man on the other side of the road gives her a well wrapped gift.**
6	A man is hurt, walking with sticks, and a woman approaches. **The woman shows him a cake.***	A man is hurt, walking with sticks, and a woman approaches. **The woman laughs.**
7	A woman is happily climbing across monkey bars. **She successfully makes it to the end and a man gives her a cold drink.**	A woman is happily climbing across monkey bars. **She falls from it and a man points at her.***
8	A man is riding a bike, almost falling down, and a woman approaches. **The woman holds the bike.***	A man is riding a bike, almost falling down, and a woman approaches. **The woman throws a rock at him.**

§ While in trials 3 to 8 the videos in set A and set B were parallel, the first two trials had a different structure. We designed two videos with conceptually similar, but not the same, contextual scenes (e.g., crying vs. feeling pain) and each ends with an emotion in the opposite valence. These two videos were placed in the same set.
*The video had a twist in the plot, i.e., from positive to negative emotion, or vice versa.

S3.3. Fixation Duration

Table S3.3.1. Fixed and random effects in the generalized linear mixed model of fixation ratios within video frame (binomial distribution, link function = logit).

Fixed and random effect	Coefficient	95% CI	z-value (p-value)
Intercept	5.30	[4.74, 5.86]	18.51 (< .001)
Age	**.04**	[.01, .06]	3.38 (.001)
Group	*ns*		
Valence	**-.46**	[-.76, -.16]	-2.98 (.003)
Valence x Group	*ns*		
Variance - Intercept	1.90	[1.53, 2.37]	

Note: Group was coded as -1 = DHH, 1 = TH. Valence was coded as -1 = negative, 1 = positive. The last category was used as the reference. An "*ns*" indicates that the variable was removed from the final model due to insignificance. CI = confidence interval.

Table S3.3.2. Mean (SD) of fixation duration (ms) and ratio within each area as a function of hearing status, device use, and chronological age.

		Hearing status		Device use		Chronological age	
Area		DHH (*n* = 57)	TH (*n* = 68)	CI (*n* = 52)	HA (*n* = 5)	< 6 years (*n* = 77)	≥ 6 years (*n* = 48)
Target Head	ms	647.75 (384.83)	845.92 (501.63)	665.43 (382.31)	463.95 (404.28)	634.33 (433.44)	950.02 (441.12)
	ratio[a]	0.15 (0.07)[#]	0.18 (0.08)[#]	0.16 (0.07)	0.11 (0.08)	0.14 (0.07)***	0.20 (0.07)***
Target Body	ms	452.53 (323.29)	494.1 (359.59)	473.34 (323.63)	236.04 (252.29)	503.63 (392.94)	429.43 (238.46)
	ratio[a]	0.13 (0.07)	0.11 (0.08)	0.13 (0.07)	0.10 (0.07)	0.12 (0.08)	0.10 (0.06)
Partner Head	ms	963.97 (598.61)	1077.50 (654.02)	974.10 (598.70)	858.65 (656.87)	872.12 (602.3)	1272.14 (598.29)
	ratio[a]	0.23 (0.11)	0.23 (0.11)	0.23 (0.11)	0.22 (0.13)	0.20 (0.11)***	0.27 (0.10)***
Partner Action	ms	466.10 (292.23)	531.74 (332.46)	482.37 (293.20)	296.91 (245.53)	470.87 (334.45)	551.44 (277.85)
	ratio[a]	0.11 (0.05)	0.11 (0.05)	0.11 (0.05)	0.07 (0.03)	0.10 (0.06)	0.12 (0.05)
Within video	ms	3845.59 (1495.81)	4395.06 (1587.74)	3925.78 (1440.33)	3011.55 (1979.97)	3956.52 (1709.09)	4446.05 (1258.83)
	ratio[a]	0.97 (0.13)	0.96 (0.08)	0.97 (0.14)	0.95 (0.07)	0.95 (0.13)*	0.99 (0.03)*
Within screen	ms	3889.36 (1498.80)	4527.17 (1532.56)	3969.32 (1444.30)	3057.86 (1976.24)	4089.27 (1696.54)	4472.24 (1243.66)
	ratio[b]	0.57 (0.22)*	0.66 (0.22)*	0.58 (0.21)	0.44 (0.28)	0.60 (0.24)	0.66 (0.18)
Off-screen	ms	2987.01 (1591.86)	2311.53 (1530.15)	2910.40 (1549.23)	3783.71 (2001.34)	2779.31 (1756.23)	2363.26 (1249.65)
	ratio[b]	0.43 (0.22)*	0.34 (0.22)*	0.42 (0.21)	0.56 (0.28)	0.40 (0.24)	0.34 (0.18)

