Infant Behavior and Development 67 (2022) 101699

Contents lists available at ScienceDirect

Infant Behavior and Development

journal homepage: www.elsevier.com/locate/inbede

Review

Language development in infants with hearing loss: Benefits of infant-directed speech

Irena Lovcevic [a,*], Denis Burnham [b], Marina Kalashnikova [b,c,d]

[a] International Research Center for Neurointelligence (IRCN), The University of Tokyo, 7-3-1 Hongo Bunkyo-ku, Tokyo 113-0033, Japan
[b] The MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Locked Bag 1797, Penrith, NSW 2751, Australia
[c] BCBL. Basque Center for Cognition, Brain and Language, Paseo Mikeletegi 69, San Sebastian-Donostia, Guipuzcoa 2004, Spain
[d] IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

ARTICLE INFO

Keywords:
Infants
Hearing loss
Infant-directed speech
Language development

ABSTRACT

The majority of infants with permanent congenital hearing loss fall significantly behind their normal hearing peers in the development of receptive and expressive oral communication skills. Independent of any prosthetic intervention ("hardware") for infants with hearing loss, the social and linguistic environment ("software") can still be optimal or sub-optimal and so can exert significant positive or negative effects on speech and language acquisition, with far-reaching beneficial or adverse effects, respectively. This review focusses on the nature of the social and linguistic environment of infants with hearing loss, in particular others' speech to infants. The nature of this "infant-directed speech" and its effects on language development has been studied extensively in hearing infants but far less comprehensively in infants with hearing loss. Here, literature on the nature of infant-directed speech and its impact on the speech perception and language acquisition in infants with hearing loss is reviewed. The review brings together evidence on the little-studied effects of infant-directed speech on speech and language development in infants with hearing loss, and provides suggestions, over and above early screening and external treatment, for a natural intervention at the level of the carer-infant microcosm that may well optimize the early linguistic experiences and mitigate later adverse effects for infants born with hearing loss.

1. Introduction

Approximately two out of every 1000 infants worldwide are born with unilateral or bilateral hearing loss (HL) (van Wieringen et al., 2019). Congenital HL, which refers to HL present at birth, has major negative effects on children's early development and subsequent effects on quality of life including speech and language acquisition, literacy, mental health, social and cognitive functioning, as well as academic achievement (Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007; Qi & Mitchell, 2011; von Hapsburg & Davis, 2006; Wake, Hughes, Poulakis, Collins, & Rickards, 2004). Accordingly, it is important to determine the factors that are crucial for optimal language development in infants and children with normal hearing (NH) and with HL, and which of these are possibly operating sub-optimally or differently as a result of HL. There are two main moderators that may attenuate the negative effects of HL on spoken language development: intervention via hearing devices ("hardware") and the nature of the infant's social and

* Corresponding author.
E-mail address: irena.lovcevic@ircn.jp (I. Lovcevic).

https://doi.org/10.1016/j.infbeh.2022.101699
Received 6 September 2021; Received in revised form 25 January 2022; Accepted 27 January 2022
Available online 2 February 2022
0163-6383/

linguistic environment (“software”).

This article is concerned with the software component – the quality of the linguistic environment that infants with HL experience in infancy. Extensive research with infants with NH has demonstrated that the quality and quantity of infant-directed speech (IDS) to which infants are exposed in their first years of life are significant predictors of concurrent and future language abilities. Critically, the quality of IDS is dynamically adjusted to the cognitive, sensory, and linguistic needs of each infant. Congenital HL in the infant is one of the factors that can impact the acoustic and linguistic properties of IDS by the caregiver. The evidence in this review will provide the basis for understanding the extent of this impact and the implications for children’s subsequent spoken language development. The review is divided into three sections. First, we provide a general overview of the types of interventions provided to infants with HL and their early oral language development in the first years of life. Second, we review the quality of early linguistic environment experienced by infants with HL and infants’ sensitivity to the acoustic features present in their caregivers’ IDS. As this is the main focus of the present work, we present a comprehensive review of published studies with infants with HL from 0 to 24 months of age (see Supplementary Materials for a detailed description of the systematic review approach used in this section). Finally, we provide a discussion about the linguistic function of the acoustic properties of IDS and their implications for early language development in infants with HL and identify directions for future research.

2. Overview of the early detection and remediation of hearing loss and oral language development in infants with hearing loss

Before proceeding to the discussion of oral language development in infants with HL, we provide a general overview of the detection of HL and its subsequent remediation. It is important to consider such detection and remediation due to their significant effects on infants’ language development. For HL intervention to be optimally beneficial for infants, two of the most critical factors are the age at which HL is detected and the timing of subsequent intervention. Delayed HL detection may significantly affect restoration of hearing, thus exacerbating the negative effects of HL. This occurs due to the absence of auditory input early in life, and it may impair not only the development of the auditory pathways, but also the neural pathways connecting the auditory cortex with other parts of the brain. Delayed intervention, therefore, can compromise the establishment of attentional and cognitive neural networks important for auditory processing (Kujala, Alho, & Näätänen, 2000; Neville & Bruer, 2001; Ponton, Moore, & Eggermont, 1999), leading to negative effects on infants’ speech perception, attention, language development and learning (Houston, Pisoni, Kirk, Ying, & Miyamoto, 2003; Neville & Bruer, 2001; Tomblin et al., 2014). Fortunately, the recent introduction of Universal Newborn Hearing Screening programmes (UNHS; mid to late 1990 s in USA, Russ, White, Dougherty, & Forsman, 2010; 1998 in Europe, Skarżyński & Ludwikowski, 2018; 2000 in Australia, Coates & Gifkins, 2003) allows for much earlier identification of HL than ever before (now on average at three to four months of age), and earlier access to interventions, such as device fitting before six months (on average 13–16 months earlier than before) (Yoshinaga-Itano, & Apuzzo, 1998; Vohr et al., 1998). Children with HL who had access to Newborn Hearing Screening and were diagnosed with HL before nine months of age have been shown to have higher receptive language scores than those who were diagnosed after nine months (Kennedy et al., 2006; Korver et al., 2010), thus indicating the importance of early diagnosis of HL for language development.

It is noteworthy that infants with HL differ widely in the type of remedial device they receive (Korver et al., 2017; Moore, 1991, 2007; Myrthe, Bosman, Snik, Mylanus, & Cremers, 2005; Niparko, Cox, & Lustig, 2003). The type of hearing device used in HL intervention depends on various factors including the context (such as country and infant age), and on the degree (severity) and configuration (unilateral or bilateral HL) of HL. Extant studies of HL examine language development in infants fitted with various devices – hearing aids (McGowan, Nittrouer, & Chenausky, 2008; Verhaert et al., 2008), cochlear implants (Houston et al., 2003; Verhaert et al., 2008), and bone-anchored hearing aids (Snik, Leijendeckers, Hol, Mylanus, & Cremers, 2008) – so a brief guide to their use will be useful here. The majority of infants with mild to severe HL are fitted with hearing aids. For infants with severe to profound HL, restoration of HL is achieved by cochlear implants. For infants with conductive or mixed HL, bone-anchored hearing aids are used.

It is, of course, important to provide the infants with HL with the appropriate hearing intervention, but it is doubly important to provide this as early as possible. There are many studies that demonstrate that the age of intervention affects infants’ language development. For example, in a prospective study with 350 children, Ching et al. (2017) demonstrated that language outcomes at five years of age are significantly better for infants who receive hearing aids or cochlear implants at three and six months of age than infants who receive their hearing devices at 24 months. Furthermore, such early intervention gains were greater for children with higher degrees of hearing loss. Additionally, it has been found that infants fitted with hearing aids or cochlear implants before six months of age had better receptive and expressive language scores between two and seven years of age than infants who were fitted after six months of age (Çelik *et al.* 2021; Ching, 2015; Ramkalawan and Davis, 1992; Shojaei, Jafari, & Gholami, 2016). Together these findings strongly suggest that age of fitting with a hearing device has important facilitative effects on infants’ language development, effects that persists through at least to the school years.

Device fitting before six months is particularly beneficial, as it augments hearing during the period when infants’ perceptual capacities become attuned to the language present in their environment (see Mattock & Burnham, 2006; Polka & Werker, 1994; Werker & Hensch, 2015). It is during this period that infants reach (or do not reach) critical milestones in the development of native language speech perception, an ability that provides the basis for later phonological, lexical, and syntactic development. Achievement of each milestone is partially determined by maturational factors, but experience plays a fundamental role (Werker & Hensch, 2015). Literature on early speech perception development in infants with HL is much more limited compared to speech perception development in infants with NH, and we review the available studies here to understand how infants who have received early remediation through device fitting perform on speech perception tasks compared to NH controls.

For infants fitted with hearing devices, despite any degradation or modification of the signal delivered through such devices, there is evidence that speech perception is functionally operational quite early after fitting. For example, within one to two months of fitting, infants with cochlear implants successfully discriminate basic speech pattern differences (e.g., /hɒp hɒp hɒp/ vs. /ahhh/) (Houston et al., 2003), and prefer their native to a foreign language (Kishon-Rabin, Harel, Hildesheimer, & Segal, 2010). Similarly, infants with four months of device use prefer to listen to speech compared to static (white noise) and dynamic (time-reversed speech) nonspeech stimuli (Segal & Kishon-Rabin, 2011); a preference that is comparable to that by infants with NH, and which increases with age and hearing experience (Segal & Kishon-Rabin, 2011). Thus, it seems that despite impaired hearing ability, basic mechanisms for speech perception are intact in infants with HL with fitted devices, even with limited hearing experience and device use.

When it comes to more fine-grained speech perception, that of specific phonemes and phoneme contrasts, infants with HL struggle to discriminate some of the contrasts that their counterparts with NH can discriminate. For example, whereas infants with HL are able to discriminate some vowel and consonant contrasts within six months of cochlear implant fitting, they experience difficulty with some place of articulation consonant contrasts (e.g., /z/ - /v/) even after 12 months of cochlear implant use (Schauwers, Gillis, Daemers, De Beukelaer, & Govaerts, 2004; Uhler et al., 2011). Furthermore, they struggle to discriminate some vowel contrasts as well. For example, the vowel place contrast /do:/ vs. /de:/ has been found to be discriminated by infants with mild HL fitted with hearing aids (less than 60 dB), but not by infants with severe to profound HL (greater than 70 dB) fitted with hearing aids and subsequently with cochlear implants (Martinez, Eisenberg, Boothroyd, & Visser-Dumont, 2008). Thus, in addition to discrepancies between speech sound discrimination in infants with HL and NH, it appears to be the case that discrimination of consonant place and vowel place contrasts is more challenging as a function of the severity of infants' HL.

