Development of vocalizations in deaf and normally hearing infants

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Development of vocalizations in deaf and normally hearing infants

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Christina Jacoba Clement

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Chapter 1

Introduction

This thesis discusses the development of vocalizations in hearing impaired and deaf (HI)[1] infants[2] and normally hearing (NH) infants in the first year of life, that is before infants enter the first word stage. Vocalizations include all types of non-vegetative sounds that infants produce before starting to produce the first words around the age of twelve months, but do not include sounds such as laughing and crying. The importance of vocalization development for later speech and language development has been doubted in the past and so it has been somewhat neglected. Over the last decades however more research has been done on this topic, resulting in several models for vocalization development. Longitudinal studies have shown that infants produce several different types of vocalizations over various periods. These periods have been given the status of stages and since the onset of some of these stages, such as babbling[3], are abrupt and salient, several researchers have even called them milestones (Koopmans-van Beinum and Van der Stelt, 1986; 1998; Masataka, 2001). Some theories on vocalization development and the relationship between vocalizations and later speech and language development will be discussed in section 1.1.

There is considerable agreement on the course of vocalization development of NH infants. It is still not totally clear, however, how the development and onset of the vocalization stages can be explained and what factors are involved. For instance, the influence of hearing on vocalization development has not been explored. Although some researchers report differences between HI and NH infants in their vocalization development, such as a delayed babbling onset, it is still not known how and from what age onwards hearing affects vocalization development in infants (see also section 1.2). This leads to the main research question of this thesis: are vocalizations produced by HI infants in the same way and at the same age as by NH infants? In section 1.3 we will show an overview of the content of Chapters 2 to 9.

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[1] In this thesis *HI* refers to hearing impaired (including deaf) and *NH* to normally hearing. The definition of hearing impaired and deaf will be discussed in Chapter 3.1.

[2] In this thesis *infant* refers to a child under 12 months of age.

[3] In this thesis *babbling* stands for sequences of syllables containing consonant and vowel alternations, such as [bababa]. See also Chapter 7.2.1 for the complete definition of babbling.

1.1 The relationship between vocalizations and later speech and language development

Over the last thirty years, infant speech development and the relationship between infant speech production during the first year of life, and the speech and language development after the first year, have become research topics of growing interest. Prior to that only little research had been done on this topic, probably due to an assumption that infant behavior, including vocalizations, within the first year of life, was not related to later speech and language development. The assumption of discontinuity between infancy and childhood was not specific to language; it has also been assumed for cognitive development, according to Bornstein and Sigman (1986). The studies of Jakobson (1968) proposing a gap between infant speech productions and child speech influenced the literature for a while. According to Locke (1993) one of the arguments for the 'discontinuity theory' was that observers thought that:

> "in the babbling of babies they could hear a little bit of everything while in the speech of young children they heard no more than a handful of sounds. No one systematically tabulated babies' actual sounds, so this misconception prevailed for a time."
>
> (Locke, 1993, p. 372)

In support of the discontinuity theory references have often been made to the studies of Lenneberg, Rebelsky and Nicols (1965) and Lenneberg (1967) who claimed that deaf infants vocalize exactly the same way as hearing infants do. It was concluded that hearing has no influence on vocalization development and that hearing (and the language environment) no sooner starts to influence speech and language development than after the first year. It was argued that vocalization development is influenced only by biological constraints such as anatomical and neurological development and is unrelated to the subsequent speech and language development after the first year. As will be argued in Chapter 3.3.5 there are several reasons why the conclusions from the studies of Lenneberg et al. (1965) and Lenneberg (1967) are most probably incorrect. The concept that deaf infants vocalize exactly the same way as hearing infants do is still persistent, as reflected in some textbooks.

In several recent studies a relationship between vocalizations and first words productions has been shown. Studies like those of De Boysson-Bardies and Vihman (1991) and Elbers (1989) show a clear relationship between the consonant- or vowel-like sounds produced in the babbling stage and the production of the first words. De Boysson-Bardies and Vihman studied, among others, the place and manner of the consonant-like segments produced by infants from several linguistic environments. They found that, during babbling, NH infants produced more often the consonant-like segments specific to the input language as opposed to other segments, and these were also the segments produced more frequently by adults from the same environment. For instance, French infants produce relatively many labials, just as French adults do (see also Chapter 3.1.3). Elbers (1989) studied the sound productions of one Dutch child longitudinally and also found a strong correlation between the type of sound productions during babbling and during the productions of first words.

A relationship between the number of vocalizations and the later speech and language development has also been found. Kagan (1971) found a relationship between high number of vocalizations and larger vocabulary development at 27 months for girls. Also, Roe (1977) found a positive correlation between the number of vocalizations at three months of age and the amount of talking at three years, as well as the vocabulary development at five years in his study of 14 boys. Camp, Burgess, Morgan and Zerbe (1987) studied 141 normally developing infants and reported a correlation between the number of vocalizations at four to six months of age and word use at one year. Also, in studies of atypically developing children a relationship between number of vocalizations and later speech and language development is found. In the study of McCathren, Yoder and Warren (1999) a clear positive correlation was found between rate of vocalizations at 17-34 months of age and later expressive vocabulary of 58 children with a developmental delay.

If a relationship between vocalization development and the later speech and language development exists, it might be the case that an abnormal vocalization development might be related to an abnormal spoken language development. We might expect that, for instance, disordered babbling (for instance a small amount or atypical babbling) will be related to disordered language development. Stoel-Gammon (1989) found in her group of 34 infants, two children who produced an abnormal type of babbling. One of them produced only few repetitive babbles, the other infant produced an unusual pattern of sound preferences in the babbling sounds. Both children produced at 24 months words with a limited sound repertoire and with simpler syllable shapes than the other 32 children. Jensen, Boggild-Andersen, Schmidt, Ankerhus and Hansen (1988) studied the development of infants who were at risk for a developmental delay (low birth weight, low Apgar score, neonatal cerebral symptoms) and compared them to infants not at risk. The infants at risk produced significantly fewer consonant-like segments and less reduplicated babbling than the children not at risk. A larger proportion of the children at risk also scored below age level on a language test. Moreover, Oller, Eilers, Neal and Cobo-Lewis (1998) argued that a late babbling onset might possibly function as an early marker of abnormal development. In a recent study the relationship between vocalizations and later speech and language performance was shown for infants with a cleft lip and palate (Chapman, Hardin-Jones and Halter, 2003). It was suggested that the production of stop consonants in vocalizations at 9 months of age was related to phonological development at 21 months.

These studies clearly indicate a connection between vocalizations, babbling in particular, and later language development. Based on these previous studies we assume that vocalizations are important for later speech and language development. This assumption will not be a topic for research in this thesis, since we focus on the vocalization development of infants only, but the assumption forms part of the motivation for this study.

Assuming that vocalizations are important for the later speech and language development it is interesting to speculate about reasons why infants possibly vocalize. A part of the reason might be that infants vocalize as a training for early speech development in order to coordinate the separate devices of the speech apparatus, such as phonation and articulation. Vocalization production might also be necessary in order to train internal feedback. Auditory internal feedback might be necessary in order to learn how to attune speech perception and one's own speech productions. Also proprioceptic, kinesthetic and tactile internal feedback probably needs to be trained. Infants learn how to move and to position their speech organs and to combine this with the tactile feeling of the position of the speech organs. If infants lack the possibility to vocalize within the first year, it results in serious phonological delays at a later age as suggested by studies of tracheostomatized infants (Locke and Pearson, 1990; Kamen and Watson, 1991; Kertoy, Guest, Quart and Lieh-Lai, 1999, see also Chapter 3.2.3). These studies indicate the importance of the possibility to exercise the speech organs by vocalizing in order to develop a normal phonological and phonetic system later. From this perspective it can be expected that the vocalization development is very important for several aspects of the infant's speech and language development.

A quite different explanation for infant vocalizations might be the (probably unintentional) expression of (pleasant or unpleasant) feelings, especially during the first months of life. We expect also that vocalizations play an important role in parent-infant interaction. An infant may vocalize in order to attract and keep the attention of his[4] parent. Also vocalizations may have an important effect on the emotional bonding between infants and parents (Papoušek and Papoušek, 1992; Perry, 2004). Since vocalizations are thus probably of great importance for the development of a child, it is important to know what factors might influence vocalization development.

It is also interesting to know why infants vocalize the way they do. The insights into the continuity between vocalizations and later speech and language development have led to more interest and research in this area from several researchers worldwide. These studies have resulted in several models for infant vocalization development, especially with respect to babbling (e.g. Oller, 1980; Stark; 1980; Netsell; 1981; Koopmans–van Beinum and van der Stelt, 1986, 1998; Roug, Landberg and Lundberg, 1989; Locke, 1993; MacNeilage, 1989; MacNeilage and Davis, 1990, 2000, 2001). From most of these studies we know that all NH infants seem to go through certain stages, such as cooing and babbling (see also Chapter

[4] In this thesis in case of infants: *he* stands for both male and female.

3.1). It is not clear, however, why these particular stages occur, but it is likely that the onset of these stages is influenced by several aspects.

In the literature several of these aspects have been discussed. For instance, some studies focus on the impact of the motor development, such as anatomy and neurology, on vocalization development (e.g. MacNeilage and Davis, 2001), while others focus on the influence of hearing (e.g. Oller, 1980, 2000; Oller, Eilers, Bull and Carney, 1985; Oller and Eilers, 1988; Locke and Pearson, 1990). Other examples of such factors are cognition, internal feedback, parent-infant interaction, speech and language input and auditory speech and language processing. The influence of these factors on the vocalization development will be discussed in Chapter 3.2 based on previous literature.

Thus far, not much work has been done on the influence of these factors on different vocalization stages. This thesis focuses on the influence of hearing on all vocalization stages of infants within the first year of life. Also the influence of hearing in interaction with other factors will be discussed. The influence of hearing will be investigated by studying the vocalization development of HI infants compared to NH infants.

1.2 Hearing as a factor influencing vocalization development

It is not exactly clear what the influence of hearing is on early speech and language development (also in interaction with other influencing factors) and from what age onwards. The spoken language delay of HI children after the first year has been described by a number of investigators. Clear difficulties in lexicon, syntax and phonology have been noted (e.g. Hadadian and Rose, 1991; Moores, 1987; Schirmer, 1985; Suty, 1986; see also Bishop and Mogford (1993) for a review on this topic). It is not clear, however, from what age onwards a lack of hearing starts to influence the speech and language development. Assuming that vocalization development is related to later speech and language development, we might expect that lack of hearing influences vocalization development already within the first year of life.

In the present study our main research question is: how exactly and from what age onwards does hearing affect vocalization development? To answer this question we studied the vocalization development in HI and NH children. So far, not much work has been done on the speech production of deaf infants (that is before the age of twelve months) and none of the previous studies have been performed systematically. The present study should fill this gap. If we find abnormal vocalization development in HI infants, this will have both theoretical and practical implications for the early speech and spoken language development of HI children.

This study will only deal with vocalizations in the spoken modality. It is clear that the language development of HI infants can also be studied with respect to the visual-spatial modality, that is signing. The signing of hearing impaired infants within the first year of life has become a topic of growing interest over the last decade. Several studies have reported that deaf infants 'babble' with their hands by producing repetitive movements (Petitto and Marentette, 1990, 1991; Masataka, 2000, 2001; Takei, 2001). Meier and Willerman (1995), however, have suggested that not only HI infants but also NH infants produce these manual babbles and also several other studies showed a peak in other rhythmic activities in the same age period (Thelen, 1981, 1991; Ejiri, 1998). In our study we have not looked at any signed utterances, since our focus was on the sound utterances of hearing impaired infants in order to explore the influence of hearing in this area.

1.3 Overview of this thesis

In Chapter 2 we will describe several aspects of hearing impairment in children, including detection and intervention[5]. In Chapter 3 we will describe the early speech development in NH and HI infants, such as the stages in vocalization development. We will discuss three stage models and propose a fourth model that includes hearing as one of the factors that can influence the stages of vocalization development. Also in Chapter 3 we formulate the research questions of the present study. In Chapter 4 the research methodology will be discussed, including the description of the six HI and six matched NH infants, and the description of the recording sessions.

Chapter 5 will describe the number of spoken utterances of the NH infants and the HI infants and of their hearing mothers. Chapter 6 describes the utterance duration and fundamental frequency for NH and HI infants. In Chapter 7 we describe the types of utterances that can be possibly related to the developmental stages of NH infants, such as cooing and babbling. Also the number of syllables and the syllable structures of the infant utterances will be described here. In Chapter 8 place and manner of articulation of the utterances with articulation (consonant-like) movements are established for the NH and HI subjects. Place and manner of the babbled utterances (mainly of NH infants) will be discussed specifically. Furthermore, the number of different place/manner categories will be described for all subjects. Finally in Chapter 9 the parameters described above are related to each other, combined with final conclusions. Also practical implications of this study and suggestions for further research will be discussed.

[5] Since the study is carried out with Dutch subjects only the Dutch situation will be described here.

Chapter 2

Hearing impairment in young children[1]

This thesis deals with the effect of hearing impairment on early speech. We know that in normally hearing children the development of auditory perception already starts before birth. A severe hearing impairment has therefore effect from that time on. Hearing impaired infants also vary in their access to auditory information and how they can function in a spoken language. In this chapter classification and prevalence of hearing impairment in children will be discussed (2.1), followed by causes of hearing impairment in infancy (2.2). Also, the possibilities of early detection of hearing loss will be discussed (2.3) followed by the intervention possibilities in the Netherlands (2.4).

2.1 Classification and prevalence of hearing impairment in children

The most common way of measuring and then classifying hearing losses is by expressing the hearing loss in dB. Normally the Pure Tone Average (PTA; the average hearing loss of 500, 1000, and 2000 Hz in the best ear) is used as a basis for these classifications. In different countries, the term "deafness" refers to a different level of dB loss. In Europe usually losses under 90 dB are classified as (mild to severe) hearing impairment and losses over 90 dB are classified as very severe hearing impairment or deafness (see Table 2.1). For enrolment in intervention programs for the deaf a criterion of a loss of 80 dB or more is recommended by the Commission Sign Language of the Netherlands ('Meer dan een gebaar', 1997). In the United States, however, a different classification is used (Bess and McConnell, 1981; see Table 2.1).

Hearing loss	USA	Hearing loss	Europe
26-40 dB	mild hearing impairment	0-30 dB	mild hearing impairment
41-55 dB	moderate hearing impairment	30-60 dB	moderate hearing impairment
56-70 dB	moderate-severe hearing impairment	60-90 dB	severe hearing impairment
71-90 or 95 dB	Severe deafness		
≥ 96 dB	profound deafness	≥ 80 or 90 dB	deafness

Table 2.1. Overview of classification of hearing loss in the USA and in Europe.

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1 Substantially revised version of earlier publication: Clement and Den Os (1993) (section 2.3.2).

The classification in the USA shows that the term deafness is used for hearing losses of 71 dB or more, in contrast with Europe (≥80 or 90 dB). This difference has contributed to confusion about the interpretation of the literature on the speech production of deaf infants. Interpreting and comparing results is even more difficult since often no specification of the exact loss is given or the way the hearing loss was measured. A hearing loss measured with pure tone audiometry and expressed in dB gives an indication of the loss. However, it does not indicate whether the person functions, or can be expected to function, within the hearing society or not. The issues of detection and intervention will be discussed later in 2.3 and 2.4. In this thesis the term 'hearing impaired' is used for all types of losses, since it is not relevant to strictly distinguish the varying degrees in this study. If the term 'deaf' is used, it refers to losses over 90 dB.

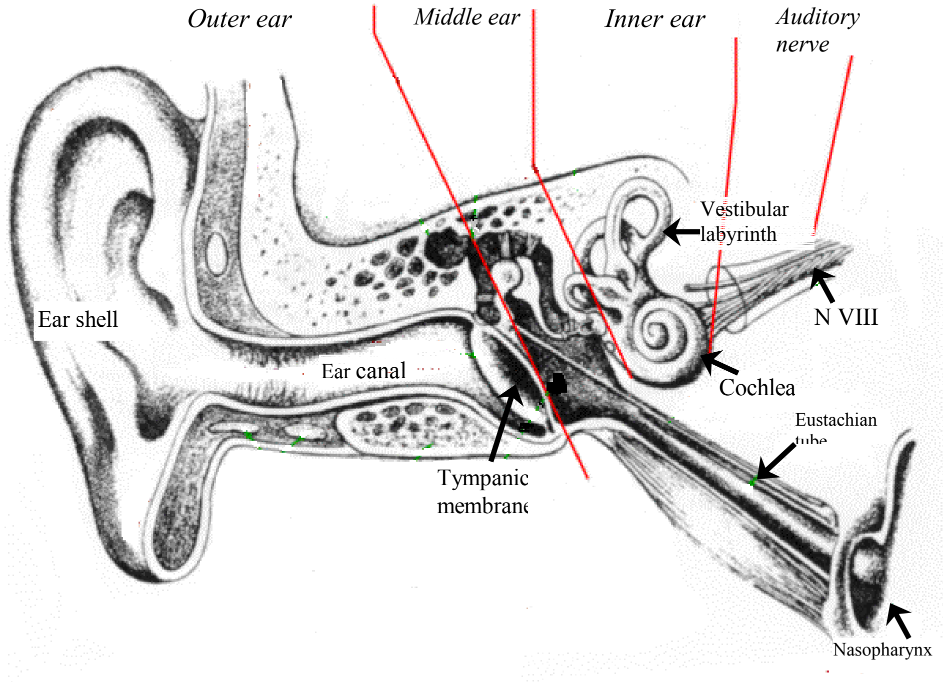

Figure 2.1. Anatomy of the outer, middle, inner ear and N VIII. Adjusted figure retrieved from internet (2004), http://www.audiologieboek.nl/niveau2/hfd3/indexn2h3.htm.

A different type of classification of hearing loss is based on the anatomical location of the impairment. The auditory system consists of the outer ear, middle ear, inner ear and the neural pathway. The outer and middle ear form together the conductive part; the inner ear forms the receptive part and the neural pathway transports neural information. A short overview of the anatomical characteristics of each of the four parts follows is shown in Figure 2.1. There are two main groups of hearing impairment based on the anatomical location of the impairment. The term 'conductive hearing impairment' is used for hearing loss due to conditions affecting the external or middle ear. The term 'sensorineural hearing impairment' is applied to hearing loss, due to conditions affecting the cochlea and the 8th cranial nerve (Nervus Acusticus – Nervus VIII) up to auditory cortex (Bamford and Saunders, 1985).

The outer ear is formed by the ear shell and the external ear canal (see Figure 2.1). The funnel shape of the ear shell helps the sound to enter the canal. Also, it plays a role in the location of sounds. Damage to the ear shell and external ear canal can lead to hearing loss but this is usually minimal.

The tympanic membrane or eardrum separates the ear canal from the middle ear. The middle ear contains a chain of three ossicles: the malleus, incus and stapes, connecting the tympanic membrane with the inner ear. The shape of the middle ear plays an important role in the amplification of the sound at certain frequencies (maximum about 20 dB). Problems with the formation of the ossicles can lead to a hearing loss around 30 dB.

The middle ear is air-filled and vented by the Eustachian tube, which connects the middle ear and the nasopharynx (see Figure 2.1). By swallowing and yawning the tube opens and creates equal air pressure in the middle ear and outer ear, via the air pressure in the upper pharynx. The malfunctioning of the Eustachian tube plays an important role in the onset of middle ear infections. The Eustachian tube of infants is short and nearly horizontal compared to the tube of adults. Therefore, infected material from the sinuses, throat, or upper respiratory tract can quite easily enter the middle ear and often causes Otitis Media (Perkins, 1986). A frequent occurrence of middle ear infections results in a glue-like liquid in the middle ear space. This causes the middle ear bones and tympanic membrane to vibrate less, leading to losses of around 20 dB. This, Otitis Media with Effusion (OME), is the most frequently occurring type of hearing loss in children. Studies carried out on preschool children suggest that a conductive loss due to Otitis Media is very common in children younger than two years of age and probably occurs most frequently between six and ten months of age (Task Force, 1978; Anteunis and Engel, 2000). Estimates have been made of a prevalence rate of even 50 to 60 percent within the first year of life (Anteunis and Engel, 2000; Klein, 1978). It can be seen from the above that problems with the outer and middle ear lead to relatively small hearing losses. It also should be noted that Otitis Media causes temporarily hearing losses, whereas sensorineural loss is usually permanent.

The cochlea[2] looks like a snail's shell (see Figure 2.1 and 2.2). It has two and a half turns and is divided into three channels, the so-called scalae (see Figure 2.3).

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[2] Note that in Europe the term 'inner ear' includes the cochlea only, while in the USA the term 'inner ear' also includes the vestibular labyrinth.

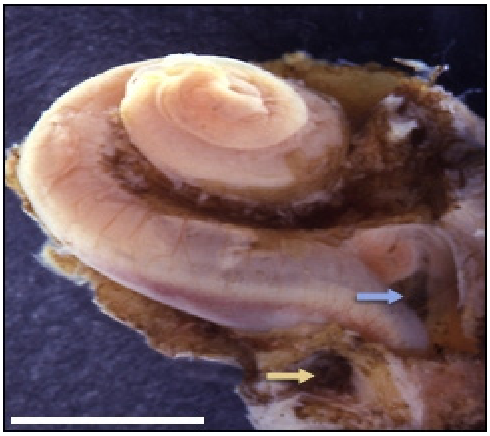

Figure 2.2. Cochlea of a human foetus of 5 months of gestation. Retreived from internet (2004) http://www.iurc.montp.inserm.fr/cric/audition/fran%E7ais/cochlea/fcochlea.htm

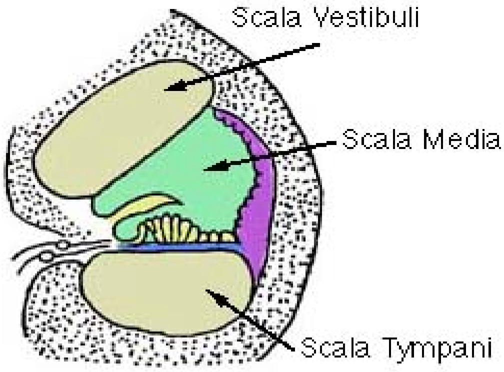

Figure 2.3. Cross section of the cochlea. Retreived from internet (Hoversland, 1996).

The anatomical structure in the scala mediais is called the organ of Corti (see Figure 2.4). It contains the auditory sensory cells (the ‘hair cells’), supporting cells and the peripheric endings of the auditory nerve, the Nervus Acusticus. The 3000 inner hair cells and 12000 outer hair cells are connected to the fibres of the VIII cranial nerve. On the upper side, the cilia, hair-like outgrowths of the hair cells, touch the tectorial membrane. The anatomical and mechanical characteristics of the basilar membrane make the organ of Corti able to carry out a frequency analysis, resulting in a maximum sensitivity of each place for a certain frequency. At the base the basilar membrane is sensitive to higher frequencies and to lower frequencies at the apex. The movement of the cilia is thought to be the effective stimulus for auditory sensation (e.g. Glattke, 1973).

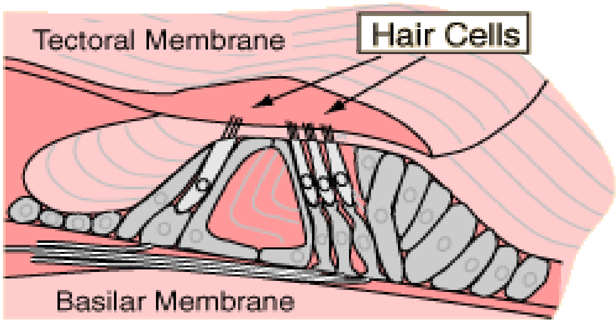

Figure 2.4. Organ of Corti (http://hyperphysics.phy-astr.gsu.edu/hbase/sound/corti.html#c2)

Hair cells may be damaged by disease (e.g. meningitis), as a result of genetic defects or by external factors such as noise or ototoxic drugs. This is called 'inner ear lesion'. A sensorineural hearing loss can also be caused by a lesion (for instance as a result of a tumor) in the retrocochlear part of the auditory system, that is in the part that contains the VIII cranial nerve and the auditory cortex (the part of the system processing auditory information). The losses caused by a sensorineural defect can vary from a slight loss to total deafness. Middle ear problems do not lead to a hearing loss more than 30 dB, which means that such a severe loss always has a sensorineural origin.

A combination of a sensorineural and conductive hearing loss is also possible. A child with a sensorineural hearing loss might also have a conductive hearing loss, due to the large rates of conductive hearing losses in the first year of life (Klein, 1978; Anteunis and Engel, 2000). For infants with sensorineural hearing loss the impact of otitis media with effusion (OME) is greater than for infants with normal cochlear function and prompt treatment is indicated in those cases (Joint Committee on Infant Hearing, Position Statement, 2000).

The ear is anatomically fully developed already before birth. The outer and middle ear start to develop in the fourth week of gestation. Already at three months of gestation the outer ear is anatomically fully developed (although the outer ear reaches adult size when the child is about eight years old). The middle ear is already fully developed in the tenth week of gestation and in the period around birth (37-40 weeks) it reaches the adult size (Rubel, 1984). The cochlea reaches its full size already by five months of gestation and is one of the few organs with adult size before birth (Rubel, 1984; see also Figure 2.2). In section 2.2 some factors possibly disturbing this prenatal development of the ear and possibly causing hearing impairment, are discussed.

Moreover, from this description of the early anatomical development we can expect that auditory perception starts already prenatally in NH infants. The development of early speech and language processing before and after birth in NH infants will be discussed in Chapter 3.2.1.

In the Netherlands the estimated prevalence rate of deafness is estimated on 0.46 per 1000 children (Breed and Swaans-Joha, 1986). Lamoré and Vermeulen (2002) estimated that approximately 169 infants are born every year with a hearing loss of at least 50 dB and that around 40% of these infants have a hearing loss over 100 dB. Therefore it is estimated that around 68 infants with a hearing loss over 100 dB are born in The Netherlands every year.

2.2 Causes of hearing impairment in infancy

Hearing impairment in infancy can be caused by extrinsic factors or genetic defects. The extrinsic factors are different at different stages of the infants' development:

- prenatal influence: viral infections such as rubella or flu during pregnancy of the mother, certain medicines during pregnancy, pregnancy poisoning, bleeding during the pregnancy, drug abuse by the mother
- perinatal influence: lack of oxygen during the delivery, a low birth weight, premature delivery
- postnatal influence: meningitis, viral infections, use of certain medicines

Hearing impairment can also be caused by genetic defects. Many of these genetically caused hearing impairments are recessive and occur only in one child or his siblings and not in their parents. Ninety percent of HI infants are born to hearing parents and in such cases the hearing impairment of the child is often totally unexpected for the parents. Some of these infants have a syndrome (e.g. Pendred, Waardenburg, or Usher) that causes both hearing impairment and additional disorders.

Hearing loss can be either isolated or combined with disorders that also might influence the communication development. In the USA the estimation is that in 60 to 70 percent of the children the hearing loss is isolated. Thus, 30 to 40 percent of children with hearing loss have additional disabilities, which may have concomitant effects on communication and related development (Gallaudet University Center for Assessment and Demographic Study, 1998; Schildroth and Hotto, 1993). Also in The Netherlands it is estimated that over one third of the children enrolled in early intervention programs has additional disabilities. Such additional disabilities may have an effect on communication and related development and may complicate the early intervention (Lamoré and Vermeulen, 2002; see also Section 2.4).

2.3 Early detection of hearing impairment

2.3.1 Goals of early detection and early intervention

The National Institutes of Health (1993) and the Bright futures guidelines (Green, 1994) recommend universal screening of all infants before age 3 months (see also 2.4 for more information about early intervention). Early detection and early intervention have a very important influence on several aspects of the child's development. Early-identified children have better speech intelligibility (Apuzzo and

Yoshinago-Itano, 1995), better language development (Yoshinaga-Itano, Sedey, Coulter and Mehl, 1998;Yoshinaga-Itano, Coulter and Thomson, 2000), better social-emotional development and their parents have better attachment (Yoshinaga-Itano, 2002). According to Arehart and Yoshinaga-Itano (1999) identification of hearing loss in the first months of life, followed by intervention by the age of six months, probably results in better language development.

The concept of “critical period” or “sensitive period” is the basis for the view that early detection and the subsequent early intervention have a positive influence on the development of hearing and in turn on the development of spoken language. It is generally accepted that during the first years of the infant's life the development of the neural system and the myelinization process of the nerve depends on stimulation. When the nerves myelinizes, the speed with which a neural signal can be transported will increase considerably. It has been argued that, although the fine tuning of the auditory neural system continues throughout childhood and adolescence, a great deal of the neural development of the auditory system is completed during the first year (Boothroyd, 1997; Ponton, Eggermont, Kwong and Don, 2000; Moore, 2002; see also 3.2.2). It was stated that the myelinization of the neural pathways from brainstem to the auditory cortex is complete at the age of five years, but the myelinization of the auditory nerve and brainstem is already completed at the age of six months of age (Boothroyd, 1997; Moore, 2002).

It has been suggested by several researchers (e.g. Paradise, 1981; Neville and Bavelier, 2002) that the critical period for the development of the auditory system falls within the first years of life. If the infant is not exposed to sounds within this period, the auditory nerves and auditory cortex will not be (sufficiently) stimulated. The result might be auditory deprivation, even leading to atrophy of the auditory system (Paradise, 1981; Neville and Bavelier, 2002). This will cause speech and language problems at later ages. Several types of investigations have supported this view: animal experiments (e.g. Iyengar and Bottjer, 2002; Wu, Lecain, Chiappini, Yang and Huy, 2003), evoked potential registrations (e.g. Ponton and Eggermont, 2001; Eggermont and Ponton, 2003), evaluations of Cochlear Implant use (e.g. Ponton, Moore and Eggermont, 1999) and OME studies (Anteunis and Engel, 2000). In a recent study, this concept was confirmed. Anteunis and Engel (2000) found longer auditory brainstem latencies (the time a neural signal uses for reaching the auditory brainstem) in children with hearing losses or OME during the first two years of life. They concluded that even a relatively small hearing loss significantly influenced the maturation of the auditory brainstem. This implies that greater losses will influence the maturation of the auditory paths to an even greater extent. Evidence for the critical period can also be found in studies of Cochlear Implants (CI) in deaf infants. Deaf children who received Cochlear Implants at an early age, before 18 months of age, were found to have better spoken language development (Novak, Firszt, Rotz, Hammes, Reeder and Willis, 2000; Hammes, Novak, Rotz, Willis and Edmondson, 2002), although also two or three years of age was mentioned as upper limit (Hassanzadeh, Farhadi, Daneshi and Emamdjomeh, 2002;

Baumgartner, Pok, Egelierler, Franz, Gstoettner and Hamzavi, 2002; see also 2.4 for more information about CI). Also, a limit of 30 months was mentioned in another study in which was found that the probability of transition from manual to oral communication significantly diminished if the CI was placed after that age (Hammes et al., 2002). These studies indicate a critical period for auditory development in children.

In an animal study with fetal sheep, three sheep were deafened, received CI and were stimulated by sounds, three sheep were not stimulated by sounds, and four control sheep had normal hearing. It was found that in the deafened and under-stimulated sheep metabolic changes in the central auditory system took place already within a week, which was not the case in the sheep which were stimulated after receiving the CI (Antonelli, Gerhardt, Abrams and Huang, 2002). This finding suggest that auditory deprivation takes place within a short period, and also starts before birth, anyway in animals. Eggermont and Ponton (2003) found deviating evoked-potential measurements in children with CI who were deaf for at least three years below six years of life. They concluded that the upper layers of the auditory cortex could not fully mature even after placing CI, suggesting a critical period for auditory development.

Thus it seems that auditory stimulation at early age is critical for the development of the auditory system and subsequently for spoken language development. Therefore early detection methods for hearing impairment are necessary.

2.3.2 Screening methods and audiometry in infants

It is only ten years ago that the average age of fitting the hearing aids, in losses over 80 dB, was 25 months in the United States and in the Netherlands (Mace, Wallace, Whan and Stelmachowicz, 1991; Snik, Admiraal and Van den Broek, 1992). In a relatively short period a great deal of work has been done on the development of early detection methods worldwide. The results are very promising. For instance, in the state of Colorado the average age of identifying a congenital loss is 2 months of age at this moment (Yoshinaga-Itano, 2002). At present several methods are available for detecting a hearing problem within the first year of life. These early detection methods can be divided into three groups; screening, behavioural (or subjective) hearing tests and objective or electro-audiometry.

A first step in detecting hearing loss can be a screening method. An auditory screening method is a quick test with the aim to trace hearing impaired children. When hearing impairment in a child is suspected, other hearing tests will usually be applied to confirm the hearing loss and to establish the hearing threshold. Conditional audiometry, such as tone audiometry (the child listens to beeps and responses with, for instance, pressing a button), cannot be used for children at this early age.

Screening can be used on all new born infants, for example in a health center. Often a behavioural hearing test is used as screening, but nowadays also more objective forms of audiometry are available. Behavioural audiometry during the first months of life is based on behavioural responses of normal hearing infants to sounds. For instance, at sounds of approximately 90 dB the auropalpebral reflex occurs. This is a quick closing of the eyes or a tightening of the already closed lids. Also, arousal from sleep can be expected at noises of approximately 75 dB. After the first months these responses may be inhibited (Mencher, Davis, DeVoe, Beresford and Bamford, 2001).

From the age of three to four months, rudimentary localization reflexes to relatively loud sounds can be observed. The term 'localization response' means that the child looks in the direction of the source of sound by turning its head. At 9 to 13 months a direct localization of sounds at 25-35 dB is possible (Northern and Downs, 1984). The test method based on this response is called the Ewing test (Ewing and Ewing, 1944). During the test the child sits on his parent's lap and his visual attention is attracted by a person in front of him, while another person produces sound stimuli from behind. In the Netherlands another test based on the Ewing test has been developed: the Compact Amsterdam Paedo Audiometric Screening Test (CAPAS). In this screening method, digital sound stimuli and a computerized control of the test protocol are used. The advantage of this method is an exact frequency and intensity definition of the stimuli resulting in higher objectivity (Baart de la Faille, 1990).

Another method of detection is the use of lists of criteria, the so-called high-risk registers. These registers can be used for the detection of infants with a higher risk of hearing impairment, based on factors such as low birth weight and low Apgar score. Riko, Hyde and Alberti (1985) indicate that the high-risk register is a valuable, but imperfect, primary screening tool that should not be the sole early detection method. Feinmesser, Tell and Levi (1982) describe a screening method that combines hearing tests and a set of high-risk criteria. This study indicates that most of the children suffering from severe to profound hearing losses were detected before the age of one year.

To provide a more objective procedure, the Crib-O-Gram or "auditory response cradle" was developed. The Crib-O-Gram is an automatic device that measures the movements of a neonate after exposure to a loud sound. Motion sensitive transducers placed under the mattress in the crib pick up the infant's activity. Fixed quantitative criteria are used to establish the presence of a response (Simmons and Russ, 1974; McFarland, Simmons and Jones, 1980). The detection rate of the Crib-O-Gram is 100% in a well-baby-nursery and 91% in an intensive care unit. One of the disadvantages is the relatively high amount of false positives (i.e. the false detection of a hearing loss): 7% in a well-baby-nursery and 15% in an intensive care unit (MacFarland et al., 1980).

An objective form of hearing screening is the Automated Aditory Brainstem Response Audiometry (AABR). Conventional ABR is an electrophysiological measure of the auditory system's response to sound. A soft click is presented to the ear via earphones or a probe and electrodes record the response as the sound travels from the ear through the auditory nervous system to the brain. To establish the hearing loss, electrodes are placed on the mastoid (the bone behind the auricle) and on the forehead of the infant to measure electric potential activity between these points. The size of the potentials and their latency time are measured. The latter is the time between the start of the stimulus and the response. In normal ears, five response peaks on different latency times can be distinguished, originating in different places in the brain. The strongest peak is the fifth, which originates in the brainstem. To establish the hearing threshold, clicks are presented on several intensity levels. The ABR threshold is defined as the lowest stimulus intensity where the fifth peak can be seen. The ABR is relatively easy and quick to perform because it requires no general anesthesia. This is useful for infants below six months of age, since it can easily be carried out when the infant is asleep. Conventional ABR requires a trained technician or audiologist to perform the evaluation and an audiologist to interpret the screening results.

Automatic ABR (AABR) uses technology similar to conventional ABR. However, the equipment is fully automated and elicits a pass/refer response. There is no visual interpretation required, and is often performed by nurses. The screening level is around 35 dB.

ABR and AABR have some disadvantages. The usual stimulus is a click; and since a click stimulus contains broad spectral information, it will not provide frequency-specific measurements. The ABR responses correlate most closely with frequencies around the 3 kHz area, low frequency hearing losses are missed (Van der Drift, Van Zanten and Brocaar, 1989; Riko et al., 1985). Because frequency-specific information is necessary for fitting of hearing aids, additional tests must be used.

Another objective form of hearing screening is the OtoAcoustic Emmissions (OAE) measurements, first described by Kemp (1978). The OAE's are generated by the motile activity of the unimpaired outer hair cells. When an inner ear is exposed to sound, the hair cells themselves produce a tiny sound. This sound is recorded and measured by the computer. An ear with a hearing loss exceeding 15-40 dB shows no OAE's according to Kemp. Evoked OAE can be divided into several subclasses. The types most often used are the Transient Evoked Otoacoustic Emissions (TEOAE) measurements and Distortion Product Otoacoustic Emissions (DPOAE) measurements. In the TEOAE method the transmitter sends out a series of click sounds. In the DPOAE method simultaneously applied two-tone stimuli are applied. These two-tone stimuli (f1 & f2, where f2 is the higher frequency) evoke a third tone at a lower frequency (2f1 - f2). This response tone can be measured, after amplification and spectral analysis. In principle all OAE tests are performed in the same way. The infant lies quietly, and a small tube with a little microphone is inserted in one ear. Within a few minutes the result is known. Automated OAE technology is now available for both TEOAE and DPOAE (Thomson and Colorado Infant Hearing Advisory Board, 2000).