Note: DHH = deaf and hard of hearing. TH = typically hearing. CI = cochlear implant. HA = hearing aid.
[a] Ratio against fixation duration within the entire screen. [b] Ratio against the duration of the video (key-action scene).
# $p < .08$; * $p < .05$; *** $p < .001$ for the differences in fixation ratios between the comparison groups according to t-tests (two-tailed).

S3.4. Analyses on Children with Cochlear Implants

When analyses were conducted excluding the children with only a hearing aid (HA), i.e., including only children with a cochlear implant (CI), the directions of results generally remained the same. Below we discuss the differences observed between the analyses on all DHH children and the analyses on children with a CI. See Table S4.1 for the complete final models.

Encoding

Regarding the fixation ratios within the video frame, all results were in line with the previous analyses where the entire DHH group was included.

In the analysis on fixation ratios within the AOIs, all the effects remained the same as previous analyses, except for the interaction of Group x Partner Head. When only children with a CI were included, this effect became marginal, $b = .03$, 95% CI [-.00, .06], $\delta = .17$. The interaction of Group x Target Body remained significant, $b = .04$, 95% CI [.01, .07], $\delta = .23$.

Interpretation

All the results were congruent with previous analyses, except that an effect for Valence was observed, $b = .06$, $p = .038$, 95% CI [.003, .11], $\delta = .09$. In children with CIs and with TH, negative emotions were interpreted more accurately than positive emotions. No interaction effects were observed, in line with previous analyses.

Effect of Encoding on Interpretation

For nonverbal interpretation, we observed two additional interactions: Group x Target Body, $b = -.39$, 95% CI [-.68, -.10], $\delta = .60$, and Group x Partner Head, $b = -.30$, 95% CI [-.56, -.03], $\delta = .46$. These results suggest that, while looking longer at Target Body and Partner Head decreased the nonverbal interpretation scores in the two groups alike, these effects were even stronger in children with a CI.

For verbal interpretation, we observed an additional main effect of Partner Head, $b = -.17$,95% CI [-.29, -.05], $\delta = .28$. This indicates that longer looking times at Partner Head were associated with lower verbal scores in the two groups. We also observed two additional interactions, Group x Target Head, $b = .30$, 95% CI [.02, .59], $\delta = .49$, and Group x Partner Action, $b = .48$, 95% CI [.18, .78], $\delta = 78$. Although looking longer at Target Head increased verbal interpretation scores in the two groups alike, this effect was stronger in the children with a CI. Also, the association between longer looking times at Partner Action and lower verbal scores was observed only in the TH children, but not in the children with a CI.

Discussion

Despite these differences between the analyses on all DHH children and the analyses on only children with a CI, the overall picture derived from the results was similar. DHH children decreased their attention to the target person's head and increased their attention to the target person's body. This finding further supports our claim that DHH children tend to divert their attention away from ambiguous cues to explicit, visually observable information, especially the body cues.

Also, the cues we examined in this study appear to work differently on interpretation in the two groups. DHH children were more easily misled by explicit cues, such as target person's body and interaction partner's head. This is most likely because they did not have adequate social-emotional knowledge to support their use of these explicit cues, as we discussed in the main text. The extra interactions of Group x Target Body and Group x Partner Head we observed in the analyses on only the children with a CI suggest that children with a CI might need even more support for gaining social-emotional knowledge in order to make proper interpretation when encountering social situations.