There is also evidence that infants with HL begin to rely on language-specific prosodic patterns to segment words from continuous speech after a period of five to nine months of post-fitting language exposure, similar to that of normal hearing five- to nine-month-old infants (Jusczyk, 1997; Jusczyk, Houston, & Newsome, 1999; Mattys & Jusczyk, 2001; Saffran, Newport, & Aslin, 1996). For example, infants with cochlear implants between one and six months of experience with hearing devices discriminate words based on different stress patterns, but their performance is poorer than that of NH infants of the same chronological age (between 11 and 14 months) (Segal, Houston, & Kishon-Rabin, 2016). Similarly to NH infants, German-acquiring infants with cochlear implants exhibited mismatch negativity (MMN) responses to words with iambic but not trochaic stress patterns after six months of cochlear implant use (Vavatzanidis et al., 2016).

These studies indicate that when infants with HL have access to auditory input, they reach language acquisition milestones along a similar timeline to that of their peers with NH. This timeline is based on the accumulated amount of language exposure, that is, hearing age, and not chronological age. Hearing age in infants with NH and in infants with HL is not the same. It is a difference that begins prenatally. The auditory system is functional in utero at six months post-conception (Gerhardt & Abrams, 2000), and from this time infants begin to hear sounds from the external world, including and especially their mother's voice but also other voices speaking in the ambient language(s). Therefore, at birth infants with HL likely already have three months less hearing experience, and this deficit continues at least until infants with HL have their hearing (partially) restored or improved with either hearing aids or cochlear implants. Therefore, in comparative studies of NH and HL infants, it is necessary to compare infants with HL with two NH control groups, one with the same chronological age as the infants with HL, and the other with the same hearing age as the infants with HL. Such controls are essential if the effects of maturational and experiential factors on language development in infants with HL are to be disentangled.

Comparisons of infants with HL to controls with NH who are only chronological- and not also hearing age-matched has indeed led to evidence for delayed language development in infants with HL. Such evidence may be not only misleading but may also result in erroneous attribution of causality and even introduction of intervention. For example, the onset of canonical babbling in infants with NH is around seven to eight months of age, whereas for infants with HL (without device intervention) onset is approximately six-and-a-half months later (at around 14 months of age) (Moeller *et al.* 2007a). A similar delay (seven months) has been found in the production of individual sounds – vowels, stops, nasals, glides, and liquids in infants with HL compared to infants with NH. In addition, it has been found that infants with HL produce fewer multisyllabic utterances and more vowel-only utterances in comparison to infants with NH of the same age (McGowan et al., 2008; Moeller et al., 2007a; von Hapsburg & Davis, 2006). With respect to vocabulary development, two studies with infants between eight and 37 months of age showed, using the MacArthur Communicative Development Inventory (MCDI, Fenson et al., 1993), that infants with HL have a significant delay in receptive and expressive vocabulary development in comparison to their peers with NH (Mayne, Yoshinaga-Itano, Sedey, & Carey, 1999a; Mayne, Yoshinaga-Itano, & Sedey, 1999b). Moreover, the vocabulary spurt in infants with HL occurs around 25 months of age, which is about eight months later than that observed in infants with NH (Moeller *et al.* 2007b). This latter study showed that infants with HL not only had delayed receptive and expressive vocabulary development, but that their word production at 24 months was less accurate, less intelligible, and less phonologically complex than word production of infants with NH at the same age (Moeller et al., 2007b). Despite this apparent delay, Moeller et al. (2007b) also compared NH infants to infants with HL with the same amount of hearing experience as their NH counterparts and found that there was no difference in the onset of canonical babbling between NH infants and infants with HL of the same *hearing age*.

These findings further corroborate that early hearing experience achieved through early device fitting allow infants with HL to access the rich oral language input available in their environment. Several studies now provide evidence that infants with HL whose hearing has been restored through a cochlear implant or a hearing aid indeed receive a similar amount of language input as their peers with NH (VanDam et al., 2012; Vanormelingen et al., 2016). For example, VanDam and colleagues (2012) compared the quantity of speech to infants with hearing aids and to infants with NH using day-long audio recordings of infants' speech environment in the home. They operationalized the quantity of speech as the total number of adult words and the number of conversational turns between the caregiver and the infant. Their results showed that infants with HL heard a similar number of adult words, and they engaged in a similar number of conversational turns as their peers with NH. Hence, this evidence indicates that in terms of the quantity of speech input, infants with HL receive a similar amount as do infants with NH. Next, we turn to the quality of speech input.

3. Quality of language input: infant-directed speech, acoustic and phonetic features

The overview above indicates that the *quantity* of exposure to language input, as determined by infants' hearing age, is essential for early speech perception and production development. However, infants' early language acquisition is also determined by the *quality* of language input that they receive and importantly, whether hearing devices provide access to the same or similar qualitative aspects of human speech as those available to infants with NH. In this section, our review focuses on infant-directed speech, specifically, its acoustic and phonetic qualities, early preferences for this register in infants with HL, and the degree of prosodic and phonetic exaggeration in IDS to infants with HL.

Infant-directed speech (IDS) refers to the speech register used in interactions with infants. Compared to adult-directed speech (ADS), IDS to infants with NH has shorter and grammatically simplified utterances (Kavanaugh & Jirkovsky, 1982; Phillips, 1973; Snow, 1977), a higher proportion of questions (Soderstrom, Blossom, Foygel, & Morgan, 2008), increased repetition, longer duration of vowels and pauses (Andruski & Kuhl, 1997), slower speech rate (Fernald & Simon, 1984), greater positive affect (Fernald & Kuhl, 1987; Uther et al., 2007), greater pitch (fundamental frequency, F0) variations (McRoberts & Best, 1997), and exaggerated articulation of speech sounds (Burnham, Kitamura, & Vollmer-Conna, 2002; Kuhl et al., 1997). In addition, in the visual modality, facial movements made in producing IDS differ from those in ADS (Chong, Werker, Russell, & Carroll, 2003; Shepard, Spence, & Sasson, 2012), with IDS showing characteristics such as exaggerated lip movements (Green, Nip, Wilson, Mefferd, & Yunusova, 2010), exaggerated smiles, increased eyebrow raising, and greater eye widening (Werker & McLeod, 1989).

IDS is not an epiphenomenon; it serves specific functions and involves both the speaker (an adult, usually a parent or caregiver, or even an older child) and the listener. Because it is difficult to reproduce IDS features in the absence of an infant (Fernald & Simon, 1984), it has been argued that the production of IDS is a reflexive, instinctive, and unconscious speech behaviour that is elicited in the interlocutor as a product of speaking to an infant (Papoušek, Bornstein, Nuzzo, Papoušek, & Symmes, 1990). Despite – or even because of – interaction with an infant involuntarily engaging the interlocutor, IDS appears to serve specific functions: to communicate affect to infants (Papoušek et al., 1990; Trainor et al., 2000), to attract and maintain infants' attention (Cooper & Aslin, 1990; Fernald & Simon, 1984), and to aid language acquisition (Fernald & Mazzie, 1991). In parallel and quite possibly due to these functions, infants with NH prefer to listen to IDS over ADS in their native (Cooper & Aslin, 1990; Fernald, 1985) and even in a foreign language (Fernald & Morikawa, 1993; ManyBabies Consortium, 2020; Werker et al., 1994). This preference may well focus their attention (Cooper & Aslin, 1990; Fernald & Simon, 1984) and facilitate processing of early linguistic input (Kalashnikova, Peter, Di Liberto, Lalor, & Burnham, 2018a; Peter, Kalashnikova, Santos, & Burnham, 2016; Zangl & Mills, 2007; Zhang et al., 2011). It is of particular interest here to determine whether this is also the case in infants with HL.

Two features in IDS have been identified as central for attracting infants' attention to this register and in facilitating early language development. These are the prosodic exaggeration of pitch height and pitch range and the phonetic exaggeration of vowels (i.e., vowel hyperarticulation). Exaggerated pitch in IDS refers to an increase in mean height and/or range of fundamental frequency (F0) compared to ADS (Fernald & Simon, 1984; Fernald *et al.* 1989; Trainor et al., 2000). Many studies show that, compared to ADS, exaggerated pitch-related features are observed more often in IDS to infants with NH: F0 mean values are higher in IDS compared to ADS (Fernald & Simon, 1984; Grieser & Kuhl, 1988); F0 excursions are much wider and smoother in IDS (Fernald & Mazzie, 1991; Fernald & Simon, 1984); and F0 contours, such as rising, falling, and sinusoidal-bell shapes are more commonly observed in IDS, whereas flat pitch productions are more prevalent in ADS (Fernald & Simon, 1984; Knoll & Costall, 2015).

Exaggerated pitch in IDS has been found to play an important role in affect regulation of young infants and in the transmission of maternal emotional and communicative intent to the infant (Fernald, 1992; Kitamura & Burnham, 2003; Song, Demuth, & Morgan, 2010; Spinelli & Mesman, 2018; Stern, Spieker, Barnett, & MacKain, 1983). Furthermore, it has been proposed that exaggerated pitch in IDS aids language acquisition by attracting and maintaining infants' attention to the speech stream (Cooper & Aslin, 1990; Fernald & Simon, 1984). In turn, this increased attention to the speech stream may facilitate language learning by increasing infants' arousal and priming their system for learning (Kaplan, Jung, Ryther, & Zarlengo-Strouse, 1996). Accordingly, it has been demonstrated that pitch exaggeration in speech to infants predicts their associative learning (Kaplan, Bachorowski, & Zarlengo-Strouse, 1999), and exaggerated pitch height and pitch range in IDS promote speech processing skills during infants' first (Thiessen et al., 2005; Trainor & Desjardins, 2002) and second years (Graf Estes & Hurley, 2013; Ma, Golinkoff, Houston, & Hirsh-Pasek, 2011). Over this period, pitch height and pitch range of IDS to infants with NH increases or remains steady up to around 16–18 months of infants' age (Kalashnikova & Burnham, 2018; Kitamura & Burnham, 2003; Kitamura, Thanavishuth, Burnham, & Luksaneeyanawin, 2001: Narayan & McDermott, 2016), and then begins to decrease (Stern et al., 1983) possibly due to infants' changing needs at later developmental stages.