The use of click evoked OAE as a screening method has been evaluated at several settings and the results are promising. For example, Stevens Webb, Hutchinson, Conell, Smith and Buffin (1990) tested 723 neonates admitted to a NICU (neonatal intensive care unit) by using OAE and ABR. The ratio OAE results / ABR results gives a sensitivity of 93%. The mean test time for the OAE was only 12 minutes. Bonfils, Uziel and Pujol (1988) and Bonfils, Avan, Francois, Marie, Trotoux and Narcy, 1990) have compared results obtained with OAE with those of behavioral audiometry in 100 ears of infants. The false positive rate was lower than 2 %. These results suggest that the OAE screening method can be considered as the primary screening method (Stevens et al., 1990). The disadvantage is the non-frequency specificity, due to the use of clicks as discussed above. Because of the use of continuous stimuli the DPOAE method has the ability to be frequency specific and is probably the most promising screening method (Lonsbury-Martin and Martin, 1990) (see Table 2.2). In the Netherlands several studies have been performed in order to develop a screening method for neonates. In this screening there are three stages: twice a TEOAE screening and if failing a third TEOAE screening combined with an AABR screening. July 2005 almost all newborns in the Netherlands will be screened by this method (Kauffman-de Boer, De Ridder-Sluiter, Schuitema, Uilenburg, Vinks Van der Ploeg, Lanting, Oudshoorn and Verkerk, 2001).

Also the Electrocochleography (ECoG) method is based on the measurement of compound action potentials. The ECoG provides frequency specific information, since tone pulses are used as stimuli. An electrode is placed on the promontorium on the cochlea using a long needle, stuck through the tympanic membrane. The registered potentials are relatively high, because the electrode is placed closely to the generator of the responses (the nerve endings). The stronger potential makes the measurements of separate frequencies possible. Compared to the ABR, the ECoG is more invasive, because the infant requires some general anaesthesia.

Table 2.2. Overview of the most common methods for early detection of hearing impairment.

Method	**Main advantage**	**Main disadvantage**
Observation	Easily applicable	Only severe losses, moderate reliability
Crib-O-Gram	High detection rate	High amount of false positives
Ewing	Easily applicable	Only reliable from 9 to 13 months
CAPAS	Exact frequency and intensity of the stimuli is controlled	Only reliable from 9 to 13 months
AABR	Reliable	No frequency specific information
TEOAE	Easily and quickly applicable, reliable	No frequency specific information
DPOAE	Easily and quickly applicable, frequency specific information	The reliability is not completely known yet (however promising)
ECoG	Frequency specific information	Some general anaesthesia is necessary

2.4 Early intervention[3]

The advantage of early intervention (or education) is shown by several studies (e.g. Watkins, 1987, Yoshinaga-Itano et al., 1998; Yoshinago-Itano, 2002; see also section 2.3.1). Optimal intervention strategies for the infant with any hearing loss require that intervention begins as soon as there is confirmation of a permanent hearing loss to enhance the child's acquisition of developmentally appropriate language skills (Joint Committee on Infant Hearing, Position Statement, 2000). It is beyond the scope of this thesis to describe all programs used. In the following sections only the early intervention for severely hearing impaired infants and young children in The Netherlands will be described, since this is relevant background information for this study.

After a severe hearing impairment has been diagnosed in an infant at an Audiology Centre, a team of professionals from one of the seven early intervention teams in The Netherlands becomes involved. Five of these early intervention teams are related to the Institutes for the Deaf in The Netherlands[4] and two teams[5] are a collaboration of several regional Audiology Centres.

The audiologist takes care of the early fitting of hearing aids or cochlear implants. The speech/language therapist is involved in the program for language and communication development, if possible already during the first year of life. Often a linguist or speech/language pathologist is involved. Social workers may also play an important role in the intervention program, as well as psychologists and pedagogues. The early intervention is as much as possible adjusted to the individual infant and his parents. In almost all hearing impaired infants, however, intervention involves fitting cochlear implants or hearing aids, early communication, speech and language assessment and auditory stimulation.

Early fitting of hearing aids is one of the main goals of early detection and intervention. Most infants and children with bilateral hearing loss benefit from some form of personal amplification or sensory device (Pediatric Working Group of the Conference on Amplification for Children with Auditory Deficits, 1996). Delay between confirmation of the hearing loss and amplification should be minimized (Arehart, Yoshinaga-Itano, Thomson, Gabbard and Stredler Brown, 1998). Early use of hearing aids apparently has a large positive influence on the perception of sounds and of speech (Hoekstra, 1986). For the fitting of hearing aids the results of objective audiometry and behavioral audiologic assessments are combined (Joint committee on infant hearing, position statement, 2000). However, it is not that easy to know to what extent the infant is able to make use of its residual hearing. After

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[3] The information in this section is partly based on interviews with H. de Ridder (NSDSK), M. van Ommen (Effatha/Guyot), M. Dirksen (Effatha/Guyot), Viataal (Lieke de Leuw) and several speech and language pathologists (e.g. M. Stark and M. Eng, Stichting Gezinsbegeleiding Zuid-Oost Nederland).

[4] The Effatha/Guyot group (Voorburg and Haren), Nederlandse Stichting voor het Dove en Slechthorende Kind (Amsterdam), Royal Auris-group (Rotterdam) and Viataal (Sint Michielsgestel).

[5] Stichting Gezinsbegeleiding Midden-Oost Nederland and Stichting Gezinsbegeleiding Zuid-Oost Nederland.

approximately two years of age the child can be tested with tone audiometry and headphones ; this helps to make the fitting more precise. Within the first year the behavior of the infant needs to be observed carefully to establish the effect of the hearing aids. If the fitting takes place very early, the child gets either the so-called body-worn hearing aid, or the behind-the-ear model. The body-worn model has the microphone located at the front of the box. The child can wear it around the neck, or it can be put in the infant's crib or play pen. The sound is amplified in the aid and is conducted via two cords to the earphones. The advantage of the body-worn model is that it can amplify up to a very high level and it is probably more comfortable for a very small infant than the behind-the-ear model. The disadvantage is that the sound is picked up by the microphone at one location and conducted to both ears, making it impossible for the infant to develop sound localization, one of the basic auditory functions. The behind-the-ear-hearing aids have the microphone and amplification in the hearing aids itself, which makes the sound localization possible. With both models the ear mould has to be adjusted every couple of months because of the growth of the ear canal. This is important especially in case of the behind-the-ear model, because sound leakage (resulting in a loud interfering high tone), disturbs the infant's perception probably even more.

A relatively new method for early intervention, Cochlear Implantation (CI), is normally applied in children older than twelve months, since medical complications due to anesthesia are eight times higher in infants under twelve months compared to older children (Young, 2002). Deaf children who received Cochlear Implants at early age were found to have a better spoken language development (Yoshinaga-Itano et al., 1998; Downs and Yoshinaga-Itano, 1999; Hammes et al., 2002, Novak et al., 2000; Ertmer and Mellon, 2001, see also 2.3.1), although much individual variation is found as well (Health council of the Netherlands Advise-report, 2001). In the study of Richter, Eissele, Laszig and Lohle (2002) improvements of both speech perception and production was found in children after two years of CI use, although they mention that some of the children with CI at early age showed unsatisfactory speech development. A combination of cochlear implantation at a young age, family support and regular intervention seems to contribute to normal speech and language development (Ertmer and Mellon, 2001). However, it seems that infants with CI show less overall attention to speech sounds than NH infants, which may have an impact on the speech perception and speech and language development (Houston, Pisoni, Kirk, Ying and Miyamoto, 2003). Thus, communication training and hearing training seem to be a necessity after placing CI in infants. At this moment several studies are carried out with respect to the speech and language development of children with CI at early age in the Netherlands (e.g. UMC St. Radboud Nijmegen, LUMC, UMCU, NSDSK[6]) and in Belgium (University of Antwerp and The Ear Group[7]).

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[6] LUMC=Leids Universitair Medisch Centrum, UMCU= Universitair Medisch Centrum Utrecht, NSDSK=Nederlandse Stichting voor het Dove en Slechthorende Kind.

[7] Antwerp-Deurne

Few studies are performed on vocalizations of children with CI. It seems that babbling starts on average a few months after the implantation (Moore and Bass-Ringdahl, 2002). The nine HI infants with CI studied by Gillis, Schauwers and Govaert (2002) received the CI between 6 and 18 months. Seven of these HI infants started babbling between 8 and 21 months, only one to three months after activation of the CI. Two other children started babbling in the same period or before the CI was activated. Seven HI infants acquired their first words between 17 months and 26 months of age and two infants did not acquire the first words yet at the time the study was published. Eight infants started signing before the start of their spoken words (Gillis, et al., 2002; Schauwers, Gillis, Daemers, De Beukelaar and Govaerts, 2004).

Language and communication should be stimulated as early as possible. A primary focus of early intervention programs is to support families in developing the communication abilities of their deaf infant (Carney and Moeller, 1998). Early language intervention, independently of the language method chosen, almost always includes training of the primary communication skills such as eye contact, turn taking, joint reference, etc.

Since early screening methods identify hearing impairment at very early ages nowadays (see 2.3.2) parents might be confronted with a choice as to what kind of input to offer their child when it is only a few months old. The decision will be influenced by several factors, such as the choice of auditory habilitation (for instance CI or not), residual hearing, and the hearing status of the parents or siblings of the infant. Basically the choice is between spoken language only (Oral Method), sign supported speech (Total Communication), a full sign language (Sign Language of the Netherlands) or bilingual input (combination of spoken Dutch and Sign Language of the Netherlands). In the Oral method only speech and lip reading are used. Total Communication (TC) is the communication method that stimulates communication with the child using any method, such as signing, lip reading, sound gestures, facial expression, and so on. An important part of TC is 'Dutch supported by signing', which means that the person speaks Dutch and uses signs simultaneously, but following the grammar of spoken Dutch. Sign Language of the Netherlands (SLN) is the language used by Dutch deaf people and has a different grammar compared to Dutch. Increasingly advice is given to parents to provide bilingual input (e.g. National Association of the Deaf, 1994; Preisler, 1999), although the opinion differs on the moment at which spoken language should be introduced. All seven early intervention teams in the Netherlands provide bilingual educational programs nowadays.

Auditory training is also a part of most intervention programs, because the residual hearing (including the internal auditory feedback) needs to be stimulated within the critical period, even if it is not yet known whether the hearing impaired child has usable residual hearing. Also after the fitting of hearing aids or cochlear implant, the infant still needs to get auditory training to be able to make optimal use of them. An initial part of the training is to make the infant more aware of sounds, and of the meaning of sounds, such as warning signals. Also localization of sounds, by using both ears, and head phone training can be part of the training. Few pc-programs for auditory stimulation are available, such as the 'Interactieve Hoortraining' for older children. Training of detection of sounds, discrimination between sounds, identification of sounds, speech recognition and understanding of speech and language are important building blocks of this auditory training (Van Hedel and Coninx, 1995).

Speech training can be a part of early intervention programs as well. It starts by showing the infant the positive effect of producing sounds. At a later stage the intervention focuses more on the infants' control over their own voice and articulation. The development of phonation and articulatory coordination and the internal feedback (e.g. proprioceptive, kinesthetic and tactile, see also Chapter 3.2.3) can be stimulated with help of visual feedback, such as a mirror, toys with visual feedback or with computer programs such as the Visual Speech Apparatus in older children (Povel and Arends, 1993; Öster, 1996).

A complicating factor for intervention is that a large number of children with hearing loss have additional disabilities that may have an effect on communication and on related development (Lamoré and Vermeulen, 2002; see also Section 2.2). For hearing impaired children in the USA even thirty to forty percent is mentioned (Gallaudet University Center for Assessment and Demographic Study, 1998; Schildroth and Hotto, 1993). These additional disabilities influence the type of intervention and make interdisciplinary assessment even more necessary (Cherow, Dickman and Epstein, 1999).

To conclude: early intervention programs for HI infants include assessment of communication, language and speech development. If possible, assessment and stimulation of the communication, language and speech development, including vocalizations, starts already within the first year of life. In the next chapter the early speech development of NH and HI infants will be discussed based on results of previous studies.

Chapter 3

Early speech development in normally hearing and hearing impaired infants

In this chapter the early speech development of normally hearing infants, and to a lesser extent that of hearing impaired infants, is described. The influence of factors such as parent-infant interaction, language input, auditory speech processing, neurology, and anatomy/physiology on the normal development of vocalizations is described, and the influence of hearing on these factors. The results of previous studies on the vocalizations of hearing impaired infants are presented, followed by the questions the present study will try to answer.

3.1 Stages in early speech production in hearing infants

There are a small number of studies which have described stages in the process of normal speech development within the first year of life, e.g. Oller (1980); Stark (1980); Mowrer (1980); Koopmans-van Beinum and Van der Stelt (1986, 1998); and Roug, Landberg, and Lundberg (1989). Three of these studies are frequently referred to in the literature and will be described here in further detail (Oller, 1980; Stark, 1980; Koopmans-van Beinum and Van der Stelt, 1986).

Stark (1980) proposed that early speech development can be classified into six stages (see Table 3.1), based on her study of American English infants. Stage I, between birth and 1½ months of age, is characterized by reflexive vocalization. These vocalizations comprise cry and fussing (discomfort) sounds, and vegetative sounds. In Stage II, between 1½ months and 3 months of age, cooing and laughter are typical. These sounds are first produced in pleasurable interaction with an adult or older child. Stage III, the vocal play stage, is between approximately 4 and 7 months of age. It is characterized by playful use of behaviors such as growling, squealing, and yelling, and production of noises by blowing air, food, or saliva through a constriction in the mouth or pharynx, like raspberries (bilabial trills). Stage IV, between 7 and 12 months, is the stage of reduplicated babbling sounds such as [bababa][1] or [dadadada]. The babbling is characterized by series of

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[1] In the present thesis we restrict ourselves mainly to the *vocalizations* or *speech-like* productions of infants. Related to that point, it will be our convention that whenever in this thesis a segment produced by an infant is described, it will not be called a vowel or consonant, but a vowel-like or consonant-like segment. These will be placed between square brackets for example [x]-like in the case of a back trill.

consonant – vowel syllables in which each syllable is produced as similar to every other. In Stage V, the so-called nonreduplicated babbling stage (10 and 14 months) is characterized by the use of different consonants and vowels in consonant – vowel syllables such as [badaga]. A greater variety of stress pattern and intonation contour is found in this type of babbling, giving the impression of adult-like speech; it is also known as 'jargon babbling'. In stage VI the first words are produced. Those early words are used as symbols and refer to specific, recurring sets of objects or events.

Also Oller (1980) studied American English infants. The stages he described overlap partially with the description of Stark. During the 'phonation stage' (0-2 months) infants produce sounds with normal speech-like phonation. These sounds, also called quasi-resonant nuclei (or quasi-vowels) are precursors to fully resonant vowels in later stages. Syllables with both consonants and vowels are rare during this stage. During the 'gooing stage' (2-4 months) sounds are produced which involve both the vowel-like sounds of the previous period and articulated sounds in the back of the vocal cavity. During the 'expansion stage' (4-6 months) infants produce a variety of new sound types, such as raspberries, squeals, growls, yells, whispers, isolated vowel-like sounds, and marginal babbles (precursors of canonical babbles). During the 'canonical stage', well-formed syllables in reduplicated sequences are produced, such as [mamama], [dadada]. Canonical syllables can be identified by phonetically trained listeners as having the following properties:
1) at least one fully resonant nucleus (well-formed vowel)
2) one non-glottal margin (consonant)
3) duration of syllable and formant transitions that fit within the range of mature syllable production
4) normal phonation and pitch range
These 'requirements' are specified acoustically, for instance a peak-to-peak duration between 100 and 500 Hz and a duration of formant transitions between margin and nucleus between 25 and 120 ms (Oller, 1986).

By around 10 to 12 months 'variegated babbling' is produced, whereby different CV units are strung together, as in [gabada] (Oller, 1980).

The term "cooing" or "gooing" is frequently used in infant speech literature, but is surprisingly enough not precisely defined. One possible definition can be that "gooing" (which seems to be an onomatopaeic word) is the production of voiced velar and pharyngeal stops or trills, normally combined with vowels, typically produced around two and three months of age. These productions are presumably the first speech productions in which phonation and articulation movements are combined.

If the same segment is pronounced in a meaningful word by a child, it is called a consonant and is placed between forward slashes according to IPA standards (e.g. /x/).

Koopmans-van Beinum and Van der Stelt (1986), basing their description on phonatory and articulatory movements during one breath unit, proposed six stages within the first year of life of (Dutch) infants. Stage I (birth - 1½ months) is the stage with uninterrupted phonated utterances without articulation movements (i.e. without consonant-like productions). In stage II (from ± 1½ months) interruptions in phonation during one utterance are produced. During stage III (from ± 2½ months) utterances with one articulation movement are produced. In stage IV (from ± 4½ months) variation in the phonation is characteristic, such as squeals, growls, and so on. Fewer articulation movements are produced during this stage compared to stage III. During stage V (from ± 7 months) babbled utterances are produced, e.g. two or more articulation movements are produced during two or more syllables. From stage VI (from ± 12 months) the first words are produced. In another study it was concluded that babbling starts at the average age of 31 weeks (Van der Stelt and Koopmans-van Beinum, 1986).

Part of the speech development of infants is to learn to coordinate the phonatory and articulatory movements, especially needed for babbling as suggested by Koopmans-van Beinum and Van der Stelt (1998) and Koopmans-van Beinum, Clement and Van den Dikkenberg-Pot (2001). Repeated articulatory movements without voicing are seen at the start of the babbling phase, in the so called jaw wags (Meier, McGarvin, Zakia and Willerman, 1997). At the start of the babbling phase, infants might still have some problems with the coordination of the articulation and phonation, resulting in jaw wags and other types of voiceless utterances.

Table 3.1 Stages in speech development according to three models: Stark (1980), Oller (1980), and Koopmans-van Beinum and Van der Stelt (1986).

Stark (1980)	Oller (1980)	Koopmans/v.d. Stelt (1986)
Reflexive (0- 1 ½ months)	Phonation (0-2 months)	Uninterrupted phonation (0-1 ½ months)
		Interrupted phonation (1 ½ - 2 ½ months)
Cooing (1 ½ – 3 months)	Gooing (2-4 months)	One articulatory movement (2 ½ - 4 ½ months)
Vocal play (4 – 7 months)	Expansion (4-6 months)	Variegated phonation (4 ½ - 6 months)
Reduplicated babbling (7-10 months)	Canonical babbling (7-10 months)	Babbling (7 – 12 months)
Nonreduplicated babbling (10-14 months)	Variegated babbling (10-12 months)	
First words	First words	First words

These three studies show considerable similarities as shown in Table 3.1, in spite of some differences in onset and quality (content) of the stages. Stages such as cooing and babbling are described in all models. Thus, it seems that all hearing infants go through the same stages roughly at the same ages. These stages and their timing can therefore be used as a starting point for comparing the development of vocalizations of normally hearing and hearing impaired infants; this has not been done before.

The main topic of this thesis is the influence of *hearing* on the development of the speech stages of infants. If hearing affects the speech development of infants, we expect deaf infants to undergo either different stages of speech development, or the same stages but later. It also might be the case that some stages are influenced by hearing, whereas other stages are not influenced.

To be able to interpret our results well, we first need to understand how the early speech development stages are influenced by factors *other than hearing*. Factors such as anatomy and physiology of the vocal tract are expected at least to contribute to the speech development stages (Kent, 1976, 1992). In the section 3.2 we will discuss several of such factors namely;

- auditory speech processing
- spoken language used during interaction between parents and infants
- internal feedback
- cognition
- anatomy of the speech organs
- physiology of the speech organs
- neurology of the speech organs

These factors might have an influence on vocalizations, since they are involved in the normal communication chain of speech production and perception processes (Denes and Pinson, 1993). However, it is not totally clear in which way or at what moment these factors influence the vocalization development of hearing infants. In section 3.2 we will discuss some assumptions of the influence of these factors on the described stages in vocalization development.

Moreover it is not clear how hearing impacts on speech development in relation with these factors. In section 3.3 we will discuss the results of several previous studies done on the vocalization development of hearing impaired infants. In section 3.4 we will attempt to show how hearing influences vocalization development followed by a model proposal. In section 3.5 our research questions will be discussed.

3.2 Factors influencing early speech development

3.2.1 Development of auditory speech and language processing

Speech perception is part of the complex field of reception of spoken language, which covers two main areas: the ear (anatomy and physiology of the internal structure of the ear) on the one hand and the neural system on the other (auditory speech processing) (see also Chapter 2.1). The auditory speech processing system includes the cochlea, the N VIII, the brainstem, the auditory pathways between brainstem and auditory cortex and the auditory cortex itself (see also Chapter 2.1). Auditory processing is the combination of the auditory processes, such as sound localization, auditory discrimination, pattern recognition, temporal ordering and auditory performance with competing or degraded acoustic signals (ASHA, 1996).

In the neurological development of the auditory system several stages can be found, cumulating in a relatively mature system after the first year of life (see also 2.3.1). Moore (2002) found that the human auditory neural system matures in several developmental periods both prenatally and after birth. During the 16th and 28th fetal weeks the auditory nerve and the auditory part of the brainstem start to develop and myelinization of these parts starts. This means that information is already conducted through the brainstem between the 26th and 28th week of gestation. The fetus' brainstem has the ability to respond to rapid sounds in click evoked brain stem responses in the 29th week. At that moment both cochlea and brainstem are relatively neurologically mature (see also Chapter 2.1).

By inspecting the length of the axons in the tissue of the auditory cortex, Moore found that the auditory cortex matures in several stages (2002). During the last prenatal months until 4.5 months after birth the marginal layer at the surface of the cortex develops. Between 4.5 and 12 months of age, axons reach to deeper parts of the cortex and the thalamocortical[2] afferents mature, resulting in more complex cortical processing of auditory information. This stage might correlate with a more complex auditory speech processing which has been found in the second half year of life, such as the increased perceptual sensitivity for the segmental contrasts of the infant's native language (e.g. Kuhl, 1993; Iverson and Kuhl, 2000).

After the first year the density of the auditory axons increases until the age of five years, indicating another stage in auditory processing. Between five and twelve years of age a fine neural tuning process takes place: the axons from the auditory cortex make more connections between the different parts of the cortex and the two hemispheres. The result is greater complexity in auditory speech processing from that age onwards (Moore, 2002).

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[2] The thalamocortex is part of the neocortext and is believed to play an important role in visual and auditory processing.

As can be expected from the development of the neural auditory system stages have also been found with respect to auditory speech and language processing by means of several perception experiments. It appears that auditory processing starts to develop already prenatally in fetuses with normal hearing (see also Chapter 2.1 for description of prenatal anatomical development of the ear). The most basic form of auditory processing, the awareness of sounds, starts in the fetus at about 26 weeks of gestation. Studies measuring cardiac activity after exposure to pure tones, show that heart rate decelerates significantly a few seconds after presentation of the stimuli (Wedenberg, 1965). In another study the auropalpebral reflex (eye blink reflex to loud sounds) was shown in fetuses between 28 and 36 weeks of gestation by using ultrasound recording (Birnholtz and Benacerraf, 1983). Infants are able to hear their mother's voice, despite the fact that other sounds can exceed 95 dB SPL at low frequencies, in particular noise mainly from the mother's blood flow and heart beat (Walker et al., 1971). It was found by Querleu, Renard and Versyp (1981) and Querleu, Boutteville, Renard and Crepin (1985) that these sounds do not mask the mother's voice and that the fetus can easily perceive it. In the classic experiment of DeCasper and Fifer (1980) it was shown that the fetus could become familiar with its mothers' voice and recognize it directly after it was born. Lecanuet, Granier-Deferre and Busnel (1989) showed that fetuses in the last prenatal trimester are even able to recognize the differences between nonsense words e.g. [babi] and [biba] indicating auditory discrimination and temporal ordering even before birth. In light of these results we can expect that deaf fetuses miss a very valuable stage with respect to their auditory speech and language processing development.

During the first year of life an important development with respect to auditory speech processing also takes place. In several studies it has been shown that infants recognize and prefer their native language within the first months of life, especially with respect to prosodic information. The preference for the native language was measured already at two months of age with brainstem response latencies using French and English (Dehaene-Lambertz and Houston, 1998). Moreover, the preference for the native language disappeared if the prosodic information was distorted indicating a major role for prosody in the recognition of the native language at this early age. Preference for the native language was also measured with head-turning experiments at a somewhat later age: at six and nine months of age (for prosody) and at nine months of age (for segmental information) (Jusczyk, Friederici, Wessels, Svenkerud and Jusczyk, 1993). For instance, in case of Norwegian and English, languages with a different prosody, infants preferred their native language at six months of age, even if the segmental information was distorted (Jusczyk et al., 1993). The sensitivity for prosody in the first months of age was also shown by the experiment of Jusczyk (1989) in which four and a half-months old English infants preferred prosodic complete sentences above sentences with a distorted prosody.

The perceptual development with respect to prosody influences the production of vocalizations already within the first months of life. The effect of perception of prosody on the production of prosody in vocalizations, could be shown by examples of imitation of the duration and pitch of maternal utterances by a three-month-old infant (Sandner, 1981). Also several studies indicate that the intonational patterns of the environmental language can be reproduced by infants in the second half of the first year of life (De Boysson-Bardier, Sagart, Hallé and Durand, 1986; De Boysson-Bardies and Vihman, 1991; Whalen, Levitt and Wang, 1991; Levitt and Utman, 1992). For instance, Whalen et al. (1991) found that the intonation contour of vocalizations of English and French learning infants between six and twelve months differed. The English learning infants more often produced a falling intonation, whereas the percentage of a falling and rising intonation was roughly equal for the French learning infants.

Therefore we expect that the influence of auditory speech processing with respect to prosody on the production of vocalizations starts already within the first months of life. The exact age at which this effect starts is not known, but we assume that it is around three months. Around that same age the cooing/gooing/one articulatory movements stage starts (see also section 3.1) which might indicate a relationship with auditory speech processing.

Moreover, several studies have also been done on the development of segmental perception, on consonants as well as vowels. In the classic study of Eimas, Siqueland, Jusczyk and Vigorito (1971) it was shown that one-month-old infants already perceive the phonemes /b/ and /p/ in categorical terms. This indicates that categorial perception of consonants is either innate or learned within the first month. Moreover, it has been shown at later ages that infants have the capacity to discriminate nearly every phonetic contrast, even if it is not present in their native language (Trehub, 1976; Streeter, 1976; Best, McRoberts and Sithole, 1988). For instance, Best et al. (1988) found that English learning infants of 6 to 14 months could perceive Zulu click contrasts, as well as and adults.

Even a more refined discrimination of consonant perception develops in infants within the first year of life. However, at the end of the first year infants lose the ability to perceive some contrasts not present in their own language. This inability to perceive such contrast stays apparent in older children and adults. It is known that, for instance, Chinese adult listeners have problems with discriminating /l/ and /r/, although they are able to perceive the difference as infants. Werker, Golbert, Humphrey and Tees (1981) and Werker and Tees (1984) showed that English infants could still perceive the Hindi contrast (/ʈa/-/ta/) at six to eight months, but were no longer able to do so at ten to twelve months of age. Thus, at the end of the first year of life, the child loses the capacity to discriminate those segmental contrasts that do not occur in his native language and becomes more sensitive to the segmental contrasts relevant for the native language (Kuhl, 1993; Iverson and Kuhl, 2000).

It was found that infants in the same period recognize and prefer the native language with respect to segmental information. Nine months old infants prefer their native language with respect to segmental information. If the segmental features were distorted by presenting the infants low-pass filtered stimuli[3], the nine month old infants showed no preference between languages, such as Dutch and English; languages that have a similar prosody (Jusczyk et al., 1993). Note that these studies indicate that the infants' auditory speech and language processing is sensitive at an earlier age for prosody than for segmental information.

The perceptual focus on the segmental features of the native language influences the production of phoneme-like segments at the end of the first year of life (e.g. De Boysson-Bardier, Hallé, Sagart and Durand, 1989; De Boysson-Bardies and Vihman, 1991; De Boyson-Bardier, Vihman, Roug-Hellichius, Durand, Landberg and Arao, 1992; Vihman and De Boysson-Bardies, 1994; see also 3.2.2). For instance in the study of De Boysson-Bardies et al. (1992) it was found that place and manner of articulation of consonant-like segments were influenced by the adult language (English, French, Japanese and Swedish) already during the babbling stage. For instance, French infants produced more labials than the infants from the other language environments, as do French adults. Therefore we assume that from that moment on, infants do not only perceive the phonological contrasts of his native language, but also produce them in his own vocalizations. We expect that this effect becomes more apparent at the end of the first year, especially during the babbling, nonreduplicated babbling or variegated babbling stage (see also section 3.1).

Evidence of the influence of auditory processing on speech production can also be found in children with an auditory processing disorder (APD). Normal hearing does not guarantee normal speech processing; thus one might be able to hear well, but not be able to perceive or understand what is heard. An APD is defined as

> "a deficit in the processing of information that is specific to the auditory modality. It may be associated with difficulties in listening, speech understanding, language development, and learning. In its pure form, however, it is conceptualized as a deficit in the processing of auditory input" (Jerger and Musiek, 2000, p. 3).

In children an APD is not always due to a structural defect of the auditory pathways or the auditory cortex, but can also be the consequence of slow maturation of these areas. Nowadays, APD can be established reliably in children from six year of age (Stollman, 2003). A relationship between APD and speech and language problems has been found (Tallal, 1985; ASHA, 1996). Although not easy to study, it might be that APD not only influences speech and language development negatively at that age but also in early infancy, during the development of early vocalizations.

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[3] In low pass filtering the higher frequencies are attenuated, while the lower frequencies remain audible.

In summary: we see that before birth and in the first year of life considerable neurological development takes place. Auditory processing begins prenatally and goes through major developmental stages already within the first year of life. We assume that the auditory processing starts to influence the production of vocalizations around three months of age, the same age the cooing/gooing/one articulatory movements stage starts (see section 3.1). We therefore expect that in this stage prosodic aspects will be influenced. We expect that the influence of the auditory processing with respect to segments development starts at the end of the first year, thus around the age the babbling/nonreduplicated babbling/variegated babbling stage starts (see section 3.1).

3.2.2 Parent-infant interaction and spoken language input

Interaction between young infants and their parents and language input as a part of that interaction is seen by some researchers as a fundamental factor in early speech and language development. In a normal situation the child interacts with his environment and receives language input from its parents. Both the quantity of language input during parent-child interaction and quality of parent-child interaction and their influence on the speech and language development of the child have been studied (e.g. Huttenlocher, Haight, Bryk, Seltzer and Lyons, 1991; Kuhl, Andruski, Chistovich, Chistovich, Kozhevnikova, Ryskina, Stolyarova, Sundberg and Lacerda, 1997). It is clear from the studies of so-called wolf-children (that is children raised without any human interaction and language input) that a minimum of parent-child interaction and language input is necessary for a normal speech and language development. One well known example is that of Genie (Curtiss, 1977). Genie was discovered by the authorities at the age of 13, having been kept in virtual isolation for most of her life. Thus, there was no normal parent-child interaction and Genie did not receive spoken language input until puberty. After she was exposed to language input, she started to acquire language, but to a limited extent only, especially regarding syntax and phonology. This study shows the importance of a minimum of parent-infant interaction and of language input for normal speech and language development, as well as the importance of spoken language input in relationship to a possible critical period. Of course it is not possible to test the effect of lack of parent-infant interaction and spoken language input on vocalizations in a controlled experiment.

In a normal situation, the quantity of language input during parent-infant interaction can be calculated by counting the number of utterances of the mother during a fixed time interval. Only few studies have been done on the amount of language input of mothers to children of 12 months or younger (Snow, 1977; Kaye, 1980; Van der Stelt, 1993; Hart and Risley, 1999). If we compare the results of these studies taken the various durations of these samples into account, we find large differences; the averages vary between 52 and 210 utterances during ten minutes. In some studies a relationship between the number of utterances of the mother and language development in the child has been reported (Huttenlocher et al., 1991; Tomasello and Farrer, 1986). They concluded that the more spoken language the mother directs to the child, the faster the language development of the child.

The age that parent-infant interaction affects the vocalization development of infants is not totally clear. According to Bloom (1988, 1998) syllabic sound productions of three-month-old infants are elicited by verbal communication with their parents. Around the same age imitation of the duration and pitch of maternal utterances was found in a three-month-old infant (Sandner, 1981, see also 3.2.1). Therefore we can assume that from this age onwards the vocalization productions can be produced somewhat more intentionally and that the vocalization development is affected by parent-infant interaction. It was discussed in section 3.1 that around the same age the cooing/gooing/one articulatory movements stage starts. This might indicate a relationship between parent-infant interaction and language input on the one hand and this stage on the other.

Moreover, communication skills during parent-infant interaction like turn-taking might also affect the quality of infant vocalizations. Berger and Cunningham (1983) found in normally developing infants that vocalization sharply decreased between sessions held at 13 to 16 weeks and 19 to 20 weeks of age. From that time on (the observations continued until 23 to 24 weeks) infants vocalized less when their mothers spoke and vocalized more when their mothers were silent, indicating the start of turn-taking behavior. Also Ginsburg and Kilbourne (1988) report that the cessation of vocal overlapping and the beginning of vocal alternation with adult speakers may occur at 12 to 18 weeks of age. Also Bloom, Russell and Wassenberg, (1987) mention that turn-taking increases between three and four months of age in normally hearing infants. It was seen in section 3.1 that around the same age the vocal play/expension/variegated phonation stage starts. Therefore we assume that turn-taking as part of the parent-infant interaction affects the vocalization development from the vocal play/expension/variegated phonation stage onwards.

Some studies report that environmental and social factors, such as birth order within the family, age of the mother, socio-economic status of the parents and education of the parents might have some influence on the parent-child interaction and therefore indirectly on the speech and language development of children. For instance, Oshima-Takane, Goodz and Derevensky (1996) report that second-born children acquire pronouns earlier than first-born children, suggesting that second-borns benefit from overhearing the conversations between caregivers and older siblings. In several studies (e.g. Hoff-Ginsberg, 1998; Hart and Risley, 1999; Landry, Smith and Swank, 2002) was shown that a lower socio-economic status and or education affected the language development of children negatively.

The influence of spoken language input is reflected in effects that different environmental languages have on the type of vocalizations. Languages vary in the frequency of specific types of sounds as well as the prosodic features produced by adults. The effect of the type of environmental language has been studied in considerable detail in a series of experiments (e.g. De Boysson-Bardies et al., 1986, 1989, 1992; De Boysson-Bardies and Vihman, 1991; Whalen, Levitt and Wang, 1991; Levitt, Utman and Aydelott, 1992; Blake and De Boysson-Bardies, 1992; Vihman and De Boysson-Bardies, 1994; see also 3.2.1). We assume that prosodic features of the environmental language become apparent in vocalizations during the cooing stage, while segmental features appear more during the babbling stage, especially during the nonreduplicated babbling/variegated babbling stage (see also 3.2.1).

To summarize: several studies have emphasized the influence of parent-infant interaction and the type of language input on vocalization development. Parent-infant interaction and language input seem to influence several stages and might start to affect the vocalizations from the cooing/gooing/one articulatory movements stage onwards.

3.2.3 Internal feedback

Internal feedback is the system which makes it possible that the child perceives and controls his own speech and language productions via his own perception, thus via his own hearing, tactile and proprioceptive information and sight (for instance in a mirror). It has been argued by Fry (1966) that vocalizing is important, since it helps the infant to create a link between his auditory, tactile, kinestetic and proprioceptive feedback via the speech-like sounds he produces.

It is likely that there is influence from internal feedback on vocalization development, as shown in studies of children who have no possibility to train their internal feedback system and their speech productions. A clear example of such a situation is in children with tracheostomy[4]. The tracheostomy prevents the child from producing vocalizations and spoken language, since the ear-stream leaves the lungs via the trachea opening instead of via the mouth cavity. The internal feedback system cannot be trained. Few studies described the early speech and language of tracheostomatized infants, but all of them describe severe phonological disorders even a long time after the tracheostomy.

Locke and Pearson (1990) reported on the speech development of a child, Jenny, who was intubated during her first months and tracheostomatized at five months. That is, she was able to move her speech articulators, but not able to produce voicing because the air escaped via the tracheostoma, not via the mouth. After

[4] Tracheostomy is an opening in the trachea which is needed in case of an obstruction of the normal airway, due to for instance a deficit in the larynx.

decannulation (removing the tracheostoma), at approximately 20 months, the child did not produce words, but vocalized instead. The number of spontaneous utterances per minute increased dramatically, but the number of different consonant-like segments and the number of canonical syllables were much lower than from normally developing children of that age. The first vocalizations involved much more labial consonants rather than coronals (Locke and Pearson, 1990; Bleile, Stark and Silverman-McGowan, 1993). Unfortunately it is not known whether the child produced voiceless speech-like movements such as jaw wags at the period normally developing infants babble (see also Chapter 3.2.3).

In another study, Kamen and Watson (1991) found that children tracheostomatized before twelve months of age, even a year or more after decannulation produced vowels with a restricted vowel space. Also in the study from Kertoy, Guest, Quart and Lieh-Lai (1999), of the six infants who had undergone tracheostomy before the age of eight months, five infants exhibited phonological delays, such as stridency deletion, deviating vowel formant frequencies and cluster reduction, even after a period of speech training. Despite the fact that these children received normal speech input, had normal auditory speech perception, normal neural development and normal anatomy of the speech organs (above the larynx), the lack of internal feedback seems to have influenced their spoken language development.