Considering that we only had five children with a HA, it is hard to draw a conclusion whether different types of amplification or degrees of hearing loss might have an effect. Future research is suggested to look further in this direction.

Table S3.4.1. Fixed and random effects in the generalized linear mixed models excluding children with only a hearing aid (n = 5).

	Fixation ratio				Interpretation		Verbal interpretation			
	within AOIs		Video frame				Interpretation		Effect of encoding	
Parameters	*b*	95% CI	*b*	95% CI	*b*	95% CI	*b*	95% CI	*b*	95% CI
Intercept	.18	[.17, .20]	.97	[.95, .99]	1.10	[1.03, 1.18]	1.14	[1.07, 1.21]	1.12	[1.05, 1.18]
Age	**.00**	[.00, .00]	**.00**	[.00, .00]	**.01**	[.01, .01]	**.01**	[.01, .01]	**.01**	[.01, .01]
Group	**-.02**	[-.05, -.00]	ns		**-.16**	[-.25, -.06]	**-.18**	[-.28, -.08]	**-.14**	[-.24, -.04]
Valence	*ns*		**-.01**	[-.02, -.01]	**.06**	[.00, .11]	ns		ns	
Group x Valence	*ns*		*ns*		**.07**	[.02, .13]	ns		ns	
Group x Task					ns					
Group x Valence x Task					ns					
TarHead	*ref*		--		ns		--		**.18**	[.02, .35]
TarBody	**-.07**	[-.09, -.05]	--		--		--		-.11	[-.31, .09]
ParHead	**.05**	[.03, .07]	--		--		--		**-.17**	[-.29, -.05]
ParAction	**-.07**	[-.09, -.05]	--		--		--		**-.59**	[-.80, -.39]
Group x TarHead	*ref*		--		--		--		**.30**	[.02, .59]
Group x TarBody	**.04**	[.01, .07]	--		--		--		**-.42**	[-.69, -.15]
Group x ParHead	.03	[-.00, .06]	--		--		--		*ns*	
Group x ParAction	.03	[-.00, .06]	--		--		--		**.48**	[.18, .78]
Var(Intercept)	.00	[.00, .00]	.01	[.01, .01]	--		.07	[.05, .10]	.07	[.05, .09]
Residual	.03	[.02, .03]	.01	[.01, .01]	.05	[.03, .07]	.33	[.32, .35]	.31	[.29, .32]

Note: Group was coded as -1 = DHH, 1 = TH. Valence was coded as -1 = negative, 1 = positive. Task was coded as -1 = nonverbal, 1 = verbal. AOI was coded as -2 = interaction partner's head (ParHead), -1 = interaction partner's action (ParAction), 1 = target person's body (TarBody), 2 = target person's head (TarHead). The last category was used as the reference ("ref"). An "ns" indicates that the variable was removed from the final model due to insignificance. A "--" indicates that the effect was not included in the full model. Significant fixed effects ($p < 0.05$) are bolded. CI = confidence interval.