Vowel hyperarticulation, the phonetic exaggeration of the vowel space, refers to an increase in the area encompassed by the three corner vowels /i/, /u/, /a/ in IDS compared to ADS. It is indexed by plotting the centroid of exemplars of each of these three vowels in two-dimensional Formant 1 / Formant 2 (F1/F2) space and calculating the area of the triangle formed by joining the centroids of plots of the three vowels. This measure was devised and first used by Kuhl and colleagues (1997), and it has since been used in the majority of studies on vowel hyperarticulation in IDS (and on other special speech registers). Vowel hyperarticulation in IDS has been observed in American English (Adriaans & Swingley, 2017; Cristia & Seidl, 2014; Kuhl et al., 1997), British English (Uther et al., 2007), Australian English (Burnham et al., 2002; Kalashnikova & Burnham, 2018; Kalashnikova, Carignan, & Burnham, 2017; Kalashnikova, Goswami, & Burnham, 2018b; Lam & Kitamura, 2010, 2012; Xu et al., 2013), Mandarin Chinese (Liu, Kuhl, & Tsao, 2003; Tang et al., 2017), Japanese (Miyazawa, Shinya, Martin, Kikuchi, & Mazuka, 2017), Swedish and Russian (Kuhl et al., 1997), and Spanish and Basque (Kalashnikova & Carreiras, 2021), but not in some other languages, including Dutch, Norwegian, and German (Audibert and Falk, 2018; Benders, 2013; Englund, 2018).

A larger vowel triangle area (as is usually found in IDS compared to ADS) entails greater phonetic separation of vowel categories, which in the case of IDS and ADS could be interpreted as rendering at least these corner (and possibly other) vowels more discriminable than they are in ADS. Accordingly, it has been proposed that vowel hyperarticulation in IDS is a didactic device that facilitates infants' language acquisition (Kuhl et al., 1997). In support of this proposed linguistic function, it has been shown that infants are successful in a number of language processing tasks when stimuli are presented in IDS with hyperarticulated vowels but not when they are presented in ADS. For example, IDS vowels presented to nine-month-old infants result in a mature mismatch negativity response (MMN), whereas ADS vowels do not (Peter et al., 2016). Additionally, in six- to 12-month-olds input of vowels that are hyperarticulated versus those that are not result in increased neural synchronisation, which is important for phonetic encoding (Zhang et al., 2011). Moreover, the presence versus absence of vowel hyperarticulation in speech facilitates word recognition in 19-month-old infants (Song, Demuth, & Morgan, 2010). Furthermore, within mother-infant dyads, the degree of a mother's vowel hyperarticulation in IDS compared to ADS is correlated with their infant's speech discrimination (Kalashnikova & Carreiras, 2021; Liu et al., 2003), and mothers' degree of vowel hyperarticulation to young infants has been specifically linked to their infants' vocabulary at 15 and 19 months (Kalashnikova & Burnham, 2018) and at two years of age (Hartman, Bernstein Ratner, & Newman, 2017). Therefore, IDS with its hyperarticulated vowels, not only attracts infants' attention to speech and facilitates their speech perception at both behavioural and neural levels, but it also facilitates the development of their later vocabulary.

3.1. Preference for Infant-Directed Speech in Infants with Hearing Loss

We now turn to review the studies that have investigated the early sensitivity to IDS in infants with HL, and that have assessed the acoustic features of this speech register (see Supplementary Materials for detailed information on how these studies were selected). Robertson, von Hapsburg, and Hay (2013) examined IDS to 19-month-old infants with HL with seven months hearing experience and found that infants with HL prefer IDS over ADS to a similar extent as do infants with NH matched by hearing age, but not with infants with NH matched by chronological age. In another study, Wang, Bergeson, and Houston (2018) found that nine-month-old infants fitted with HAs and with four months hearing experience display a preference for IDS over ADS comparable to that of infants with NH of the same *chronological* age. This finding suggests that infants with HL may develop a preference for IDS comparable to their counterparts with NH due to a combination of their residual hearing before fitting with HAs and their augmented hearing after fitting. These similarities carry through to older infants; Wang et al. (2018) showed that 17-month-old (chronological age) infants with HL with 12 months HA-assisted hearing experience, just like infants with NH of the same chronological age, did not show the IDS over ADS preference. Taken together, these findings suggest that infants with HL prefer to listen to IDS over ADS early but not later in their development, an attentional pattern identical to that of infants with NH.

Preference for IDS by infants with HL is not simply a sensory phenomenon, it also has functional sequalae; infants reap important benefits from this preference. Wang, Bergeson, and Houston (2017) found that a preference for IDS enhances attention to speech in infants with cochlear implants 12 months post-implantation, and that the degree of the IDS over ADS preference was related to infants' later vocabulary development at 18 months post-implantation. Therefore, IDS appears to be an important tool that aids language acquisition in infants with HL; IDS promotes healthy language outcomes in infants with HL.

3.2. Pitch Modifications in Infant-Directed Speech to Infants with Hearing Loss

The reviewed evidence indicates that mothers exaggerate pitch height (Miyamoto, Houston, & Bergeson, 2005), pitch range, and pitch variability (Bergeson, Miller, & McCune, 2006) in IDS to infants with cochlear implants between 10 and 37 months of age. Mothers exaggerate pitch height and pitch range to a similar degree as they do to infants with NH matched by hearing experience but not to infants with NH matched by chronological age, suggesting that the nature of IDS is a response to infants' behaviour specifically related to their hearing experience, not behaviour that is a product of more general maturational growth or cognitive development (Bergeson et al., 2006; Miyamoto et al., 2005). As for infants with hearing aids, previous studies have demonstrated that pitch height and range are exaggerated in IDS to infants with HL to a similar degree as to infants with NH (Lovcevic, Kalashnikova, & Burnham, 2020; Traci, 1998).

With respect to developmental adjustments in pitch in IDS to infants with HL, Kondaurova and colleagues (2013) examined pitch height, pitch range, and pitch variability in IDS to infants with cochlear implants at three, six-, and 12-months post-implantation and compared them to chronological-age and to hearing-age matched NH controls. Although pitch height, range, and variability were exaggerated in speech to all three groups of infants, there was greater exaggeration of all features in IDS to infants with HL compared to NH controls matched by chronological age, and all three pitch features were exaggerated to a similar degree in IDS to infants with HL compared to infants with NH matched by hearing age. Additionally, there was no change over the 12-month period similarly to previous findings of no changes in pitch adjustments at six-months post-implantation (Kondaurova & Bergeson, 2011). Seemingly different results were reported by Bergeson (2011) who found that pitch height in IDS to infants with cochlear implants decreased over the three-, six, and 12-months post-implantation period to a similar degree as to chronological age-matched NH controls. Nonetheless, the chronological age of infants in this study was up to 22 months, so as noted above, it is not surprising that a decrease in pitch height was observed – similarly to findings reported for infants with NH (Kitamura & Burnham, 2003; Stern et al., 1983). Taken together, these studies support the view that there is equivalence with the NH literature on pitch exaggeration: an increase or stabilisation during the first year of life and then, after the first year, a decrease; and more generally, the results point to mothers adjusting their speech in accord with their infants' hearing experience.

Bergeson (2011) also included infants fitted with hearing aids, and contrary to the results for infants with cochlear implants, found that pitch height in IDS increased from three to six months post-fitting and then began to decrease. These different trajectories for pitch modification in IDS to infants with cochlear implants (decrease over age) and hearing aids (increase and then decrease) may stem from two sources: from the different frequency responses of cochlear implants and hearing aids and/or from the confounding factor that hearing aids and cochlear implants are generally fitted to infants with quite different levels of residual hearing (see Section 3.3.1 for further detail). Because Bergeson (2011) did not include controls with NH matched by hearing age, it is difficult to determine whether the observed results were due to infants' chronological age or hearing experience.

Overall, the evidence presented in this section shows that the pitch-related exaggerations typically found in IDS to infants with NH are also present to a large degree in IDS to infants with HL. Additionally, these studies suggest that IDS modulations to infants with HL across development are due to interlocutors reacting to the infants' behavioural manifestations/sequelae of their hearing experience rather than to their level of chronological maturation. These studies provide valuable information, and highlight the need for further research, specifically (i) research employing controls with NH matched for hearing-age to infants with HL, and (ii) as suggested by Bergeson (2011), research on IDS to infants fitted with different hearing devices (hearing aids vs. cochlear implants) to assess the effect of hearing device on IDS, which may be related to the amount of residual hearing these infants have.

3.3. *Vowel Hyperarticulation in Infant-Directed Speech to Infants with Hearing Loss*

In the last decade there have also been studies of vowel hyperarticulation to infants with HL. Unfortunately, despite the range of languages in which vowel hyperarticulation in IDS to infants with NH is evident, to our knowledge, all studies on vowel hyperarticulation in IDS to infants with HL have been conducted in English. One of the earliest studies with this infant population was conducted by Lam and Kitamura (2010), who recorded IDS produced by a mother speaking to her twin sons, one who had bilateral HL and the other who had NH, on two occasions, once at 12.5 months and again at 22 months of age. They found that the mother hyperarticulated vowels in IDS to the twin with NH but not to the twin with HL. This finding could be taken to indicate that IDS to infants with HL does not contain the supposed didactic device of vowel hyperarticulation. However, the findings of this study must be interpreted with caution because it is a single (twin) case study and could reflect idiosyncrasies in this mother's speech production patterns. Or, given the unusual situation of one twin with NH and one with HL, it could be that the results are influenced by the mother's conscious or unconscious use of contrasting styles of IDS to her twins, one known to have and the other known not to have HL. Nevertheless, this result opens the intriguing possibility that infants' hearing loss could modulate the presence and degree of vowel hyperarticulation in maternal speech.