It is not known exactly what influence internal feedback has on the development of vocalizations in infants. Unfortunately it does not become clear from studies on tracheostomatized infants, from what age or stage exactly onwards (lack of) internal feedback affects the vocalization development, since the infants described are trachostomatized for a long period during the vocalization development. However, we can assume that internal feedback becomes important from the age onwards that infants produced certain types of vocalizations intentionally and with more control over their own productions. Therefore, we assume that internal feedback is involved already from the cooing/gooing/one articulatory movements stage onwards, when infants seem to be able to imitate prosodic features of their mother's utterances (Sandner, 1981, see also section 3.2.1 and 3.2.2). Also at later stages internal feedback is most probably involved, especially when the vocalizations become more complex and even influenced by the environmental language at the end of the first year, as described in sections 3.2.1 and 3.2.2.

3.2.4 Cognition

Only a few studies have been performed on the influence of cognition on vocalizations. According to Bloom (1998) growth in cognitive attention might serve vocalization development already at three months of age. Infants might respond to visual stimuli attracting their attention with movements of articulators such as the tongue and jaw (Jones, 1996). Also from that age on vocalizations can be elicited by verbal communication, suggesting a more intentional type of vocalizing at that early stage of development, possibly related to cognitive development (Bloom, 1998). Therefore, it might be the case that from the cooing/gooing/one articulatory movements stage onwards cognition starts to affect the vocalization development.

Some studies have been done on the influence of cognitive delays on vocalization development. Most of these studies focused on the age of the onset of the babbling stage in children with Down syndrome. Smith and Oller (1981) studied place of articulation of consonants in children with Down syndrom and normally developing infants between 3 and 21, respectively 3 and 15 months of age. They found that both groups produced about the same place of articulation in the same period, and it was concluded that the level of cognitive development had no effect on the place of articulation of consonants (Smith and Oller, 1981). On the other hand, in another study children with Down syndrome started on average two months later with babbling (Lynch, Oller, Steffens, Levine, Basinger and Umbel, 1995). The researchers concluded that cognition probably affects the age at which babbling starts. The age of the babbling onset correlated with a test of social and communication behavior at 27 months of age.

However Down syndrome children may not be the best group methodologically to test the relationship between cognition and early speech. Beside babbling also hand-banging patterns started somewhat later in Down syndrome infants (Cobo-Lewis, Oller, Lynch and Levine, 1996). That suggests an underlying neurologic relationship between hand banging and babbling, which had already been suggested by Thelen (1991) (see also 3.2.6) and the late onset of babbling in Down syndrome infants may be the result of a neurologic delay, rather than of a cognitive delay only. Beside that, a somewhat deviant anatomy of the speech organs in Down syndrome children (e.g. relatively large tongue) might effect the onset of the babbling stage.

A subject group with infants with cognitive delays other than Down syndrome, is hard to select, since cognitive tests are hard to perform reliable within the first year of life. In somewhat older mentally retarded infants (17 to 34 months old), both vocalizations and early word production was studied (McCathren et al., 1999). The results showed that cognition had an effect on vocalization development: children with cognitive delay produced relatively few utterances (on average 39.5 during ten minutes) compared to normally developing infants (see section 3.2.2). Unfortunately no control group with normally developing children was studied, thus exact comparisons were not made.

Thus we can conclude from the above that the cognition might have an influence on the development of vocalizations. The exact stage this effect starts to appear is still unclear due to methodological reasons, although we assume that cognition affects the onset of the babbling stage and number of utterances. Possibly cognition starts to affect vocalizations during the cooing/gooing/one articulatory movements stage onwards.

3.2.5 Development of anatomy and physiology of the speech organs

Anatomy and physiology most probably have an influence on onset and duration of several developmental stages of speech. The anatomy (the structures) and physiology (the movements) of the newborn's speech apparatus is quite different from that of an adult or even of a child of two years of age. The vocal tract is short, with a relatively short pharyngeal cavity. During the reflexive/phonation/ uninterrupted phonation stage the larynx is relatively high and the epiglottis and velum close to each other. The tongue is relatively big and fills the oral space almost completely (see Figure 3.1) and the velum (soft palate) hangs down passively, almost touching the tongue and epiglottis. The extrinsic (outer) velum muscles cannot actively lift up the velum yet, since the velum is still located in more upward position than these muscles (Fletcher, 1973). This results in actively lowering the velum instead of raising it, as we find in older infants and adults. In the first months many sounds are produced with the lips closed. For those reasons the air stream goes mainly via the nose and not via the mouth in newborns. This explains the nasality in this stage. Kent and Murray (1982) call the infant an obligate nasal breather and an obligate nasal vocalizer.

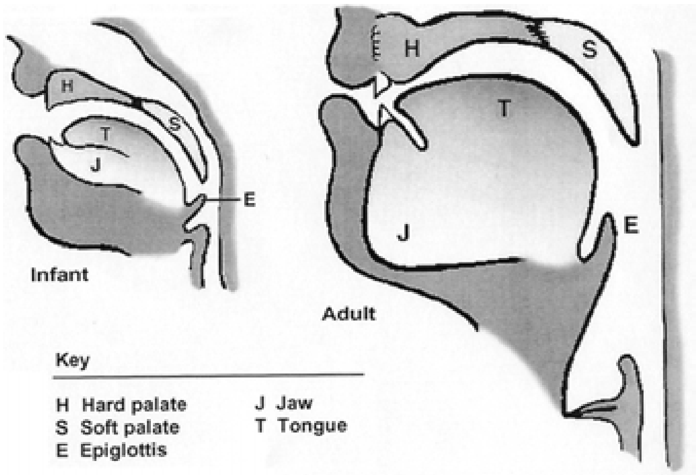

Figure 3.1. The cross-section of the vocal tract of a newborn infant and the vocal tract of an adult (Thinking Publications, 1996)

From two or three months onwards the air stream moves more via the oral cavity, and not only via the nasal cavity. This is probably not due to a more active use of the velum muscles, but to the anatomical growth. Because the tongue and the velum are close together, with the jaw and the tongue in rest position, the air stream between the velum and the tongue makes both articulators vibrate, producing back trill-like or fricative-like sounds. This results in a higher amount of velar fricatives and trills during the cooing/gooing/one articulatory movements stage (see also 9.1).

Moreover, around three months, the rib cage has restructured in the direction of a more adult-like configuration (Langlois, Baken and Wilder, 1980). From that age on, infants can produce a higher sub-glottal air pressure, and have better control of the duration and fundamental frequency of their utterances[5] by regulating the air pressure. Therefore, we can find longer utterance duration, as well as more variation in their F0 in this period. The better voicing control is, for instance, shown by examples of imitation of the duration and pitch of maternal utterances by a three-month-old infant (Sandner, 1981). In normal hearing infants the laryngeal muscles need to be exercised already in the first months of life otherwise deficits in phonation control may result (Lieberman, 1986).

At the age of four to six months the anatomy of the oral and pharyngeal areas changes again (Sasaki, Ohno, Matsubara, Kobayashi, Mashita, Kaii, Mishima, Kato and Yamaguchi, 1977). The mandible grows more downward, giving the tongue more space to move and giving the air the possibility to go through the oral cavity, without causing the tongue or velum to vibrate. In the same period the human (and chimpanzee) larynx descends gradually during infancy, possibly associated with developmental changes of the swallowing mechanism. The descending of the larynx contributes physically to an increased independence between the processes of phonation and articulation for vocalization, according to Nishimura, Mikami, Suzuki and Matsuzawa (2003). Bloom (1998) mentions also increased neuromotor control of the intercostals muscles at that age and a relatively smaller tongue compared to the oral cavity as aspects contributing to more control of several articulators resulting in different types of vocalizations. For instance, the higher air pressure combined with closed or almost closed lips results often in a bilabial raspberry. Moreover, the tongue can also be protruded between the lips (although infants are able to move the tongue to a fronted position at an earlier age while swallowing), resulting in an interlabial raspberry.

Thus, clear anatomical changes take place in this period and we therefore assume that they are related to the onset of the vocal play/expension/variegated phonation stage.

Around seven months it becomes anatomically and physiologically possible to move the jaw freely up and down. In this period infants starts to chew. If the up en down movement is repeated, the result might be babbling; a rhythmic up-and-down movement of the jaw, normally during voicing and the reduplicated babbling/ canonical babbling/babbling stage starts.

If the infant opens the jaw after a closed position, the result can be heard as a consonant-like segment, such as a front plosive, a front glide or a front nasal. This movement is done with the jaw, while the lips and tongue are not actively involved yet (see also the 'first frames than content'-theory, MacNeilage and Davis, 1990; 2000, 2001). When the jaw and lips close, the upper lip is passive and moves a

[5] An infant utterance is normally defined as a sound production of any type, such as a vocalization, a babbling, or a spoken word (see for the definition used in this thesis Chapter 4.4).

little bit upwards pushed by the bottom lip (Munhall and Jones, 1998). In babbling the tongue still moves passively up and down together with the jaw. If the tongue touches the palate, teeth gum, or lips during the upward movement of the jaw, the result can be heard as a consonant-like segment at the central place of articulation, normally a central stop, a central glide and a central nasal. However, in the productions of central consonants such as /d/ and /t/ by older children or adults, the tongue movement is different than in babbling and early words. Normally after the second or even third year the tongue is able to move separately from the jaw, which is not possible during infancy.

In the same period the development of the control of the voice muscles continue into the second half year of life, resulting in more control of the utterance duration and fundamental frequency. The fact that infants can reproduce the intonational patterns of the environmental language in the second half year of life was discussed in 3.2.1 and 3.2.2.

During the nonreduplicated babbling/variegated babbling stage various consonants are produced during one babbled utterance as described by Oller (1980) and Stark (1980). In the same period the segmental features of the environmental language appear more in the vocalizations (see sections 3.2.1 and 3.2.2). We assumed that language input and development of auditory speech and language processing are involved in that stage. However, although we did not find evidence in previous literature, we assume that also anatomical developmental processes are involved, making it physically possible to produce such utterances.

It is not exactly known at which age the velum can be lifted up of pulled down actively. Fritzell (1963) observed electromyographically that activity of the levator and tensor muscles occurs prior to the actual onset of word productions. It seems to be evident that a closure of the nasal cavity due to an active lifting up of the velum is possible during the babbling stage. The closure of the velum seems to be necessary to be able to build up enough air pressure in the oral cavity, in order to produce stops, which are typical consonants at this stage. It might be that at a later stage the velum can be pulled down actively by the musculus palatopharyngeus, the antagonist of the two velum lifters. It was shown that infants produce nasalized vowels in the neighborhood of nasal consonants (Matyear, MacNeilage and Davis, 1998). This shows that the velum is either up or down during the whole utterance. Even at the age of two or three years children can have problems with the production of nasals (and thus the movement of the velum) in words. The result is often nasalization or de-nasalization of all consonants in the word.

Evidence of the influence from anatomy and physiology on the vocalization development can be found in studies on disorders in the anatomical system. In a recent study of 30 nine-month-old infants with unrepaired cleft palate, several differences were found compared to 15 normally developing infants (Chapman, Hardin-Jones, Schulte and Halter, 2001). The cleft palate infants started babbling later compared to normally developing children. Only 57% of the cleft palate

infants started babbling, while 93% normally developing infants babbled at nine months of age. The cleft palate infants also had smaller consonant inventories in their vocalizations, and also clear differences with respect to both place and manner of articulation were found. Fewer stops and glides, and fewer velars were produced, while glottals occurred more often. Similarities were also found; no differences were made in number of vocalizations and utterance types, such as CV. The lack of stops in cleft palate infants was explained by the inability to produce enough air pressure, due to the inability to close the velum. The lack of velars was explained by the reduced palatal tissue available for the contact between tongue and velum (Chapman et al., 2001). These differences continue in some cleft palate children until two years of age (Jansonius-Schultheis, 1999).
Thus we can conclude that the enormous anatomical and physiological changes during the first year of life have an influence on the development of vocalizations in all vocalization stages.

3.2.6 Development of neurology of the speech organs

Neurological maturation and motor control of the speech organs most probably have an influence on the onset and duration of the developmental stages of speech (Netsell, 1981). The brain of a newborn infant and the neurological paths for the innervation[6] of the speech organs undergo intensive development in the first years of life. Not many studies have been performed on the relationship between infants' speech development and neurological maturation of the speech organs in the first year. It has been suggested by Ploog (1979) that the pre-babbled vocalizations are related to an early maturing part of the subcortex involved in the vocalization subsystem common to most mammals. Unfortunately he did not mention at what age exactly these pre-babbled vocalizations are affected to the maturation of the subcortex.

From studies of monkey vocalization it is known that their vocal output is controlled by both the subcortex and by the medial cortex. The parts of the medial cortex involved are the anterior cingulate gyrus and the Supplementary Motor Area (SMA) (Jurgens, 2002). Higher primates are able to produce a communicative gesture in the form of rhythmic open-close movement of the jaw, the so-called lip-smack (Redican, 1975). Several investigators have shown that humans produced rhythmic syllable-like vocalizations when the SMA was electrically stimulated (Penfield and Welch, 1951). Also, patients with lesions of the SMA produced involuntary rhythmic syllable-like vocalizations (Jonas, 1981). These syllable-like productions can be possibly related to the babbling stage (see also MacNeilage and Davis (1990) for an overview).

[6] Innervation is the neurological input to an organ via one or several nerves.

Moreover, in the classic studies of Conel (1939-1967) a distinct peak in the rate of growth of the motor cortex was found at approximately six months. At that age more dendritic branching was found in the left hemisphere in both motor and speech-motor areas than in the right hemisphere (Simonds and Scheibel, 1989). Also, the intra- and interhemispheric cortical association bundles begin to myelinate at about five to six months, which means that the velocity of the action potentials increases from that age (Lecours, 1975). This is the age most hearing infants start babbling, suggesting a relationship between neurological maturation overall and babbling. Several studies have pointed out a relationship between the start of the babbling stage and other repetitive motor behavior such as clapping and rocking (e.g. Thelen, 1991).

Evidence of the influence of the neurological development on the vocalization development can be found in studies on disorders in the neurological system of the speech organs. These neurological speech disorders have several different names such as Childhood Apraxia of Speech (CAS, also known as DVD - Developmental Verbal Dyspraxia, and DAS - Developmental Apraxia of Speech). Neurological speech problems can already appear during the first year of life, resulting in little or no babbling in infancy, and the production of few consonants (Velleman, 1994).

Broca's area is responsible for the main part of language production in human children and adults, probably from the period of the first word productions onwards. The location of Broca's area is in the inferior frontal gyrus of the frontal lobe on the left side of the brain. However, it seems that Broca's area is not involved in vocalizations, as shown by lesion studies in monkeys and humans. Lesion studies in monkeys have shown that the lateral frontal cortex and primary motor cortex of the precentral gyrus, which is comparable with the Broca's area in humans, has almost no effect on monkeys' vocalizations (Jurgens et al., 1982). Aphasia patients with severe Broca aphasia (due to lesion of the Broca area) have an almost normal language perception, but the language production is disordered. These patients can often still produce speech production "ingredients" such as prosody, syllables and phonemes, without a relationship with meaningful words in paraphasias[7].

Thus, it seems that the neurological development of the speech organs is involved in the vocalization development. The maturation of subcortical areas is involved in the prebabbling stages, the maturation of the medial cortex, and especially the SMA, is probably involved in the onset of the babbling stage, while the maturation of the Broca area seems to be involved in the early word production.

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[7] Paraphasia is the production of unintended syllables, words, or phrases during the effort to speak (Goodglass and Kaplan, 1983).

3.2.7 Summary

From the discussion in sections 3.2.1 to 3.2.6 we argued that several factors such as parent-infant interaction and language input, auditory speech and language processing, internal feedback, cognition, anatomy, physiology and neurology probably have an influence on the stages in vocalization development. Next, we expect that these vocalization stages are related to developmental steps in the described factors. Figure 3.2 shows the influence of several factors that affect the vocalization stages. In this figure the plausible effects are dark grey, the unsure effects are light gray and no effect is displayed transparent.

The development of anatomy and physiology is expected to affect all vocalization stages (see section 3.2.5). The development of the neurology of the speech organs is expected to influence both the pre-babbling stages, although is could not been argued from previous literature what stages exactly. Also the babbling/ reduplicated babbling/canonical babbling/ stage is expected to be influence by neural development (see section 3.2.6).

The age that the development of cognition affects the vocalization development is not totally known for methodological reasons. However, we can assume that cognition affects the onset of the reduplicated babbling/canonical babbling/babbling stage and number of utterances, although it can not be excluded that also earlier stages are affected by cognition (see section 3.2.4).

Parent-interaction and language input seem to influence several stages (see section 3.2.2). Around the age the cooing/gooing/one articulatory movements stage starts more infant utterances can be elicited during parent-infant interaction. Around the age the vocal play/expension/variegated phonation stage starts more turn-taking is seen. Language input is assumed to affect the vocalizations during the babbling stage and especially the nonreduplicated babbling or variegated babbling stage (see section 3.2.2). The age internal feedback affects the vocalization development is not totally clear, but we assume that internal feedback is involved already from the cooing/gooing/one articulatory movements stage (see section 3.2.3).

We expect that development of auditory speech processing affects several stages (see section 3.2.1). Already at two months of age infants are sensitive for prosodic information of the own language and we assume that this sensitivity for prosody starts to influence the vocalization development during the cooing/gooing/one articulatory movements stage (see section 3.2.1). The perceptual sensitivity for segmental information of the own language is expected to affect the vocalizations somewhat later; during the babbling stage and especially nonreduplicated babbling or variegated babbling stage (see section 3.2.1).

We did not discuss the influence of hearing on vocalization development yet. In section 3.3 we will discuss the effect of the influence of hearing loss on the

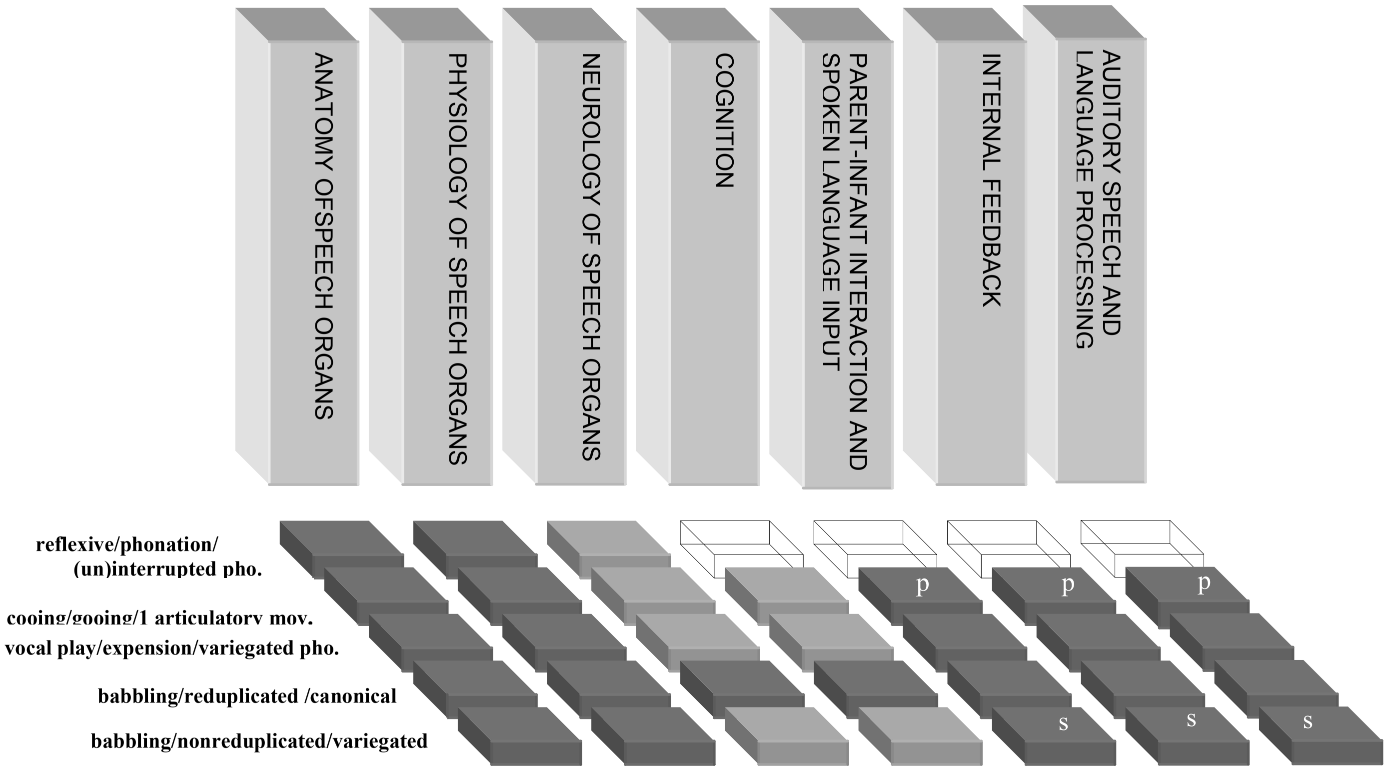

Figure 3.2. Model of factors influencing the vocalization stages. Transparant=no effect is expected, dark grey is assumed effect, light grey is uncertain effect. p=prosody, s=segmental information.

vocalizations of deaf infants based on previous work. We address the question whether vocalization development is different between deaf and hearing infants, with respect to which aspects and from what age onwards. The several aspects, such as number of utterances, segmental and prosodic characteristics and stages in vocalization development of deaf infants will be discussed. Also, we will discuss problems with the interpretation of the results of these previous studies.

3.3 Influence of hearing on vocalization development: previous research

In the previous sections we argued that normally hearing infants undergo the same vocalization development stages roughly at the same time (section 3.1) and that several factors seem to influence these vocalization development stages (section 3.2). In section 3.3 we will discuss the way vocalization development presumably is influenced by hearing. Therefore we will discuss previous research done on the vocalization development of HI infants.

To date we do not know exactly if HI infants go through the same stages of speech development as hearing infants, or at which age. Several aspects of the speech development of HI infants, such as number of utterances, babbling, and place and manner of articulation, have been previously studied. Unfortunately, most of these studies have led to unclear and contradictory results.

3.3.1 Number of utterances

The amount of speech sound productions might be influenced by lack of hearing in several ways. If infants mainly vocalize in order to practice the coordination of their auditory, tactile and propioceptive internal feedback (see 3.2.3), we might expect fewer utterances in HI infants, since the internal auditory feedback system definitely will be influenced by the hearing loss. On the other hand, if the normal turn-taking process for spoken language, as described in 3.2.1, is deviant in HI infants, this might result in more utterances for HI infants, compared to NH infants.

Strangely enough, only few studies report on the number of utterances of HI infants, although this is a parameter that is easier to obtain than other qualitative speech measures. It seems that the general intuition is that HI infants within the first year of life produce fewer utterances than hearing infants. It might be that this widespread belief is based at least partly on results of studies of HI children after the first year of life. HI children of three years old produce clearly fewer spoken language utterances than NH children according to Lederberg and Everhart (1998). Between twelve and eighteen months of age contradictory results were found. Van den Bogaerde (2000) found fewer vocalizations in 12-month-old HI infants compared to 12-month-old NH infants all studied in interaction with their deaf mothers. Spencer (1993) found no significant difference between the groups of 12 and 18 months-old NH and HI infants studied in interaction with hearing mothers. Gregory (1985) on the other hand found that at the age of 1;3 years HI children in interaction with hearing mothers produced twice as many expressive vocalizations as hearing children did.

Although this topic is not very systematically studied, some researchers, like Mavilya (1972), Maskarinec, Cairns, Butterfield and Weamer (1981) and Stoel-Gammon and Otomo (1986) report an increase in the number of utterances of HI infants during the first year, followed by a reduction after the first year. In a study with the same children as in the present thesis, but between 12 and 18 months, it was found that a reduction clearly took place after the first year of life (Van den Dikkenberg-Pot, Koopmans-van Beinum and Clement, 1998).

Within the first year of life it has been observed that HI infants produce more utterances than their hearing peers. In the study of Oller et al. (1985) one profoundly HI infant was studied in comparison with eleven hearing infants. The number of utterances within the recording sessions of around 30 minutes each for the HI infant at 11, 12, and 13 months was 62, 75, and 90, respectively. The NH infants of 11, 12, or 13 months produced in their samples between 33 and 68 utterances. Thus, the HI infant produced on average more utterances. The number of utterances in the HI infant is comparable to the number of utterances found by Yoshinaga-Itano, Stredler-Brown and Jancosek (1992), namely on average 89.5 utterances within 30 minute samples for 28 HI infants between six and twelve months. Unfortunately, they did not compare her results with those of NH infants.

Kent, Osberger, Netsell and Hustedde (1987) studied an identical twin of which one boy had a severe hearing loss, while his twin brother had normal hearing. It was mentioned by the authors that "… he was a prolific vocalizer – sometimes producing more utterances within a recording session than the hearing twin" (p. 71). Also, Locke and Pearson (1992) observed that deaf infants vocalize more than hearing infants. They report

> "there are indications that deaf infants may vocalize more than NH infants do…" (p. 105).

Locke and Pearson interpret this in comparison with the results of experiments on kittens raised in the dark (Dodwell, Timney and Emerson, 1976; Timney, Emerson and Dodwell, 1979), that is HI infants use their own vocalizations as a way to get extra auditory stimulation for their brains to compensate for the lack of auditory input. They concluded

> "… perhaps that auditorily deprived humans do expend extra effort to get auditory stimulation" (p. 105).

To summarize: with respect to number of utterances few studies were done within the first year of life. Unfortunately, the few studies that report on speech productions of HI infants within the first year of life, suffer from methodological problems. Some studies investigate utterances within various time intervals per recording and do not report on the number of utterances in a fixed time interval (e.g. Stoel-Gammon, 1986, 1988) or report only global observations (Locke and Pearson, 1992). The few studies performed on the number of utterances systematically within a certain time interval study the infants after the first year (e.g. Spencer, 1993), report about one specific profoundly HI infant (Oller et al., 1985; Kent et al., 1987), or make no comparisons with hearing infants (Yoshinaga-Itano et al., 1992). Therefore it is not yet clear whether HI infants produce fewer or more utterances than NH infants in the first year of life. Our results will be presented in Chapter 5.

3.3.2 Prosodic characteristics: utterance duration and phonation

If a specific language environment has a noticeable influence on the production of prosody of NH infants already at the end of the first year (see 3.2.1 and 3.2.2), we can expect also an influence from a *lack* of audible language input on the production of prosodic elements, such as utterance duration and F0, of HI infants. Investigating the cries of infants, Möller and Schönweiler (1997) studied several acoustic parameters, such as duration, and F0 in their study of seven profoundly HI infants and seven NH infants between two and eleven months. They found a longer duration and more variation in melodic structure, that is, more extreme F0 maxima and minima for the HI infants. Unfortunately only 153 cries were analyzed in this study, thus the conclusions were based on a relatively small amount of data. Kent et al. (1987) studied fundamental frequency of non-cry sound productions of an eight month old deaf infant and compared these with those of his hearing twin brother. A higher peak F0 and a slightly larger range of peak F0 values of the deaf infant, compared to his hearing brother were found. More variation within the utterances, like strong changes within the F0 contour and intervals of vocal fry, were observed as well. Unfortunately, this study was performed on only one child during one session within the first year. The authors suggest that the lack of feedback and therefore the lack of fine control of the voice plays a role in a deviant phonation of HI infants.

In older children, we know that both duration and F0 are influenced by a hearing loss. In a study on syllable duration of children of six to ten years of age a clear effect of the hearing status on duration was found (Ryalls and Larouche, 1992; Ryalls, 1993). They found an average syllable duration of 294 ms for NH subjects, 349 ms for moderate-to-severely HI children and 540 ms for profoundly HI children. The profoundly HI children had a significantly longer syllable duration compared to the two other groups.

Also in younger HI children a longer utterance duration was found. Data of the same infants as in the present study, but between 12 and 18 months of age, show that the utterance duration was longer in the HI group compared to the NH group for almost all months studied (Dikkenberg-Pot et al., 1998).

Ryalls and Larouche also found a significantly higher F0 for six to ten years old profoundly HI children than in the other two groups. Moreover, in the study by

Elsendoorn and Beijk (1993) it was found that differences in fundamental frequency between normally hearing children and deaf children (ages between 4 and 20 years) were apparent only from the age of seven years onwards. From that age deaf children speak on average at a pitch about 60 Hz higher than their hearing peers. It is not known why HI children produce a higher F0 than the NH children, neither why from that age on. But also at this age F0 might already be influenced by the lack of internal feedback.

Furthermore, to our knowledge no study yet has been done on voicing of infants, by considering for example the number of voiceless utterances. Voiceless utterances with articulation, such as jaw wags, might be interesting to study (see also 3.1). During the early phase of babbling (around six to eight months), it might be a part of the normal development, indicating problems with the coordination of phonatory and articulatory movements (Koopmans-van Beinum and Van der Stelt, 1998; Koopmans-van Beinum et al., 2001; see also Chapter 3.1). However, we might expect a higher number of voiceless utterances for deaf infants, during a longer period, since the lack of hearing will possibly result in more problems with coordination of articulation and phonation.

To summarize, no systematic longitudinal study has been performed on prosodic characteristics, such as duration and F0 of non-cry sound productions of deaf infants as early as from the first half year of life onwards. Therefore differences between HI and NH infants are not known. Our results will be presented in Chapter 6.

3.3.3 Prosodic characteristics: Utterance structure and number of syllables

In only few studies is the utterance structure or mean number of syllables described, although these are parameters which are quite easy to obtain. According to Koopmans-van Beinum (1993) adult listeners are, generally speaking, well aware of the syllable-like structure of early infant sound productions. Even children are able to syllabificate[8] adult speech intuitively as shown in a study of Gillis and De Schutter (1996). Fifty five- and six- and fifty eight-year-old children were able to syllabify intuitively according to universal principles, such as

1. The Obligatory Onset Principle (Hooper, 1972): the consonant immediately preceding a vowel is the onset of the syllable, rather than the coda (final consonant) of the preceding syllable.
2. The Maximal Onset Principle (Kahn, 1976; Selkirk, 1982): all prevocalic consonants belong to the syllable’s onset, as long as the cluster does not violate the language specific constraints.
3. The Sonority Sequencing Principle (Clements, 1990): the sonority within a syllable is scaled as following: Obstruents (least) < Nasals < Liquids < Glides <

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[8] Syllabification is the deviation of utterances in separate syllables.

Vowels (most). The preferred syllable has maximal sonority rising from the onset of the syllable toward the vowel and minimal falling from the vowel to the final consonant.

These three principles would all predict that the infant utterance VVCCVCV[9] should be divided into VV.CCV.CV, thus rendering three syllables.

The number of syllables in sound production of HI infants was described in the work of Yoshinago-Itano et al. (1992; see 3.3.1 for number of utterances in that study). The number of speech units (comparable to our definition of infants' syllables, see Chapter 7.2.4) was measured in HI children between 6 and 36 months. The average number of units was 1.8 for infants of six to twelve months and did not change significantly with age. Unfortunately, no comparison is made with NH children. Moreover, the number of syllables per utterance was not reported exactly, for instance the number of utterances with only one syllable, or with four or more syllables. Furthermore, we have no indication from their study, how the syllabification by the hearing impaired infants studied was performed.

Kent et al. (1987) described the utterance structure of utterances of their two subjects. They found that, at that age of eight months, 92% of the utterances of the NH infant contained a consonant, while this was the case in only 12% of the utterances of the HI infant. The HI infant produced mainly V utterances, while the NH infant produced all types of variations in the syllable structures, such as CV, CVC, and CVCV. Unfortunately only one sample within the first year of life was analyzed (at the age of eight months). Also Spencer (1993) found that twelve month old NH infants produce seven times more vocalizations including one or more consonants than HI infants of the same age. Unfortunately she did not study younger HI infants.

To summarize, only few studies report on the utterance structure of HI infants and only one of these studies started in the first half year of life. This study was done with only one subject. The number of syllables of HI infants has been studied to an even lesser extent, and has unfortunately not been compared to the number of syllables of NH infants. Our results will be presented in Chapter 7.

3.3.4 Segmental characteristics

If the phonology of a specific language environment has a noticeable influence on the production of segments already at the end of the first year (see 3.2.1 and 3.2.2), we can expect also an influence from a *lack* of audible language input on the production of segments by HI infants.

[9] V stands for a Vowel-like segment and C stands for Consonant-like segment.

Only few studies have been performed on place and manner of articulation of HI infants, and so far this has neither been done very systematically nor did such studies start within the first half year of life. Stoel-Gammon and Otomo (1986) and Stoel-Gammon (1988) studied 14 HI infants with hearing losses between 15 dB aided (with hearing aids) and 110 dB unaided (without hearing aids). Three infants were recorded starting before six months of age; 4.2 months was the youngest age. They reported a limited consonant repertoire for the HI infants compared to NH infants. Also, Stark (1983) noted that HI infants had smaller consonant inventories than NH infants. In a recent study the number of different consonant types were studied for HI children of 14 months and older (Yoshinaga-Itano, 2002). The number of consonant types was strongly related to the hearing loss; mild-to-moderate children between 14 and 18 months produced about 7.5 different consonants, which seems to be comparable to the seven acquired different consonants found by Beers (1995) for normally hearing children of 1;3 – 1;8 years. Moderate-to-severely HI children produced five different consonants and the profoundly deaf children only three different consonants (Yoshinaga-Itano, 2002). Thus, HI infants seem to produce fewer different consonant-like segments. Therefore, it would be interesting to see how the infants differ with respect to place and manner of articulation.

Smith (1982) studied place of articulation of consonants, e.g. labial, alveolar, velar, of 15 moderate-to-profoundly hearing impaired infants. He found that in the first three to six months the HI infants produced mainly velar articulations. At the end of the first year, at 9-15 months, around 60 % of the articulations were central. About the same results were found in a study of normally hearing and Down syndrome infants (Smith and Oller, 1981). The authors concluded that hearing impairment did not influence place of articulation in infant vocalizations, but it should be noted that the HI subjects in their study had relatively small losses. In some other studies actual differences between deaf and hearing infants are found, but the results are contradicting. Kent et al. (1987) found more stops and very few fricatives in the vocalizations of a HI infant compared to his hearing twin brother at eight months of age. Furthermore, alveolar consonants were far more frequent than labials and velars. On the other hand, Stoel-Gammon (1988) and Stoel-Gammon and Otomo (1986), found *fewer* stops in the vocalizations of deaf infants compared to hearing peers. They also found that the HI infants produced *more* labials compared to the hearing children. These unclear and contradictory results are almost certainly caused by the use of small subject-groups, not systematically created recordings and diversity within the subject-groups (e.g. moderate and profound hearing impairment combined).

With respect to vowels few studies have been performed on formant frequencies of HI infants. Investigating the cries of infants, Möller and Schönweiler (1997) studied also spectral information of HI and NH infants. They found a reduced vowel space for the deaf infants. This was confirmed by some other studies (Kent et al., 1985; Van der Stelt, Wempe and Pols, 2003a and 2003b). In the study of Kent and colleagues the absence of the F2 frequencies above 3000 Hz for the HI child at 15 months of age was striking, the hearing brother on the other hand produced frequencies up to 3600 Hz. This might possibly be related to the form of the infants' audiogram, because his hearing loss was greater at the higher frequencies.

In contrast, a considerable amount of studies has been performed on the phonological development of HI and NH children *after* the first few years of life. E.g. Dutch NH children of 1;3-1;8 years have already acquired front and central stops, front and central glides and front and central nasals and they are able to produce them correctly in words (Beers, 1995). From that age onwards several differences in phonological development between HI and NH children have been described. A delayed and different phonological development is found in the speech productions of HI children. Perhaps the most striking phonological process is labializing (fronting). In the study of Carr (1953) on the spontaneous speech of five-year-old English speaking HI children it was found that the subjects more often produced front consonants than central or back consonants. Also more voiced than voiceless consonants were produced, and more front than back vowels. In another study the percentage of incorrectly produced segments of ten-year-old French speaking deaf children was calculated (Ryalls, 1993). Bilabial and alveolair consonants were pronounced for 50% incorrectly (often a devoicing of the consonant in final position), but velar consonants were produced mostly incorrectly, namely 83% incorrect (mainly omissions). It can be presumed that the reason the bilabial segments are produced more often, and more often correctly, is because they are more visual compared to back consonants. However, Fourcin (1978) remarked that bilabials are not only more visual, but also acoustically/auditorily easier to perceive than alveolars and velars. Moreover, it is also the case that the articulation movement of bilabials is easy, by just closing the jaw from a neutral position (Jakobson, 1986, originally printed 1941). NH infants often produce more babbles with front articulation and dental movements than with back articulation. Also, first words are often produced with bilabial consonants, in words such as /mama/, /ba/, etc. (Jakobson, 1962; McCune and Vihman, 2001).

Other phonological processes heard in the speech of HI children are mainly like in younger NH children. Beside the fronting described above, Oller and Kelly (1974) mention also gliding, devoicing of final obstruents, and minor processes such as cluster reduction, stopping of fricatives, fricativization of other stops, and vowel substitutions. Abberton, Hazan and Fourcin (1990) found a less fast development in production of vowels and voicing contrasts for children with a loss above 100 dB SPL than in children with a smaller loss.

To summarize, with respect to the segmental characteristics in vocalizations of HI infants, only few previous studies have been done. The vowel space seems to be limited in HI infants compared to NH infants. Also a smaller consonant inventory was found for HI infants. However, with respect to place and manner of articulation of these consonants contradictory results were found. In older HI children labialization is found, as well as other phonological processes which are heard in the speech of younger NH children. Our results with respect to such segmental characteristics will be presented in Chapter 8.