SUPPLEMENTARY MATERIALS CHAPTER 4

S4.1. Parent reports

Table S4.1.1. Items in each parent-report measure

Emotion recognition	
1.	Can your child fully acknowledge others' emotions?
2.	Does your child see when you are angry?
3.	Does your child see when you are happy?
4.	Does your child see when you are afraid?
5.	Does your child see when you are sad?
6.	Does your child see when you are having fun?
Empathy (3-5 years old)	
1.	When another child cries, my child gets upset too.
2.	When I make clear that I want some peace and quiet, my child tries not to bother me.
3.	When my child sees other children laughing, he/she starts laughing too.
4.	My child also needs to be comforted when another child is in pain.
5.	When another child starts to cry, my child tries to comfort him/her.
6.	When an adult gets angry with another child, my child watches attentively.
7.	When another child makes a bad fall, shortly after my child pretends to fall too.
8.	When another child gets upset, my child tries to cheer him/her up.
9.	My child looks up when another child laughs.
10.	When another child is upset, my child needs to be comforted too.
11.	When I make clear that I want to do something by myself (e.g. read), my child leaves me alone for a while.
12.	When adults laugh, my child tries to get near them.
13.	When another child gets frightened, my child freezes or starts to cry.
14.	When two children are quarrelling, my child tries to stop them.
15.	My child looks up when another child cries.
16.	When other children argue, my child gets upset.
17.	When another child gets frightened, my child tries to help him/her.
18.	When another child is angry, my child stops his own play to watch.
19.	When another child cries, my child looks away.
20.	When other children quarrel, my child wants to see what is going on.
Empathy (6-10 years old)	
1.	If I am happy, my child also feels happy.
2.	My child understands that a friend is ashamed when he/she has done something wrong.
3.	If a friend is sad, my child likes to comfort him.
4.	My child feels awful when two people quarrel.
5.	When a friend is angry, my child tends to know why.
6.	My child would like to help when a friend gets angry.
7.	If a friend is sad, my child also feels sad.
8.	My child understands that a friend is proud when he/she has done something good.
9.	If a friend has an argument, my child tries to help.
10.	If a friend is laughing, my child also laughs.
11.	If a friend is sad, my child understands mostly why.
12.	My child wants everyone to feel good.
13.	When a friend cries, my child cries himself/herself.
14.	If a friend cries, my child often understands what has happened.
15.	If a friend is sad, my child wants to do something to make it better.
16.	If someone in the family is sad, my child feels really bad.
17.	My child enjoys giving a friend a gift.
18.	When a friend is upset, my child feels upset too.

Table S4.1.1. Continued

Negative emotion expression	
1.	How often does your child show anger?
2.	How intense is this usually?
3.	How long does it usually last?
4.	Is your child easy to calm down when angry?
5.	How often does your child show sadness?
6.	How intense is this usually?
7.	How long does it usually last?
8.	Is your child easy to calm down when he is sad?
Positive emotion expression	
1.	How often does your child show happiness?
2.	How intense is this usually?
3.	How long does it usually last?
4.	How often does your child show joy?
5.	How intense is this usually?
6.	How long does it usually last?
Social competence	
1.	Rather solitary, tends to play alone (R)
2.	Has at least one good friend
3.	Generally liked by other children
4.	Picked on or bullied by other children (R)
5.	Gets on better with adults than with other children (R)#
6.	Considerate of other people's feelings
7.	Shares readily with other children (treats, toys, pencils etc.)
8.	Helpful if someone is hurt, upset or feeling ill#
9.	Kind to younger children
10.	Often volunteers to help others (parents, teachers, other children)
Externalizing behaviors	
1.	Restless, overactive, cannot stay still for long
2.	Constantly fidgeting or squirming
3.	Easily distracted, concentration wanders
4.	Thinks things out before acting (R)
5.	Sees tasks through to the end, good attention span (R)
6.	Often has temper tantrums or hot tempers#
7.	Generally obedient, usually does what adults request (R)
8.	Often fights with other children or bullies them
9.	Often lies or cheats
10.	Steals from home, school or elsewhere

Note: R = reversely scored; # = removed from the analyses, given the reason provided in the main text.

S4.2. EmQue and EmQue-CA

Table S4.2.1. Correlations of Empathy Questionnaire (EmQue) and Empathy Questionnaire for Children and Adolescents (EmQue-CA) with other study variables (pooled results after multiple imputations)

	Negative emotion expression	Positive emotion expression	Emotion recognition	Social competence	Externalizing behaviors
EmQue	-.199	.182	.475***	.392**	-.236
EmQue-CA	-.028	.065	.589***	.295*	-.351**
Fisher's r to z	-.963	.660	-.885	.611	.699
p (z)[a]	.336	.509	.376	.541	.485

*p < .05; **p < .01; ***p < .001 for correlations between EmQue/EmQue-CA and study variables.
[a] Significance of the z-score after Fisher's r-to-z transformation, which was applied to compare the strength of correlations.