In a later study, Kondaurova, Bergeson, and Dilley (2012) investigated vowel space area and vowel duration for American English tense (/i/, /u/) and lax (/I/, /ʊ/) vowels in IDS to infants with HL prior to cochlear implantation and to chronologically age-matched NH controls. In contrast to the twin case study by Lam and Kitamura (2010), they found that mothers hyperarticulated vowels to infants with HL to a similar degree as to infants with NH. In a follow-up study by Wieland and colleagues (2015), vowel hyperarticulation in IDS to infants with cochlear implants and hearing aids between three and six months after fitting was assessed, along with measures of individual F1 and F2 frequencies and vowel space dispersion, in order to provide more detailed evidence regarding vowel production in IDS to infants with HL. Wieland et al. (2015) showed higher F1 for /i/ in IDS to infants with hearing aids, and higher F2 for the vowels /a/ and /i/ in IDS to infants with cochlear implants compared to both age-matched and experience-matched groups of NH controls. High F1 and F2 frequencies are important cues for vowel intelligibility and vowel identity (Ferguson & Kewley-Port, 2002; 2007), so these results open the intriguing possibility that mothers of infants with HL compensate for their infants' HL by producing higher formant frequencies, which make their vowels clearer and more intelligible.

The contrasting findings of the studies by Kondaurova et al. (2012) and Wieland and colleagues (2015) reinforce the possibility that the Lam and Kitamura (2010) results were due to the mother contrasting her style of IDS according to her twins' contrasting hearing status. More generally, these results underline the notion that there will, of course, be individual differences in mothers' speech, their IDS, and their use of vowel hyperarticulation, and it opens the possibility that, as is the case for infants with NH, individual differences in vowel hyperarticulation may affect later language development (Hartman et al., 2017; Kalashnikova & Burnham, 2018; Liu et al., 2003). In this regard, Dilley and colleagues (2020) assessed the effect of individual variations in maternal IDS to infants 15 months after cochlear implantation on the infants' language ability both at 24 months after implantation and up to nine years after implantation. They found that individual variations in vowel hyperarticulation, but not in pitch height or pitch variability, influenced language scores at and after 24 months post-implantation, while controlling for mothers' socioeconomic status and infants' age of hearing intervention. In a similar vein, Lovcevic and colleagues (2020) found a positive relation between individual mothers' formant distances (distances between F1 and F2, an additional measure of clarity in vowel production) for vowels /i/ and /u/, their degree of vowel hyperarticulation, and their 15-month-old HL infants' concurrent receptive vocabulary size. Together these findings suggest that features of caregivers' IDS play an important role in language acquisition by infants with HL, and more specifically, that the degree of individual mothers' vowel hyperarticulation in IDS to infants with HL has a direct effect on infants' concurrent and future language outcomes. In short, the more mothers of infants with HL hyperarticulate vowels in their IDS, the better are the language outcomes for their infant.

3.3.1. *Effects of Hearing Device on the Qualities of Infant-Directed Speech to Infants with Hearing Loss*

This review reveals that the acoustic and phonetic features of IDS to infants with HL differ as a result of both the software components – infants' experience (quantity and quality of speech input), and the hardware components – different intervention devices with which the infant is fitted (hearing aids or cochlear implants). With respect to the interaction of hardware and software, there is evidence that the IDS speaker's pitch height tends to decrease over the first six months of device use when speaking to infants with cochlear implants but, conversely, tends to increase for infants with hearing aids (Bergeson, 2011; Kondaurova, Bergeson, & Xu, 2013). Similarly, whereas the evidence regarding vowel hyperarticulation is more mixed, the findings by Wieland and colleagues (2015) suggest that vowel production may follow different patterns in IDS to infants with hearing aids and infants with cochlear implants with higher F1 for /i/ in IDS to infants with hearing aids, and higher F2 for the vowels /a/ and /i/ in IDS to infants with cochlear implants compared to infants with NH, impacting the manifestation of individual vowel categories and the degree of speech clarity and intelligibility in this register.

Taken together, these findings may be interpreted in terms of the variability in the auditory information available to infants with HL resulting from the type of hearing device, the level of HL, and the left-right configuration and the frequency configuration of the HL. For example, although cochlear implants successfully provide infants with severe to profound HL access to auditory stimulation, frequency discrimination with cochlear implants is lower (Zeng et al., 2014), and the dynamic range is narrower (Zeng, 2004) compared to sound discrimination with normally functioning ears. Secondly, it is important to note that the nature of the acoustic input from hearing aids and from cochlear implants is not only significantly different from the sound coded by the hair cells in the cochlea but also significantly different from each other (Macherey & Carlyon, 2014; Zeng, 2004; Zeng, Tang, & Lu, 2014). In addition, the pre-requisites for fitting vary; for infants fitted with hearing aids the degree of HL can vary from mild to moderate, whereas for infants fitted with cochlear implants it can vary from severe to profound (Joint Committee on Infant Hearing, 2007). Thus, the hardware differences may result in variability in auditory information that is available and is perceived via different devices, which in turn, may affect the communicative exchanges between the caregivers and infants and result in different acoustic and phonetic qualities in speakers' production of IDS. Clearly, further studies of the degree of modifications in mothers' speech to their infants with HL under various environmental conditions at different chronological and hearing ages, and with different hearing prostheses is required.

3.4. Summary of Findings and Open Questions

Concerning the acoustic feature of IDS pitch, the evidence suggests that the degree of maternal pitch exaggeration in IDS to infants with HL is attuned to infants' hearing age and not to their chronological age. Given the findings on lowered responsiveness in mother-infant interactions of infants with HL compared to infants with NH of the same chronological age (Koester, 1995), it is possible that mothers of infants with HL face more challenges in engaging and retaining infants' attention to speech than do mothers of NH infants.

Turning to the phonetics of IDS, while vowel hyperarticulation is evident in IDS to infants with HL, the evidence indicates that (i) vowel hyperarticulation in caregivers' IDS positively correlates with infants' spoken language outcomes (Dilley et al., 2020; Hartman et al., 2017; Kalashnikova & Burnham, 2018; Lovcevic et al., 2020), and (ii) the level of vowel hyperarticulation or vowel formant exaggeration may be modulated by known contrasts in hearing status (NH versus HL, Lam & Kitamura, 2010), or by the type of hearing prosthesis, hearing aids versus cochlear implants (Wieland et al., 2015). These vowel hyperarticulation findings raise two important questions. First, what are the mechanisms underlying the presence of vowel hyperarticulation in caregivers' speech? Second, if vowel hyperarticulation is aimed at facilitating language development, why might it be attenuated in IDS to some infants with HL (Lam & Kitamura, 2010), who would, it would seem, require additional support in their language acquisition? Indeed, the view that vowel hyperarticulation benefits early language acquisition has been disputed. A *lack* of vowel hyperarticulation in IDS has been documented in three languages (Dutch, Norwegian, and German; Audibert and Falk, 2018; Benders, 2013; Englund, 2018), and this in conjunction with other findings has given rise to alternative explanations. For instance, it has been suggested that vowel hyperarticulation is a by-product of other features of IDS, and that it does not serve any dedicated role in early language development (McMurray, Kovack-Lesh, Goodwin, & McEchron, 2013). Importantly, even in cases in which vowel space has been found to be expanded in IDS (which results in greater phonetic distance *between* different vowel categories), it has also been noted that IDS is characterised by greater variability in vowel production that results in more variance in distributions *within* individual vowel categories in IDS compared to ADS (Cristia & Seidl, 2014; Englund, 2018; Martin et al., 2015; McMurray et al., 2013; Miyazawa et al., 2017). This greater within-vowel dispersion results in greater overlap in vowel categories, which could be considered to complicate infants' acquisition of vowel category membership.

This debate is ongoing, so further evidence is required to evaluate arguments regarding the origins of vowel hyperarticulation in IDS and its potential linguistic function. However, so far, the possibility that both views can be seen to be correct should be considered. In this regard, whereas detailed comparisons of tongue, lips and laryngeal movements in IDS and ADS show that vowel hyperarticulation does not have an explicitly articulatory linguistic *basis* (Kalashnikova et al., 2017), it does have a specifically linguistic *outcome*. This linguistic outcome is underlined by evidence that greater degrees of vowel hyperarticulation in maternal speech are linked to better linguistic outcomes for infants (Dilley et al., 2020; Hartman et al., 2017; Kalashnikova & Burnham, 2018; Kalashnikova & Carreiras, 2021; Lovcevic et al., 2020).

4. Conclusions and future directions

The evidence presented in this review highlights the relative paucity of research on language development and speech input to infants with HL. However, there is sufficient evidence to draw a number of important conclusions and to pave the way for future research.

Fundamentally, there are physical limitations to the hearing experience of infants with HL and these have in the past and will in the future be partially overcome by improvements in the hardware available to improve infants' hearing. However, large steps forward in hardware development have already been made, and it appears that future improvements will provide increasingly small returns and asymptotic levels of advantage. Although earlier hearing device fitting is now possible due to universal screening, and it allows infants with HL to develop early speech perception abilities on par with NH peers of the same hearing age, there remains a high degree of variability in individual performance with observable delays in different domains of language development (Mayne et al., 1999a, 1999b; McGowan et al., 2008; Moeller et al., 2007b; von Hapsburg & Davis, 2006). These delays may be due to the age of fitting and the type of hearing device, which in turn are determined by multiple factors including, but not limited to, the severity and configuration of HL and the amount of residual hearing, all of which can impact infants' later language outcomes (Nicholas & Geers, 2007; Szagun, 2001, 2004).

Considerably more research is required in order to determine if and how the type of hearing devices affects first the caregivers' speech to infants, and subsequently infants' language development. So far, findings for infants with hearing aids and cochlear implants seem to differ, with these differences stemming not only from the device itself, but also from the dependence of device choice on the degree of HL. An important factor that should be included and controlled in all studies with infants with HL is the amount of the time infants are wearing the hearing device. Although it is implicitly assumed that infants fitted with devices have access to ambient sounds and speech, evidence suggests that infants might not use the fitted device optimally due to inconsistent use that might reduce their exposure to speech and language (Walker et al., 2013). Although clinicians recommend the use of devices for eight to ten hours per day to achieve optimal benefits (Contrera *et al.* 2014), evidence suggests that infants wear the device approximately four hours per day, and this time increases with age (Walker et al., 2013). Previously it was difficult to estimate objectively the actual wear-time of hearing devices, but now this estimation is possible due to the introduction of a datalogging feature that tracks the average wear-time of both hearing aids and cochlear implants. Evidence from such datalogging suggests that greater wear-time of hearing devices results in better language outcomes, including both speech perception and receptive vocabulary development (Easwar, Sanfilippo, Papsin, & Gordon, 2018; Gagnon, Eskridge, & Brown, 2020; Guerzoni & Cuda, 2017). Hence, futures studies should use this datalogging feature to document the actual wear-time of hearing devices, and thus determine efficacy more accurately.