3.3.5 Stages in vocalization development

In NH infants the stages of early speech development are well described by several researchers (see 3.1). If we want to know whether HI infants undergo the same stages and at the same age or later as NH infants, we can compare the stages specifically. Most studies done on the speech development of deaf infants have focused on babbling or other stages in the development. For instance, Lenneberg et al. (1965) and Lenneberg (1967) claimed that hearing impaired infants, like normally hearing infants, started cooing at two to three months and start babbling at six to seven months. There are several reasons why this conclusion is probably incorrect. First of all, their conclusion was based on the study of just one deaf subject. Furthermore, systematic recordings had been made and analyzed only during the period between birth and three months of age, and not in the period hearing infants usually babble. Finally, the term babbling was perhaps not used only to refer to the canonical, reduplicated babbling, but also for the pre-canonical, marginal babbling or for cooing (see Table 3.1). The other problem with the Lenneberg study is that only some global descriptions comparing the stages of HI infants and NH infants were given. Some other studies also suffer from the same problem. For instance Oller et al. (1985) mentioned that the HI infant they studied between eight and thirteen months of age produced vocalizations which resembled that of four to six month old NH infants.

The vocalization development stages can be used as a starting point for comparing vocalizations of normally hearing and hearing impaired infants, by designing a procedure of analysis, which enables classification of each utterance related to these early speech development stages. Since both articulation and phonation are involved in the developmental stages in all models, such an analysis procedure should include both. So far, no studies based -to our knowledge- their method on the analysis of *each* infant utterance related to all stages of vocalization development. In our study each infant utterance was related to the vocalization stages. The results are presented in Chapters 7 and 9.

In some studies each utterance was analyzed separately but the focus was on the babbling stage only. Oller et al. (1985) and Oller and Eilers (1988) calculated the ratio of the total number of canonical syllables to the total number of utterances, as a measure of whether the child had started to babble (ratio 0.2 or more). In these studies it was shown that seven deaf infants did not start babbling before eleven months of age, unlike all nine hearing subjects who produced canonical babbles before ten months of age. It was concluded that the traditional belief that deaf infants produce the same kinds of babbling sounds as hearing infants is wrong and that audition plays an important role in infant vocal development. According to Spencer (personal communication, 1994) babbling before about eleven months always implies usable residual hearing. Kent et al. (1987) studied the sound utterances of a deaf infant and his hearing twin brother at 8, 15, and 20 months. They showed that the deaf infant produced only one babbled utterance during the speech sample at eight months of age while his brother babbled frequently at the same age. The HI infant started babbling at 20 months of age. Thus the babbling stage seems to be delayed in HI infants compared to NH infants. Unfortunately in none of the previous studies systematic information was collected on the pre-babbling stages, such as cooing and variegated phonation. Our results with respect to all vocalization stages are presented in Chapter 9.

3.3.6 Summary

In this thesis we want to answer the question from which age onwards hearing influences the vocalization development of infants, and in what way. Unfortunately only few studies have previously been done on this topic, and even fewer within the first half year of life. Although some of these previous studies indicate that the vocalization development might be different between HI and NH infants, contradictory and unclear results were found on several points. This is probably due to methodological problems, such as small subject groups. Some studies described only one or two subjects.

No systematic longitudinal study with several subjects has been performed on aspects such as number of utterances (see also section 3.3.1), utterance structure (see also section 3.3.3), duration and F0 (see also section 3.3.2) of non-cry sound productions of deaf infants from the first half year of life onwards. The number of syllables produced by HI infants have been studied to an even lesser extent, and was unfortunately not compared to the number of syllables of NH infants (see also section 3.3.3). With respect to place and manner of articulation of these consonants contradictory results were found (see also section 3.3.4).

In the most of the studies describing the developmental stages of HI infants, often only a general description of the sound utterances in a certain period is given. In none of the studies each utterance has been analyzed with respect to the vocalization development stages. Only the babbling stage has been studied more thoroughly. It has been concluded that babbling is probably delayed in HI infants compared to NH infants. Unfortunately none of the previous studies have reported systematically on the pre-babbling stages, such as cooing/gooing/one articulatory movements stage or the reduplicated babbling/canonical babbling/babbling stage (see section 3.1).

3.4 Influence of hearing on vocalization development: proposing a model

In section 3.2 it has been discussed that vocalization development is influenced by several factors such as parent-infant interaction and anatomy. We related the stages in vocalization development to the development of these factors and concluded that these stages are related to the development of each of the factors. From section 3.3 we have some indications that hearing also has an influence on the vocalization development. However, it is not clear in what way exactly hearing influences the vocalization development. We assume that hearing (loss) has no direct influence on the vocalizations, but indirectly via some of the factors. Therefore we will first discuss the relationship of hearing with each factor in section 3.4.1. On the other hand, in case vocalizations are absent or deviating they might influence the development of some of the factors, such as neurological development or the development of auditory processing. This issue will be discussed in section 3.4.2. Then in section 3.4.3 we will propose a model for vocalization development based on the relation between the hearing and the factors, as well as the relationship between the factors and the vocalization development.

3.4.1 Influence of hearing on the factors

With respect to auditory speech and language processing, we found that several important stages in auditory speech processing occur before birth and during the first year of life. We therefore concluded that auditory speech and language processing influences vocalization development from the cooing/gooing/one articulatory movements stage onwards with respect to prosody and from the babbling/nonreduplicated babbling/variegated babbling stage onwards with respect to segmental information (see 3.2.2). Hearing definitely influences the development of speech processing. Parts of the auditory processing development are definitely learned; e.g. recognizing the mother's voice and tuning in on the segmental and supra-segmental information of the own language. These parts are definitely expected to be influenced by a hearing loss, since the child needs to process the language input auditory to be able to develop these skills. Therefore, in a causal chain we expect influence from hearing via the auditory speech and language processing on vocalizations from the cooing/gooing/one articulatory movements stage onwards with respect to prosody and from the babbling/nonreduplicated babbling/variegated babbling stage onwards with respect to segmental information.

Several studies have emphasized the influence of parent-infant interaction and language input on early speech and language development (see 3.2.1). Moreover, we expect that hearing has an influence on these factors. A hearing loss in an infant might affect the interaction with his parents and their language input. If we combine these two expectations, we also might expect that hearing loss, which makes the spoken input less accessible, will have an influence on vocalizations.

Spencer (1993) concluded that the hearing mothers of the HI infants (12 and 18 months) produced more gestural and tactile communication compared to the mothers of the hearing infants. The number of spoken utterances did not differ between the two groups of mothers. On the other hand, in somewhat older children, the study of Lederberg et al. (1989) suggests a smaller amount of spoken language of hearing mothers communicating with their HI children (between 22 and 36 months) compared to mothers talking to their NH children of the same age. Also Van den Bogaerde (2000) found a clear effect of the hearing loss in children on the form of the language input they received from their HI mother. HI children (1-2 years) received more Sign Language of the Netherlands (SLN) and less spoken Dutch, and NH children received more spoken Dutch and less SLN from their mothers. Thus, although it is not clear yet from what age onwards, we expect that the amount and form of the parent-infant language input is influenced by the hearing loss of HI children. Therefore, we expect with respect to this aspect, an effect from hearing loss on parent-infant interaction and language input.

In NH infants it was found that a higher number of utterances was elicited by the parent-infant interaction during the cooing/gooing/one articulatory movements stage (see section 3.2.2). We do not know whether this process is the same in HI infants compared to NH infants, since it is not known what aspects influence this process. If the auditory part of the spoken language of the parent elicits the higher number of infant utterances we expect in HI infants fewer utterances in this stage compared to NH infants. On the other hand, if the visual part of the spoken language input also affects the number of utterances, we expect no differences in number of infant utterances in HI infants in this stage.

On the other hand, we might expect an influence from prosodic aspects of the spoken language input on the production of these prosodic aspects already in the cooing/gooing/one articulatory movements stage as argued in section 3.2.2). Therefore, although the influence of hearing via parent-infant interaction and language input on cooing/gooing/one articulatory movements stage is unclear with respect to number of utterances, we might expect an influence on the prosodic features of the vocalization in this stage.

In NH infants turn-taking starts around three or four months during the vocal play/expension/variegated phonation stage (see section 3.2.2). We have no information about turn-taking behavior in spoken interaction with HI infants within the first year of life, but we assume that it will be affected by hearing loss, since a deaf child is not able to hear the pauses in his parents speech that indicate his turn to vocalize. Therefore we assume that hearing affects the vocalization development from the vocal play/expension/variegated phonation stage onwards.

Moreover, during the babbling stage spoken language input might have more influence on the vocalizations, since it can be seen that in that period the segmental part of vocalizations of NH infants are influenced by the environmental language (see also section 3.2.2). Therefore we might expect influence from hearing in the babbling/nonreduplicated babbling/variegated babbling stage.

Vocalizations are probably also influenced by internal feedback from the cooing/gooing/one articulatory movements stage onwards (see section 3.2.3). It seems likely that a loss of hearing will result in problems in internal feedback, at least with respect to the auditory internal feedback (the possibility for the child to hear himself). Therefore, we expect that hearing (loss) has an influence on the development of vocalizations via this factor from the cooing/gooing/one articulatory movements stage onwards.

On the other hand, we have no reason to expect that loss of hearing will directly result in problems with anatomy, physiology and neurology of the speech organs. Also we do not expect that a lack of hearing affects the (non)verbal cognitive development. Schick, De Villiers, De Villiers and Hoffmeister (2002) found equal socio-cognitive development (theory of mind) in deaf children from deaf parents compared to normally hearing children of four to eight years. On the other hand, hearing might have an indirect influence on several factors as will be discussed in section 3.4.2.

To summarize, we expect that hearing has a direct influence on parent-infant interaction and language input, auditory speech processing and internal feedback. Since these factors have an influence on the vocalization development, we expect also an influence from hearing on vocalizations via these three factors. This influence might start from the cooing/gooing/one articulatory movement stage onwards, especially with respect to prosodic features in infant vocalizations.

3.4.2 Indirect influence of vocalization development on the factors

We have shown in sections 3.2 and 3.4.1, that we expect that several developmental aspects, including hearing, will influence early vocalizations. The picture is more complex, however, since the production of vocalizations in turn might influence these aspects of development.

It is likely that the children's vocalizations have an influence on the parent-infant interaction and the speech and language input. Mothers of three month old infants produced more spoken language in response to the speech sounds of their children than in the months before, especially if the sounds contained syllables including consonants (Bloom, 1988, 1998). Thus, it is plausible that there is a relationship between the vocalizations of infants and the spoken language of their mothers. For instance if an infant does not vocalize at all or in an extremely different way compared to other children, the parents might adjust their interaction or their speech input.

It is also plausible that the production of vocalizations affects the development of the auditory speech processing via their internal feedback. The auditory speech and language processing, as well as the internal feedback system develops need training in order to develop fully (see also 3.3.1 and 3.3.2). If a child produces few vocalizations, the auditory speech processing of his own vocalizations might be influenced. This might affect the development of the auditory pathways. Therefore, few or abnormal types of vocalizations might influence the development of the internal feedback.

We also might expect that the form or amount of vocalizations will affect the cognition of an infant. A deviating language development seems to influence cognitive development (Johnson, 1985). Also Schick, Hoffmeister, De Villiers and

De Villiers (2002) found slower socio-cognitive development (theory of mind) in four to eight years old deaf children from hearing parents compared to normally hearing children and deaf children of the same age from deaf parents. They conclude that a delayed language development might influence the total cognitive development. However, it is not clear whether we can expect an influence of a deviant vocalization development on cognition. The tracheostromized child studied by Locke and Pearson (1990; see also 3.2.5) could not vocalize between 5 and 20 months of age, but had a normal cognition and near-normal language comprehension. Therefore, the influence of vocalizations on cognition is not clear yet (see also 3.2.4).

We have no reason to expect that the form or amount of vocalizations will effect the anatomical structure of an infant. On the other hand, an influence of vocalizations on the physiology and neurology of the speech organs, via tactile or propioceptive[10] internal feedback cannot be totally excluded (see also 3.2.5). For instance, if a child produces few or abnormal types of vocalizations, it might effect the development of both physiology and the neurological pathways for the speech organs normally involved (see also 3.2.6).

To summarize: it is likely that vocalization development in turn influences several developmental aspects. The factors parent-infant interaction and speech input, auditory speech and language processing, internal feedback, physiology and neurology are probably influenced by vocalization development. The effect of the factor cognition is unclear and anatomy is not expected to be influenced by the vocalizations.

This implies that, if hearing loss causes deviating vocalizations via one or more factors (see section 3.4.1), an abnormal development of vocalizations this might in turn influence these aspects indirectly. Moreover, these factors might even affect vocalization development. We therefore cannot exclude neurology, physiology and perhaps cognition as factors influenced indirectly by hearing (loss) (see sections 3.2.7 and 3.2.8).

3.4.3 Discussion: interaction of developmental aspects

Early speech development is influenced by several aspects of development. These aspects are: auditory speech processing (see section 3.2.1), parent-child interaction and speech input (discussed in 3.2.2), internal feedback (3.3.3), cognition (3.3.4), anatomy and physiology (3.3.5) and neurology (3.2.6). With respect to some developmental aspects a change takes place in a certain time period and we assume that those changes might be related to or even are responsible for the onset of a new stage.

Hearing (loss) might influence three of these factors directly, namely parent-child interaction and speech input, auditory speech processing, and internal

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[10]Proprioceptive feedback is the system which gives a person information about his own movements.

feedback (see section 3.4.1). On the other hand, as discussed in section 3.4.2 it is possible that the vocalizations also have an influence on these aspects of development. Few or abnormal types of vocalizations might affect the development of physiology, neurology and maybe cognition. Therefore, hearing might influence the vocalization development via these aspects indirectly. We expect no influence from hearing (loss) on anatomy. Figure 3.3 presents a model of our expectations of the way hearing affects the vocalization stages. The direct effects of hearing on the factors are displayed with a bold arrow, while the indirect effects are shown with a dashed arrow. Plausible effects from hearing on the stages are shown with a dark grey cell, the unsure effects are light gray and no effect is displayed white.

We expect that during the first one or two stages from birth onwards, the reflexive or phonation stage with uninterrupted phonation and interrupted phonation, the vocalizations are mainly influenced by anatomy and physiology, while the effect of neurology in that period is unclear (see section 3.2). The velum muscles cannot actively lift up the velum yet and the air stream goes mainly via the nose and not via the mouth in newborns. Anatomy is not influenced by hearing and does not affect vocalizations in this stage directly or indirectly. Physiology and neurology are both factors that might be indirectly influenced by hearing. If no deviant vocalizations are expected in this stage, also no indirect influence is expected via these factors in this stage (see section 3.4.2). Thus: we do not expect that hearing affects this stage (see Figure 3.3).

It can be expected that the cooing/gooing/one articulatory movement stage is influenced by several factors. Anatomical and physiological changes are probably involved, since in that period the tongue and the velum are close together, with the jaw and the tongue in rest position. Therefore the air stream between the velum and the tongue makes both articulators vibrate, producing back trill-like or fricative-like sounds. Moreover, the infants can produce a longer utterance duration in the same period, as well as more variation in their phonation, which is probably influenced by a higher sub-glottal air pressure due to a restructuring of the rib cage (see also section 3.2.5). The influence of neural development of the speech organs as well as cognitive development on this stage are not totally clear from previous studies (see section 3.2.4 and 3.2.6).

On the other hand, we expect an influence from parent-infant interaction and language input, auditory speech processing and internal feedback on vocalizations in this stage and mainly with respect to prosody. We also assume that these factors are directly affected by hearing in this early stage. Therefore we expect that hearing affects this stage (see Figure 3.3). However, we expect that mainly the prosodic features of the vocalizations are affected in this stage, as discussed in section 3.4.1 for these three factors separately. As discussed in section 3.4.1 the influence of hearing via parent-infant interaction and language input on this stage is unclear with respect to number of utterances.

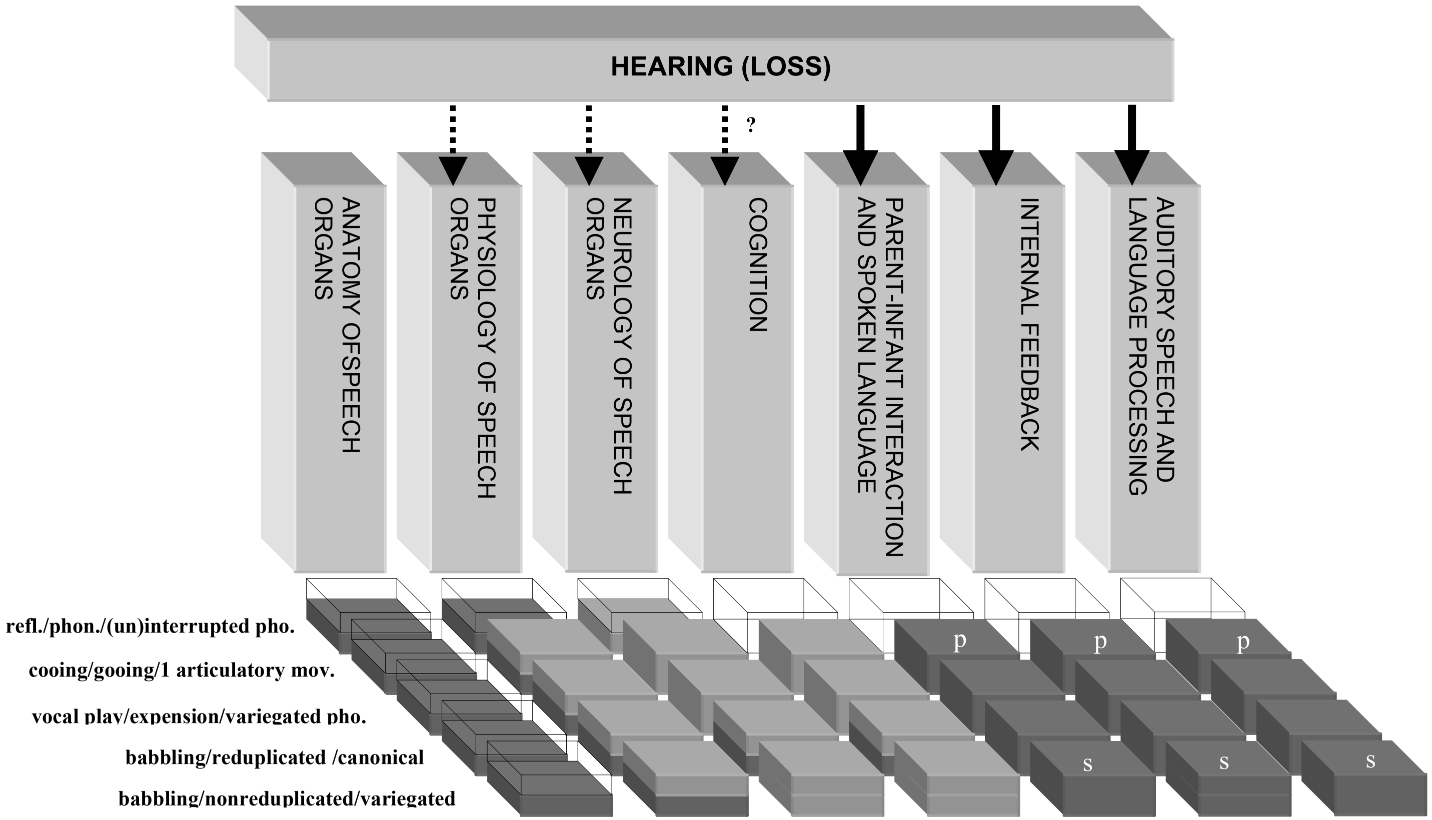

Figure 3.3. Adjusted model (see also Figure 3.2): Model of factors influencing the vocalization stages. The bottom cells represent the influence of the factors on the vocalization development stages. The upper cells represent the influence of the hearing on the vocalization stages via these factors. Transparant=no effect, dark grey is assumed effect, light grey is uncertain effect. Dashed arrow is indirect effect and ?=unclear effect. p=prosody, s=segmental information

Moreover, as argued in section 3.4.2, most aspects might be influenced by vocalization development and hearing might affect this stage indirectly via these aspects. Language input and parent-infant interaction, auditory speech and language processing and internal (auditory) feedback might be influenced by a abnormal vocalization pattern. Also physiological, neurological and may be cognitive development, that are not directly influenced by hearing loss, might affect by abnormal vocalization development, which in turn may be affected by deviant or delayed development in these areas. Therefore, it can not be excluded that hearing affects this stage via the indirect influence of these three factors.

The vocal play/expansion/variegated phonation stage might be influenced by several factors. Anatomy and physiology might have an influence in that stage. For instance, the mandible grows more downward, giving the jaw and tongue more space to move, which implies that the tongue and lips are able to vibrate more. Also the descending larynx explains a variety of new types of vocalizations in this stage (see also section 3.2.5). We expect that this stage is also influenced by parent-infant interaction, since it is known that turn-taking starts from this period onwards (see also section 3.2.1). Moreover, we expect that auditory processing and internal feedback needs to be developed in order to be able to hear the spoken language input and to respond to it during the turn-taking process (see also section 3.2.2). The effect from neurology and cognition on this stage is not totally clear from previous studies.

As discussed in section 3.4.2 we expect that hearing has influence on the this vocal play/expansion/variegated phonation stage directly via parent-infant interaction and language input, auditory speech and language processing and internal feedback. We might also expect indirect effect from hearing via physiological, neurological and may be cognitive development, on this age. Therefore, similarly to the previous stage, it can not be excluded that hearing affects this vocal play/expansion/variegated phonation stage via the indirect influence of these three factors (see Figure 3.3).

Also the babbling/reduplicated babbling/canonical babbling stage might be influenced by several factors. Changes with respect to anatomical and physiological development might have influence. It becomes anatomically and physiologically possible to move the jaw freely up and down in case of babbling and chewing. Also the neurologic development might have more influence on this stage, and several studies have pointed out a relationship between the start of the babbling stage and other repetitive motor behavior such as clapping and rocking (see also section 3.2.6). Also internal feedback (see also Chapter 3.2.3) and cognition (see also 3.2.4) seem to affect this stage, since the babbling onset was delayed in infants without internal feedback and delayed cognitive development. Therefore hearing probably affects the onset of the babbling stages in several ways, both directly (via spoken language input, auditory speech processing and internal feedback) and indirectly (via physiology, neurology and maybe cognition) (see Figure 3.3).

In the babbling/nonreduplicated babbling/variegated babbling stage hearing is expected to affect the vocalization development directly (via spoken language input, auditory speech processing and internal feedback) and indirectly (via physiology, neurology and maybe cognition). Probably spoken language input and auditory speech processing have an influence on the vocalizations, since it was shown that NH infants produce more articulations similar to that of the environmental language in that stage (see also Chapter 3.2.1 and 3.2.2). Therefore we expect that hearing affects this stage even more and especially with respect to the segmental features of the vocalizations (see Figure 3.3).

To conclude: we expect not much influence from hearing in the first stage (reflexive/phonation/uninterrupted phonation stage and interrupted phonation stage). More influence of hearing is expected in the cooing/gooing/one articulatory movement stage especially with respect to prosodic features (see Figure 3.3). Moreover, the model predicts that hearing has also an influence on the onset of the vocal play/expansion/variegated phonation stages and the babbling stages. Therefore we expect that the onsets of these stages are delayed in HI infants compared to NH infants or that these stages are produced somewhat different by HI infants compared to NH infants (if they are very differently, we can not identify patterns in the vocalizations as a stage). However, in that case it is not possible to predict exactly in what way hearing affects the vocalization stages, since hearing influences the vocalization development in interaction with several factors. It is possible to evaluate our model presented in Figure 3.3 by analyzing the vocalization development of HI infants compared to NH infants. In the section 3.5 we will address our research questions with respect to several aspects of the vocalization development of both NH and HI infants in order to be able to answer our main research question. In Chapter 9 we will re-evaluate the model after discussing the results of our research questions described in Chapters 5, 6, 7 and 8.

3.5 Research questions

Several research questions will be studied with respect to a number of aspects that have been discussed in sections 3.1 to 3.4.

With respect to quantity of vocalizations and relation to the spoken language input (results see Chapter 5):

1. Do deaf infants produce more or fewer utterances than hearing infants and from which age onwards?
2. Do mothers of deaf infants produce more or fewer utterances than mothers of hearing infants and from which age onwards?

With respect to development of prosodic characteristics[11]: (results see Chapter 6)

3. Do deaf infants produce utterances with a longer or shorter duration than hearing infants and from which age onwards?
4. Do deaf infants produce a different F0, than hearing infants with respect to mean F0, maximal F0, and minimal F0, and F0 variation and from which age onwards?
5. Do deaf infants produce more or fewer voiceless utterances than hearing infants and from which age onwards?

With respect to utterance structure and utterance type (results see Chapter 7):

6. Do deaf infants produce different types of utterance structures, such as CV, VC or CVCV, than hearing infants and from which age onwards?
7. Do deaf infants produce more or fewer syllables per utterance, and from which age onwards?
8. Do deaf infants produce different articulation and phonation types of utterances than hearing infants, such as babbling and variegated phonation, and from which age onwards?

With respect to segmental characteristics[12] (results see Chapter 8):

9. Do deaf infants produce more or less variety of different consonantal articulation categories than hearing infants and from which age onwards?
10. Do deaf infants produce different consonantal articulation movements than hearing infants with respect to place and manner of articulation and from which age onwards?

And overall (results see Chapter 9):

11. Do we find relationships between the results of the aspects studied?
12. Can we relate the results of the different aspects studied to the speech development stages?
13. Do we need to adjust our proposed model for vocalization development?

In Chapters 5 to 9 we will present our data and try to answer our research questions. However, first of all, in the following Chapter 4 the research methodology will be discussed, including the description of the twelve subjects, and the description of the recording sessions.

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[11] With the restrictions of a Ph.D. project there is a limit of the number of aspects that can be analyzed. With respect to prosodic characteristics also other aspects can be studied such as intonation patterns. We choose to study utterance duration and F0, parameters that could be studied acoustically, for both practical as well as reliability reasons. Another possible type of acoustical measurement, intensity, is not performed in the present study either. The reason for this decision is that we had no possibility to control the recording situation sufficiently enough (for instance distance to the microphone, recording volume) enough, which is needed for measuring this parameter.

[12] We decided to restrict ourselves to consonantal features and did not study vowels, e.g. formant frequencies, in this part of the study. Results of vowel formant frequencies of the same infants as in the present study are presented in Van der Stelt, Wempe and Pols, 2003.

Chapter 4

Methodology

This chapter focuses on the experimental design for this longitudinal study on six deaf and six hearing infants. The first section describes the subjects participating in this study. The infants are matched in pairs, thus, each of the six hearing impaired children was matched with a hearing infant. In the next section the hearing impaired infants are described in more detail, with respect to their hearing status and language method used by the parents. The third section explains the way the data are collected by audio and video recordings and the last section gives preliminary information on the procedure of analyses described in more detail in Chapters 5, 6, 7, and 8.

4.1 Subjects

Twelve mother-infant pairs participated in this study: six infants who were deaf according to the European classification (see Chapter 2.1) (group HI) and six matched infants with normal hearing (group NH). All infants have normally hearing parents.

The criteria for participation of the HI infants were:

- a congenital loss over 90 dB PTA[1]
- maximum age of 6 months at start of the recordings
- no additional disabilities or health problems
- normal cognitive development
- normal motor development
- normal mouth motor development
- normal pregnancy duration
- hearing and cooperative parents

Because we were interested in the effect of a maximal lack of hearing on the vocalizations of infants, we decided to include infants which were diagnosed as deaf according to the European classification (see Chapter 2.1). Moreover, we wanted to include infants at maximum age of six months, since very little information is known about the vocalizations of deaf infants within the first year, and especially within the first half year of life (see also Chapter 3.3). As described in Chapter 2.3 it is difficult to find deaf infants within the first half year of life. However, nowadays

[1] PTA=Pure Tone Average, see also Chapter 2.1.

reliable objective audiometry is possible within the first months of life, which makes it possible to perform this study and to start at this early age.

Only infants without additional health problems were included, since we aimed to study the effect of the lack of hearing, without the interference of other factors. Normal health was an important criterion, since 30 to 40 percent of the HI have additional health problems (see also Chapter 2.2). To exclude health problems, we relied on the health screening right after birth on the basis of the Apgar score[2]. We included only infants born after normal pregnancy duration, to exclude high risk infants. It was required that the parents had normal hearing and were cooperative because they were supposed to make the recordings themselves.

The selection criteria for the NH infants were as following:
- maximum age of 2.5 months at possible start of the recordings
- neither hearing problems of the child, nor of any direct family member,
- no disabilities or health problems
- normal cognitive development
- normal motor development
- normal mouth motor development
- normal pregnancy duration
- hearing and cooperative parents
- meeting the matching criteria (see below)

The age of 2.5 months was chosen for the NH infants for starting the recordings, because the earliest recording of the HI infants was made from that age onwards. Only infants with normal hearing were chosen for obvious reasons. We only selected NH infants with no family history of hearing impairment. This was done since hearing problems are very often genetic (see also Chapter 2.2), and a family history of hearing loss would increase the chance of finding a hearing problem in an infant from the NH group. We included only infants without health problems and born after normal pregnancy duration, since we wanted to study normal development, without the interference of other factors. It was required that all parents had normal hearing and were cooperative because they were supposed to make the recordings themselves[3].

Furthermore, the infants had to meet five matching criteria. We wanted to exclude the influence of additional factors, other than the hearing of the infants, as much as possible. The factors birth order within the family, age of the mother, and socio-economic status of the parents, might influence mother-infant interaction and

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[2] The Apgar score gives an indication of the health of the newborn by checking the color of the skin, alertness, muscular tension, the breathing, and heart beat.

[3] Unfortunately the instructions were not followed sufficiently in the case of one family with a hearing infant, so the recordings had to be stopped. A new subject (NH-1) was found and the recording procedure started from 2.5 months.

therefore the vocalizations of the child (see Chapter 3.2.1). Also, we matched the dialect of spoken Dutch of the parents, since dialects might contain different sound repetoires and intonation patterns. Studies of the environmental language on the vocalization development, show that a consonant repertoire and intonation have an influence (see Chapter 3.2.1 and 3.2.2), therefore we considered the possibility that a dialect of the parents could have an influence. It turned out to be impossible to keep these factors equal for all infants as a group, and to study for instance, only boys. Therefore, we decided to match the HI and NH individually.

The NH infants were matched in pairs with the HI infants on the following criteria:

- sex of the child
- birth order within the family
- age of the mother
- socio-economic status of the parents
- dialect of the parents

The age of the mothers of each matched pair at the moment the child was born was not allowed to differ by more than 5 years, because of a possible difference in interaction between mother and child due to the age of the mother. The socio-economical status of the parents was determined using two measurements: the highest level of education of the mother and the highest educational level of the father. Education was classified in three levels: 'low' (only primary school), ‘middle’ in case of middle level education (LBO or MBO in the Dutch educational system) and ‘high’ in case of high level education (HBO (BA) or university (MA) level in the Dutch educational system). Also the type and amount of dialect of the parents and the geographical area the child is living in were considered.

The HI infants were found by contacting the Audiological Centers in the Netherlands. The hearing impairment could be diagnosed within the first six months (see also Chapter 3), because five of the six HI infants had an older hearing impaired sibling, and in the sixth case hearing impairment runs in the family (brother of the mother and sister of the father). The hearing status of the HI infants is described in more detail in the section 4.2. The NH infants were found in most cases with help of Infant Welfare Centers in the geographical neighborhood of the HI infants. The subjects NH-5 and NH-6 were found with the help of the parents of HI-5 and HI-6. In some cases more than one family was available and a choice had to be made after an interview by phone with the possible candidate parents.

In Table 4.1 the characteristics of the infants are summarized in pairs. The age of the subjects at the start of the recordings was 2.5 months for all NH infants, but differed between 2.5 and 5.5 months for the HI infants. Sex of the subjects and birth order in the family was identical in each matched couple. The duration of pregnancy was for all children 40 ± 2 weeks, which can be considered as normal, except for the mother of HI-6, who was born after a pregnancy duration of 37 weeks. No correction for differences in pregnancy duration was made. The measure of socio-economic status is indicated once if it was the same for the mother and father. In case of differences both levels are shown, the mothers' level is shown first. In almost all children both levels were the same, except for HI-5. It turned out that low level education (only primary school) did not occur. The dialect used in the environment and by both parents is expressed by two parameters, the type and the strength. The dialect of the parents was similar to the environmental dialect in all cases. Most of this information was collected by the Audiology Centers and Infant Welfare Centers and was passed on to us. However, we confirmed it in an interview with the parents of all infants, before starting the recordings.

Table 4.1. The main characteristics of the subjects and their parents. Sex of the infant: M=Male, F=Female. Birth order: the first number is the number of the subject in the family, the second the total number of children in the family at the time this study was carried out. Age of the mother: at the moment the child was born.

Subject	Age start record. (months)	Sex of the infant	Birth order	Pregnancy Duration (weeks)	Age mother (years)	Socio-economic status	Dialect type	Dialect strength
HI-1	2.5	M	2(2)	41	29	Middle	South	Strong
NH-1	2.5	M	2(2)	40	28	Middle	South	Strong
HI-2	5.5	M	2(2)	40	29	Middle[4]	Veluwe	Light
NH-2	2.0	M	2(2)	40	25	Middle	Veluwe	Light
HI-3	5.5	M	2(2)	41	29	Middle	Achterhoek	Strong
NH-3	2.5	M	2(2)	40	28	Middle	Achterhoek	Strong
HI-4	2.5	M	2(2)	40	32	High	Twente	Light
NH-4	2.5	M	2(2)	40	30	High	Twente	Light
HI-5	3.5	M	2(2)	40	32	Mid/High	North	None
NH-5	2.5	M	2(2)	40	28	Middle	North	None
HI-6	5.5	F	3(3)	37	27	Middle	Randstad	Light
NH-6	2.5	F	3(3)	40	26	Middle	Randstad	Light

No significant health problems were found in a health screening right after birth by measuring the Apgar score. All infants had at least 8 out of the maximal 10 points at the Apgar score. At 12 and 18 months of age eleven infants were examined on the Denver Developmental Screening test (Frankenburg, Dodds and Fandal, 1973). The infant HI-1 was tested only once at the age of 15 months. The Denver Developmental Screening test examines social, adaptive, language and motor behavior. The language part was not evaluated for the HI infants. The development of all infants was found to be normal, with the exception of infants HI-3 and HI-6 who showed some problems with motor development (such as walking at relatively late age).

[4] The mother of HI-2 was an educated pre-school teacher.

The Mental scales of the Bayley Developmental Scales (Bayley, 1969, 1993; translated into Dutch by Van der Meulen and Smrkovsky, 1983) were also used to test the cognitive development at 12 and 18 months of age. The non-verbal version of the test was used with the HI infants and the verbal version with the NH infants. All tests are carried out by the author except the test at 18 months for subject HI-6, which was performed by a psychologist. The result of the test was expressed as a K-score[5]. The average K-score for the HI group was 7.25 and for the NH group 7.5 and the scores were not significantly different according to a Mann-Whitney U-test. Only one of the infants, HI-6, scored insufficient on the Bayley scales at both 12 and 18 months, namely a K-score of five, while on a scale of ten, six or above was sufficient. The K-score of the tests of all infants is shown in Table 4.2.

Table 4.2. The average K-scores of the Bayley Developmental Scales for the subjects. The test age is in months, Average score stands for average of 12 and 18 months.

Subject	Test age (Months)	K-score NH	Average Score
NH-1	12 18	9 8	8.5
NH-2	12 18	8 8	8
NH-3	12 18	8 6	7
NH-4	12 18	8 8	8
NH-5	12 18	7 7	7
NH-6	12 18	7 6	6.5
Mean		7.5	7.5

Subject	Test age (Months)	K-score HI	Average Score
HI-1	15	9	9
HI-2	12 18	9 9	9
HI-3	12 18	6 6	6
HI-4	12 18	6 8	7
HI-5	12 18	7 8	7.5
HI-6	12 18	5 5	5
Mean		7.25	7.25

Additionally, all parents were asked to fill in a questionnaire, with the aim to exclude problems with motor development of the mouth of their infant. It included questions about eating and drinking behavior of the child, for example: at which age did the child start to chew, does the child slaver more than normal, does the child choke on food more often than three times a meal, and so on. None of the subjects had this type of problem.

[5] The Kouweriaanse score is preferred and advised by the Dutch translators, instead of the QI score. It is a scale from 0 to 10, sufficient is 6 or more.

None of the mothers worked full-time or almost full-time outside home and all fathers worked outside home during the period the recordings were made. It was important that the parents were cooperative and had enough spare time to participate in the project, because it was rather time consuming for the parents to make the recordings themselves. Also, the visits at home by the researchers (see also Chapter 4.3) were time consuming for the parents. In some cases (HI-3 and HI-6) the profession of the father was exactly the same in case of the HI subject and the matched hearing subject. The fathers of HI-3 and NH-3 both were farmers, and were involved more than average with the family. The fathers of HI-6 and NH-6 were both fishermen and were often not at home for periods of several weeks.

4.2 Subjects' hearing and related issues

The hearing of all normally hearing infants was observed to be normal as established by means of the Ewing test at age 9-11 months at an Infant Welfare Center. NH-2 had some ear infection problems starting from the age of eight months. These were treated with medication. As can be seen in Table 4.3 all HI infants had an average hearing loss of over 90 dB (PTA) in the best ear, established within the first six months of life by Auditory Brainstem Response audiometry (ABR, see Chapter 2.3.2) in five infants (HI-1, HI-2, HI-3, HI-4 and HI-5) or Electrocochleography (EcoG, see Chapter 2.3.2) in HI-6. The profound hearing loss was confirmed by several pure-tone audiometric tests at later ages. All HI infants except HI-2 had hearing impaired older brothers or sisters and were born as second child in the family, except HI-6 who has an older hearing impaired sister and an older hearing brother.