S4.3. Analyses Excluding Children without a Cochlear Implant

Table S4.3.1. Psychometric properties and mean scores (standard deviations) of the questionnaires after excluding the five children without a cochlear implant

	Cronbach's α (*n* sample)	Mean (SD)		*t* value[a]	*p* value[ab]
		DHH	TH		
Emotion recognition	.83 (122)	3.64 (.62)	3.61 (.74)	-.29	.387
Empathy (all children)	--	1.22 (.30)	1.25 (.34)	.40	.346
Empathy (3-5 years)	.79 (58)	1.07 (.26)	1.07 (.28)	-.01	.497
Empathy (6-10 years)	.85 (60)	1.35 (.27)	1.42 (.29)	.98	.165
Negative emotion expression	.80 (123)	2.42 (.55)	2.43 (.54)	.16	.437
Positive emotion expression	.74 (123)	3.65 (.66)	3.63 (.54)	-.27	.395
Social competence	.68 (120)	1.47 (.35)	1.52 (.30)	.67	.252
Externalizing problems	.74 (121)	.72 (.39)	.62 (.30)	-1.50	.066

Note: DHH = deaf and hard of hearing; TH = typically hearing.
[a] Pooled results after multiple imputations.
[b] One-tailed.

Table S4.3.2. Hierarchical regression analyses for emotional functioning measures on social functioning after excluding the five children without a cochlear implant (pooled results after multiple imputations)

	Social competence			**Externalizing behaviors**		
	b	***p***	**95% CI**	***b***	***p***	**95% CI**
Step 1	$R^2 = .24^{**}$			$R^2 = .25^{**}$		
Age	< .001	.921	[-.003, .002]	.001	.282	[-.001, .004]
Gender	-.001	.990	[-.11, .11]	.04	.509	[-.07, .15]
Group	-.04	.481	[-.14, .07]	.08	.137	[-.03, .20]
Emotion recognition	.06	.210	[-.03, .15]	-.01	.859	[-.10, .09]
Empathy	**.25**	**.022**	**[.04, .46]**	**-.32**	**.005**	**[-.55, -.10]**
Negative emotion expression	**-.18**	**< .001**	**[-.28, -.08]**	**.21**	**< .001**	**[.10, .31]**
Positive emotion expression	.01	.872	[-.09, .10]	.02	.708	[-.08, .12]
Step 2	$\Delta R^2 = .05$			$\Delta R^2 = .07^{*}$		
Age				.002	.130	[-.001, .01]
Gender				.04	.529	[-.07, .14]
Group				-.61	.188	[-.53, .30]
Emotion recognition				.04	.455	[-.07, .15]
Empathy				**-.51**	**< .001**	**[-.77, -.25]**
Negative emotion expression				.05	.441	[-.08, .19]
Positive emotion expression				.04	.540	[-.09, .17]
Group x Emotion recognition				-.12	.222	[-.32, .07]
Group x Empathy				.38	.072	[-.03, .79]
Group x Negative emotion expression				**.33**	**.002**	**[.12, .54]**
Group x Positive emotion expression				-.05	.638	[-.24, .15]

Note: Gender was coded as 0 = male, 1 = female. Group was coded as 0 = typically hearing, 1 = cochlear implant. 95% CI: 95% confidence interval. *p < .05; **p < .001 for the change in R^2.

S4.4. Comparisons between DHH and TH Children Per Age Group

Table S4.4.1. Mean scores (standard deviations) per age group and comparisons between deaf and hard-of-hearing (DHH) children and children with typical hearing (TH)