In this review, we have shown that the speech environment, in particular the incidence and nature of IDS including such factors as pitch and vowel hyperarticulation, play important roles in speech perception, and language and vocabulary development in infants with NH. Moreover, the review shows that infants with HL are more receptive to linguistic cues than previously thought, and that the incidence and nature of maternal IDS can be and is affected by manifestations of infants' social and linguistic needs.

The studies on the quality of IDS to infants with HL highlight the importance of considering individual differences in infants' hearing and linguistic experience. The observed differences in hearing experience, hearing sensitivity, and subsequent language outcomes suggest that infants with HL develop different attentional and linguistic needs compared to both hearing-age and chronological-age matched NH infants. Their caregivers are sensitive, albeit quite possibly unconsciously, to these needs, which is reflected in dynamic adjustments to the type of speech they use to address their child (Lam & Kitamura, 2012). Additionally, involvement in interventional therapies focused on teaching parents how to interact with infants with HL and to modulate interactional experiences as a product of infants' increasing age, improve the maternal quality of interaction with infants with HL (Mohay, 2000). This in turn may influence maternal speech to infants with HL.

A positive way forward in developing interventional therapy that will improve language outcomes in infants with HL would involve studies of mothers' (and others') speech and comparisons of the degree of IDS modifications to infants without prosthetics with various levels of residual hearing, and to infants fitted with cochlear implants versus those fitted with hearing aids at various ages of fitting and time since fitting. Such a comprehensive study may be difficult in a single laboratory, but a cross-laboratory corpus of IDS collected under the same conditions in these different populations would be useful in determining the effects of the level and nature of infant hearing on incoming IDS features, and also how these features may be manipulated in clinical applications in order to develop the intervention optimised for infant's linguistic and processing needs (see Frank et al., 2020 for a discussion of multi-lab 'Many Babies' infancy research). Furthermore, the laboratory studies may well be complemented with long-format speech environment recordings using wearable devices (e.g., LENA; LENA Foundation, 2009), which will allow researchers to obtain more speech sample data in naturalistic contexts (Casillas & Cristia, 2019), which can help in gaining a better overall picture of the quantity and quality of speech input that infants with HL receive on a regular basis (e.g., VanDam et al., 2012).

Furthermore, individual IDS features may be perceptually weighted differently by infants, depending on their attentional and linguistic capacities, so IDS to infants with HL and NH may sound the same to an objective listener, but may serve quite different functions depending on the infant's hearing status and stage of development (Kalashnikova & Burnham, 2018). The field is therefore ripe for future in-depth investigations into the effects that factors such as age, hearing level, hearing prosthesis may have on infants' processing of their parents' speech. Such studies will be informative about how infants with HL process the kind of IDS that is directed to them, how they may implicitly "ask for" IDS with particular characteristics, and what these particular characteristics might be.

Such studies with NH infants have become increasingly possible in recent years through the use of neurophysiological methods (Männel & Friederici, 2010, 2013; Peter et al., 2016; Saito et al., 2007; Santesso, Schmidt, & Trainor, 2007; Zangl & Mills, 2007; Zhang et al., 2011); methods that are now possible with infants with HL due to the development of optical imaging technologies (e.g., Functional Near Infrared Spectroscopy, Bortfeld, 2019), that are safe for use with infants and are not subject to electrical or magnetic interference from hearing devices. Such future research is essential for the understanding of early language experiences of infants with HL and for the optimization of the hardware and software for successful early language development.

In conclusion, despite the advances in hardware development, universal screening resulting in early fitting of devices, and the positive effects these devices have had on hearing restoration in recent years, there is still wide variability in hearing outcomes across individuals and across different ages and devices and levels of residual hearing. We wish to emphasize that future practical and clinical developments for facilitating language outcomes (and other aspects of socio-cognitive development) in infants with HL should take particular heed of the growing research on the significant improvements that can be made by consideration of environmental influences, particularly infant-directed speech – the software that is readily available to every parent to ameliorate the effects of hearing loss.

Declarations of Competing Interest

none.

Acknowledgements

We would like to thank the Hearing Cooperative Research Centre, Australia for the grant 82631, “The Seeds of Language Development”, to the 2nd author. The 3rd author’s work was supported by the Basque Government, Basque Country, Spain through the BERC 2018–2021 program and by the Spanish Ministry of Science and Innovation through the Ramon y Cajal Research Fellowship, PID2019–105528GA-I00.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.infbeh.2022.101699.

References

Adriaans, F., & Swingley, D. (2017). Prosodic exaggeration within infant-directed speech: Consequences for vowel learnability. *The Journal of the Acoustical Society of America, 141*(5), 3070–3078. https://doi.org/10.1121/1.4982246

Andruski, J., & Kuhl, P.K. (1997). *The acoustic structure of vowels in speech*. Paper presented at the biannual Meeting of the Society for Research in Child Development, Washington, DC.

Audibert, N., & Falk, S. (2018, June). Vowel space and f0 characteristics of infant-directed singing and speech. In Proceedings of the 19th international conference on speech prosody (pp. 153–157). 10.21437/SpeechProsody.2018–31.

Benders, T. (2013). Mommy is only happy! Dutch mothers’ realisation of speech sounds in infant-directed speech expresses emotion, not didactic intent. *Infant Behavior and Development, 36*(4), 847–862. https://doi.org/10.1016/j.infbeh.2013.09.001

Bergeson, T. R., Miller, R. J., & McCune, K. (2006). Mothers’ speech to hearing-impaired infants and children with cochlear implants. *Infancy, 10*(3), 221–240. https://doi.org/10.1207/s15327078in1003_2

Bergeson, T. R. (2011). Maternal speech to hearing-impaired infants in the first year of hearing aid or cochlear implant use: a preliminary report. *Cochlear Implants International, 12*(sup1), S101–S104. https://doi.org/10.1179/146701011×13001035752741

Bortfeld, H. (2019). Functional near-infrared spectroscopy as a tool for assessing speech and spoken language processing in pediatric and adult cochlear implant users. *Developmental Psychobiology, 61*(3), 430–443. https://doi.org/10.1002/dev.21818

Burnham, D., Kitamura, C., & Vollmer-Conna, U. (2002). What’s new, pussycat? On talking to babies and animals. *Science, 296*(5572), 1435-1435.

Casillas, M., & Cristia, A. (2019). A step-by-step guide to collecting and analyzing long-format speech environment (LFSE) recordings. *Collabra: Psychology, 5*(1). https://doi.org/10.1525/collabra.209

Çelik, P., Keseroğlu, K., Er, S., Sucaklı, İ. A., Saylam, G., & Yakut, H.İ. (2021). Early-auditory intervention in children with hearing loss and neurodevelopmental outcomes: cognitive, motor and language development. *The Turkish Journal of Pediatrics, 63*(3), 450–460. https://doi.org/10.24953/turkjped.2021.03.012

Ching, T. Y., Dillon, H., Button, L., Seeto, M., Van Buynder, P., Marnane, V., & Leigh, G. (2017). Age at intervention for permanent hearing loss and 5-year language outcomes. *Pediatrics, 140*(3). https://doi.org/10.1542/peds.2016-4274

Ching, T. Y. (2015). Is early intervention effective in improving spoken language outcomes of children with congenital hearing loss? *American journal of audiology, 24*(3), 345–348. https://doi.org/10.1044/2015_AJA-15-0007

Chong, S. C. F., Werker, J. F., Russell, J. A., & Carroll, J. M. (2003). Three facial expressions mothers direct to their infants. *Infant and Child Development: An International Journal of Research and Practice, 12*(3), 211–232. https://doi.org/10.1002/icd.286

Coates, H., & Gifkins, K. (2003). Newborn hearing screening. *Aust Prescr, 26*(4), 82–84. https://doi.org/10.18773/austprescr.2003.062

Contrera, K. J., Choi, J. S., Blake, C. R., Betz, J. F., Niparko, J. K., & Lin, F. R. (2014). Rates of long-term cochlear implant use in children. *Otology & neurotology: official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 35*(3), 426. https://dx.doi.org/10.1097%2FMAO.0000000000000243.

Cooper, R. P., & Aslin, R. N. (1990). Preference for infant-directed speech in the first month after birth. *Child Development, 61*(5), 1584–1595. https://doi.org/10.1111/j.1467-8624.1990.tb02885.x

Cristia, A., & Seidl, A. (2014). The hyperarticulation hypothesis of infant-directed speech. *Journal of Child Language, 41*(4), 913–934. https://doi.org/10.1017/S0305000912000669

Dilley, L., Lehet, M., Wieland, E. A., Arjmandi, M. K., Kondaurova, M., Wang, Y., & Bergeson, T. (2020). Individual Differences in Mothers’ Spontaneous Infant-Directed Speech Predict Language Attainment in Children with Cochlear Implants. *Journal of Speech, Language, and Hearing Research, 63*(7), 2453–2467. https://doi.org/10.1044/2020_JSLHR-19-00229

Easwar, V., Sanfilippo, J., Papsin, B., & Gordon, K. (2018). Impact of consistency in daily device use on speech perception abilities in children with cochlear implants: datalogging evidence. *Journal of the American Academy of Audiology, 29*(09), 835–846. https://doi.org/10.3766/jaaa.17051

Englund, K. T. (2018). Hypoarticulation in infant-directed speech. *Applied Psycholinguistics, 39*(1), 67–87. https://doi.org/10.1017/S0142716417000480

Fenson, L., Dale, P., Reznick, J.S., Thal, D., Bates, E., Hartung, J.,. & Reilly, J. (1993). MacArthur Communicative Inventories: User’s guide and technical manual. *San Diego*.

Ferguson, S. H., & Kewley-Port, D. (2002). Vowel intelligibility in clear and conversational speech for normal-hearing and hearing-impaired listeners. *The Journal of the Acoustical Society of America, 112*(1), 259–271. https://doi.org/10.1121/1.1482078

Ferguson, S. H., & Kewley-Port, D. (2007). Talker differences in clear and conversational speech: Acoustic characteristics of vowels. *Journal of Speech, Language, and Hearing Research, 50*(5), 1241–1255. https://doi.org/10.1044/1092-4388(2007/087)

Fernald, A., & Simon, T. (1984). Expanded intonation contours in mothers' speech to newborns. In *Developmental Psychology, 20* pp. 104–113). https://doi.org/10.1037/0012-1649.20.1.104

Fernald, A., & Kuhl, P. (1987). Acoustic determinants of infant preference for motherese speech. *Infant Behavior and Development, 10*(3), 279–293. https://www.sciencedirect.com/science/article/pii/0163638387900178.