Two HI infants were raised mainly by the Oral method, two infants by Total Communication (TC), and two with a combination of Sign Language of the Netherlands (SLN) and Total Communication. In both families of subjects HI-4 and HI-5 a shift was made to more SLN and less TC during the recording period. It should be emphasized that the study was not designed to relate the results of the analyses to the language methods used. To be able to come to statistically more reliable results, larger number of infants per group should be involved. All HI infants participated in early intervention programs, including hearing training (see Chapter 2.4). In Table 4.3 the relevant audiometric characteristics of the HI subjects are presented. The indicated hearing losses for the HI infants in Table 4.3 were based on the most recent audiometric test per subject, by averaging response levels at 500, 1000 and 2000 Hz (Fletcher index). The age at the moment the test was performed is also indicated.

Table 4.3 The main audiometric characteristics of the six HI subjects. PTA= average loss at 500, 1000 and 2000 Hz at best ear. HA = Hearing Aids.

Subject	Hearing loss PTA (dB)	Age last test (months)	Loss (dB) with HA in last test	Age of diagnosis (months)	Age start HA (months)	Language method
HI-1	97	45	55	1.5	2.0	Oral
HI-2	93	37	55	3.0	3.5	TC
HI-3	110	32	65	4.0	4.5	Oral
HI-4	> 120	26	not tested	0.5	no HA	SLN/TC
HI-5	120	26	not tested	3.0	6.5/no HA	SLN/TC
HI-6	> 100	30	> 100	5.0	7.5	TC

Observational audiograms, made within 18 months (if available) of the six hearing impaired subjects, are shown in Apendix Figure A4.1. All infants had an unaided loss of over 90 dB PTA as indicated in Table 4.3, but differences in residual hearing and in the form of the audiogram can also be seen. HI-1, HI-2 and HI-3 had some residual hearing, but their curves were different: HI-2 and HI-3 had a steep audiogram with a high tone loss, while HI-1 had a more flat audiogram. HI-4, HI-5 and HI-6 had no or almost no residual hearing.

All hearing impaired subjects, except HI-4, used hearing aids. The hearing aids were used frequently by four subjects (HI-1, HI-2, HI-3, and HI-6) within the period studied. The type of hearing aids differed per subject. HI-1 and HI-6 used only 'behind-the-ear' hearing aids and HI-2, HI-3, and HI-4 started with 'box hearing aids' and used the 'behind-the-ear' model after some period, but still within the first year. HI-4 also had behind-the-ear hearing aids within the first months, but could not wear them due to a severe skin irritation. Also, already in the first months of the study it appeared that he had such a severe hearing loss, that he possibly could not make use of the hearing aids. HI-5 did not wear the hearing aid frequently. The level of hearing loss of the infants was not used as a variable in this study, since the number of subjects per group was too small to be able to perform reliable statistical tests.

4.3 Data collection

The recordings were made on the audio-channel of a Panasonic video recorder[6] (VHS NV-F 55 and 65 EV), with a unidirectional Sennheiser microphone (Black Fire 527). The audio recordings, lasting about half an hour each, were made every two weeks until the children were 12 months. The duration of the recording of half an hour was adapted on the basis of several other studies of vocalizations of hearing impaired infants and children (e.g. Oller and Eilers, 1988; Stoel-Gammon, 1988; Smith, 1982; Yoshinaga-Itano et al., 1992). Between 12 and 18 months of age the audio-recordings were made in general once a month, but in some cases still every two weeks[7].

Recordings started for all NH infants from the age of 2.5 months onwards up to 12 months (except NH-2 with whom the recordings started at 2.0 months). For two HI infants (HI-1 and HI-4) the recordings started from the age of 2.5 months onwards. With HI-5 the recordings started at 3.5 months and three HI infants were recorded from the age of 5.5 months onwards (HI-2, HI-3, and HI-6). We chose the home situation, in order to keep the situation as natural as possible. In the study of Lewedag et al. (1994) it was shown that both quantity and quality of infant vocalizations were higher with recordings at home than in a laboratory situation. We decided to restrict our recordings to audio-recordings and to make no video-recordings, for several reasons. Firstly, the audio-recordings alone gave enough information for the purpose of this study. Secondly, we asked the parents to make the recordings themselves for practical reasons. Thirdly, we expected that video-recordings would make it harder for the parents to behave naturally, and that audio-recordings are less intrusive. The recordings were made once every two weeks, but only the monthly recordings were analyzed. This made it possible to use the second recording as a reserve recording, if the first recording was not representative due to, for instance, illness of the child (the reserve recording was used in approximately 10 % of the cases). A total of 107 monthly recordings were analyzed. First, the *number*

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[6] Sound recordings on video had best quality at the time our recordings were made.

[7] At the age of 24, 30, and 36 months video recordings were made of the mother-child interaction of each of the HI infant-mother pairs and at the age of 24 months of the NH infants. Those video-recordings are not made by the parents, but by the researchers. The aim was to get an impression of the development of the language in total, including gestures and signing, as well as the spoken language development. These video recordings lasted at least 20 minutes each, 10 minutes in a naming situation with a picture book or puzzle, and 10 minutes in a free situation. The analyses of the audio-recordings from 12.5 months onwards and analyses of the video-recordings of 24 months onwards are not part of the present Ph.D. thesis. Some results of the audio- and video-data of five HI and five NH infants from 12.5 months onward have been reported by Van den Dikkenberg et al. (1998, see also Chapters 3.3 and 9.5). Also two-monthly video recordings of HI-1 during the first year of life in interaction with his speech-language therapist were available.

of infant and mother utterances were calculated. Subsequently 50 utterances of each recording (apart from one recording with only 31 utterances) were analyzed on several parameters, actually resulting in a total of 5381 utterances (see for our definition of utterance in section 4.4). No audio-recordings were made of subject NH-6 at the age of 9.5 and 10.5 months due to difficult personal circumstances in the family. However, we decided to keep the subject in the group. Unfortunately, the last recording of NH-6 did not contain more than 31 utterances and no reserve recording was available. An overview of the number of utterances analyzed per group and per month is shown in Table 4.4.

Table 4.4. An overview of the number of recordings and utterances classified per group and per month, and in total.

	NH		HI	
Age (months)	N recordings	N utterances	N recordings	N utterances
2.5[8]-3.0	6	300	2	100
3.5-4.0	6	300	3	150
4.5-5.0	6	300	3	150
5.5-6.0	6	300	6	300
6.5-7.0	6	300	6	300
7.5-8.0	6	300	6	300
8.5-9.0	6	300	6	300
9.5-10.0	5	250	6	300
10.5-11.0	5	250	6	300
11.5-12.0	6	281	6	300
Total	58	2881	50	2500

The mothers of the infants made the recordings themselves at home after having received full instructions. The instructions were given verbally and in the form of a book with guidelines. They consisted, for instance, of the following points:

- Keep the environment as quiet as possible during the recording (remove pet birds, toys with sounds, etc.).
- Talk with the child in a face-to-face situation, while the infant is sitting in an upright position.
- If the child does not produce a lot of sounds, or no representative sounds compared to his normal speech sounds, repeat the recording within a few days.
- Keep the distance between the mouth of the child and the microphone about 30 cm.
- Always check the recording afterwards to make sure that there were no problems.

[8] In this thesis 2.5 months of age means between two months and 10 days and two months and 25 days.

- Choose a moment when the infant normally produces a lot of sounds, for instance after feeding.

In order to keep the distance between the microphone and the mouth of the child at approximately 30 cm, the microphone was placed on a stand. The stand itself was placed behind the child, so as not to attract too much attention, and the microphone was directed to the child. Already during the recordings of the first months the child was sitting in an infant-chair, since laying down on the back the retracted tongue might cause a higher amount of velar/uvular sounds. By putting the infant-chair on the table, the face-to-face situation was encouraged. This was done to stimulate the parent-infant interaction, and to record the infant utterances with as high a quality as possible. It was also possible to put the infant-chair in the play-pen with the mother in front of the child, to achieve a natural situation. When the child could sit up on its own, the recordings were made with the child in a baby-chair, with the microphone in a similar position as during the first months.

At the end of the first year of life, and especially when the child started to walk during the second year of life, some mothers reported having trouble in getting the child to sit in a chair. In those cases we advised the parents to let the child sit in the play-pen to be able to keep the distance from the microphone still relatively stable. Only mother-infant recordings were used for analysis. The mothers were asked to keep the situation as natural as possible. They were advised to record in the living room, or another room familiar to the child, and to keep the recording equipment in that room to let the child get accustomed to it. They were also advised to stimulate the child to produce sounds, for instance: by playing with toys and to show him/her a mirror. In only one recording it was not possible to collect enough utterances (NH-6 at 11.5 months). After a preliminary testing period of two weeks the first recordings were globally analyzed and discussed with the parents. The author gave the parents regular feedback by visiting the family at home about every three months and by phoning them between the visits.

4.4 Overview of analyses procedure

In this section the general information is given applicable to all variables. Full details of the method of analysis used for each variable will be given in the corresponding chapter, prior to the presentation of the results.

Of every monthly audio recording until 12 months, all mother and infant spoken utterances during (at least) the first 10 minutes were transcribed (see also Chapter 5). An infant utterance was defined as a non-vegetative and non-crying sound production during one whole inspiration-expiration breath cycle; thus by definition it is not possible to produce several utterances during one breath cycle (Koopmans-van Beinum and Van der Stelt, 1986). No decision was taken on the state of the utterance as a word; that is whether the utterance was meaningful or not.

The transcriptions started approximately half a minute into the recording; usually the microphone distance had to be adjusted (resulting in noise caused by moving the microphone). The transcription started with the first infant utterance after 30 seconds. In principle the 10 minutes used for transcription were continuous, but in a few recordings two separate periods were transcribed in order to make up the 10 minutes. If the child cried, the transcription time was interrupted, and continued after the crying stopped. The mothers often stopped the recording themselves if the child was crying and continued once the child stopped crying.

Ten minutes were chosen instead of the full 30 minutes of each recording session, for practical reasons. Firstly, in Spencer (1993) ten minutes were chosen as time unit to count the number of utterances of hearing impaired and normally hearing infants, making it possible to compare some of our results with her results. Secondly, the infants, especially in the first months, often started to lose interest in the ‘conversation-situation’ after 10 to 20 minutes, and started to fuss or cry. Thirdly, we chose 10 minutes per recording, because it turned out to contain approximately 50 or more infant utterances on average, which was the amount we intended to use for several analyses. If fewer than 50 infant utterances were found within the 10 minutes (which was the case in nine recordings of the NH infants but in only one recording of the HI infants), the transcription continued until 50 utterances were transcribed. In this way at least 18 hours of mother-child interaction (108 recordings x 10 minutes) were transcribed (see also Figure 4.1).

Next, 50 infant utterances per recording were selected from the transcribed utterances occurring within the ten minutes (and if necessary longer). We chose 50 utterances of each recording, because during some recordings the children were more talkative than during other recordings, which would give an unbalanced result in, for instance, the number of babbled utterances per recording. Also, it would have been to labour intensive to analyze the total number of utterances found during the 108 x 10 minutes, resulting in 11274 utterances (4769 for NH children and 6505 for HI children). We decided therefore to limit the analysis to 50 utterances per recording per child, since 50 utterances allows statistical analysis.

The 50 infant utterances were selected from the total number of utterances within the 10 minutes. The main selection criterion for an infant utterance was that the utterance should be suitable for acoustical analysis, for example free of disturbance of the sound signal due to noises or clipping. Most recordings contained more than 50 such utterances. Secondly the utterances were selected in equal distribution over the ten transcribed minutes. For example if the ten minutes contained 150 suitable utterances every third utterance was chosen. If the recording contained fewer than 50 suitable utterances within the first 10 minutes, the first suitable utterances in the remaining of the recording (± 20 minutes) were added until the total of 50 utterances was reached. For a few recordings not enough disturbance-free utterances could be found. In those cases some utterances with some disturbance noise had to be added to be able to reach the total of 50 utterances. Only in one recording (NH-6 at 11.5

month) this was not possible; only 31 rather than the required 50 utterances could be extracted from the whole recording.

All 5381 infant utterances were digitized with a sample frequency of 48 kHz at 16 bits, and stored for further analysis. Our research questions (see Chapter 3.4), will be answered in the following chapters (see also Figure 4.1). Firstly, acoustical measurements were performed. The duration of all utterances was measured (Chapter 6). Next, the fundamental frequency (mean frequency, peak frequency, and variation of the frequency within the utterance and per subject) of the voiced utterances was measured (Chapter 6). Also, the number of voiceless utterances was established by acoustical and perceptual judgments (Chapter 6 and Chapter 7).

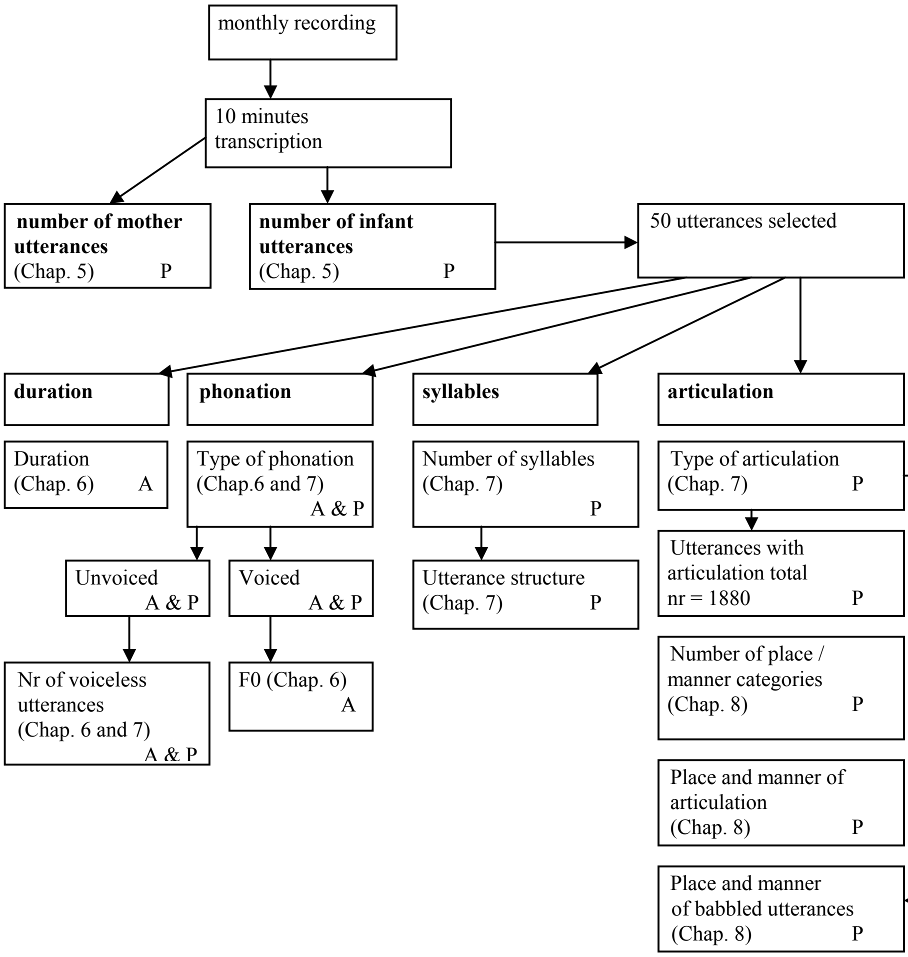

Figure 4.1. Overview of all variables used in this research and their relationship. P stands for Perceptual analysis and A stands for Acoustical analysis.

Next, all utterances were judged perceptually by the researchers. For the actual classifications all utterances were ordered in a semi-random way. That is, the 108 recordings were randomized, e.g. the recordings (across months and across infants) were randomized, but not the 50 utterances per recording. The utterances were made audible one by one, over an amplifier and a high quality headphone by clicking on the icon on the screen of the UNIX platform. If needed for making the judgement, further information was collected by creating an oscillogram or spectrogram. It was possible to listen to each utterance as often as needed.

Each of the utterances was classified according to one of five possible phonation types and one of three possible articulation types (Chapter 7). The number of syllables and syllable structure (e.g. babbling) of each utterance was established, and the moment of start of babbling for each infant was determined (Chapter 7). Of all utterances with consonant-like articulation, the consonant-like segments were classified according to their place and manner. The place and manner of the babbled utterances are reported separately (Chapter 8). Finally, the number of different consonant place/manner categories per recording was calculated (reported in Chapter 8).

The statistics were performed on the parameters studied in Chapters 5, 7 and 8 always in a similar way, or it was indicated if this was done otherwise. First of all calculations were made of the frequency of occurrence of a specific parameter, such as number of utterances or babbled utterances per month for both groups. Then the mean of all ten months combined was calculated and a t-test for paired samples was performed on this combined data. Next, to get some indication of developmental effects we performed statistical tests on the data of three months combined in order to have enough data to perform statistical tests. We performed running Mann-Whitney U-tests on these three-month periods while shifting one month at a time: a) 2.5, 3.5, 4.5; b) 3.5, 4.5, 5.5; c) 4.5, 5.5, 6.5; etc. We considered p=0.05 as minimal level for significance in all experimental chapters of this thesis. In the tables in all these chapters 'n.a.' indicated not available data. Age is expressed in months, 'NH' and 'HI' are the averages for these groups, 'running' or 'run' stand for the running averages and 'p' is the p-value as a result of Mann-Whitney U-tests or t-test.

Chapter 5

Number of utterances [1]

5.1 Introduction

In the present chapter we will report on the number of utterances of deaf and HI infants, and their mothers, during parent-infant interaction, within the first year of life.

The research questions with respect to this parameter were:

- Do deaf infants produce more or fewer utterances than hearing infants and from which age onwards?

- Do mothers of deaf infants produce more or fewer utterances than mothers of hearing infants and from which age onwards?'

In the previous studies done on the number of utterances of deaf infants compared to hearing infants, we saw conflicting results as described in Chapter 3.3.1. In some previous studies, a similar amount of utterances or fewer utterances were found for deaf infants of 12 months of age compared to hearing infants (Lenneberg et al., 1965; Lenneberg, 1967; Spencer, 1993 and Van den Bogaerde, 2000). Other researchers reported more utterances produced by deaf infants, compared to hearing infants within the first year of life (e.g. Gregory, 1985; Oller al.; 1985; Kent et al.; 1987; Locke and Pearson, 1992). Also, a peak in quantity for HI infants was reported, followed by a noticeable decrease after the first year of life (Mavilya, 1972; Maskarinec et al., 1981; Stoel-Gammon, 1986; Van den Dikkenberg-Pot et al., 1998).

Moreover, already from three to four months on, hearing infants learn turn taking behavior, that is, they learn to alternate the utterances with those of their parents as described in Chapter 3.2.1 (e.g. Berger and Cunningham, 1983; Ginsburg and Kilbourne, 1988; Bloom et al., 1987). We expect that deaf infants probably will not be able to learn this spoken turn taking in the same way and at the same time as hearing infants do. While a hearing infant learns to be silent during the turn of the parent, a deaf child may produce spoken utterances even during his parents' turn.

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[1] Substantially extended and revised version of an earlier publication (Clement et al.,1994)

Therefore, we might expect more utterances to be produced by deaf infants than by hearing infants during the first year of life.
Very few studies have been done on the number of spoken utterances by hearing mothers of deaf infants compared to mothers of hearing infants. Here also we find conflicting results (see also Chapter 3.4.1). On the one hand, it was found that hearing mothers interacting with their deaf children produce fewer spoken utterances than mothers interacting with their hearing children (Lederberg et al., 1989). On the other hand, an equal amount was found in somewhat younger infants (Spencer, 1993).

Moreover, we do not know how the form and amount of the vocalizations of the infants effects the form and amount of the spoken language they receive from their parents, and vice versa (see also Chapter 3.2.1). In the process of learning turn taking behavior, both child and parent adjust their speech to each other. It might be possible that the parents adjust their amount of speech input to the amount of the infant utterances, to balance the total amount of utterances during the interaction. For instance, in case deaf infants produce more vocalizations than hearing infants as we assume in our first hypothesis, it might be possible that the parents adjust their speech input and produce fewer utterances towards their child. Thus, we might expect a smaller amount of utterances of the mothers of hearing impaired infants during the first year of life in that case. Moreover, from that point of view, we expect that a smaller amount of the speech input from the parents of the deaf children will be noticeable only after differences in the amount of vocalizations of deaf infants become apparent.

Our hypothesis with respect to the number of the infant utterances is formulated as follows:

- A higher number of utterances will be produced by the HI infants compared to the NH infants

If this hypothesis is supported, then the following hypothesis derives from it:

- A lower number of utterances is produced by the mothers of the HI infants compared to the mothers of the NH infants.

5.2. Method

5.2.1. Selection of utterances

As described briefly in Chapter 4.4 ten minutes of each of the 108 recordings were used for analysis; 58 recordings of NH infants and 50 recordings of HI infants. The speech of the mother was transcribed orthographically in Dutch, utterance by utterance. Criteria for segmenting the mothers' utterances (M) were: semantic content in combination with intonation, and a pause duration of about one second or more between the utterances. If singing a song, the separate sentences of the song were counted as separate utterances. The communicatively intended sound productions such as tongue smacking, for instance to attract the attention of the child, were also included as mother utterances. For a definition of the infant utterances see Chapter 4.4. Every infant sound production was categorized as an utterance (U) or a non-utterance. Non-utterances were sounds like laughing, coughing, crying and vegetative sounds. They were noted, but excluded from further analysis.

Utterances that were 'crying-like' or 'whining-like' were included in all analyses. Many of the utterances produced by some HI infants gave an impression of crying or whining, although nothing in the context indicated that the child felt uncomfortable. One of the mothers of the HI infants (HI-3) reported that, when she was talking on the phone, the person at the other end often asked if the child was crying, although he was playing happily! Similar observations were also reported by some of the other mothers of the HI infants. Infant utterances are not described in more detail here, but are simply noted as 'U' for utterance, since we were interested in the number of utterances only for this aspect of analysis.

When the infant utterance could not be used for acoustical analysis, because of disturbance of the signal due to clipping or noise, an asterix was added. These acoustically disturbed utterances were included for the calculation of the number of utterances. This was the case for 25.1% of the utterances of the NH group and for 20.9% of the utterances of the HI group in the ten minutes per recording. Often the disturbance was due to simultaneous utterance productions by mother and infant.

In the following example, part of a transcription at 8.5 months of HI-6 and her mother is presented. Where the mother and infant utterances are noted on one line, which is 5 times in the example, the infant utterance was pronounced simultaneously with the mother utterance. In brackets the English translation of the Dutch utterances of the mother utterances are shown.

<u>Mother:</u>	<u>Infant:</u>
M wat zie ik op jouw trui? (what do I see on your sweater?)	
M een krokodil (a crocodile)	U *
M een krokodil (a crocodile)	U *
	U
M wat zie ik op jouw buikie? (what do I see on your tummy?)	U *
M een krokodil (a crocodile)	U *

M ja (yes)	U *
	U
	Hoesten (coughing)
	U
	U
M ja (yes)	
M een krokodil (a crocodile)	

Each monthly recording was transcribed by two transcribers out of a group of four phonetically trained researchers, who were familiar with infant and child speech. A training of the transcription method was given in advance, based on one recording of ten minutes of a hearing infant who was not one of the twelve subjects of this study. After the training period, all transcriptions were performed by one transcriber and verified by another transcriber. The first transcriber indicated whether a sound could be marked as a mother or infant utterance according to the criteria mentioned above. One of the other four transcribers checked the transcription, establishing agreement or not on each mother and infant utterance. In the case of all recordings the author was one of the two transcribers.

5.2.2 Inter-judge agreement

Each sound utterance that the two transcribers disagreed about was discussed after listening to it again. After making the final decision per utterance, which both transcribers had to agree on, the number of utterances spoken by the mother and by the infant during the 10 minutes of recording were counted. The inter-judge agreement with respect to the number of utterances based on all material (108 recordings in total, containing 11274 infant utterances and 16368 mother utterances) was 97.8% for the mother utterances and 93.0% for the infant utterances. The percentages of this inter-judge agreement is based on the number of utterances both transcribers agreed upon *before* discussion, compared to the total number of utterances that was finally calculated. There were only few sound productions on which no agreement could be reached (51 infant utterances out of 11274 and 10 mother utterances out of 16368). These utterances were left out of further analyses. No relevant difference was found in inter-judge agreement between the HI and their mothers on the one hand, and normally hearing infants and their mothers on the other hand (HI infant utterances 92.6% and their mothers 98.1%; NH infant utterances 93.5%, their mothers 97.6%).

5.3 Results

5.3.1 Number of utterances

In Table 5.1 the average number of utterances for the NH and HI infants and their mothers are shown per month as well as averaged over the ten month period of the recordings. Also the 'running averages' over three months are shown (for instance, the data in the column 'running' in the entry after 3.5 months is averaged over three months, namely 2.5, 3.5, and 4.5 months). The p-value shown in Table 5.1 is the result of the Mann-Whitney U-tests on the running averages in which the NH and HI groups were compared. The minimal significance level is 0.05 (see also Chapter 4.4).

Table 5.1 Average number of utterances for the infant groups as well as for the mother groups during 10 minutes. N=6 for each month in the NH group (both infants and mothers), except at 9.5 and 10.5 months when N=5. In the HI group (both infants and mothers) N=2 at 2.5 months, N=3 at 3.5 and 4.5 months, and N=6 from 5.5 months onwards.

Infants					
Age (m)	NH	Run-ning	HI	Run-ning	p =
2.5	60.8		73.5		
3.5	76.8	81.6	112.0	98.5	ns
4.5	107.2	86.4	110.0	118.9	<0.05
5.5	75.3	90.8	134.8	134.2	<0.025
6.5	90.0	87.2	157.8	132.5	<0.005
7.5	96.3	86.1	104.8	136.9	<0.005
8.5	71.8	87.7	148.2	133.7	<0.005
9.5	95.0	82.9	148.0	141.7	<0.005
10.5	82.0	82.0	129.0	134.3	<0.01
11.5	69.0		126.0		
Mean	82.4		124.4		<.001

Mothers					
Age (m)	NH	Run-ning	HI	Run-ning	p=
2.5	124.0		191.5		
3.5	150.3	148.5	171.7	165.1	ns
4.5	171.1	159.2	132.0	141.2	ns
5.5	156.0	166.7	119.8	125.0	ns
6.5	173.0	169.8	123.2	121.0	<0.01
7.5	180.5	178.0	120.0	126.9	<0.01
8.5	180.5	178.5	137.7	126.1	<0.005
9.5	174.4	172.4	120.5	133.7	<0.01
10.5	162.4	174.8	143.0	135.9	<.05
11.5	187.7		144.3		
Mean	166.0		140.4		<.05

In the infants, it can be observed that the mean number of utterances in almost all months is higher in case of the HI group (124.4, sd = 57.8) compared to the NH group (82.4, sd = 38.1). A t-test for matched samples on the data of the combined ten months indicates a significant difference between the two groups ($p<.001$).

Looking at the data per three months the same tendency can already be observed in the first months studied (see Table 5.1), although the Mann-Whitney U-test shows no significant difference. We did not find a decrease in number of utterances of the NH infants around four months, unlike the findings of Berger and Cunningham (1983). From 4.5 months onwards, a Mann-Whitney U-test shows that HI infants produce significantly more utterances than their hearing peers[2]. For ease of visualization the average number of utterances per month and the running averages per three months are shown for both groups in Figure 5.1. The standard deviations for the running averages are also shown.

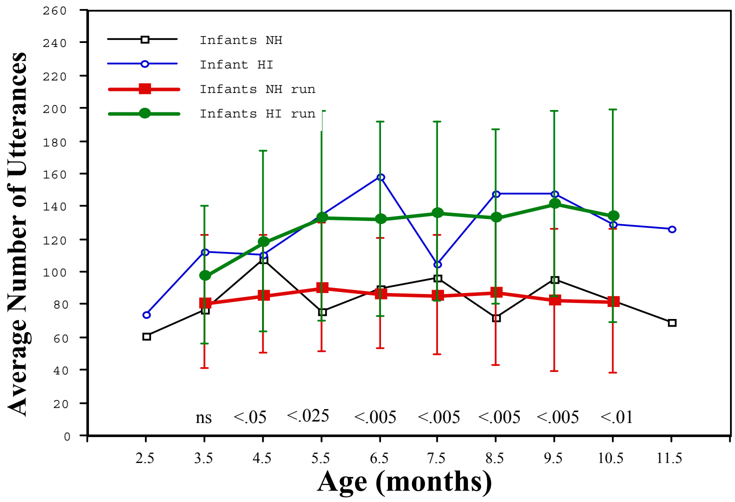


Figure 5.1. Mean number of infant utterances during ten minutes per recording for the HI and NH group. The running averages are shown by bold lines, and also the standard deviation of the running averages is given.

While the HI infants produce more utterances than their hearing peers, their mothers produce fewer utterances than the mothers of the hearing infants from 6.5 months onwards (see Table 5.1). On average, the mothers of the HI infants produced 140.4 utterances (sd = 57.8) and the mothers of the NH infants 166.0 (sd = 38.1). A t-test for matched samples on all data shows that the difference between the two groups is significant ($p<0.05$). Figure 5.2 shows the average number of utterances per month, and the running averages over three months, for both groups of mothers. At all months after 6.5 months (running), the Mann-Whitney U-test is significant: the mothers of the HI infants produce significantly fewer utterances than the mothers of the hearing infants (see Table 5.1). In the first months studied, however, there is no significant difference between the mothers. The high number of utterances of the mothers of the HI infants at 2.5 and 3.5 months, see Table 5.1 and Figure 5.2, is due to only one mother (HI-1) who produced an extremely high number of utterances

[2] Note that the difference between the average number of utterances of the NH and HI infants seems small at 4.5 months and 7.5. The significant difference according to a Mann-Whitney U-test at that age is most probably influenced by the higher differences on average between the two groups at 3.5 months and 5.5 months and 6.5 and 8.5 months respectively.

(287 and 236) in the first two recordings. This was probably because of the unfamiliarity of the recording situation. Without any instruction, the number of utterances decreased after 3.5 months.

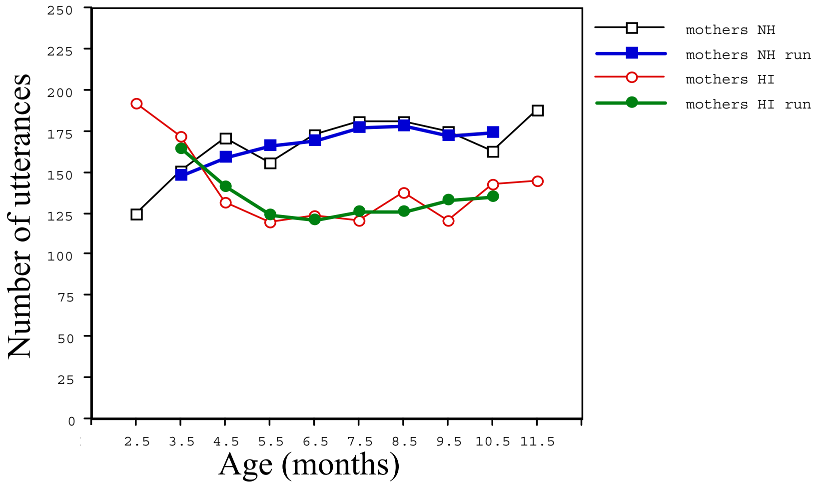


Figure 5.2. Mean number of mother utterances during ten minutes per recording for both groups. The running averages are shown by bold lines.

To get an impression of the way the number of utterances of the infants affect the number of utterances of their mothers, and visa versa, the results from both infants and mothers per group are combined in the next two figures. In Figure 5.3 the mean number of utterances of NH infants in combination with the utterances of their mothers during ten minutes per month is shown and in Figure 5.4 the mean number of utterances of HI infants and their mothers. The running averages are shown by bold lines and their standard deviation is also shown. It can be observed in Figure 5.3 that the mothers of the NH infants produced on average almost twice as many utterances as their children. The difference turns out to be significant ($p<0.001$) according to a t-test for matched samples if combining all months. In the mother-infant pairs (see Figure 5.4) of the HI infants we find a different picture: the HI infants produce on average approximately as many utterances as their mothers. A t-test for matched samples for all months combined shows no significant difference between the HI infants and their mothers. This result indicates that, as a group, the number of utterances of the mothers might be influenced by the number of utterances of the infants. This result will be discussed more thoroughly in the discussion part of this chapter.

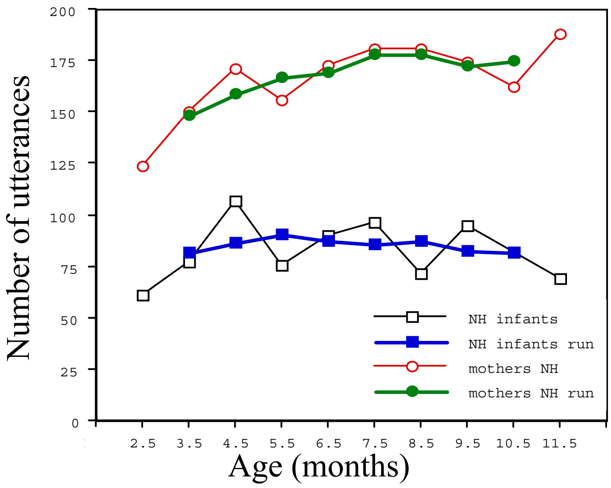


Figure 5.3. Mean number of utterances of NH infants compared to the number of utterances of their mothers during ten minutes per month. The running averages are shown by bold lines.

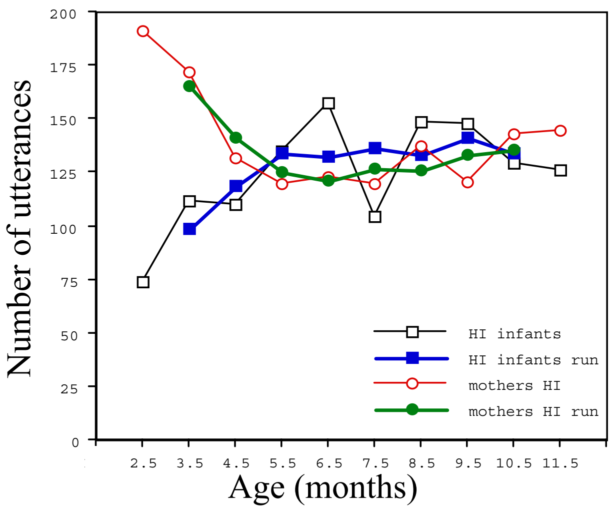


Figure 5.4. Mean number of utterances of HI infants compared to the number of utterances of their mothers during ten minutes per month. The running averages are shown by bold lines.

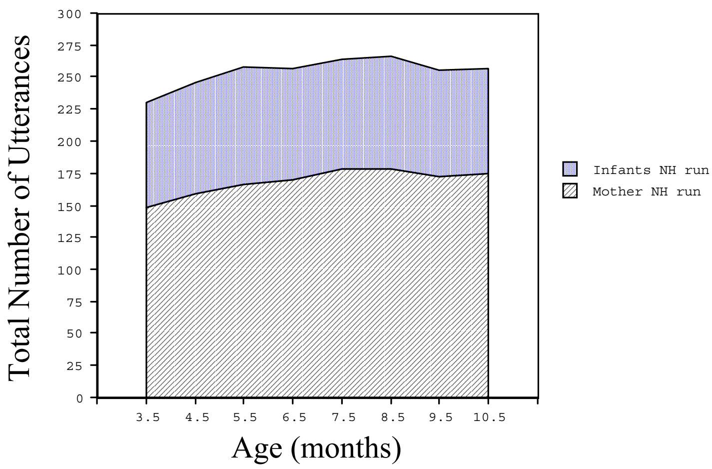
If looking in Figure 5.3 and Figure 5.4 at the mean number of utterances per month (not running) for the NH infants a drop in number of utterances can be seen at 5.5

months and 8.5 months and for the HI infants at 7.5 months. These drops will be discussed more thoroughly in Chapter 9 in relationship with other variables studied in this thesis.

It was shown Table 5.1 that first the number of utterances of the HI infants significantly exceeded the number of utterances of the NH infants (at 4.5 months), and next the mothers of the HI infants produced significantly fewer utterances than the mothers of the NH infants (at 6.5 months). However, the number of infant utterances added to the number of mother utterances, is approximately similar. The total number of speech utterances within the ten minutes is 248.4 (sd 65.2) on average for the NH infants and mothers, and 264.8 (sd 77.0) on average for the HI infants and mothers. To show the cumulative number of speech utterances within the ten minutes, the combined number of utterances in both groups of infants and their mothers are presented in Figure 5.5. In Table 5.2 the cumulative number of utterances are shown per month, as well as the running averages over three months and the average of the ten months combined. The p-value is the result of Mann-Whitney U-tests on the running averages and of a t-test for paired samples on the ten months combined. It can be seen that the cumulative number of utterances is about the same in both groups; by comparing the mean of the ten months combined no significant difference is found (p=0.40). In none of the separate months significant differences are found either. At age 5.5-7.5 up to 7.5-9.5 the p-value is even over 0.95, showing that the cumulative number of utterances of the HI-group and the NH-group is very similar. Although no further detail is given on the type of utterances by the mothers such as utterance duration, the number of utterances gives us an indication of differences and similarities in the mother-infant interaction between the two groups. Possible explanations for these results will be discussed more thoroughly in the discussion part of this chapter.

Table 5.2. The average cumulative number of utterances of mothers and infants of both groups within 10 minutes, per month and running per 3 months. Also the p-value as result of Mann-Whitney U-tests on the running averages are shown, and the result of a z-test on the 10 months combined.