	Emotion recognition	Empathy	Negative emotion expression	Positive emotion expression	Social competence	Externalizing behaviors
3-4 years						
DHH (n=18)	3.69 (.75)	1.08 (.24)	2.52 (.78)	3.60 (.60)	1.42 (.43)	.79 (.35)
TH (n=21)	3.62 (.64)	1.07 (.28)	2.46 (.47)	3.73 (.59)	1.48 (.30)	.70 (.31)
t value[a]	-.34	-.11	-.28	.68	.45	-.82
p value[ab]	.366	.457	.390	.250	.327	.208
5-6 years						
DHH (n=19)	3.79 (.73)	1.18 (.34)	2.32 (.41)	3.57 (.57)	1.46 (.31)	.65 (.38)
TH (n=35)	3.62 (.86)	1.25 (.33)	2.41 (.62)	3.56 (.51)	1.54 (.28)	.60 (.26)
t value[a]	-.84	.74	.61	-.24	.94	-.57
p value[ab]	.200	.231	.272	.407	.175	.286
7-10 years						
DHH (n=18)	3.64 (.48)	1.37 (.21)	2.31 (.43)	3.77 (.74)	1.54 (.34)	.71 (.42)
TH (n=18)	3.59 (.63)	1.45 (.30)	2.43 (.44)	3.64 (.56)	1.51 (.32)	.57 (.34)
t value[a]	-.25	.89	.82	-.59	-.22	-1.03
p value[ab]	.402	.187	.208	.278	.415	.152

[a] Pooled results after multiple imputations.
[b] One-tailed.

S4.5. Correlations between Emotional and Social Functioning Measures

Table S4.5.1. Pearson's correlations between all study variables (pooled results after multiple imputations)

	Correlation in all children (in DHH children / in children with TH)					
	1.	**2.**	**3.**	**4.**	**5.**	**6.**
1. Age						
2. Emotion recognition	-.05 (-.07/-.05)					
3. Empathy	**.38** (**.41**/**.38**)	**.45** (**.44**/**.46**)				
4. Negative emotion expression	-.07 (-.12/-.02)	-.12 (-.19/-.06)	-.19 (-.04/**-.30**)			
5. Positive emotion expression	.07 (.12/.01)	**.24** (.24/.24)	.11 (.25/.02)	.18 (.12/.25)		
6. Social competence	.09 (.10/.10)	**.27** (.35/.24)	**.38** (**.36**/**.40**)	**-.36** (**-.50**/-.24)	.02 (.05/-.01)	
7. Externalizing behaviors	-.03 (.02/-.12)	-.18 (-.25/-.14)	**-.33** (-.15/**-.48**)*	**.40** (**.55**/.27)#	.06 (.01/.11)	**-.51** (**-.52**/**-.49**)

Note. Correlations in DHH children and in children with TH are reported separately in the parentheses. Significant correlations are bolded. Given that each variable was tested against the other six variables, Bonferroni correction was applied to adjust significance level to $p < \alpha/6 = .0083$.

*$p = .040$ for the difference in the strength of correlation between DHH children and children with TH, according to Fisher's r-to-z transformation.

#$p = .064$ for the difference in the strength of correlation between DHH children and children with TH, according to Fisher's r-to-z transformation.

SUPPLEMENTARY MATERIALS CHAPTER 5

S5.1. Correlations between Study Variables

Table S5.1.1. Pearson's correlations between study variables.

	1.	2.	3.	4.	5.	6.
1. Age	-					
2. Affective empathy	-.106*	-				
3. Attention to emotions	.026	.350**	-			
4. Prosocial actions	.403**	.150**	.305**	-		
5. Emotion acknowledgment	.195**	.016	.262**	.365**	-	
6. Internalizing behaviors	.222**	.272**	.120*	.042	-.082	-
7. Externalizing behaviors	.095	.094	.067	.025	-.076*	.374**

* $p < .0083$; ** $p < .001$. Significance level was adjusted by the number of correlation analyses on each variable to $p < \alpha/6 = .0083$.