Fernald, A., & Mazzie, C. (1991). Prosody and focus in speech to infants and adults. *Developmental Psychology, 27*(2), 209.

Fernald, A. (1985). Four-month-old infants prefer to listen to motherese. *Infant Behavior and Development, 8*(2), 181–195. https://doi.org/10.1016/S0163-6383(85)80005-9

Fernald, A., & Morikawa, H. (1993). Common themes and cultural variations in Japanese and American Mothers' Speech to Infants. *Child Development, 64*, 637–656. https://doi.org/10.1111/j.1467-8624.1993.tb02933.x

Fernald, A., Taeschner, T., Dunn, J., Papousek, M., de Boysson-Bardies, B., & Fukui, I. (1989). A cross-language study of prosodic modifications in mothers' and fathers' speech to preverbal infants. *Journal of Child Language, 16*(3), 477–501. https://doi.org/10.1017/S0305000900010679

Fernald, A. (1992). 13. Meaningful melodies in mothers' speech to infants. *Nonverbal vocal communication: Comparative and developmental approaches, 262*.

Frank, M. C., Alcock, K. J., Arias-Trejo, N., Aschersleben, G., Baldwin, D., Barbu, S., … Soderstrom, M. (2020). Quantifying sources of variability in infancy research using the infant-directed-speech preference. *Advances in Methods and Practices in Psychological Science, 3*(1), 24–52. https://doi.org/10.1177/2515245919900809

Gagnon, E. B., Eskridge, H., & Brown, K. D. (2020). Pediatric cochlear implant wear time and early language development. *Cochlear Implants International, 21*(2), 92–97. https://doi.org/10.1080/14670100.2019.1670487

Gerhardt, K. J., & Abrams, R. M. (2000). Fetal exposures to sound and vibroacoustic stimulation. *Journal of Perinatology, 20*(S1), S21.

Graf Estes, K., & Hurley, K. (2013). Infant-directed prosody helps infants map sounds to meanings. *Infancy, 18*(5), 797–824. https://doi.org/10.1111/infa.12006

Grieser, D. L., & Kuhl, P. K. (1988). Maternal speech to infants in a tonal language: Support for universal prosodic features in motherese. *Developmental Psychology, 24*(1), 14.

Green, J. R., Nip, I. S., Wilson, E. M., Mefferd, A. S., & Yunusova, Y. (2010). Lip movement exaggerations during infant-directed speech. *Journal of Speech, Language, and Hearing Research, 53*(6), 1529–1542. https://doi.org/10.1044/1092-4388(2010/09-0005)

Guerzoni, L., & Cuda, D. (2017). Speech processor data logging helps in predicting early linguistic outcomes in implanted children. *International journal of pediatric otorhinolaryngology, 101*, 81–86. https://doi.org/10.1016/j.ijporl.2017.07.026

Hartman, K. M., Bernstein Ratner, N., & Newman, R. S. (2017). Infant-directed speech (IDS) vowel clarity and child language outcomes. *Journal of Child Language, 44*(5), 1140–1162. https://doi.org/10.1017/S0305000916000520

Houston, D. M., Pisoni, D. B., Kirk, K. I., Ying, E. A., & Miyamoto, R. T. (2003). Speech perception skills of deaf infants following cochlear implantation: a first report. *International Journal of Pediatric Otorhinolaryngology, 67*(5), 479–495. https://doi.org/10.1016/S0165-5876(03)00005-3

Joint Committee on Infant Hearing. (2007). Year 2007 position statement: principles and guidelines for early hearing detection and intervention programs. *Pediatrics, 120*(4), 898–921. https://doi.org/10.1542/peds.2007-2333

Jusczyk, P. W. (1997). Finding and remembering words: Some beginnings by English-learning infants. *Current Directions in Psychological Science, 6*(6), 170–174.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive psychology, 39*(3), 159–207. https://doi.org/10.1006/cogp.1999.0716

Kalashnikova, M., Peter, V., Di Liberto, G. M., Lalor, E. C., & Burnham, D. (2018a). Infant-directed speech facilitates seven-month-old infants' cortical tracking of speech. *Scientific reports, 8*(1), 1–8.

Kalashnikova, M., & Burnham, D. (2018). Infant-directed speech from seven to nineteen months has similar acoustic properties but different functions. *Journal of Child Language*, 1–19. https://doi.org/10.1017/S0305000917000629

Kalashnikova, M., Carignan, C., & Burnham, D. (2017). The origins of babytalk: smiling, teaching or social convergence? *Royal Society Open Science, 4*(8), Article 170306. https://doi.org/10.1098/rsos.170306

Kalashnikova, M., Goswami, U., & Burnham, D. (2018b). Mothers speak differently to infants at-risk for dyslexia. *Developmental Science, 21*(1), Article e12487. https://doi.org/10.1111/desc.12487

Kalashnikova, M., & Carreiras, M. (2021). Input quality and speech perception development in bilingual infants' first year of life. *Child Development*. https://doi.org/10.1111/cdev.13686

Kaplan, P. S., Jung, P. C., Ryther, J. S., & Zarlengo-Strouse, P. (1996). Infant-directed versus adult-directed speech as signals for faces. *Developmental Psychology, 32*(5), 880.

Kaplan, P. S., Bachorowski, J. A., & Zarlengo-Strouse, P. (1999). Child-directed speech produced by mothers with symptoms of depression fails to promote associative learning in 4–month-old infants. *Child Development, 70*(3), 560–570. https://doi.org/10.1111/1467-8624.00041

Kavanaugh, R. D., & Jirkovsky, A. M. (1982). Parental speech to young children: a longitudinal analysis. *Merrill-Palmer Quarterly (1982-)*, 297–311.

Kennedy, C. R., McCann, D. C., Campbell, M. J., Law, C. M., Mullee, M., Petrou, S., & Stevenson, J. (2006). Language ability after early detection of permanent childhood hearing impairment. *New England Journal of Medicine, 354*(20), 2131–2141. https://doi.org/10.1056/NEJMoa054915

Kishon-Rabin, L., Harel, T., Hildesheimer, M., & Segal, O. (2010). Listening preference for the native language compared to an unfamiliar language in hearing and hearing-impaired infants after cochlear implantation. *Otology & Neurotology, 31*(8), 1275–1280. https://doi.org/10.1097/MAO.0b013e3181f2f45d

Kitamura, C., Thanavishuth, C., Burnham, D., & Luksaneeyanawin, S. (2001). Universality and specificity in infant-directed speech: pitch modifications as a function of infant age and sex in a tonal and non-tonal language. *Infant Behavior and Development, 24*(4), 372–392. https://doi.org/10.1016/S0163-6383(02)00086-3

Kitamura, C., & Burnham, D. (2003). Pitch and communicative intent in mother's speech: Adjustments for age and sex in the first year. *Infancy, 4*(1), 85–110.

Knoll, M. A., & Costall, A. (2015). Characterising F (0) contour shape in infant-and foreigner-directed speech. *Speech Communication, 66*, 231–243. https://doi.org/10.1016/j.specom.2014.10.007

Koester, L. S. (1995). Face-to-face interactions between hearing mothers and their deaf or hearing infants. *Infant Behavior and Development, 18*(2), 145–153. https://doi.org/10.1016/0163-6383(95)90044-6

Kondaurova, M. V., Bergeson, T. R., & Xu, H. (2013). Age-related changes in prosodic features of maternal speech to prelingually deaf infants with cochlear implants. *Infancy, 18*(5), 825–848. https://doi.org/10.1111/infa.12010

Kondaurova, M. V., & Bergeson, T. R. (2011). The effects of age and infant hearing status on maternal use of prosodic cues for clause boundaries in speech. *Journal of Speech, Language, and Hearing Research*. https://doi.org/10.1044/1092-4388(2010/09-0225)

Kondaurova, M. V., Bergeson, T. R., & Dilley, L. C. (2012). Effects of deafness on acoustic characteristics of American English tense/lax vowels in maternal speech to infants. *The Journal of the Acoustical Society of America, 132*(2), 1039–1049. https://doi.org/10.1121/1.4728169

Korver, A. M., Konings, S., Dekker, F. W., Beers, M., Wever, C. C., Frijns, J. H., & DECIBEL Collaborative Study Group. (2010). Newborn hearing screening vs later hearing screening and developmental outcomes in children with permanent childhood hearing impairment. *Jama, 304*(15), 1701–1708. https://doi.org/10.1001/jama.2010.1501

Korver, A. M., Smith, R. J., Van Camp, G., Schleiss, M. R., Bitner-Glindzicz, M. A., Lustig, L. R., & Boudewyns, A. N. (2017). Congenital hearing loss. *Nature reviews Disease primers, 3*, 16094.

Kuhl, P. K., Andruski, J. E., Chistovich, I. A., Chistovich, L. A., Kozhevnikova, E. V., Ryskina, V. L., & Lacerda, F. (1997). Cross-language analysis of phonetic units in language addressed to infants. *Science, 277*(5326), 684–686. https://doi.org/10.1126/science.277.5326.684

Kujala, T., Alho, K., & Näätänen, R. (2000). Cross-modal reorganization of human cortical functions. *Trends in neurosciences, 23*(3), 115–120. https://doi.org/10.1016/S0166-2236(99)01504-0

Lam, C., & Kitamura, C. (2010). Maternal interactions with a hearing and hearing-impaired twin: Similarities and differences in speech input, interaction quality, and word production. *Journal of Speech, Language, and Hearing Research, 53*(3), 543–555. https://doi.org/10.1044/1092-4388(2010/09-0126)

Lam, C., & Kitamura, C. (2012). Mommy, speak clearly: Induced hearing loss shapes vowel hyperarticulation. *Developmental Science, 15*(2), 212–221. https://doi.org/10.1111/j.1467-7687.2011.01118.x

LENA Foundation. (2009). *The LENA pro system*. Boulder, CO: Author.