Age (m)	NH	running	HI	running	p=
2.5	184.8		265.0		
3.5	227.2	230.1	283.7	263.6	0.31
4.5	278.3	245.6	242.0	260.1	0.52
5.5	231.3	257.6	254.7	259.2	0.68
6.5	263.0	257.1	281.0	253.5	0.96
7.5	276.8	264.1	224.8	263.9	0.99
8.5	252.3	266.2	285.8	259.7	0.96
9.5	269.4	255.4	268.5	275.4	0.37
10.5	244.4	256.8	272.0	270.3	0.51
11.5	256.7		270.3		
Mean	248.4		264.8		0.40



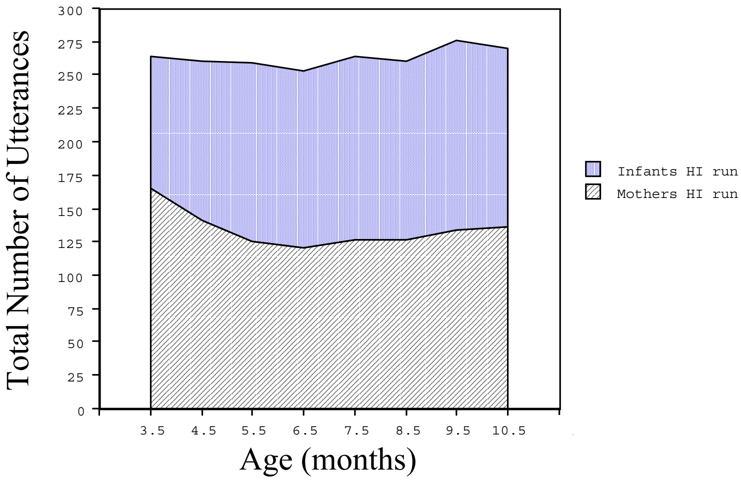


Figure 5.5. Cumulative number of utterances of the NH infants and their mothers and the HI infants and their mothers.

5.3.2 Individual data

In the previous section we described the two groups of infants and their mothers. However, we are also interested in the individual subjects and their mothers. This gives greater insight into the group statistics. In Table 5.3 and 5.4 the number of utterances of the NH and the HI infants (Table 5.3) and their mothers (Table 5.4) are shown. We find large individual differences within the groups. For instance mother NH-5 produces 103.3 utterances on average, while mother NH-6 produces 243.4 utterances on average.

In none of the infants in either group a gradual decrease or increase of number of utterances can be found. Also, a decrease in the number of utterances over time is not found in any of the mothers, except mother of subject HI-1, already mentioned in the previous section. For two mothers out of the NH group (NH-2 and NH-4) and for one mother of a HI infant (HI-4) a clear gradual increase can be found starting in the second half year of their child.

Table 5.3 Number of utterances per *infant* for each month and on average.

Age (m)	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6	Mean	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6	Mean
2.5	34	41	68	122	38	62	60.8	65	na	na	82	na	na	73.5
3.5	96	49	83	56	61	116	76.8	170	na	na	103	63	na	112.0
4.5	176	81	151	123	50	62	107.2	78	na	na	89	163	na	110.0
5.5	89	52	51	92	95	73	75.3	134	169	106	24	162	214	134.8
6.5	132	64	60	40	109	135	90.0	72	231	149	115	118	262	157.8
7.5	135	77	152	94	50	70	96.3	98	106	86	78	151	110	104.8
8.5	82	80	121	62	58	28	71.8	169	146	218	72	151	133	148.2
9.5	208	62	41	94	70	na	95.0	81	205	205	52	120	225	148.0
10.5	89	78	85	29	129	na	82.0	78	222	90	94	164	126	129.0
11.5	84	66	120	61	55	28	69.0	79	244	163	53	152	65	126.0
Mean	112.5	65.0	93.2	77.3	71.5	71.75	82.4	102.4	189.0	145.3	76.2	138.2	162.1	124.4

Table 5.4. Number of utterances per *mother* for each month and on average.

Age (m)	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6	Mean	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6	Mean
2.5	101	30	237	125	78	173	124.0	287	na	na	96	na	na	191.5
3.5	151	72	253	138	111	177	150.3	236	na	na	82	197	na	171.7
4.5	81	84	329	154	128	251	171.2	183	na	na	68	145	na	132.0
5.5	142	122	208	117	90	257	156.0	83	137	141	81	170	107	119.8
6.5	207	92	232	195	59	253	173.0	85	122	174	91	149	118	123.2
7.5	171	149	229	165	119	250	180.5	45	75	186	80	171	163	120.0
8.5	130	160	196	216	79	302	180.5	123	118	181	120	162	122	137.7
9.5	180	167	202	181	142	na	174.4	77	107	107	110	212	110	120.5
10.5	126	188	186	208	104	na	162.4	128	96	111	144	186	193	143.0
11.5	77	193	209	240	123	284	187.7	77	114	133	195	207	140	144.3
Mean	136.6	125.7	228.1	173.9	103.3	243.4	166.0	132.4	109.9	147.6	106.7	177.7	136.1	140.4

5.4 Discussion

As discussed in Chapter 3.3.1 HI infants are often believed to produce fewer utterances than NH infants. However, in our study the average number of utterances per 10 minutes in the period studied (between 2.5 and 11.5 months) is greater for HI infants (124) then for NH infants (82). The difference starts to be significant after around 4.5 months (data of 3.5, 4.5 and 5.5 months combined). This indicates that, at least as a group, these HI infants produce more utterances than their NH peers from this period onwards. In the matched pairs this was true for four of the six pairs.

In some previous studies of infants of twelve months, a similar amount, or fewer utterances were found for deaf infants compared to hearing infants (Spencer, 1993; Van den Bogaerde, 2000). On the other hand, other studies reported a peak in quantity for HI infants of this age followed by a noticeable decrease after twelve months of age (Mavilya, 1972; Maskarinec et al., 1981; and Stoel-Gammon, 1986). None of the HI infants in the present study showed a reduction in number of utterances within the first year of life, which was not unexpected.

Unfortunately, a comparison with the very few studies on number of utterances of HI infants within the first year is generally not possible, because of differences in the definition used for the term 'utterance'. Yoshinaga-Itano et al. (1992) found on average 89.5 utterances within 30 minutes samples for hearing impaired and deaf infants between 6 and 12 months. In our study we counted on average 130 utterances within 10 minutes, thus over 4 times the amount in their study. This huge difference can be explained by the criterion they used for the selection of the utterances. Yoshinaga-Itano et al. took only utterances with identifiable English speech sounds into account. They excluded speech productions such as raspberries, shrills, vowel-like utterances, and utterances with solely non-English speech sounds like velar fricatives, while we included these types of utterances in our own data set.

In Chapter 7 we shall see that HI infants produce very frequently large amounts of these types of vocalizations.

Several explanations can be found for a higher amount of vocalizations in HI infants compared to NH infants. According to Bloom (1998) vocalizations can be elicited in infants of only three month old by verbal communication with their parents. She mentions that the adult face and voice are the most powerful elicitors of infants' attention. On the other hand Jones (1996) reports that young infants react to visual stimuli by movement of the articulators (see also Chapter 3.2.4). It can be argued that not only NH infants, but also HI infants respond to the face of the mother during parent-infant interaction. An at least similar amount of utterances in the HI infants compared to the NH infants can be expected from that point of view.

Locke and Pearson (1992) propose another argumentation. They suggest that deaf infants use their own vocalizations as a way to get extra auditory stimulation for their brains to compensate for the lack of auditory input. If this is true we would expect more utterances to be produced by HI infants with at least some residual hearing, like in the case of at least three of the observed infants in the present study, and the subjects in Oller et al. (1985) and Kent et al. (1987). A profoundly deaf infant with no usable residual hearing at all, having no benefits of hearing aids, will not be able to give himself more auditory stimulation and will probably not produce more utterances. In our study the infant with the most profound hearing loss, with no response at hearing levels even over 110 dB while using hearing aids (HI-4, see Chapter 4, Table 4.2), produced the smallest number of utterances. This suggests that this explanation might be correct, but the other HI infant with such high losses (HI-5) does not confirm this explanation. In Chapter 9 a possible influence of residual hearing will be discussed in more detail.

Another explanation for the difference in number of utterances between NH and HI infants might be found in the difference in turn-taking behavior with their mothers. In NH infants turn-taking increases between three and four months of age (Bloom et al., (1987), Berger and Cunningham (1983); Ginsburg and Kilbourne (1988); see also Chapter 3.2.4). NH infants learn how to adjust their speech to the interaction, and to listen when their mothers speak, around this age.

In HI infants we can assume that the turn-taking process will be affected by the hearing loss. HI infants do not stop their vocalizations in order to listen to their mothers, but continue to produce speech sounds. The number of utterances of the NH infants seems to be rather stable during the first year, and the higher number of utterances of the HI infants becomes clear at 4.5 months (data of 3.5-5.5 months combined). Thus, the age at which the differences become significant, is right after the start of turn-taking behavior of NH infants and their mothers. This suggests a relationship between the higher number of utterances of the HI infants compared to the NH infants and the lack of turn-taking behavior in the spoken language mode.

Moreover, we found that the mothers of HI infants, in contrast to their children, produce significantly fewer utterances than mothers of NH infants, although individual differences are observed here as well. The difference appears to be significant after 6.5 month (data of 5.5, 6.5 and 7.5 month combined). There are two possible explanations for this finding.

Firstly, it might be that the number of infant utterances and mother utterances are related. In the case of the HI infants, the smaller amount of utterances in the mothers of the HI infants might be influenced by the higher amount of utterances of their children. The mothers of HI infants might adjust their amount of utterances to the amount of utterances of their HI children, in order to perform their part of the turn taking process. If the mothers aim to produce not much overlap with the utterances of their infants, simply less time is available within ten minutes for the mothers, since HI infants produce more utterances than the hearing infants.

Secondly, another explanation could be that the mother realizes that the child does not respond with communication skills, such as turn-taking, in the way she expects and as a result she decreases her spoken language input. Moreover, as described in Chapter 3.2.1, sound productions of NH infants are elicited by verbal communication with their parents. It might be that if a child produces a high number of vocalizations, parents subconsciously feel less need to elicit more utterances by their own spoken language.

Two findings indicate a relationship between the number of infant and mother utterances. The total number of utterances for the infants and their mothers in both groups, was similar (see Figure 5.5), which suggests that the mothers of the HI infants indeed adjusted their amount of spoken language. Secondly, the significant difference between the mothers appeared around the infants age of 6.5 months, thus two months *after* the significantly higher number of utterances for the HI infants appears (from 4.5 months). This suggests that the mothers of the HI infants adjust their amount of speech as a result of the higher amount of HI infant utterances.

Also another explanation might be correct, suggesting that the higher amount of infant utterances and the lower amount of mother utterances are independent. One of the mothers in our study reported that she usually did not speak to her HI child (HI-5) if she had no eye contact with him. The restriction to talk only while having eye contact with the child might reduce the amount of spoken language directed to the child. This might be the case also for the mothers of the other HI infants. To test which explanation is true, further research is necessary including video-recordings of parent-infant interaction.

Chapter 6

Duration and F0[1]

6.1. Introduction

In the present chapter we describe objectively the two suprasegmental acoustical parameters of the utterances of deaf and hearing infants measured in this study, namely utterance duration and F0. The F0 analyses consider mean F0, minimal and maximal F0, F0 range within the utterance, F0 variation, and number of voiceless utterances. Also it will be interesting to see if these objective measures correlate with the more subjective measures in the other variables (especially those to be described in Chapter 7).

The research questions we intend to answer are:

- Do deaf infants produce a longer or shorter utterance duration than hearing infants and from which age onwards?

- Do deaf infants produce a different F0 compared to normally hearing infants with respect to mean F0, maximal F0, and minimal F0, and F0 variation and from which age onwards?

- Do deaf infants produce more or fewer voiceless utterances than hearing infants and from which age onwards?

Although very few studies have been performed previously on these parameters we might expect to find some differences in duration, F0, and number of voiceless utterances between the two groups, within the first year of life (see also Chapter 3.3.2). Based on these studies, although performed with a relatively small amount of data, we expect to find a longer duration and more F0 variation for the deaf infants compared to hearing infants (e.g. Möller and Schönweiler; 1997; Kent et al., 1987). Moreover, based on the study of Elsendoorn and Beijk (1993) we expect no differences in mean F0 within the first year of life. Since no studies - to our knowledge- have been done so far on voiceless utterances of HI infants, we base our hypothesis with respect to that parameter on our own observations. We expect to

[1] Substantially extended and revised version of earlier publications (Clement et al., 1994, 1996).

find more voiceless utterances for the HI infants compared to the NH infants (see also Chapter 3.3).

Thus, our hypotheses are formulated as following:

- a somewhat longer duration is produced by the HI infants compared to the NH infants
- no differences in mean F0 will be found between the two groups
- more variation within the utterance is produced by the HI infants compared to the NH infants, thus a larger F0 range and F0 standard deviation
- more voiceless utterances are produced by the HI infants.

6.2 Method

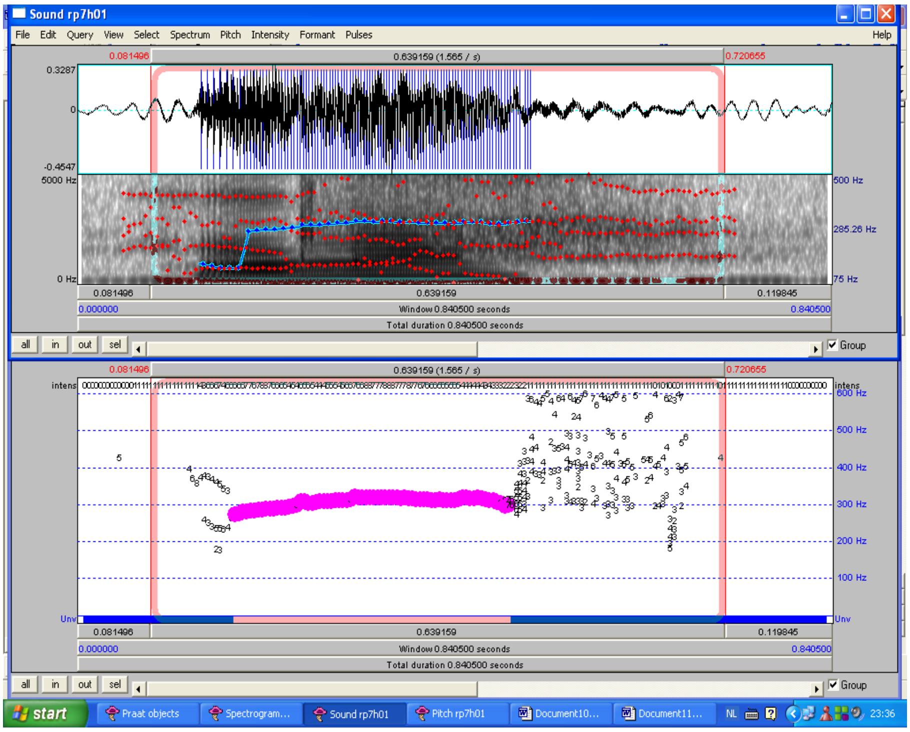
The 50 utterances per recording for this analysis were selected according to the procedure described in Chapter 4.4. As stated earlier, only utterances with little or no noise were included. An overview of the number of utterances per group and per month was given in Table 4.4.

6.2.1 Duration measurements

The duration of each infant utterance was measured in ms, if possible on positive zero-crossings. Of the 108 recordings, a sub-sample of 34 recordings (19 of HI and 15 of NH infants) was selected for a check on the measurements. 1700 Utterances were measured a second time by the same researcher. The difference between both measurements turned out to be very small. It was 16.6 ms on average per utterance for the HI infants (1.8 % of the mean duration) and 17.9 ms on average for the NH infants (2.0 % of the mean duration). Thus the duration analyses could be shown to be very reliable. The first measurements from this sub-sample were used for further analysis. The duration measurements of the other recordings were performed only once.

6.2.2 Fundamental frequency measurements

F0 measurements were carried out only on voiced utterances, or the voiced part of the utterances. If, for instance, only 50 ms of a 500 ms utterance was found to be voiced, the utterance was judged as being voiced (not unvoiced) and the F0 measurements were performed on only that 50 ms. As in some other studies in which F0 measurements were performed on infant voices (e.g. Möller and Schönweiler, 1997; McRoberts and Best, 1997) a pitch-detection program based on auto-correlation algorithm was used (Boersma, 1993) as part of the speech analysis program Praat[2]. This algorithm proved to be more accurate than the commonly used (time based) methods for speech analysis when tested with signals with additive noise or jitter. A special option of the program is the possibility to compare the pitch of the original sound wave with the measured, F0 contour (pitch tract) of each utterance by synthesizing it and comparing this pitch tract auditory and visually. In this way measurement errors, such as octave jumps, could be easily detected. In Figure 6.1 an example is shown of an oscillogram, a spectrogram and a pitch analysis of the same utterance of NH-2 at 7.5 months. The F0 was measured per 10 ms.



utterance NH-2 at 7.5 months[3]   synthesized version of the same utterance (only the calculated pitch is audible)

Figure 6.1. Example of the pitch analysis, combined with an oscillogram and spectrogram of an utterance of NH-2 at 7.5 months of age.

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[2] Praat is developed at the Institute of Phonetic Sciences Amsterdam, University of Amsterdam; for more information http://www.fon.hum.uva.nl/praat

[3] In the digital version of this thesis examples of utterances are audible by clicking on the symbol.

This double check method from Praat was important, because the deviant phonation of infants compared to that of adults caused specific problems with F0 measurements. The high F0 (on average 361 Hz for NH infants and 382 Hz for HI infants) often caused interference with the first formant. 190 Utterances turned out to have a maximum F0 of over 1000 Hz and 17 utterances were found to have a maximum F0 of even over 2000 Hz. Those extremely high voices were double checked by measuring their periodicity by hand[4], in order to reduce measurement errors. Another example of unusual phonation was an extremely low F0 because of vocal fry (creaky voice)[5], found especially within the HI group. Also irregular periodicity caused by the use of false vocal cords was found. Another problem was that in several utterances that had been perceptually judged as voiceless, a periodicity in the signal was found by the algorithm. This mainly happened when another periodic source was involved, for instance periodic velar trill sounds in case of the HI infants and periodic bilabial or tongue trill sounds (raspberries) in case of the NH infants. All these problems meant that measurement errors were made in 36.2% of the utterances (35.4% for the NH group and 37.12% by the HI group). If measurement errors were found, they were corrected in two possible ways. An option of the program is to choose another calculated possible pitch track (for instance one octave higher). If this method did not correct the measurement, the F0 contour was corrected 'by hand' and calculated again. This way we could obtain quite reliable measurements of the 5115 voiced utterances. Of the total of 5381 utterances 266 utterances were judged by the experimenter to be (totally) unvoiced.

In the present chapter the following F0 parameters were measured in each of the utterances: medial F0, maximal F0, minimal F0, F0 range and standard deviation. We decided not to use the *average* F0 per utterance, because the average of several frequency measurements can be influenced by the scaling used. We preferred not to choose between, for instance, linear and logarithmic scaling, and used the scaling-free *median* F0 per utterance. The results when using the *average* F0 per utterance were in fact almost identical to those of the median F0 described below. In Figure 6.2 an overview is given of all measured parameters related to one, imaginary, stylized F0 curve. Average and 10%-90% range gave almost identical results as the median and total range respectively and will therefore not be presented in the results section; only the median will be presented.

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[4] Calculation of number of zero-crossings per second by hand.

[5] Vocal fry or creaky voice is a special kind of phonation with tightly compressed vocal folds, becoming relatively slack and compact, and forming a large, irregularly vibrating mass. The frequency of the vibration is extremely low (20-50 pulses per second) and the airflow through the glottis is very slow.

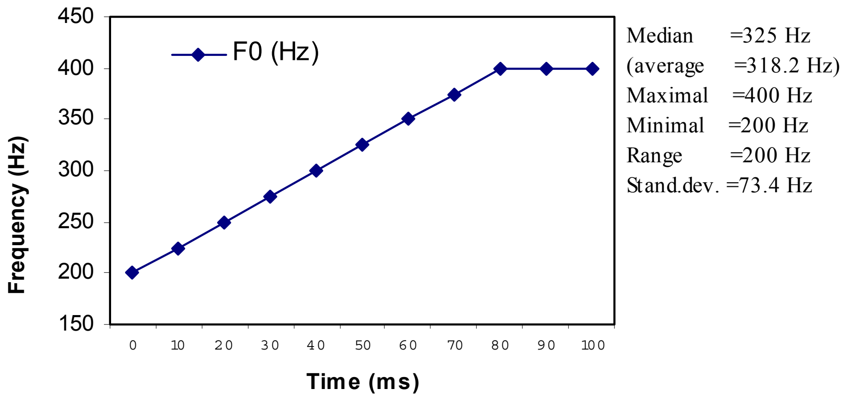


Figure 6.2. Examples of parameters measured in the present chapter related to a hypothetical F0 curve.

6.3. Results

6.3.1. Utterance duration

In Figure 6.3 the mean utterance duration in ms of the 50 selected utterances is presented per month. In Table 6.1 also the average duration over the ten months for both groups can be seen. It can be observed that the mean utterance duration for the ten months combined is somewhat longer for the HI infants (940 ms, sd=752 ms) than for the NH infants (915 ms, sd=758 ms) although this difference is not significant. At 3.5 months, however, the NH infants produce a highly significant longer duration than the HI group (1441 ms for the NH infants versus 842 ms for the HI infants). This special phenomenon will be discussed in detail in section 6.3.2. At 5.5 months the HI group produces a significantly longer duration than the NH group. The differences at other months were not significant.

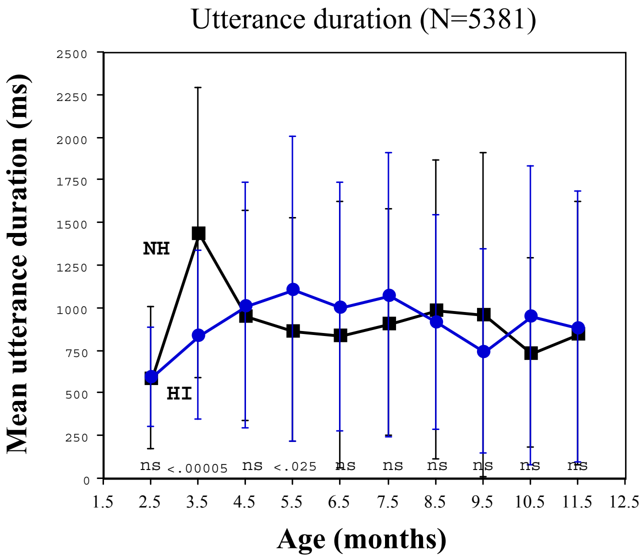


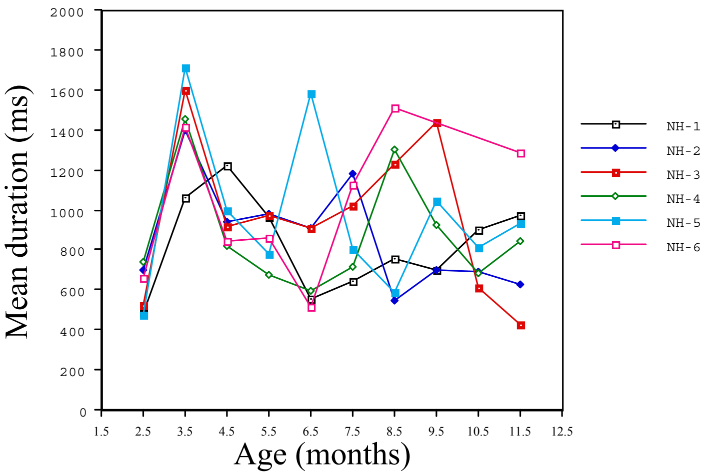
Figure 6.3. Mean utterance duration in ms for the HI and the NH group per month.

Table 6.1. Mean utterance duration and standard deviations in ms for the HI and the NH group per month, as well as the mean duration over the period of 10 months. Also, the p-value as a result of an ANOVA (average of 10 months) and Tukey post-hoc (per month) test is shown.

Age (m)	NH	sd NH	HI	sd HI	p=
2.5	593	416	595	287	ns
3.5	1441	850	842	494	<.00005
4.5	956	614	1016	717	ns
5.5	871	655	1110	897	<.025
6.5	843	785	1007	727	ns
7.5	916	666	1076	831	ns
8.5	986	877	916	628	ns
9.5	959	950	750	598	ns
10.5	739	558	956	878	ns
11.5	818	772	889	796	ns
Mean	915	758	940	752	ns

6.3.2 Individual results

In Figure 6.4 and Table 6.2 the utterance duration in ms is shown for every month for each of the twelve subjects individually.



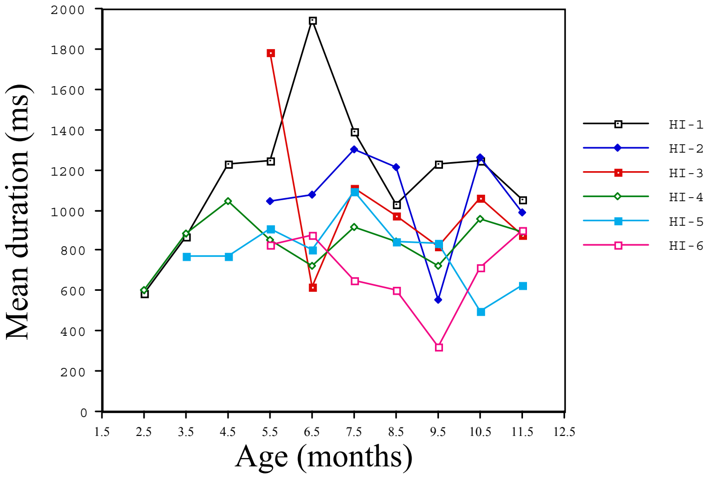


Figure 6.4. Mean utterance duration in ms per month and per subject for the six NH infants (upper panel) and the six HI infants (lower panel).

Table 6.2. Mean utterance duration in ms per month and per subject for the six NH and six HI infants.

Age (m)	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
2.5	479	695	525	736	470	655	584	na	na	606	na	na
3.5	1060	1401	1602	1457	1708	1417	868	na	na	885	772	na
4.5	1217	941	917	821	997	841	1231	na	na	1047	769	na
5.5	965	983	972	674	776	857	1247	1044	1786	850	910	824
6.5	557	907	904	596	1582	511	1942	1075	617	722	806	877
7.5	640	1182	1019	716	803	1127	1387	1303	1111	915	1090	650
8.5	752	548	1225	1301	583	1509	1032	1210	970	842	843	599
9.5	702	695	1439	920	1041	-	1232	556	823	726	837	324
10.5	899	694	610	679	814	-	1244	1260	1062	958	498	711
11.5	975	625	429	840	928	1287	1053	989	874	892	628	896
Mean	825	867	964	874	970	1026	1182	1062	1035	844	795	697

An analysis of variance with utterance duration as dependent factor and group and age as independent factors, shows a significant effect for age and for the interaction group and age ($p<.00001$). Tukey post-hoc tests indicate that this interaction effect is caused by the long utterance duration at 3.5 months for the NH infants (see Figure 6.4 and Table 6.2). To illustrate this point further, Figure 6.5 shows the individual utterance duration at 3.5 months with standard deviation for all six NH and for the three HI children who were recorded at that age. It can be seen that all NH infants produce a longer utterance duration than the HI infants at that age. The mean duration of the NH infants utterances at 3.5 months (1441 ms) is considerably longer than that of the HI infants (842 ms) and longer than at any other age in the period studied ($p<.00005$) according to a Tukey post-hoc test. Also, as shown by a Tukey post-hoc test on the data at 3.5 months, there was a significant difference ($p<.01$) between the three HI infants and each of the six NH infants, except for one hearing infant NH-1. He produced a (weaker) peak in duration at 4.5 months (see also Figure 6.4).

Thus, at 3.5 months the NH infants produced a highly significant longer utterance duration than the HI infants. This was significantly longer than at 2.5 and 4.5 months taken on average over the 50 utterances. To be able to explain why the duration differences between the two groups occur at that age, we should not only consider the average duration, but also take a look at the number of long utterances of all subjects. In Table 6.3 the number of utterances with a relatively long (arbitrarily chosen) duration of 2000 ms or more is shown per subject per month.

Table 6.3. Number of utterances with long duration (over 2000 ms) per subject, per month.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	HI1	HI2	HI3	HI4	HI5	HI6
2.5	0	1	0	0	1	2	0	na	na	0	na	na
3.5	6	12	15	8	18	8	3	na	na	1	3	na
4.5	3	1	3	5	5	3	7	na	na	4	0	na
5.5	3	3	5	2	2	6	10	1	20	5	2	4
6.5	0	5	2	0	16	1	19	4	0	0	1	0
7.5	3	5	3	1	2	8	13	8	8	7	4	0
8.5	2	2	11	9	1	14	6	7	2	1	1	2
9.5	1	0	10	4	5	na	5	0	2	3	3	0
10.5	2	1	1	2	2	na	5	10	4	6	1	1
11.5	6	1	0	4	5	10	8	5	2	4	1	4

It is striking that, at 2.5 months, we find none or almost none of those long utterances in the individual infants. This probably indicates that the infants are physically capable of producing longer utterances from 3.5 months onwards, but not in the period before. It can be observed that at 2.5 months only few of the NH subjects, and none of the HI produced some utterances over 2000 ms (see Table 6.3). At 3.5 months however, all infants, including the three HI infants, produced these extremely long utterances. The three HI subjects were physically able to produce the long utterances, but the number of long utterances was smaller (3, 1, and 3 at 3.5 months) than in the case of the NH subjects (6, 12, 15, 8, 18, and 8 at 3.5 months) causing a longer average duration for the NH than for HI infants at that age. At 4.5 months the number of long utterances (>2000 ms) decreased for all NH subjects, whereas it increased for two of the three HI subjects. In section 6.4 and Chapter 9 we will discuss these phenomena further.

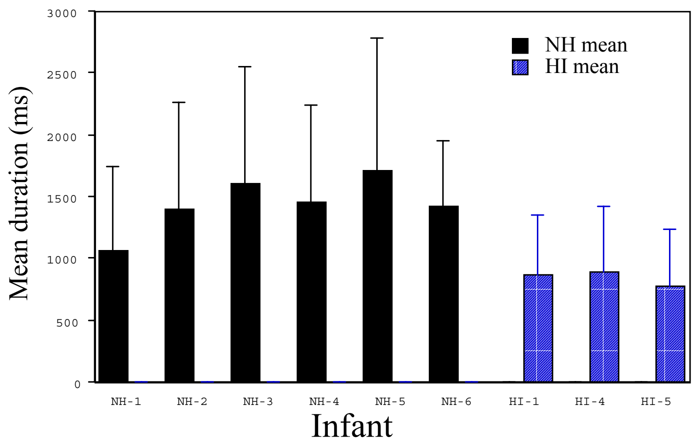


Figure 6.5. Mean utterance duration and standard deviations of the 50 utterances for each of the six NH subjects and the three HI subjects at 3.5 months. N=50 for each infant.

In Figure 6.4 and in Table 6.3 to lesser extent it can be observed that almost all NH infants produced, beside the primary duration peak at 3.5 months, a secondary duration peak at ages varying between 6.5 and 9.5 months (NH-2 at 7.5 months, NH-3 at 9.5 months, NH-4 at 8.5 months, NH-5 at 6.5 months, and NH-6 at 8.5 month, NH-1 did not show a secondary duration peak). These secondary peaks are clearly more variegated in start and height than the primary peak at 3.5 months. The three HI subjects who were studied at 3.5 months (HI-1, HI-4, and HI-5) lacked the primary duration peak and also a second peak could not be found clearly. Only HI-1 produced a strong duration peak at 6.5 months and HI-3 produced a long mean utterance duration at 5.5 months. The meaning of the duration peaks in the data of the NH infants and the lack of it in the HI data, and the relationship between utterance duration and other parameters, such as number of syllables and phonation type, will be discussed further in section 6.4.

6.3.3. Fundamental frequency

As stated in section 6.2.2, totally unvoiced utterances were excluded from the F0 analyses presented here, but will be discussed in more detail in section 6.3.5. A total of 70 voiceless utterances for the NH group and of 196 utterances for the HI group were found, leaving 2811 voiced utterances for the NH group and 2304 voiced utterances for the HI group on which F0 measurements could be carried out.

Table 6.4 shows that the median F0 for the ten months combined is somewhat higher for the HI infants (328 Hz, sd=170 Hz) than for the NH infants (294 Hz, sd=152 Hz). The factors group, age, as well as the interaction between group and age all turn out to be significant ($p<.0001$). A Tukey post-hoc test shows a significantly lower F0 at the age of 2.5 months for both groups compared to any other age ($p<.005$), except compared to 3.5 months. A higher F0 of the HI infants compared to the NH infants can be found mainly after 8.5 months and turns out to be significant at 9.5, 10.5, and 11.5 months ($p<.01$, $p<005$ and $p<.05$). A Tukey post-hoc test on the data of those months shows that this effect is due mainly to two HI infants (HI-2 and HI-6) with an extremely high median F0. In Table 6.5 the average F0 for each of the six NH subjects and each of the six HI subjects is shown per month. In the next section the variation in F0 among the individual subjects will be described and discussed. In Appendix Figure A6.1 several examples of utterances with high and low F0 are shown.

Table 6.4. Median F0 and standard deviations in Hz for the HI and the NH group per month, as well as the median F0 for the 10 months combined. Also, the p-value as a result of an ANOVA and Tukey post-hoc test is shown in case of significance.

Age (m)	NH	sd NH	HI	sd HI	p=
2.5	293	64	283	77	ns
3.5	328	79	342	119	ns
4.5	383	221	388	198	ns
5.5	395	235	364	87	ns
6.5	364	135	402	138	ns
7.5	392	142	373	139	ns
8.5	367	106	395	163	ns
9.5	370	148	418	239	<.01
10.5	372	153	422	246	<.005
11.5	363	114	400	143	<.05
Mean	294	152	328	169	<.001

Table 6.5. Median F0 in Hz of 50 utterances per month for the six NH and six HI subjects.

Age (m)	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
2.5	240	332	297	318	253	319	309	na	na	256	na	na
3.5	320	301	411	320	249	363	332	na	na	306	389	na
4.5	286	289	431	601	320	373	303	na	na	398	462	na
5.5	380	313	491	581	235	369	358	334	401	306	396	390
6.5	321	406	406	483	278	291	393	449	398	454	341	375
7.5	386	386	477	378	370	355	296	374	445	284	412	427
8.5	405	334	358	405	338	364	334	476	391	284	469	416
9.5	324	361	447	340	379	na	335	739	354	270	381	426
10.5	345	436	395	347	336	na	322	663	358	396	383	409
11.5	288	334	449	354	330	422	301	527	413	320	326	512
Mean	330	349	416	413	309	357	328	509	394	327	395	422

The mean maximal (=peak) F0 per utterance was also measured. As shown in Table 6.6 it turns out to be significantly higher ($p<.0001$) for the HI infants (459 Hz, sd=264 Hz) than for the NH infants (430 Hz, sd=234 Hz) when the data over all months are combined. However, only when tested per month, a Tukey post hoc shows that only at 11.5 months the differences between the groups are significant ($p<.05$).

Also the mean minimal F0 is higher in the HI group (328 Hz, sd=114) than in the NH group (294 Hz, sd = 110). For all months combined the difference is significant (p<.005). At 9.5 months the minimal F0 is higher for the HI group than for the NH infants (p<.005) as showed by a Tukey post hoc test.

Table 6.6. Maximal and Minimal F0 and standard deviations in Hz for the HI and the NH group per month, as well as the mean Maximal and Minimal F0 for the 10 months combined. Also, the p-value as a result of ANOVA and Tukey post-hoc tests is shown for a comparison of groups.

Age (m)	NH Max	Sd NH	HI Max	Sd HI	p=	NH Min	sd NH	HI Min	sd HI	p=
2.5	338	120	321	135	ns	242	66	249	65	ns
3.5	402	156	434	302	ns	256	84	264	74	ns
4.5	466	346	518	394	ns	288	120	276	68	ns
5.5	492	324	439	172	ns	306	148	287	77	ns
6.5	437	211	480	215	ns	293	120	311	100	ns
7.5	477	246	463	276	ns	316	131	284	93	ns
8.5	416	182	475	262	ns	298	80	303	104	ns
9.5	428	200	482	277	ns	308	122	351	174	<.005
10.5	440	257	514	343	ns	311	83	319	128	ns
11.5	401	149	463	175	<.05	312	91	333	132	ns
Mean	430	234	459	264	<.0001	294	110	328	114	<.005

Moreover, to study F0 variation within the utterances, the F0 range and F0 standard deviation of each utterance are measured. We expected more variation within the utterances for the HI infants, as observed in a previous study by Kent et al. (1987). In Table 6.7 the range and the standard deviation of each utterance is shown. As expected, over all months combined, both measurements show significantly more F0 variation within utterances produced by the HI infants compared to the NH infants (range: p<.0005, standard deviation: p<.005). The mean range within the utterance of the HI infants is 161 Hz and of the NH infants 137 Hz and the mean standard deviation within the utterance of the HI infants is 46 Hz and of the NH infants 41 Hz. Although no significant differences are found between both groups per month, we can conclude that with the data of all months combined indeed more variation is found in the utterances of the HI infants compared to the NH infants.

Moreover, a high median F0 (Table 6.4) and the highest F0 range and standard deviation within the utterance were both found at 4.5 and 5.5 months (see Table 6.7), as well as the highest standard deviation between utterances (see Table 6.4). This topic will be discussed in more detail in Chapter 9.1.

Table 6.7. Mean F0 range and mean F0 standard deviation in Hz for the HI and the NH group per month, as well as for the 10 months combined. Also, the p-value as a result of a ANOVA and Tukey post-hoc test is shown.