S5.2: Individual Variations

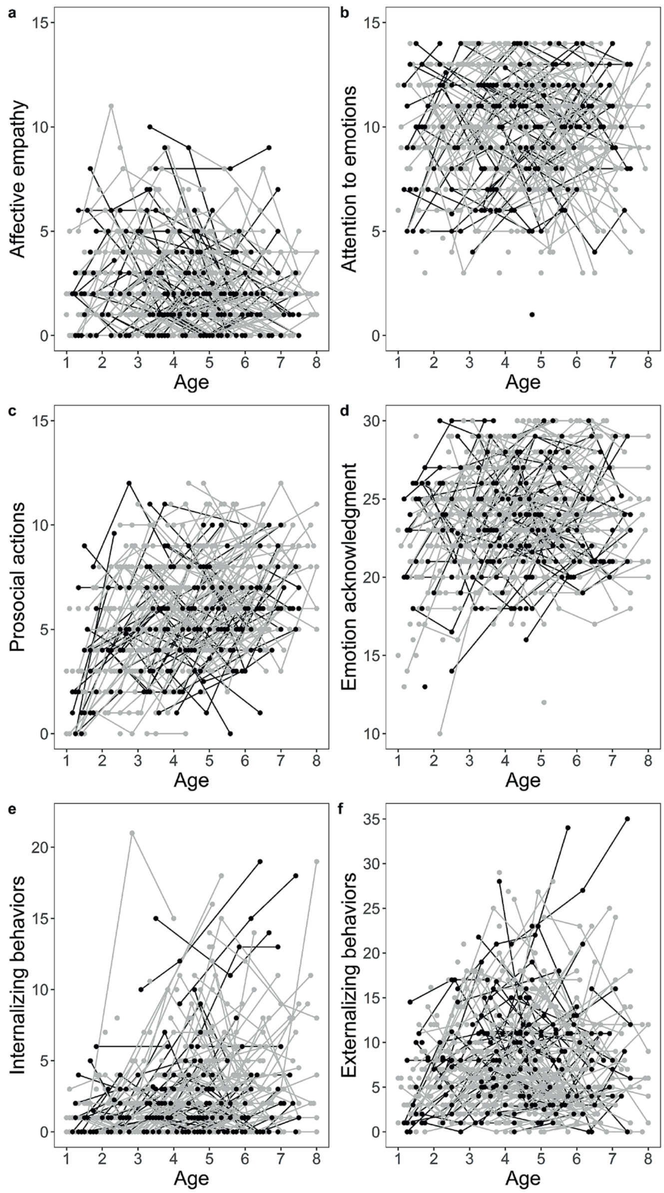

Figure S5.2.1. Longitudinal graphic representation of age at the four time points of **1a.** affective empathy; **1b.** attention to others' emotions; **1c.** prosocial actions; **1d.** emotion acknowledgment; **1e.** internalizing behaviors; **1f.** externalizing behaviors. Each participant is presented by an individual line and each time point is presented by a point. Children with a cochlear implant are displayed in black, and typically-hearing children in grey.

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CURRICULUM VITAE

Yung-Ting Tsou was born in 1988 on the 24th of April in Keelung, Taiwan. In 2006, she graduated from the Affiliated Senior High School of National Taiwan Normal University. She later obtained her bachelor degree in Foreign Languages and Literatures at National Taiwan University in 2011, and won the Presidential Award in 2009. In 2012, she received her master degree in Linguistics at Leiden University. After graduation, she worked as a research assistant at the Department of Otorhinolaryngology – Head and Neck Surgery at Chang-Gung Memorial Hospital, Linkou, Taiwan, and studied language and social development in children with cochlear implants. In 2016, Yung-Ting started her PhD project at the Institute of Psychology of Leiden University, under the supervision of Prof. dr. Carolien Rieffe, Prof. dr. ir. Johan H. M. Frijns, Dr. Boya Li, and Dr. Mariska E. Kret. Her research focused on the processing of emotions in social contexts in children who are deaf or hard-of-hearing, using eye-tracking and pupillometry technologies. After her PhD, Yung-Ting will work as a postdoctoral researcher in the "Breaking the cycle" research project with Prof. dr. Carolien Rieffe and Dr. Els Blijd-Hoogewys (INTER-PSY), also at Leiden University. She will work on the development and implementation of an intervention scheme for creating a more inclusive environment at schoolyards.

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