Liu, H. M., Kuhl, P. K., & Tsao, F. M. (2003). An association between mothers' speech clarity and infants' speech discrimination skills. *Developmental Science, 6*(3), F1–F10. https://doi.org/10.1111/1467-7687.00275

Lovcevic, I., Kalashnikova, M., & Burnham, D. (2020). Acoustic features of infant-directed speech to infants with hearing loss. *The Journal of the Acoustical Society of America, 148*(6), 3399–3416. https://doi.org/10.1121/10.0002641

Ma, W., Golinkoff, R. M., Houston, D. M., & Hirsh-Pasek, K. (2011). Word learning in infant-and adult-directed speech. *Language Learning and Development, 7*(3), 185–201. https://doi.org/10.1080/15475441.2011.579839

Macherey, O., & Carlyon, R. P. (2014). Cochlear implants. *Current Biology, 24*(18), R878–R884. https://doi.org/10.1016/j.cub.2014.06.053

Männel, C., & Friederici, A. D. (2010). Prosody is the key: ERP studies on word segmentation in 6-and 12-month-old children. *Cognitive Neuroscience Society ((CNS)) 2010 Annual Meeting,* 261-261.

Männel, C., & Friederici, A. D. (2013). Accentuate or repeat? Brain signatures of developmental periods in infant word recognition. *Cortex, 49*(10), 2788–2798. https://doi.org/10.1016/j.cortex.2013.09.003

ManyBabies Consortium. (2020). Quantifying sources of variability in infancy research using the infant-directed-speech preference. *Advances in Methods and Practices in Psychological Science, 3*(1), 24–52. https://doi.org/10.1177%2F2515245919900809.

Martin, A., Schatz, T., Versteegh, M., Miyazawa, K., Mazuka, R., Dupoux, E., & Cristia, A. (2015). Mothers speak less clearly to infants than to adults: a comprehensive test of the hyperarticulation hypothesis. *Psychological Science, 26*(3), 341–347. https://doi.org/10.1177%2F0956797614562453.

Martinez, A., Eisenberg, L., Boothroyd, A., & Visser-Dumont, L. (2008). Assessing speech pattern contrast perception in infants: Early results on VRASPAC. *Otology & neurotology: official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 29*(2), 183. https://doi.org/10.1097/MAO.0b013e3181625114

Mattock, K., & Burnham, D. (2006). Chinese and English infants' tone perception: evidence for perceptual reorganization. *Infancy, 10*(3), 241–265. https://doi.org/10.1207/s15327078in1003_3

Mattys, S. L., & Jusczyk, P. W. (2001). Do infants segment words or recurring contiguous patterns? *Journal of Experimental Psychology: Human Perception and Performance, 27*(3), 644.

Mayne, A. M., Yoshinaga-Itano, C., Sedey, A. L., & Carey, A. (1999a). Expressive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review, 100*(5), 1–28.

Mayne, A. M., Yoshinaga-Itano, C., & Sedey, A. L. (1999b). Receptive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review, 100*(5), 29–52.

McGowan, R. S., Nittrouer, S., & Chenausky, K. (2008). Speech production in 12-month-old children with and without hearing loss. *Journal of Speech, Language, and Hearing Research.* https://doi.org/10.1044/1092-4388(2008/064)

McMurray, B., Kovack-Lesh, K. A., Goodwin, D., & McEchron, W. (2013). Infant directed speech and the development of speech perception: Enhancing development or an unintended consequence? *Cognition, 129*(2), 362–378. https://doi.org/10.1016/j.cognition.2013.07.015

McRoberts, G. W., & Best, C. T. (1997). Accommodation in mean f0 during mother-infant and father-infant vocal interactions: a longitudinal case study. *Journal of Child Language, 24*, 719–736. https://doi.org/10.1017/S030500099700322X

Miyamoto, R. T., Houston, D. M., & Bergeson, T. (2005). Cochlear implantation in deaf infants. *The Laryngoscope, 115*(8), 1376–1380. https://doi.org/10.1097/01.mlg.0000172039.26650.9b

Miyazawa, K., Shinya, T., Martin, A., Kikuchi, H., & Mazuka, R. (2017). Vowels in infant-directed speech: More breathy and more variable, but not clearer. *Cognition, 166*, 84–93. https://doi.org/10.1016/j.cognition.2017.05.003

Moeller, M. P., Tomblin, J. B., Yoshinaga-Itano, C., Connor, C. M., & Jerger, S. (2007). Current state of knowledge: Language and literacy of children with hearing impairment. *Ear and Hearing, 28*(6), 740–753. https://doi.org/10.1097/AUD.0b013e318157f07f

Moeller, M. P., Hoover, B. M., Putman, C. A., Arbataitis, K., Bohnenkamp, G., Peterson, B., et al. (2007a). Vocalizations of infants with hearing loss compared to infants with normal hearing. Part I: Phonetic development. *Ear and Hearing, 28*(5), 605–627. https://doi.org/10.1097/AUD.0b013e31812564ab

Moeller, M. P., Hoover, B. M., Putman, C. A., Arbataitis, K., Bohnenkamp, G., Peterson, B., et al. (2007b). Vocalizations of infants with hearing loss compared to infants with normal hearing. Part II: Transition to words. *Ear and Hearing, 28*(5), 628–642. https://doi.org/10.1097/AUD.0b013e31812564c9

Mohay, H. (2000). Language in sight: Mothers' strategies for making language visually accessible to deaf children. *The deaf child in the family and at school: Essays in honor of Kathryn P. Meadow-Orlans*, 151–166.

Moore, D. R. (1991). Anatomy and physiology of binaural hearing. *Audiology, 30*(3), 125–134.

Moore, D. R. (2007). Auditory processing disorders: acquisition and treatment. *Journal of Communication Disorders, 40*(4), 295–304. https://doi.org/10.1016/j.jcomdis.2007.03.005

Myrthe, K. S., Bosman, A. J., Snik, A. F., Mylanus, E. A., & Cremers, C. W. J. (2005). Bone-anchored hearing aids in unilateral inner ear deafness: an evaluation of audiometric and patient outcome measurements. *Otology & Neurotology, 26*(5), 999–1006. https://doi.org/10.1097/01.mao.0000185065.04834.95

Narayan, C. R., & McDermott, L. C. (2016). Speech rate and pitch characteristics of infant-directed speech: Longitudinal and cross-linguistic observations. *The Journal of the Acoustical Society of America, 139*(3), 1272–1281. https://doi.org/10.1121/1.4944634

Neville, H. J., & Bruer, J. T. (2001). Language processing: How experience affects brain organization. *Critical thinking about critical periods*, 151–172.

Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech, Language, and Hearing Research.* https://doi.org/10.1044/1092-4388(2007/073)

Niparko, J. K., Cox, K. M., & Lustig, L. R. (2003). Comparison of the bone anchored hearing aid implantable hearing device with contralateral routing of offside signal amplification in the rehabilitation of unilateral deafness. *Otology & neurotology, 24*(1), 73–78.

Papoušek, M., Bornstein, M. H., Nuzzo, C., Papoušek, H., & Symmes, D. (1990). Infant responses to prototypical melodic contours in parental speech. *Infant Behavior and Development, 13*(4), 539–545. https://doi.org/10.1016/0163-6383(90)90022-Z

Peter, V., Kalashnikova, M., Santos, A., & Burnham, D. (2016). Mature neural responses to infant-directed speech but not adult-directed speech in pre-verbal infants. *Scientific Reports, 6*, 34273. https://doi.org/10.1038/srep34273

Phillips, J. R. (1973). Syntax and vocabulary of mothers' speech to young children: Age and sex comparisons. *Child Development*, 182–185. https://doi.org/10.2307/1127699

Polka, L., & Werker, J. F. (1994). Developmental changes in perception of non-native vowel contrasts. *Journal of Experimental Psychology: Human perception and performance, 20*(2), 421. https://doi.org/10.1037/0096-1523.20.2.421

Ponton, C. W., Moore, J. K., & Eggermont, J. J. (1999). Prolonged deafness limits auditory system developmental plasticity: evidence from an evoked potentials study in children with cochlear implants. *Scandinavian Audiology*.

Qi, S., & Mitchell, R. E. (2011). Large-scale academic achievement testing of deaf and hard-of-hearing students: Past, present, and future. *Journal of Deaf Studies and Deaf Education, 17*(1), 1–18. https://doi.org/10.1093/deafed/enr028

Ramkalawan, T. W., & Davis, A. C. (1992). The effects of hearing loss and age of intervention on some language metrics in young hearing-impaired children. *British journal of audiology, 26*(2), 97–107. https://doi.org/10.3109/03005369209077877

Robertson, S., von Hapsburg, D., & Hay, J. S. (2013). The effect of hearing loss on the perception of infant-and adult-directed speech. *Journal of Speech, Language, and Hearing Research.* https://doi.org/10.1044/1092-4388(2012/12-0110)

Russ, S. A., White, K., Dougherty, D., & Forsman, I. (2010). Preface: Newborn hearing screening in the United States: Historical perspective and future directions. *Pediatrics, 126*(Supplement 1), S3–S6. https://doi.org/10.1542/peds.2010-0354D

Saffran, J. R., Newport, E. L., & Aslin, R. N. (1996). Word segmentation: The role of distributional cues. *Journal of Memory and Language, 35*(4), 606–621. https://doi.org/10.1006/jmla.1996.0032

Saito, Y., Aoyama, S., Kondo, T., Fukumoto, R., Konishi, N., Nakamura, K., & Toshima, T. (2007). Frontal cerebral blood flow change associated with infant-directed speech. *Archives of Disease in Childhood-Fetal and Neonatal Edition, 92*(2), F113–F116. https://doi.org/10.1136/adc.2006.097949

Santesso, D. L., Schmidt, L. A., & Trainor, L. J. (2007). Frontal brain electrical activity (EEG) and heart rate in response to affective infant-directed (ID) speech in 9-month-old infants. *Brain and Cognition, 65*(1), 14–21. https://doi.org/10.1016/j.bandc.2007.02.008

Schauwers, K., Gillis, S., Daemers, K., De Beukelaer, C., & Govaerts, P. J. (2004). Cochlear implantation between 5 and 20 months of age: the onset of babbling and the audiologic outcome. *Otology & Neurotology, 25*(3), 263–270.