Age (m)	NH range	HI range	p=
2.5	96	72	ns
3.5	145	170	ns
4.5	179	242	ns
5.5	186	152	ns
6.5	144	169	ns
7.5	160	180	ns
8.5	118	172	ns
9.5	120	130	ns
10.5	130	195	ns
11.5	88	130	ns
Mean	137	161	<.0005

NH stdev	HI stdev	p=
29.9	21.0	ns
38.8	51.3	ns
51.0	69.7	ns
58.0	42.3	ns
42.1	47.0	ns
46.2	50.6	ns
34.0	50.3	ns
36.2	38.1	ns
41.1	55.3	ns
27.3	37.7	ns
40.5	46.3	<.005

6.3.4 Fundamental frequency: variation among the subjects

Despite the significant differences between the groups (when data over all months are combined) for median F0, maximal and minimal F0 and F0 variation, it would be incorrect to conclude that *all* six HI infants had a higher median F0, maximal and minimal F0 and more F0 variation. In the HI group we observed many examples of unusual phonation, such as vocal fry and the use of false vocal cords (resulting in an extremely low and minimally variegated F0 within the utterance), or screaming (with an extremely high and often markedly variegated F0 within the utterance), etc. To give an impression of the variation between the subjects of the HI group, we show in Table 6.8 the subject with the highest and lowest value for Median F0 and Maximal F0, and the highest and lowest value for F0 variation aspects: F0 Range, and F0 Standard Deviation (both SD over each utterance, as well as the SD of the median F0 among the 50 utterances per month). The data is shown from 5.5 months onwards, since the recordings of all subjects are available from that age onwards (except of NH-6 at 9.5 and 10.5 months). The gray cells represent the HI subjects and the white cells the NH infants. Between 7.5 and 11.5 months we found that in most months one of the HI subject had on average, the highest and lowest mean and maximal F0, and most and least variation within the utterance. Thus, within the first year of life, we find more diversity within the HI group than in the NH group with respect to F0. This makes it harder to compare the HI subjects as a group with the NH subjects as a group with respect to this variable.

Table 6.8. Overview of subjects with on average the highest and lowest Median F0, Maximal F0, Range F0 and Standard Deviation of F0 over each utterance and Standard Deviation of the median F0 among the 50 utterances per month. The gray cells are of the HI subjects.

Age (m)	Median per utterance		Maximal per utterance		Range per utterance		SD per utterance		SD over 50 utterances	
	Highest	Lowest	Highest	Lowest	Largest	Smallest	Highest	Lowest	Highest	Lowest
5.5	NH-4	NH-5	NH-4	NH-5	HI-4	NH-5	NH-4	NH-5	NH-4	HI-6
6.5	NH-4	NH-5	HI-4	NH-6	HI-4	NH-6	HI-4	NH-6	HI-4	NH-6
7.5	NH-3	HI-1	HI-3	HI-4	HI-3	NH-5	HI-3	NH-5	NH-1	HI-4
8.5	HI-2	HI-4	HI-5	HI-4	HI-5	NH-2	HI-5	NH-2	HI-5	HI-3
9.5	HI-2	HI-4	HI-2	HI-4	HI-2	HI-4	HI-2	NH-4	HI-2	HI-3
10.5	HI-2	HI-1	HI-2	HI-1	NH-2	HI-5	HI-2	HI-5	HI-2	HI-3
11.5	HI-2	HI-1	HI-2	HI-1	HI-4	NH-3	HI-4	NH-1	HI-2	HI-5

6.3.5 Number of unvoiced utterances

The number of voiceless utterances are established by the same pitch detection algorithm as used for the F0. In Table 6.9 the mean number of voiceless utterances per group and per month is presented together with the average value over the ten months. It can be observed that the average number of voiceless utterances for the ten months combined is higher for the HI infants (6.8) than for the NH infants (2.4) according to a t-test for matched pairs. The differences start to appear at the age of 8.5 months and turn out to be significant ($p < .05$) according to a Mann-Whitney U test at the ages of 9.5, 10.5, and 11.5 months combined.

Table 6.9. Mean number of voiceless utterances out of the 50 selected utterances for the HI and the NH group per month and on average. Also the p value as result of a MWU test is shown. (N=6 at each age of the NH infants, except at 9.5 and 10.5 months when N=5. N=2, 3 and 3 at 2.5, 3.5 and 4.5 months respectively and 6 at 5.5 to 11.5 months in the case of the HI infants.)

Age (m)	NH	Running	HI	Running	p=
2.5	3.3		0.0		
3.5	0.0	1.6	2.7	1.8	ns
4.5	1.3	1.0	2.7	2.1	ns
5.5	1.7	1.4	1.0	1.3	ns
6.5	1.3	3.4	0.3	1.2	ns
7.5	7.3	4.1	2.3	4.9	ns
8.5	3.7	4.5	12.0	9.8	ns
9.5	2.4	2.4	15.0	14.9	ns
10.5	1.2	1.8	17.7	15.7	p<.05
11.5	1.8		14.3		
Mean	2.4		6.8		p<.05

It can be seen in Figure 6.6 that the NH subjects NH-1, NH-4, NH-5 produce voiceless utterances at 7.5 month of age. The period in which the HI subjects produced voiceless utterances, differed. HI-2 produced voiceless utterances at 7.5 months of age and HI-1 and HI-4 at 8.5 months of age. Subjects HI-3 and HI-5 produce a very high number of unvoiced utterances in the last months studied. Most of the unvoiced utterances of the HI infants are produced as velar fricative or trill sounds, while this is not the case for the NH infants (see also Chapter 7.3.3 and 7.3.5).

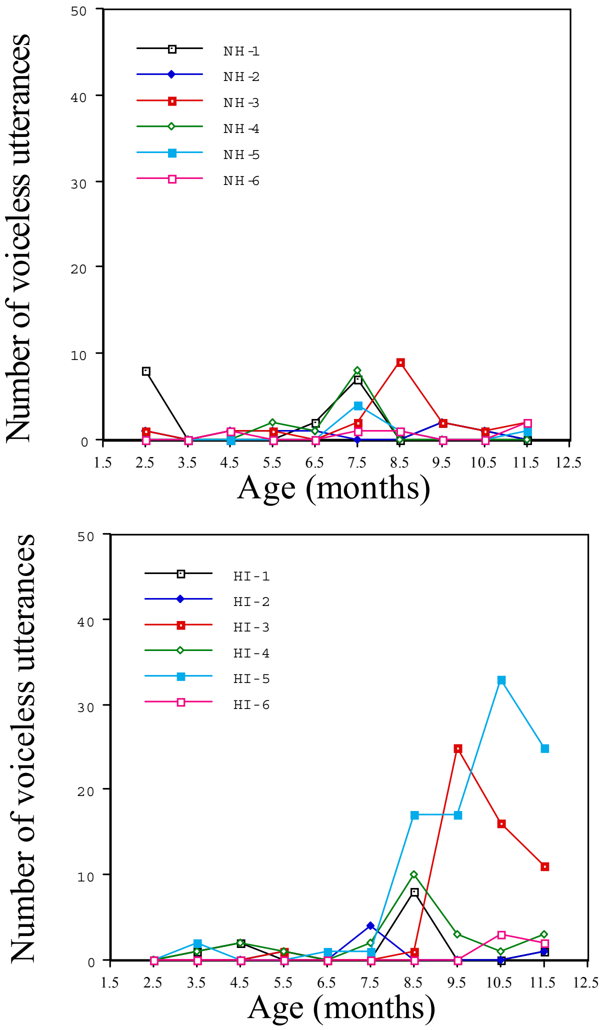


Figure 6.6. Mean number of voiceless utterances out of the 50 selected utterances for the six NH and six HI subjects per month. (for N see Table 6.8).

6.4. Discussion

Within the period investigated (between 2.5 and 11.5 months of age), several differences in the speech production between HI and NH infants can already be found on acoustic measurements. The differences become more clear from about 8.5 months onwards, especially with respect to median, maximal, and minimal F0, F0 variation, and voiceless sound production. Already during the first few months differences between the two groups are also observed with respect to the utterance duration. This suggests an influence of hearing on vocalizations already in these first months.

We found a considerably longer utterance duration for the six NH infants at age 3.5 months compared to the six HI infants. This 'duration peak' for the hearing infants had not been measured in any other study before. All NH infants produced that peak in the duration, except one NH infant who produced that peak (to a lesser extent) at 4.5 months. Our finding was recently confirmed by Giesbrecht (2002) who found a longer average utterance duration at four months of age (1950 ms) than at three months of age (1199 ms) in his subject[6]. In our study we found that all subjects, including the HI infants, seemed to be able to produce long utterances (over 2000 ms). The strong similarity between the length of the utterance duration at 2.5, 3.5, 4.5 and 5.5 months of the six NH subjects, including the extreme lengthening at 3.5 months, suggests that speech development in this period, is at least in part based on neurology, anatomy and physiology. In Chapter 3.2.5 we indicated that infants are able to produce longer utterances after their third month of life, when their rib cage has restructured towards the adult configuration (Langlois et al., 1980). The rib bones turn to a more flat position and as a result, infants can control the duration of their utterances by regulating their sub-glottal air pressure from that age on.

A more intentional controlling of the utterance duration, resulting in intentionally long or short utterances might be possible from that age onwards according to Bloom (1998). A more developed fine controlling system for the voice, is also suggested by the imitation of the duration and pitch of mother utterances by a three-month old infant (Sandner, 1981). Intentionally creating utterances with a shorter or longer duration is an effect of a more well developed system for voice controlling as will be discussed in more detail in section 9.2.2.

During the turn-taking process the utterance duration needs to be adjusted. As described in Chapter 3.2.1 turn-taking starts between three and four months of age. The infant has to learn in that period to start his turn on the right time and create pauses for the turn of the parent. For this complicated task, a well developed system

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[6] Unfortunately Giesbrecht had a very small data set: 10 utterances at four months and 11 utterances at three months of age for only one infant.

for fine controlling of the voice is needed. The drop in utterance duration between 3.5 and 4.5 months might be explained as part of this turn-taking process. It might be the case that the NH infants shorten their utterances in order to shorten their turns and creating more pauses, easing their parents to start their turn.

The three HI infants differ clearly from the six NH infants with respect to utterance duration. They lack the duration peak at 3.5 months and produce a relatively small amount of the long (over 2000 ms) utterances. This suggests that not only central anatomical and physiological aspects (see Chapter 3.2.5), but also hearing is necessary to produce the duration peak at this age. The lack of hearing might affect the internal feedback needed for the fine controlling of the voice, which makes it possible to lengthen or shorten the utterance duration more or less intentionally (Kent et al., 1987).

Moreover, the HI infants produced on average a significantly longer utterance duration than the NH infants at 5.5 months. It might be the case that this is a result of a somewhat slower speech development with respect to utterance duration and its control in HI infants compared to NH infants. In that case we expect that the duration peak at 3.5 for the NH infants is delayed to 5.5 months in the HI infants. It also might be that the longer utterances for the NH infants at 3.5 months and the HI infants at 5.5 months are related to certain types of phonation and articulation. These topics will be discussed in more detail in Chapters 7.4 and 9.2.2.

Secondly, it also might be the case that the average longer utterance duration at 5.5 months in the HI infants were actually a lack of more intentionally shortened utterances, that were found in NH infants at 4.5 months. The shorter utterances might be related to a start of the turn-taking behavior in NH infants as argued above. It is expected that HI infants have a different turn-taking process with their parents compared to NH infants, since a deaf child is not able to hear the pauses in his parents speech, indicating his turn to vocalize (see also Chapter 3.2.1). These issues will be discussed more in detail in Chapter 9.2.2.

With respect to the fundamental frequency we found some further differences between the two groups. We found a higher median fundamental frequency for the HI group compared to the NH infants from 9.5 months onwards. In previous studies also a significantly higher fundamental frequency had been found for older profoundly HI children (Ryalls and Larouche, 1992, 1993; Elsendoorn and Beijk, 1993; see also Chapter 3.3). Moreover, differences were also found for most other F0 parameters studied. Taking the data of all ten months into account, a significantly higher maximal F0, higher minimal F0, larger F0 range, higher F0 standard deviation and more voiceless utterances were found for the HI group compared to the NH group. This confirms the results from the deaf infant studied by Kent et al. (1987) who showed on average a higher peak F0 and a wider range in the peak F0 of his utterances, compared to his hearing twin brother (see also Chapter 3.3.2). On the other hand, studying the individual subjects, we found that the subjects not only showed more variation in the F0 of their utterances, but also within their group, than their hearing peers. The variance within the HI group is due to the observed unusual phonation, such as vocal fry and extremely high screaming, or a high number of unvoiced utterances. Kent et al. (1987) explains the deviant phonation of HI infants by the lack of internal feedback and therefore the lack of fine control of the voice.

According to Lieberman (1986) it might be the case that an innate propensity for sub-glottal air pressure and laryngeal muscles needs to be exercised within a critical period. In Chapter 5.3.1 it was shown that at 4.5 months the NH infants produced many utterances (107 per 10 minutes), more than at 3.5 months (76.8) or in any other month studied. This high number of utterances at this age seems to support this idea.

Thus it might be that a developing system for fine controlling of the voice, including further neurological, anatomical, physiological and internal feedback development, enables the NH infants to control the duration of the voice more from only 3.5 months onwards. Therefore from that age onwards, the duration can be adjusted for more intentional type of vocalizations, such as imitation and turn-taking. Lieberman (1986) suggests that a lack of exercising in this period might result in the extremely poor control of sub-glottal air pressure and of larynx muscles by older deaf children (see also Chapter 3.2.4). This explanation might be applicable to the infants in our study. The longer duration at 5.5 months, the higher F0, the higher variation within the utterances and within the HI group in our study, seems to support this idea. Moreover, the lack of hearing might affect this fine controlling system and the turn-taking process, in its turn influencing the utterance duration as will be discussed in more detail in Chapter 9.2.2.

Chapter 7

Phonation and articulation types of utterance and utterance structure

7.1 Introduction

In the present chapter we intend to answer the question whether differences can be found, and from which age onwards, between NH and HI infants with respect to phonation and articulation types of utterances, such as babbling and variegated phonation, as well as utterance structure and number of syllables.

The research questions with respect to this parameter were:

- Do deaf infants produce a different type of utterances than hearing infants with respect to articulation and phonation types of utterances, such as babbling and variegated phonation, and from which age onwards?

- Do deaf infants produce a different type of utterance structures, such as CV or VC, than hearing infants and from which age onwards?

- Do deaf infants produce more or fewer number of syllables per utterance, and from which age onwards?

Although very few studies have been performed previously on these parameters, we might expect to find some differences in articulation and phonation types, number of syllables and utterances structure between the two groups, within the first year of life (see also Chapter 3.3).

In some studies more variation in the F0 were observed such as strong changes within the F0 contour as well as intervals of vocal fry (Kent et al., 1988; Möller and Schönweiler, 1997) as described in Chapter 3.3.2. These studies indicate more variation in the phonation patterns of deaf infants. The results of our own data confirm this: we found a higher F0 range and standard deviation in F0 for our deaf subjects (see Chapter 6.3.3), also suggesting more variation in the phonation pattern compared to hearing infants. Thus, in the present chapter we expect that HI infants will tend to produce more complex utterances with respect to phonation, resulting, for instance, in more variation, compared to hearing infants.

Only few studies were performed on utterance structure of a deaf infant, such as babbling, as described in Chapter 3.3.3. These studies indicate that the utterance structure of deaf infants is less complex than that of hearing infants with respect to articulation (Kent et al., 1987; Spencer, 1993). It was suggested that deaf infants do not babble before 11 months of age, which is considerably later than hearing infants (Oller et al., 1985; Oller and Eilers, 1988). Therefore, we expect that in our study the HI subjects will tend to produce utterances with a simple type of articulation and no babbling.

To our knowledge, only one other study has been performed on number of syllables in young hearing impaired children, unfortunately not comparing the results with number of syllables of hearing infants (Yoshinago-Itano et al., 1992). Syllabification can be done, theoretically, by either articulation or phonation. Since we expect that the phonation in HI might be more complex, which might result in more syllabification, and the articulation might be less complex, resulting in less syllabification, we might expect an equal number of syllables between the two groups. Thus, our hypotheses are formulated as following:

- A more complex type of phonation is produced by the HI infants, than by the NH infants
- A more complex type of articulation, such as babbling, is produced by the NH than by the HI infants
- An equal number of syllables is produced by both groups

7.2 Method

7.2.1 Classification in types of phonation and articulation

All 5381 digitized utterances were classified, having been judged as to phonation and articulation. These were perceptual judgements (see also Chapter 4.4). Each utterance was classified in one of the five possible types of phonation and in one of the three possible types of articulation. The model of Koopmans-van Beinum and Van der Stelt (1986, 1998), which focuses on the separate development of phonatory and articulatory movements (see also Chapter 3.1), was the most useful for our purposes. This model gave us the possibility to split up the source (phonation) and filter (articulation) in order to describe them separately for each utterance (see also Clement and Den Os, 1993; Clement and Koopmans-Van Beinum, 1994). The different types of phonation were produced with movements at the larynx level, while in our definition the types of articulation were the articulatory constrictions produced supralaryngeally, resulting in supralaryngeal consonant-like segments[1]. A precise description of each of the articulation and phonation types is given below.

[1] Vowel-like segments were not analyzed in this thesis (see Chapter 3.5).

Phonation:

1 *NoPho:* no phonation during the entire utterance. Whenever some voicing is heard, the utterance is classified as one of the other four phonation types.

2 *SimPho:* simple phonation, in which there is neither interruption of the voiced airstream nor variegated phonation as in the following phonation types. No deviant voicing is heard; the voicing is relaxed; there is hardly any variation in intonation, pitch, loudness, or voice quality.

3 *IntPho:* interrupted phonation, the voiced airstream is interrupted. The voicing is clearly stopped, often by glottal stops as in the [?a?a]-like utterance.

4 *VarPho:* variegated phonation, variation in the intonation, pitch, voice quality or loudness, while the phonation is uninterrupted. In most cases a relatively large amount of tension in the larynx is heard, resulting in a variegated voicing type. For example, vocal fry (creaky voice) when produced during almost the complete utterance (thus not only during the start of the utterance, such as in many baby utterances with relaxed voicing). Other examples are screaming, quick changes in the intonation pattern during the utterance, or alternations of rising and falling intonation during one utterance. The use of false vocal cords is also included in this category. Also, extremely long utterances (>2 seconds) if not containing articulation movements, were included in this category.

5 *ComPho:* a combination of interrupted and variegated phonation. For instance a series of coughing-like sounds produced by some of the infants.

Articulation:

1 *NoArt:* no articulatory movement during the whole utterance. This type of utterances can be produced as a vowel-like sound or with the lips closed during the whole utterance (e.g. [m]-like during the whole utterance).

2 *SimArt:* Articulation movement, but no babbling. The articulation movement can occur during one syllable with often one articulatory movement, as in an utterance sounding like [ba], or during two syllables, such as in an [axa]-like utterance. Also two articulatory movements were possible during one syllable as in [gax]. Only supraglottal articulation movements are considered, thus laryngeals are not included in this classification of articulation. Utterances with glottal stops clearly interrupting the air stream are classified in the phonation type in the category IntPho, but as NoArt in the articulation type.

3 *Babbling*: two or more articulatory movements during two or more syllables. During the utterance at least two syllables containing CV-like combinations are produced. In the combination of Babbling and IntPho the voicing has to be clearly interrupted between two or more syllables, as in an utterance sounding like [pa...pa] in which '...' stands for an interruption of the airstream including the voicing. A short interruption of the airstream, as usually in the closure part of the second consonant in a [papa]-like utterance, is not considered as IntPho. These interruptions normally turn out not to be unvoiced in infant speech, as concluded from several inspections of oscillograms and spectrograms by the author. The babbled utterance can be voiceless, but in a CVCV-like utterance the last V-like segment should be voiced, because a whispered (unvoiced) vowel following a plosive can be confused with the release of the plosive.

The three types of articulation can be combined with each of the five types of phonation. The only exception is of course the combination of NoArt and NoPho. The combination of NoPho and Babbling is possible in the form of jaw wags (see also Chapter 3.1, but could not be measured in our data set, since we made only audio-recordings.

Table 7.1 The possible types of articulation and phonation combined.

Phonation	Articulation		
	NoArt	SimArt	Babbling
NoPho	not possible	X	not observed
SimPho	X	X	X
IntPho	X	X	X
VarPho	X	X	X
ComPho	X	X	X

The system described above incorporates the results on the most important speech developmental stages for NH infants, like gooing and babbling, as described in Chapter 3.1. In Table 7.2 the phonation and articulation types are related to the development stages as described by Stark (1980), Oller (1980), and Koopmans-van Beinum and Van der Stelt (1986). We can see that each of the developmental stages is related to the introduction of a new type of utterance.

Table 7.2 Speech development stages from studies of Stark (1980), Oller (1980), and Koopmans-van Beinum and Van der Stelt (1986) related to the phonation and articulation types described in this study.

Stark (1980)	Oller (1980)	Koopmans/v.d. Stelt	Phonation in this study	Articulation in this study
Reflexive	Phonation	Uninterrupted phonation	SimPho	NoArt
		Interrupted phonation	IntPho	NoArt
Cooing	Gooing	One articulatory movement	SimPho/IntPho	SimArt
Vocal play	Expansion	Variegated phonation	VarPho/ComPho	NoArt/SimArt
Redupl. babbling	Canonical babbling	Babbling	any Pho type	Babbling

7.2.2 Interjudge agreement for types of articulation and phonation

Two independent judges (trained phoneticians) classified the 50 selected utterances of the infants produced during the transcribed 10 minutes per monthly recording (see Chapter 4.4). Initially both listeners trained themselves for several hours with a subset of the data, which was also described in a previous publication (Clement et al., 1994). The inter-judge agreement for all utterances amounted to 90.9% for type of articulation and to 83.2% for type of phonation, which we considered as high enough to be reliable. 76.4% of the utterances were agreed upon for both articulation and phonation. In some of the utterances that were not agreed upon for both articulation and phonation it was hard to identify whether the constriction was made supralaryngeally, resulting in an articulated utterance (often with back fricative/trill) or glottally resulting in non-articulated variegated phonation. This type of utterances was found in some HI infants, especially in the last months (as will be discussed in detail in Chapter 9.2.2). After the individual classification was completed, the two researchers discussed each utterance to reach a final decision.

7.2.3 Utterance structure of articulated utterances

The two types with articulation, SimArt en Babbling (see 7.2.1), were further specified as shown in Table 7.3. C stands for a consonant-like segment and V for a vowel-like segment. The SimArt utterances were classified as C, CV, VCV, VC or CVC. The Babbled utterances were classified as CVCV or VCVCV, CVCVCV or VCVCVCV, VCVC or else.

Table 7.3. Specification of the articulated utterances.

SimArt	C	CV	VCV	VC	CVC
Babbling	(V)CVC V	(V)CVC VCV	VCVC	Else	

Clusters of two or more consonant-like segments were classified as only one consonant-like segment in this part of the study (see also Chapter 8.2.1). For instance an utterance sounding like [akRa] was classified as VCV. Glottals (glottal stops and aspiration) were excluded in this section as in section 7.2.1. Thus an utterance sounding like [haXa] was classified as VCV, not as CVCV. A second judge, a trained phonetician familiar with infant speech, verified a subset of the data, namely all those utterances of 20 (out of 21) recordings at 8.5 and 9.5 months. Agreement was more than 80%. In the present chapter we will just study the syllable structure and number of syllables, but not their content. This will be done in the Chapter 8, by specifying the articulation movements (consonant-like segments) of each utterance.

7.2.4 Number of syllables

The number of syllables per utterance was counted. Four classification categories were used: utterances of one syllable, utterances of two syllables, utterances of three syllables and utterances of four or more syllables. The definition for 'syllable' was rather broad; ‘pseudo-syllables’ consisting of only a continuant or a vowel were also counted as syllables (Clement et al., 1994). The classification of the number of syllables was done on the basis of intuitive judgments, although some ‘indicators’ were used. Indicators of syllable boundaries were:

a) In case of vowel – consonant alternation the syllable starts with a consonant, according to the Obligatory Onset Principle and Maximal Onset Principle (Kahn, 1976; Selkirk, 1982), e.g. VCCV -> V.CCV

b) interruptions of the voicing by glottal stops between vowels e.g. V.V.CV

c) strong pitch difference in the F0 pattern within the utterance, e.g. __—, even in case of a pseudo-syllable.

A subset of the data consisting of a total of 1500 utterances (five recordings of three NH and three HI infants, between 5.5 and 9.5 months of age, with 50 utterances each) was classified by an independent second judge, a trained phonetician familiar with infant speech. The inter-judge agreement between the author and the second judge for that subset was 87%, which we considered high enough. The final decision was made by the author.

7.2.5 Quantitative analysis

Firstly, the numbers of the three different types of articulation and the five different types of phonation for both subject groups are presented in section 7.3.1, 7.3.2 and 7.3.3, and summarized in section 7.3.4. In section 7.3.5 the individual data is described. Next, the utterances with articulation are further analyzed with respect to utterance structure in 7.3.6. And finally, the number of syllables are described for both subject groups in section 7.3.7.

7.3. Results

7.3.1 Types of phonation and articulation

Table 7.4 shows the number of utterances for each possible combination of phonation and articulation type. On the horizontal axis we see the three possible articulation types and on the vertical axis the five possible phonation types, creating 13 possible combinations as previously shown in Table 7.1. In each sub-table the mean number of utterances of the articulation-phonation combinations is shown per group per month, as well as the running averages over three subsequent months (see also Chapter 5.3.1) and the results of Mann-Whitney U tests over the running averages for matched pairs. At the bottom of each sub-table the averages over all ten months are shown as well as the result of a t-test on these averages of both groups. In the next sections we will discuss the results of the phonation and articulation types separately.

7.3.2 Phonation

It can be seen in Table 7.4 that the most commonly used type of utterance, in both groups and across all months, was the most uncomplicated one, namely utterances without any articulatory movements and with simple, uninterrupted phonation (NoArtSimPho). The NH group produced on average for all months combined 20.1 utterances without articulation and simple phonation. The HI infants produced on average 21.5 utterances on a total of 50 utterances per month. No significant difference was found between the NH and HI group for this type. In other words, the most simple type of utterance was not produced more often by the HI infants than by the NH infants as also can be seen in Figure 7.1.

Table 7.4 (next page). Number of utterances with a certain type of utterances, for both groups, during ten minutes per months. The three types of articulation are shown horizontally and the five types of phonation are shown vertically. Also the combination of the articulation and phonation types are shown, as well as the results of the Mann-Whitney U tests.

Phon	Art	NoArt					SimArt					Babbling					Total				
							SimArt NoPho										NoPho Total				
No Phon	Age						NH	Run	HI	Run	p=						NH	Run	HI	Run	p=
	2.5						0.3		0.0								0.3		0.0		
	3.5						0.2	0.2	0.0	0.0	ns						0.2	0.2	0.0	30.0	ns
	4.5						0.0	0.1	0.0	0.2	ns						0.0	0.1	0.0	0.2	ns
	5.5						0.2	0.1	0.3	0.2	ns						0.2	0.1	0.4	0.2	ns
	6.5						0.0	0.8	0.2	0.5	ns						0.0	0.8	0.2	0.5	ns
	7.5						2.3	1.0	1.0	1.5	ns						2.3	1.0	1.0	1.5	ns
	8.5						0.7	1.2	3.3	3.4	ns						0.7	1.2	3.3	3.4	ns
	9.5						0.4	0.5	6.0	5.4	ns						0.4	0.5	6.0	5.4	ns
	10.5						0.4	0.3	7.0	6.3	<.025						0.4	0.3	7.0	6.3	<.025
	11.5						0.0		5.8								0.0		5.8		
	Mean						0.4		2.4		<.001						0.4		2.4		<.001
		NoArt SimPho					SimArt SimPho					Babbling SimPho					SimPho Total				
Sim Phon	Age	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=
	2.5	30.8		37.0			8.3		3.0			0.0		0.0			39.2		40.0		
	3.5	14.3	20.9	31.3	28.0	ns	9.7	10.3	4.7	4.8	ns	0.0	0.0	0.0	0.0	ns	24.0	31.2	36.0	32.8	ns
	4.5	17.7	17.4	18.7	23.3	ns	12.8	11.0	6.0	6.3	ns	0.0	0.1	0.0	0.1	ns	30.5	28.6	24.7	29.6	ns
	5.5	20.3	21.3	21.5	19.5	ns	10.5	10.1	7.2	9.9	ns	0.3	0.4	0.2	0.1	ns	31.2	31.8	28.8	29.5	ns
	6.5	25.8	21.1	17.8	19.5	ns	7.0	10.1	14.7	10.4	ns	1.0	1.0	0.0	1.2	ns	33.8	32.2	32.5	31.1	ns
	7.5	17.0	20.2	19.2	18.3	ns	12.8	11.7	9.5	11.0	ns	1.7	2.1	3.3	1.7	<.025	31.5	33.9	32.0	31.0	ns
	8.5	17.8	17.0	17.8	18.3	ns	15.2	14.9	8.8	8.8	<.025	3.5	2.8	1.8	1.8	<.005	36.5	34.8	28.5	28.9	ns
	9.5	16.0	17.9	18.0	17.8	ns	17.2	15.4	8.0	7.8	<.01	3.4	3.0	0.0	0.7	<.001	36.6	36.3	26.0	26.4	<.01
	10.5	19.8	19.4	17.7	17.3	ns	13.8	14.4	6.7	6.9	<.01	2.0	3.6	0.2	0.1	<.001	35.6	37.4	24.5	24.2	<.001
	11.5	21.8		16.2			12.6		6.0			5.1		0.0			39.5		22.2		
	Mean	20.1		21.5		ns	12.0		7.5		<.025	1.7		0.6		ns	33.8		29.5		<.001
		NoArt IntPho					SimArt IntPho					Babbling IntPho					IntPho Total				
Int Phon	Age	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=
	2.5	4.2		6.5			1.0		0.0			0.0		0.0			5.2		6.5		
	3.5	2.2	2.8	3.0	3.9	ns	3.3	2.2	1.0	0.8	ns	0.0	0.0	0.0	0.0	ns	5.5	5.0	4.0	4.6	ns
	4.5	2.2	2.2	3.0	2.0	ns	2.2	2.7	1.0	1.2	ns	0.0	0.1	0.0	0.0	ns	4.3	4.9	4.0	3.2	ns
	5.5	2.2	1.8	1.0	1.3	ns	2.5	2.3	1.3	1.0	ns	0.2	0.1	0.0	0.0	ns	4.8	4.2	2.3	2.3	ns
	6.5	1.2	1.8	0.8	1.2	ns	2.2	1.7	0.7	1.2	ns	0.0	0.4	0.0	0.0	ns	3.3	3.9	1.5	2.3	ns
	7.5	2.0	1.5	1.7	1.4	ns	0.5	1.1	1.5	1.3	ns	1.2	0.9	0.0	0.0	<.025	3.7	3.5	3.2	2.8	ns
	8.5	1.3	1.6	1.8	1.7	ns	0.7	0.9	1.8	1.2	ns	1.5	1.2	0.0	0.0	<.001	3.5	3.8	3.7	2.9	ns
	9.5	1.6	1.4	1.5	1.6	ns	1.8	1.0	0.3	0.8	ns	0.8	1.1	0.0	0.0	<.001	4.2	3.5	1.8	2.4	ns
	10.5	1.2	1.0	1.5	1.3	ns	0.6	0.9	0.3	0.4	ns	1.0	0.9	0.0	0.0	<.001	2.8	2.9	1.8	1.7	ns
	11.5	0.4		0.8			0.5		0.5			0.8		0.0			1.8		1.3		
	Mean	1.8		2.2		ns	1.5		0.9		<.05	0.5		0.0		<.002	3.9		3.0		<.005

Phon	Art	NoArt					SimArt					Babbling					Total				
		NoArt VarPho					SimArt VarPho					Babbling VarPho					VarPho Total				
Var Phon	Age	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=
	2.5	2.3		3.0			0.7		0.0			0.0		0.0			3.0		3.0		
	3.5	8.2	6.3	5.0	8.3	ns	5.0	2.7	2.3	1.4	ns	0.0	0.0	0.0	0.0	ns	13.2	9.0	7.3	9.6	ns
	4.5	8.3	8.2	15.0	11.0	ns	2.5	3.3	1.3	2.1	ns	0.0	0.0	0.0	0.0	ns	10.8	11.5	16.3	13.1	ns
	5.5	8.2	8.1	12.0	12.7	ns	2.3	2.2	2.3	1.8	ns	0.0	0.0	0.0	0.0	ns	10.5	10.3	14.3	14.5	ns
	6.5	7.8	7.9	12.3	10.1	ns	1.8	2.3	1.5	2.4	ns	0.0	0.1	0.0	0.0	ns	9.7	10.4	13.8	12.5	ns
	7.5	7.8	7.2	5.8	8.3	ns	2.8	1.8	3.5	2.1	ns	0.3	0.4	0.0	0.2	ns	11.0	9.5	9.3	10.6	ns
	8.5	6.0	6.4	6.7	7.7	ns	0.8	1.9	1.3	2.0	ns	1.0	0.5	0.7	0.3	ns	7.8	8.8	8.7	10.0	ns
	9.5	5.0	5.4	10.7	8.8	ns	2.0	1.6	1.2	1.2	ns	0.2	0.6	0.2	0.5	ns	7.2	7.6	12.0	10.5	ns
	10.5	5.0	4.7	9.0	11.2	<.05	2.2	2.0	1.2	1.1	ns	0.4	0.5	0.7	0.3	ns	7.6	7.2	10.8	12.6	ns
	11.5	4.2		13.8			1.9		1.0			0.8		0.0			6.9		14.8		
	Mean	6.3		9.3		<.05	2.2		1.6		ns	0.3		0.2		ns	8.8		11.1		ns
		NoArt ComPho					SimArt ComPho					Babbling ComPho					ComPho Total				
Com Phon	Age	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=
	2.5	1.8		0.5			0.5		0.0			0.0		0.0			2.3		0.5		
	3.5	4.7	3.4	2.0	2.6	ns	1.7	0.9	0.7	0.4	ns	0.8	0.3	0.0	0.0	ns	7.2	4.6	2.7	3.0	ns
	4.5	3.8	3.7	4.7	2.6	ns	0.5	0.9	0.3	1.4	ns	0.0	0.3	0.0	0.0	ns	4.3	4.9	5.0	4.0	ns
	5.5	2.7	3.2	1.8	2.5	ns	0.7	0.4	2.3	1.0	ns	0.0	0.1	0.0	0.0	ns	3.3	3.6	4.2	3.5	ns
	6.5	3.0	2.0	2.0	2.3	ns	0.0	0.4	0.0	1.2	ns	0.2	0.2	0.0	0.1	ns	3.2	2.7	2.0	3.6	ns
	7.5	0.3	1.4	3.0	3.3	ns	0.7	0.3	1.3	0.7	ns	0.5	0.3	0.2	0.1	ns	1.5	2.1	4.5	4.1	ns
	8.5	1.0	0.8	5.0	4.0	ns	0.2	0.4	0.8	0.8	ns	0.3	0.3	0.0	0.1	ns	1.5	1.5	5.8	4.8	ns
	9.5	1.2	1.6	4.0	4.8	ns	0.4	0.4	0.2	0.5	ns	0.0	0.1	0.0	0.0	ns	1.6	2.2	4.2	5.3	ns
	10.5	2.8	1.6	5.3	4.8	<.05	0.8	0.6	0.5	0.5	ns	0.0	0.1	0.0	0.0	ns	3.6	2.3	5.8	5.3	ns
	11.5	1.0		5.0			0.5		0.8			0.3		0.0			1.8		5.8		
	Mean	2.2		3.3		ns	0.6		0.7		ns	0.1		0.0		ns	3.0		4.1		ns
		NoArt Total					SimArt Total					Babbling Total					ArtTot PhoTotal				
Total	Age	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	p=	NH	Run	HI	Run	
	2.5	39.2		47.0			10.8		3.0			0.0		0.0			50		50		
	3.5	29.3	33.5	41.3	42.3	ns	19.8	16.2	8.7	7.3	ns	0.8	0.3	0.0	0.0	ns	50	50	50	50	
	4.5	32.0	31.6	41.3	38.8	ns	18.0	18.0	8.7	11.1	ns	0.0	0.4	0.0	0.1	ns	50	50	50	50	
	5.5	33.3	34.4	36.3	36.0	ns	16.2	15.1	13.5	13.9	ns	0.5	0.6	0.2	0.1	ns	50	50	50	50	
	6.5	37.8	32.8	33.0	33.0	ns	11.0	15.4	17.0	15.8	ns	1.2	1.8	0.0	1.2	ns	50	50	50	50	
	7.5	27.2	30.4	29.7	31.3	ns	19.2	15.9	16.8	16.7	ns	3.7	3.7	3.5	2.0	<.025	50	50	50	50	
	8.5	26.2	25.8	31.3	31.7	ns	17.5	19.4	16.2	16.2	ns	6.3	4.8	2.5	2.2	<.005	50	50	50	50	
	9.5	23.8	26.3	34.2	33.0	ns	21.8	18.9	15.7	15.8	ns	4.4	4.8	0.2	1.2	<.001	50	50	50	50	
	10.5	28.8	26.7	33.5	34.5	<.05	17.8	18.2	15.7	15.2	ns	3.4	5.1	0.8	0.3	<.001	50	50	50	50	
	11.5	27.4		35.8			15.5		14.2			7.0		0.0			50		50		
	Mean	30.5		36.4		ns	16.8		12.9		ns	2.7		0.7		<.025					

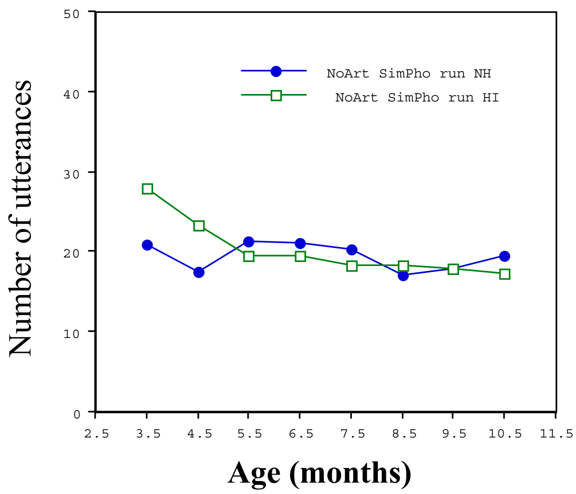

Figure 7.1 Total number of utterances with simple phonation and no articulation is shown for both groups per 3 month period (running average). No significant differences are found.