Segal, O., & Kishon-Rabin, L. (2011). Listening preference for child-directed speech versus nonspeech stimuli in normal-hearing and hearing-impaired infants after cochlear implantation. *Ear and Hearing, 32*(3), 358–372. https://doi.org/10.1097/AUD.0b013e3182008afc

Segal, O., Houston, D., & Kishon-Rabin, L. (2016). Auditory discrimination of lexical stress patterns in hearing-impaired infants with cochlear implants compared with normal hearing: influence of acoustic cues and listening experience to the ambient language. *Ear and Hearing, 37*(2), 225–234. https://doi.org/10.1097/AUD.0000000000000243

Shepard, K. G., Spence, M. J., & Sasson, N. J. (2012). Distinct facial characteristics differentiate communicative intent of infant-directed speech. *Infant and Child Development, 21*(6), 555–578. https://doi.org/10.1002/icd.1757

Shojaei, E., Jafari, Z., & Gholami, M. (2016). Effect of early intervention on language development in hearing-impaired children. *Iranian journal of otorhinolaryngology, 28*(84), 13.

Skarżyński, P. H., & Ludwikowski, M. (2018). Hearing Screening Around the World. *An Excursus into Hearing Loss*. IntechOpen,.

Snik, A. D., Leijendeckers, J., Hol, M., Mylanus, E., & Cremers, C. (2008). The bone-anchored hearing aid for children: recent developments. *International journal of audiology, 47*(9), 554–559. https://doi.org/10.1080/14992020802307354

Snow, C. E. (1977). The development of conversation between mothers and babies. *Journal of Child Language, 4*(1), 1–22. https://doi.org/10.1017/S0305000900000453

Soderstrom, M., Blossom, M., Foygel, I., & Morgan, J. L. (2008). Acoustical cues and grammatical units in speech to two preverbal infants. *Journal of Child Language, 35*, 869–902. https://doi.org/10.1017/S0305000908008763

Song, J. Y., Demuth, K., & Morgan, J. (2010). Effects of the acoustic properties of infant-directed speech on infant word recognition. *The Journal of the Acoustical Society of America, 128*(1), 389–400. https://doi.org/10.1121/1.3419786

Spinelli, M., & Mesman, J. (2018). The regulation of infant negative emotions: the role of maternal sensitivity and infant-directed speech prosody. *Infancy, 23*(4), 502–518. https://doi.org/10.1111/infa.12237

Stern, D. N., Spieker, S., Barnett, R. K., & MacKain, K. (1983). The prosody of maternal speech: Infant age and context related changes. *Journal of Child Language, 10*(1), 1–15. https://doi.org/10.1017/S0305000900005092

Szagun, G. (2001). Language acquisition in young German-speaking children with cochlear implants: Individual differences and implications for conceptions of a 'sensitive phase'. *Audiology and Neurotology, 6*(5), 288–297. https://doi.org/10.1159/000046134

Szagun, G. (2004). Individual differences in language acquisition by young children with cochlear implants and implications for a concept of 'sensitive phase'. In *International Congress Series* (Vol. 1273, pp. 308–311). Elsevier,. https://doi.org/10.1016/j.ics.2004.08.016 (November).

Tang, P., Xu Rattanasone, N., Yuen, I., & Demuth, K. (2017). Phonetic enhancement of Mandarin vowels and tones: Infant-directed speech and Lombard speech. *The Journal of the Acoustical Society of America, 142*(2), 493–503. https://doi.org/10.1121/1.4995998

Traci, M.A. (1998). Fundamental frequency in speech directed to deaf or hearing infants by Deaf or hearing mothers.

Trainor, L. J., Austin, C. M., & Desjardins, R. N. (2000). Is infant-directed speech prosody a result of the vocal expression of emotion? *Psychological Science, 11*(3), 188–195. https://doi.org/10.1111%2F1467-9280.00240.

Trainor, L. J., & Desjardins, R. N. (2002). Pitch characteristics of infant-directed speech affect infants' ability to discriminate vowels. *Psychonomic Bulletin & Review, 9*(2), 335–340.

Thiessen, E. D., Hill, E. A., & Saffran, J. R. (2005). Infant-directed speech facilitates word segmentation. *Infancy, 7*(1), 53–71.

Tomblin, J. B., Oleson, J. J., Ambrose, S. E., Walker, E., & Moeller, M. P. (2014). The influence of hearing aids on the speech and language development of children with hearing loss. *JAMA Otolaryngology–Head & Neck Surgery, 140*(5), 403–409. https://doi.org/10.1001/jamaoto.2014.267

Uhler, K., Yoshinaga-Itano, C., Gabbard, S. A., Rothpletz, A. M., & Jenkins, H. (2011). Longitudinal infant speech perception in young cochlear implant users. *Journal of the American Academy of Audiology, 22*(3), 129–142. https://doi.org/10.3766/jaaa.22.3.2

Uther, M., Knoll, M. A., & Burnham, D. (2007). Do you speak E-NG-LI-SH? A comparison of foreigner-and infant-directed speech. *Speech Communication, 49*(1), 2–7. https://doi.org/10.1016/j.specom.2006.10.003

VanDam, M., Ambrose, S. E., & Moeller, M. P. (2012). Quantity of parental language in the home environments of hard-of-hearing 2-year-olds. *Journal of deaf studies and deaf education, 17*(4), 402–420. https://doi.org/10.1093/deafed/ens025

Vanormelingen, L., De Maeyer, S., & Gillis, S. (2016). A comparison of maternal and child language in normally-hearing and hearing-impaired children with cochlear implants. *Language, Interaction and Acquisition, 7*(2), 145–179. https://doi.org/10.1075/lia.7.2.01van

van Wieringen, A., Boudewyns, A., Sangen, A., Wouters, J., & Desloovere, C. (2019). Unilateral congenital hearing loss in children: challenges and potentials. *Hearing Research, 372*, 29–41. https://doi.org/10.1016/j.heares.2018.01.010

Vavatzanidis, N. K., Mürbe, D., Friederici, A. D., & Hahne, A. (2016). The perception of stress pattern in young cochlear implanted children: an EEG study. *Frontiers in neuroscience, 10*, 68. https://doi.org/10.3389/fnins.2016.00068

Verhaert, N., Willems, M., Van Kerschaver, E., & Desloovere, C. (2008). Impact of early hearing screening and treatment on language development and education level: evaluation of 6 years of universal newborn hearing screening (ALGO®) in Flanders, Belgium. *International journal of pediatric otorhinolaryngology, 72*(5), 599–608. https://doi.org/10.1016/j.ijporl.2008.01.012

Vohr, B. R., Carty, L. M., Moore, P. E., & Letourneau, K. (1998). The Rhode Island hearing assessment program: Experience with statewide hearing screening (1993-1996). *The Journal of Pediatrics, 133*(3), 353–357. https://doi.org/10.1016/S0022-3476(98)70268-9

von Hapsburg, D., & Davis, B. L. (2006). Auditory sensitivity and the prelinguistic vocalizations of early-amplified infants. *Journal of Speech, Language, and Hearing Research*. https://doi.org/10.1044/1092-4388(2006/057)

Wake, M., Hughes, E. K., Poulakis, Z., Collins, C., & Rickards, F. W. (2004). Outcomes of children with mild-profound congenital hearing loss at 7 to 8 years: a population study. *Ear and Hearing, 25*(1), 1–8. https://doi.org/10.1097/01.AUD.0000111262.12219.2F

Walker, E.A., Spratford, M., Moeller, M.P., Oleson, J., Ou, H., Roush, P., & Jacobs, S. (2013). Predictors of hearing aid use time in children with mild-to-severe hearing loss. https://doi.org/10.1044/0161–1461(2012/12–0005).

Wang, Y., Bergeson, T. R., & Houston, D. M. (2018). Preference for infant-directed speech in infants with hearing aids: effects of early auditory experience. *Journal of Speech, Language, and Hearing Research, 61*(9), 2431–2439. https://doi.org/10.1044/2018_JSLHR-H-18-0086

Wang, Y., Bergeson, T. R., & Houston, D. M. (2017). Infant-directed speech enhances attention to speech in deaf infants with cochlear implants. *Journal of Speech, Language, and Hearing Research, 60*(11), 3321–3333. https://doi.org/10.1044/2017_JSLHR-H-17-0149

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: evidence for perceptual reorganization during the first year of life. *Infant Behavior & Development, 7*(1), 49–63. https://doi.org/10.1016/S0163-6383(84)80022-3

Werker, J. F., & Hensch, T. K. (2015). Critical periods in speech perception: new directions. *Annual review of psychology, 66*, 173–196. https://doi.org/10.1146/annurev-psych-010814-015104

Werker, J. F., & McLeod, P. J. (1989). Infant preference for both male and female infant-directed talk: A developmental study of attentional and affective responsiveness. *Canadian Journal of Psychology, 43*(2), 230–246.

Werker, J. F., Pegg, J. E., & McLeod, P. J. (1994). A cross-language investigation of infant preference for infant-directed communication. *Infant Behavior and Development, 17*(3), 323. https://doi.org/10.1016/0163-6383(94)90012-4

Wieland, E. A., Burnham, E. B., Kondaurova, M., Bergeson, T. R., & Dilley, L. C. (2015). Vowel space characteristics of speech directed to children with and without hearing loss. *Journal of Speech, Language, and Hearing Research, 58*(2), 254–267. https://doi.org/10.1044/2015_JSLHR-S-13-0250

Xu, N., Burnham, D., Kitamura, C., & Vollmer-Conna, U. (2013). Vowel hyperarticulation in parrot-, dog-and infant-directed speech. *Anthrozoös, 26*(3), 373–380. https://doi.org/10.2752/175303713×13697429463592

Yoshinaga-Itano, C., & Apuzzo, M. R. L. (1998). Identification of hearing loss after age 18 months is not early enough. *American Annals of the Deaf*, 380–387.

Zangl, R., & Mills, D. L. (2007). Increased brain activity to infant-directed speech in 6–and 13–month-old infants. *Infancy, 11*(1), 31–62. https://doi.org/10.1207/s15327078in1101_2

Zeng, F. G., Tang, Q., & Lu, T. (2014). Abnormal pitch perception produced by cochlear implant stimulation. *PloS One, 9*(2), Article e88662. https://doi.org/10.1371/journal.pone.0088662

Zeng, F. G. (2004). Trends in cochlear implants. *Trends in Amplification, 8*(1), 1–34. https://doi.org/10.1177%2F108471380400800102.

Zhang, Y., Koerner, T., Miller, S., Grice-Patil, Z., Svec, A., Akbari, D., & Carney, E. (2011). Neural coding of formant-exaggerated speech in the infant brain. *Developmental Science, 14*(3), 566–581. https://doi.org/10.1111/j.1467-7687.2010.01004.x