A higher number of utterances with simple phonation combined with articulation, SimArtSimPho and BabblingSimPho for the NH infants was found from 7.5 months onwards. This was influenced by the significantly higher number of utterances with a simple phonation, with or without articulation (SimPhoTotal), produced by the NH group compared to the HI group at 8.5-10.5 and 9.5-11.5 months and on average over the ten months as shown in Table 7.4.

The number of utterances with an interrupted air stream without articulation (NoArtIntPho) was not significant different between the NH and the HI infants. The mean number of NoArtIntPho utterances for all months combined was 1.8 for the NH group and 2.2 for the HI group. Combining the interrupted phonation with articulation, however, significant differences are found. The NH infants produced both more interrupted phonation utterances with simple articulation (SimArtIntPho), when the data from ten months is combined or if combined with babbling from 7.5 months onwards (BabblingIntPho). This is for example the case with voiceless plosives with a clear closure before the release, e.g. an [a...pa]- or a [pa...pa]-like utterance in which '...' stands for a small silent pause. When all interrupted phonation utterances (IntPhoTotal) are summed the NH infants produced more interrupted utterances if combining the data for all months, but influenced by the combination with articulation.

The HI infants produced more utterances with a variegated phonation (NoArtVarPho) without any articulatory movements than NH infants. This effect is significant in the last three months and on average over the whole period (see

Table 7.4 and Figure 7.2). The mean number of NoArtVarPho utterances was 6.3 for the NH group and 9.3 for the HI group, combining all months studied. Combining the variegated phonation with articulation (SimArtVarPho and BabblingVarPho) no significant differences were found, as well as when all variegated phonation utterances (VarPhoTotal) were combined.

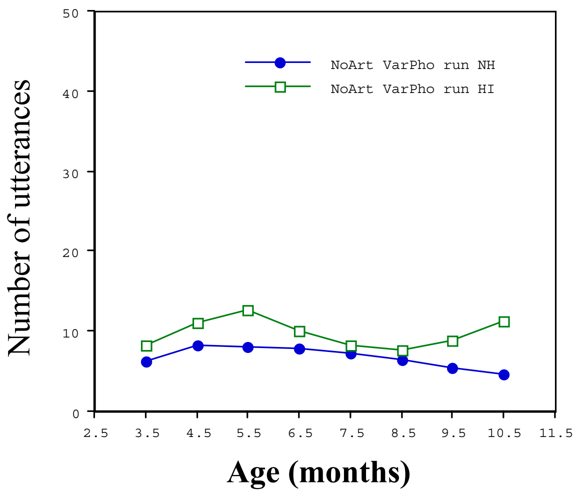

Figure 7.2 Number of utterances with variegated phonation and no articulation per group (expressed as running averages per 3-month period). The HI infants produce significantly more NorArtVarPho utterances at 9.5-11.5 months and if all months are combined.

Furthermore, the HI infants produced more utterances than the NH infants, with an even more complicated type of phonation: with both variation and interruption of the air stream and no articulation (NoArtComPho). This starts to occur at about the same time that the NH infants started to babble (7.5-9.5 months onwards) as shown in Figure 7.3. The difference was significant in the period 9.5-11.5 (see Table 7.4). In most of those utterances by the HI infants the interruption of the air stream and voicing gave the impression of syllabification. In section 7.3.5 the NoArtVarPho and NoArtComPho utterances will be discussed for the individual subjects.

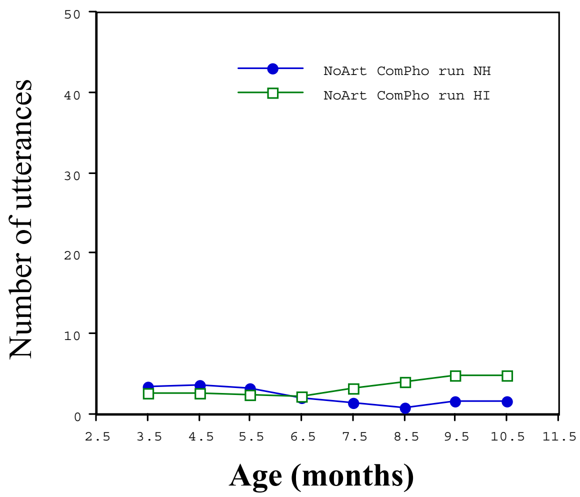

Figure 7.3 Number of utterances with combined (variegated and interrupted) phonation and no articulation per group (expressed as running averages per 3-month period). The HI infants produce significantly more NoArtComPho utterances at 9.5-11.5 months.

7.3.3 Articulation

A total of 1880 utterances out of the 5381 utterances studied contained articulation movements. In Figure 7.4 and Table 7.5 the total number of articulations, thus the sum of the SimArt and Babbling utterances, independent of the type of phonation, is shown per month for both groups. It can be seen that the NH group produced first an increase and then a decrease of total number of articulations in two separate periods during the first year: the first peak during the first half year and the second during the second half of the first year of life. These peaks seem to be related to the two stages in the first year with an increase of number of articulations, as described by for instance Stark (1980) and Koopmans-van Beinum and van der Stelt (1986), as will be discussed more thoroughly in Chapter 9. The HI group produced only one broad peak, around 7.5 months. Table 7.5 shows that only in the last age period (9.5-11.5 months) significantly fewer articulations (ArtTot) were found in the HI group compared to the NH group ($p<.05$) (see also section 7.3.5 for a discussion of the data of the individual subjects).

Table 7.5 Mean number of utterances with articulation movements per month (SimArt and BabblingArt combined), for the NH and HI group separately.

Age	NH	NH run	HI	HI run	p=
2.5	10.8		3.0		
3.5	20.7	16.5	8.7	6.8	ns
4.5	18.0	18.3	8.7	10.4	ns
5.5	16.2	15.5	13.7	13.1	ns
6.5	12.2	17.1	17.0	17.0	ns
7.5	22.9	19.6	20.3	18.7	ns
8.5	23.8	24.3	18.7	18.3	ns
9.5	26.2	23.7	15.9	17.1	ns
10.5	21.2	23.3	16.6	15.6	<.05
11.5	22.5		14.2		
Mean	19.5		13.7		ns

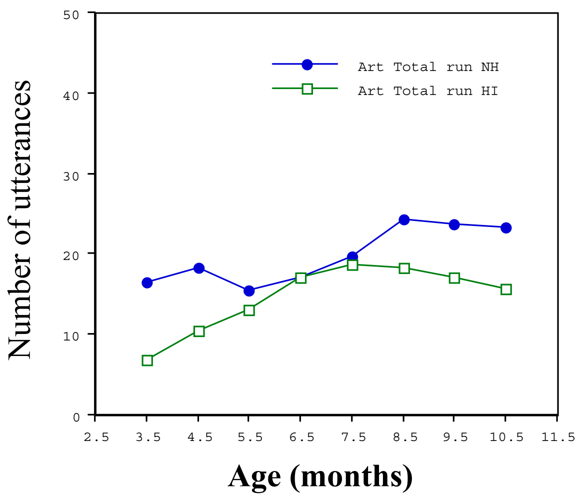

Figure 7.4. Total number of articulations per month as a function of age (expressed as running averages per 3-month period).

The total number of utterances with just one articulation (SimArtTot) was not different between the two groups as shown in Table 7.4. Looking at the SimArt utterances combined with certain types of phonation, it can be seen that the NH infants produced utterances with simple articulation and uninterrupted, simple phonation (SimArtSimPho) significantly more often than the HI infants, starting from 7.5-9.5 months onwards (p<.025) and if combining all months (p<.025) (Figure 7.5 and Table 7.4). The mean number of SimArtSimPho utterances was 12.0 for the NH group and 7.5 for the HI group if combining all months.

On the other hand, the utterances with simple articulation without phonation (SimArtNoPho) were produced significantly more often by the HI infants, at 9.5-11.5 months and on average over the ten months (see Figure 7.6 and Table 7.4). The mean number of SimArtNoPho utterances was 0.4 for the NH group and 2.4 for the HI group if combining all months. In the last months studied this type of utterance was common for the HI infants, but not for the NH infants. At 9.5-11.5 months the NH infants produced only 0.3 SimArtNoPho utterances, but the HI infants even 6.3 utterances, almost as many as the SimArtSimPho utterances with phonation at the same age (6.9). These SimArtNoPho utterances can be compared with the voiceless utterances found during the F0 measurements at 9.5-11.5 months (see Chapter 6.3.5). The simple articulation combined with variegated phonation (SimArtVarPho) and combined phonation (SimArtComPho) was not significantly different between the two groups. In section 7.3.5 the SimArtNoPho utterances will be discussed for the individual subjects.

Thus the total number of utterances with articulation is not significantly different between the two groups, but in the last months studied, the NH infants produce these utterances more often with phonation compared to the HI infants, and the HI infants more often without phonation compared to the NH infants.

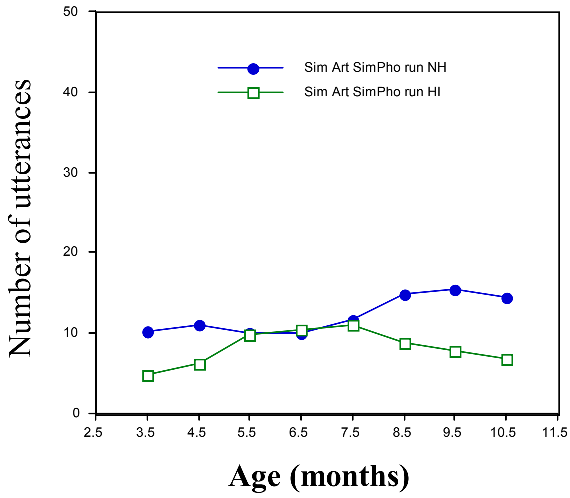

Figure 7.5 Running averaged number of utterances with one articulation and simple phonation per month and group. The NH infants produce significantly more SimArtSimPho utterances from 7.5-9.5 months onwards and if all months are combined.

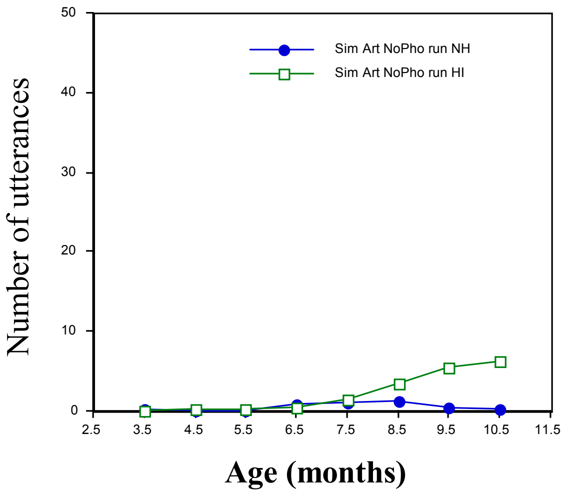

Figure 7.6 Running averaged number of utterances with one articulation and no phonation per month and group. The HI infants produced the SimArtNoPho utterances significantly more often at 9.5-11.5 and if all months are combined.

Significantly more babbled utterances (BabblingTot) were produced by the NH infants, starting from 6.5-8.5 months onwards as can be see in Figure 7.7, Table 7.4 and Table 7.6. The mean number of babbled utterances for all months combined were 2.7 for the NH group and 0.7 for the HI group, and this difference was significant (p<.025). In the last months the difference was even highly significant (6.5-8.5 months: p<.025, 7.5-9.5 months: p<.005, 8.5-10.5 months and 9.5-11.5 months: p<.001). Looking at the babbled utterances combined with simple phonation (BabblingSimPho) or interrupted phonation (BabblingIntPho) also in the last months studied highly significant differences were found. Babbling combined with variegated phonation (BabblingVarPho) and combined phonation (BabblingComPho) was uncommon for both groups and not significantly different between both groups. Babbling in the individual subjects will be discussed more thoroughly in section 7.3.6.

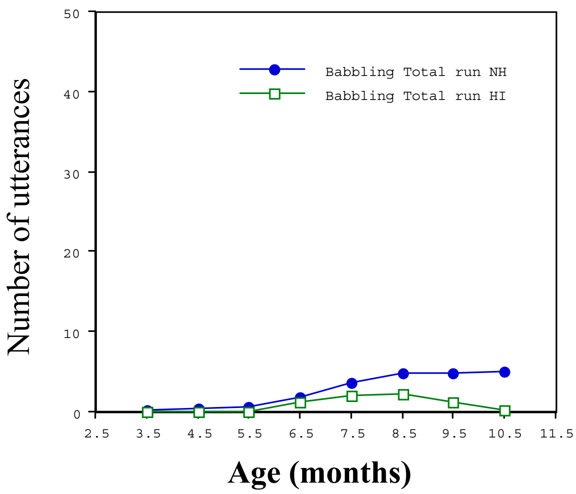

Figure 7.7. Number of babbled utterances (running average) in total per month for both groups. The NH infants produce significantly more BabblingTotal utterances if all months are combined and from 6.5-8.5 months onwards.

7.3.4 Summary and conclusions of the group results

As shown in the previous sections, the NH infants and HI infants did not differ in some articulation-phonation combinations, while they did in some other articulation-phonation combinations (see also Table 7.6). No significant differences were found for the NoArtSimPho, NoArtIntPho, SimArtVarPho, SimArtComPho, BabblingVarPho and BabblingComPho utterances for one or more months studied or all months combined. The last two combinations hardly occurred in both groups. The HI infants differed significantly as a group from the NH infants in several other articulation-phonation combinations. The NH infants produced more SimArtSimPho utterances, SimArtIntPho, BabblingSimPho, BabblingIntPho. On the other hand, the HI infants produced more SimArtNoPho, NoArtVarPho and NoArtComPho utterances.

Table 7.6. Overview of the results for all possible types of articulation and phonation combined.

	Articulation			
Phonation		NoArt	SimArt	Babbling
	NoPho	not possible	NH < HI	not measurable
	SimPho	ns	NH > HI	NH > HI
	IntPho	ns	NH > HI	NH > HI
	VarPho	NH < HI	ns	ns
	ComPho	NH < HI	ns	ns

With respect to phonation the HI infants produced more complex types than we expected, the variegated and combined phonation was produced significantly more often than by the NH infants, however, only if produced without articulation. With respect to articulation the HI infant produced less complex types (e.g. babbling) than the NH infants as we expected. The only type of utterance with articulation the HI infants produced significantly more often than the NH infants, was the type with one articulation movement and without any phonation (SimArtNoPho). Thus our hypotheses described in section 7.1 were at least partly true for articulation and the complexity of the utterances with respect to the combination of articulation and phonation. A possible difference in complexity of the utterances between the two groups will also be studied by investigating the number of syllables and utterance structure in section 7.3.6 and 7.3.7.

7.3.5 Individual data

There are three types of utterances which are produced significantly more often by the HI infants, than by the NH infants, namely SimArtNoPho, NoArtVarPho, and NoArtComPho in the second half of the first year (see also sections 7.3.2 and 7.3.3). We will next discuss the three above mentioned phonation-articulation combinations for the individual subjects in more detail. As shown in the previous sections, the HI infants differed as a group from the NH infants in various phonation-articulation combinations. Within the HI group, however, we also see in Table 7.7 differences between the HI infants. For instance, one of the HI infants (HI-1) produced almost no articulated utterances from 6.5 months onwards, in total he produced only six utterances with articulation out of the 300 between 6.5 and 11.5 months[2].

[2] This might have had some influence in the last months, resulting in significantly more utterances without articulation (NoArtTotal) at 9.5-11.5 months for the HI group as was shown in Table 7.4.

SimArtNoPho utterances with simple, not-babbled articulation, but without phonation during the whole utterance were produced more often by the HI infants (see section 3.3.3) and extremely often by two HI infants. HI-3 and HI-5 produced up to 25 and 24 of this type out of 50 utterances in one recording at 9.5 months and 10.5 months respectively (see Table 7.7). These SimArtNoPho utterances were typically voiceless back fricatives or back trills, although also voiceless front fricatives were produced. The exact place and manner of articulation of these articulated utterances will be discussed more thoroughly in Chapter 8. In Appendix A7.2 a typical example of a SimArtNoPho utterance of HI-4 at 9.5 months of age is shown in an oscillogram. The NH infants hardly produced any voiceless articulated utterances as mentioned in section 7.3. Their SimArtNoPho utterances were almost all produced at the front place of articulation (see also chapter 8.3.3).

Table. 7.7. Number of SimArtNoPho utterances combined for the individual subjects.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	Mean	HI1	HI2	HI3	HI4	HI5	HI6	Mean
7.5	5	0	1	6	2	0	2.3	0	4	0	1	1	0	1.0
8.5	0	0	4	0	0	0	0.7	4	0	0	5	11	0	3.3
9.5	1	0	1	0	0	na	0.4	0	0	25	1	10	0	6.0
10.5	1	0	1	0	0	na	0.4	0	0	14	1	24	3	7.0
11.5	0	0	0	0	0	0	0.0	0	1	10	2	21	1	5.8
Mean 7.5-11.5	1.4	0	1.4	1.2	0.4	0	0.7	0.8	1	9.8	2	13.4	0.8	4.6

Also the NoArtVarPho and NoArtComPho utterances (without articulation, but with variation in the intonation, pitch, voice quality or loudness also in combination with a clear interruption of the air stream during the utterance) were produced more often by the HI infants (see section 3.3.2). If combining these two types of utterances we find significant differences from 9.5 months onwards (running average) by means of a Mann-Whitney U-test and if combining all months[3] by means of a paired t-test. In Table 7.8 the total number of utterances NoArtVarPho and NoArtComPho is shown per month and per subject, as well as average from 7.5 months onwards. It can be seen that HI-1, HI-2, HI-3 and HI-4 produced these types of utterances very often.

[3] At 9.5 months $p<.05$, at 10.5 months $p<.01$ and with all months combined $p<.005$.

Table. 7.8. Number of NoArtVarPho and NoArtComPho utterances combined, per month and in total for the individual subjects.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	Mean	HI1	HI2	HI3	HI4	HI5	HI6	Mean
7.5	9	6	8	4	13	9	8.2	22	5	9	12	4	1	8.8
8.5	3	3	8	8	2	18	7.0	28	7	15	8	8	4	11.7
9.5	2	4	12	4	9	na	6.2	19	35	18	13	1	2	14.7
10.5	17	7	9	2	4	na	7.8	14	23	19	14	1	15	14.3
11.5	5	1	6	3	8	8	5.2	17	31	23	24	0	18	18.8
Mean 7.5-11.5	7.2	4.2	8.6	4.2	7.2	11.7	7.2	20	20.2	16.8	14.2	2.8	8	13.7

The way the NoArtVarPho and NoArtComPho utterances were produced, however, differed per subject. HI-1 produced mainly long utterances with vocal fry (creaky voice) with an F0 of around 50 Hz, often with glottal stops producing some kind of syllabification. In the last months studied he produced hardly any articulation movement. HI-2 produced in the last three months many very high pitched, short utterances. HI-3 produced utterances typically with a fast alternation of rising and falling intonation, often with glottal stops producing very short syllables. HI-4 made often the ComPhon utterances in the last three months with a 'coughing-like sound'. In Appendix A7.1 examples of NoArtComPho utterance of three HI infants at different months of age are shown visually in oscillograms. The examples illustrate the pauses and glottal stops within the utterances.

Several explanations are possible for these types of utterances. All of these types of utterances are produced with a clearly high level of tension in the area of the larynx (glottis or false vocal cords). It seems that the utterances of the HI infants share the feature, that a high level of tension in muscles of the back part of the vocal tract is audible. Either a constriction is created at the level of the velum, uvula or pharynx, possibly but not necessary combined with voicing (thus possibly SimArtNoPhon), or a constriction is produced somewhat lower at the glottis or false vocal cords (resulting in NoArtVarPho, and NoArtComPho). Moreover, possibly a problem with the coordination of articulation and phonation is causing the high number of these three types of utterances (note that either phonation or articulation is absent) (Koopmans-van Beinum et al., 2001). In Chapter 9.2.2 these explanations will be discussed in more detail.

7.3.6 Babbling in the individual subjects

In Table 7.9 the number of babbled utterances per recording per subject are shown. All six NH infants babbled while only one HI infant did within the period studied (HI-2). We considered as the starting point of babbling the month an infant produced at least 2 of the 50 utterances babbled. One NH infant started babbling at 5.5 months, two at 6.5 months and three at 7.5 months. All NH infants produced some babbled utterances within the described period, although only two of the NH infants babbled extensively (13 out of the 50 utterances for NH-2 at 7.5 months and 17 for NH-4 at 8.5 months). The other four NH infants produced at least six babbled utterances out of the 50 during at least one recording from 7.5 months onwards. The mean number of babbled utterances between 5.5 and 11.5 months (the period we had data for all infants) was 3.8 out of 50 utterances for the NH group (thus 7.6 %).

Table 7.9. Number of babbled utterances per month and per subject, with total and mean over 5.5 to 11.5 months. The gray cells represent the months for the first time two or more utterances were babbled.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	Mean	HI1	HI2	HI3	HI4	HI5	HI6	Mean
2.5	0	0	0	0	0	0	0.0	0	na	na	0	na	na	0.0
3.5	0	0	0	0	0	0	0.0	0	na	na	0	0	na	0.0
4.5	0	0	0	0	0	0	0.0	0	na	na	0	0	na	0.0
5.5	1	0	2	0	0	0	0.5	1	0	0	0	0	0	0.2
6.5	3	0	1	0	3	0	1.2	0	0	0	0	0	0	0.0
7.5	1	13	0	2	0	6	3.7	0	20	1	0	0	0	3.5
8.5	8	5	6	17	2	0	6.3	0	14	0	0	0	1	2.5
9.5	0	11	2	5	4	na	4.4	0	1	0	0	0	0	0.2
10.5	0	1	2	6	8	na	3.4	0	5	0	0	0	0	0.8
11.5	5	5	2	10	9	11.3[4]	7.0	0	0	0	0	0	0	0.0
Total	18	35	15	40	26	17.3	151.3	1	40	1	0	0	1	43
Mean 5.5-11.5	2.6	5.0	2.1	5.7	3.7	3.5	3.8	0.1	5.7	0.1	0.0	0.0	0.1	1.0

HI-2 started babbling at 7.5 months. He produced 20 babbled utterances out of 50 at 7.5 months and 14 babbled utterances at 8.5 months of age. His babbling disappeared almost at 9.5 months (one utterance), came back at 10.5 months (five utterances) and disappeared again at 11.5 months. From later observations none of the other HI infants started babbling before 18 months of life (as was observed by

[4] Corrected data, since the number of utterances in this recording was only 31 instead of 50.

the author). HI-1 and HI-6 started babbling at 18 and 19 months respectively, HI-5 at 28 months, HI-3 between 31 and 36 months and HI-4 not before 36 months of age (the latest age these children were recorded). The fact that HI-2 started babbling at 7.5 months will be discussed in detail in section 7.4 and in Chapter 9.2.3. In Appendix A7.2 examples of a babbled utterance of HI-2 and NH-2 are shown, both at 7.5 months of age to illustrate the similarity between the babbled utterances of HI with those of NH infants.

7.3.7 Utterance structure of articulated utterances

The type of utterances are related to the utterance structure. The utterances with articulation movements were categorized further as following. The SimArt utterances could be categorized as C, VC, CV, VCV and CVC, where C stands for a consonant-like segment and V for a vowel-like segment. The BabblingArt utterances could be categorized as (V)CVCV, (V)CVCVCV, VCVC and Else. In Table 7.10 on this and the next page the average number of these utterance structures is shown. First, per infant and month the number of the utterance structures is calculated. Secondly, the average number of utterances of the ten months are calculated per group. It can be seen in Table 7.10 that the most often produced utterance structure for the NH group was VCV (6.1), CV (4.3) and VC (3.2). The most commonly produced utterance by the HI infants was C (4.1), VCV (3.7) and VC (2.6).

Table 7.10. Averaged number of each utterance structure (C, CV, VCV, VC, CVC, VCVC, (V)CVCV, (V)CVCVCV) and Else per group, per months, and running per three months (run). Level of significance of the differences between the two groups as a result of Mann-Whitney U tests is given as well[5].

C						**CV**				
Age (m)	NH	NH run	HI	HI run	p=	NH	NH run	HI	HI run	p=
2.5	1.7		0.5			3.3		1.5		
3.5	2.5	2.1	0.0	0.2	ns	3.3	2.8	3.0	2.1	ns
4.5	2.2	2.3	0.0	0.3	ns	1.7	2.2	1.7	2.0	ns
5.5	2.3	1.9	1.0	1.0	ns	1.5	1.7	1.2	1.9	ns
6.5	1.2	1.9	2.0	2.1	ns	2.0	3.6	2.7	2.1	ns
7.5	2.2	2.0	3.3	3.7	ns	7.2	5.5	2.3	2.3	ns
8.5	2.5	2.3	5.8	6.4	ns	7.3	6.6	1.8	2.1	ns
9.5	2.2	1.6	10.1	8.4	<.05	5.2	6.4	2.3	1.6	ns
10.5	0.2	0.9	9.3	9.4	<.005	6.6	5.5	0.7	1.4	ns
11.5	0.4		8.8			4.7		1.2		
Mean	1.7		4.1			4.3		1.8		

5 Unfortunately we have no statistical results of the data of all months combined for technical reasons.

VCV Age (m)	NH	NH run	HI	HI run	p=
2.5	4.2		0.5		
3.5	7.5	6.4	5.3	3.4	ns
4.5	7.5	7.6	4.3	5.2	ns
5.5	7.7	6.5	6.0	5.7	ns
6.5	4.3	5.9	6.7	6.2	ns
7.5	5.8	4.4	5.8	5.2	ns
8.5	3.0	5.1	3.2	3.5	ns
9.5	6.6	5.5	1.5	1.9	ns
10.5	7.0	7.1	1.0	1.6	ns
11.5	7.8		2.2		
Mean	6.1		3.7		

VC NH	NH run	HI	HI run	p=
1.0		0.5		
5.2	4.1	0.0	0.7	ns
6.0	4.9	1.7	2.1	ns
3.5	4.2	4.5	3.3	ns
3.0	3.4	3.7	4.1	ns
3.8	2.8	4.2	4.0	ns
1.7	3.1	4.2	3.4	ns
3.8	2.4	1.8	3.3	ns
1.6	2.6	3.8	2.3	ns
2.4		1.3		
3.2		2.6		

CVC NH	NH run	HI	HI run	p=
0.0		0.0		
0.5	0.2	0.3	0.4	ns
0.0	0.3	1.0	0.6	ns
0.5	0.2	0.5	0.9	ns
0.2	0.3	1.2	0.8	ns
0.2	0.8	0.7	0.9	ns
2.0	1.4	0.7	0.6	ns
2.0	1.8	0.3	0.4	<.01
1.4	1.2	0.2	0.2	<.05
0.2		0.2		
0.7		0.5		

(V)CVCV Age (m)	NH	NH run	HI	HI run	p=
2.5	0.0		0.0		
3.5	0.0	0.0	0.0	0.0	ns
4.5	0.0	0.1	0.0	0.1	ns
5.5	0.3	0.3	0.2	0.1	ns
6.5	0.5	1.0	0.0	0.3	ns
7.5	2.3	2.0	0.8	0.6	ns
8.5	3.3	2.8	1.0	0.6	<.05
9.5	2.8	2.6	0.0	0.4	<.05
10.5	1.6	2.6	0.2	0.1	<.001
11.5	3.4		0.0		
Mean	1.4		0.2		

(V)CVCVCV NH	NH run	HI	HI run	p=
0.0		0.0		
0.0	0.0	0.0	0.0	ns
0.0	0.1	0.0	0.0	ns
0.2	0.3	0.0	0.0	ns
0.7	0.7	0.0	0.9	ns
1.3	1.7	2.7	1.4	ns
3.0	2.0	1.5	1.5	ns
1.6	2.1	0.2	0.8	<.05
1.8	2.4	0.7	0.3	<.01
3.7		0.0		
1.2		0.5		

CVC Age (m)	NH	NH run	HI	HI run	p=
2.5	0.3		0.0		
3.5	0.5	0.4	0.0	0.0	ns
4.5	0.3	0.4	0.0	0.0	ns
5.5	0.3	0.2	0.0	0.1	ns
6.5	0.0	0.2	0.2	0.1	ns
7.5	0.2	0.3	0.0	0.2	ns
8.5	0.7	0.8	0.3	0.1	ns
9.5	1.6	1.0	0.0	0.2	ns
10.5	0.8	0.9	0.3	0.2	ns
11.5	0.3		0.3		
Mean	0.5		0.1		

Else NH	NH run	HI	HI run	p=
0.3		0.0		
1.3	0.6	0.0	0.0	ns
0.3	0.7	0.0	0.1	ns
0.5	0.3	0.3	0.3	ns
0.2	0.2	0.7	0.5	ns
0	0.2	1	0.5	ns
0.3	0.2	0.2	0.2	ns
0.2	0.2	0.0	0.1	ns
0.2	0.2	0.2	0.1	ns
0.2	4.0	0.2		
0.4		0.2		

The CVC utterance structures as well as the babbled utterances (CVCV, VCVCV, CVCVCV, etc) are produced significantly more frequently by the NH group than by the HI group in the last months studied. A relationship between these late vocalizations with early word structure in the case of NH infants might be possible. The basic utterance structure for canonical babbling, the CV structure, was not produced significantly more often by the NH than by the HI group.

In Table 7.10 it can also be seen that the number of utterances with C structure is larger in the HI group than in the NH group, especially towards the end of the first year. The number of C utterances is 1.7 for the NH group and 4.1 for the HI group if combining all months. The average percentages are significantly higher from 8.5-10.5 months onwards.

We can conclude that the HI infants produced fewer utterances with a rather complex utterance structure, such as CVC, and babbled utterances, such as CVCV compared to the NH infants. Also the HI infants produced more utterances with the simple C structure. These results support our hypotheses, and we will discuss them further in section 7.4.

7.3.8 Number of syllables

In the present section we included all types of syllables, thus not only canonical (CV) syllables (Oller, 1980), but also syllables consisting of only a continuant or a vowel. In Figure 7.8 and Table 7.11 the number of utterances with one, two, three, and four or more syllables for the NH and HI infants is shown on average per month as well as the running averages[6].

For both groups, we see that the number of utterances with only one syllable is most often produced. The mean number of utterances with one syllable was 31.5 for the NH group and 35.6 for the HI group if combining all months. If looking at the NH infants' utterances with one syllable per month, a clear drop can be seen between 2.5 and 3.5 months. After 3.5 months an increase can be seen until 6.5 months and a decrease can be found until the end of the period studied when finally an increase can be seen again, as shown in Figure 7.8 and Table 7.11. In the HI group a decrease of utterances with one syllable can be found somewhat later, at 4.5 months. However, the peak is found in the same period as found in the NH group, at 6.5 months, also followed by a decrease until 11.5 months (Figure 7.8). At 4.5-6.5 months, 5.5-7.5 months and 6.5-8.5 months significantly more utterances with only one syllable were produced by the HI infants than by the NH infants.

Utterances with two syllables were also often produced in both groups; on average 13.2 utterances by the NH infants and 10.2 utterances by the HI infants. The utterances with two syllables produced by the NH infants shows a peak at 4.5

[6] Unfortunately we have no statistical results of the data of all months combined for technical reasons.

months. The number of utterances with two syllables was 14.1 at that age. After that month the number of utterances with two syllables drops until 6.5 and 7.5 months and increases again afterwards. This increase at the end of the first year is expected since the number of babbled utterances also increases in the NH group at that age.

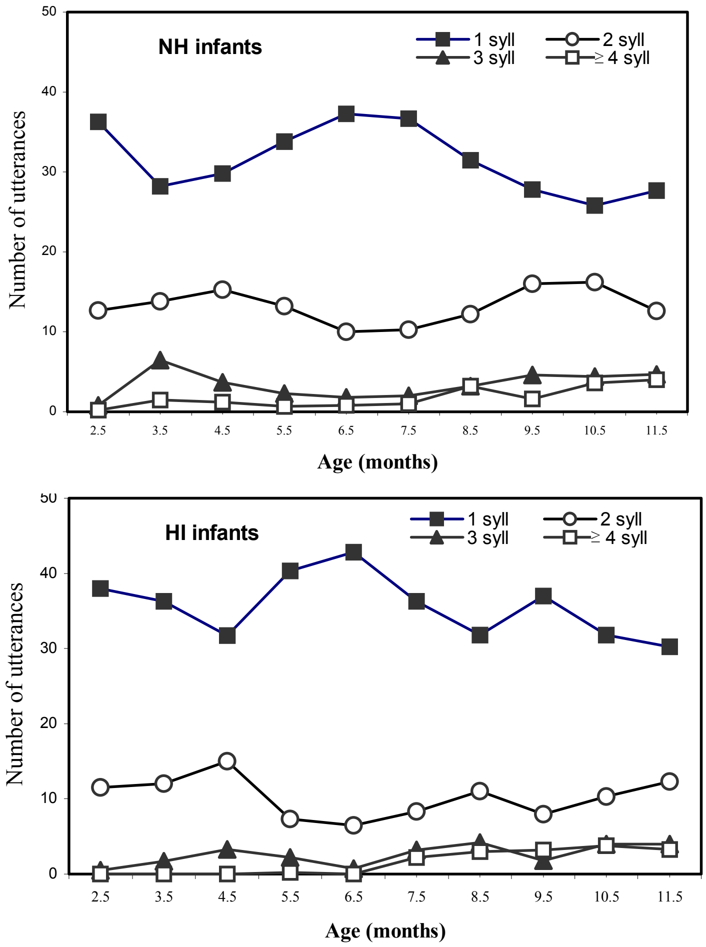

Figure 7.8. Number of utterances with one, two, three, and four or more syllables for the NH infants and HI infants. At top the averages per month per group is shown, at the bottom the running averages of three months.

Also the HI infants produced utterances with two syllables often, especially in the first months of age. At 2.5-4.5 months 13.0 utterances were found with two syllables. After the first months a clear drop of the number of utterances with two syllables is found, resulting in only 7.4 utterances around 5.5-7.5 months. After that period only a light increase could be found. The HI infants produced significant fewer number of utterances with two syllables at 4.5-6.5 months, 5.5-7.5 months, 7.5-9.5 months and 8.5-10.5 months compared to the NH infants.

In the NH group the number of utterances with three and four or more syllables show a peak at 3.5 months. At 2.5-4.5 months, 3.5-5.5 months and 4.5-6.5 months the NH groups produced significant more utterances with four or more syllables compared to the HI group. In Table 7.4 it can be seen that these utterances might be related to the NoArtComPho utterances. Also the utterances with three syllables might be related to the duration peak found for the NH infants at 3.5 months of age, but not for the HI infants (see also Chapter 6.3.1). After the peak the number of utterances with three syllables decrease halfway the first year for the NH infants.

Table 7.11. Number of utterances with one, two, three, and four or more syllables for the NH infants, as well as the p value as a result of a Mann-Whitney U test.

Age (m)	NH 1 syll	Running	HI 1 syll	Running	p=	NH 2 syll	Running	HI 2 syll	Running	p=
2.5	36.3		38.0			12.7		11.5		
3.5	28.2	31.4	36.3	35	ns	13.8	13.9	12.0	13.0	ns
4.5	29.8	30.6	31.7	37.2	<.05	15.3	14.1	15.0	10.4	ns
5.5	33.8	33.7	40.3	39.6	<.05	13.2	12.8	7.3	8.5	<.05
6.5	37.3	35.9	42.8	39.8	<.05	10.0	11.2	6.5	7.4	<.05
7.5	36.7	35.2	36.3	37.0	ns	10.3	10.8	8.3	8.6	ns
8.5	31.5	32.2	31.8	35.1	ns	12.2	12.6	11.0	9.1	<.05
9.5	27.8	28.6	37	33.6	ns	16.0	14.6	8.0	9.8	<.005
10.5	25.8	27.1	31.8	33.5	ns	16.2	14.9	10.3	9.9	ns
11.5	27.7		30.2			12.6		12.3		
Mean	31.5		35.6			13.2		10.2		

Age (m)	NH 3 syll	Running	HI 3 syll	Running	p=	NH 4 syll	Running	HI 4 syll	Running	p=
2.5	0.8		0.5			0.2		0		
3.5	6.5	3.7	1.7	2.0	ns	1.5	0.9	0	0	<.05
4.5	3.7	4.2	3.3	2.3	ns	1.2	1.1	0	0.1	<.005
5.5	2.3	2.6	2.2	1.8	ns	0.7	0.9	0.2	0.1	<.01
6.5	1.8	2.1	0.7	2	ns	0.8	0.8	0	0.8	ns
7.5	2.0	2.3	3.2	2.7	ns	1.0	1.7	2.2	1.7	ns
8.5	3.2	3.2	4.2	3.1	ns	3.2	1.9	3.0	2.8	ns
9.5	4.6	4.0	1.8	3.3	ns	1.6	2.8	3.2	3.3	ns
10.5	4.4	4.6	4.0	3.2	ns	3.6	3.1	3.8	3.4	ns
11.5	4.7		4.0			4.0		3.3		
Mean	3.4		2.6			1.8		1.6		

In both groups we can see an increase of number of utterances with three, four or more syllables towards the end of the first year. This increase might be expected in the NH infants because of their babbled utterances BabblingTotal (see also section 7.3.3). Because babbled utterances always contain two or more syllables we might expect more utterances with two or more syllables by the NH infants in the second half of the first year. However, strikingly also in the HI group more utterances with three or more syllables were found at the end of the first year. No significant differences between the two groups were found for these utterances after 6.5 months. In the HI group the increasing number of utterances with three or more syllables is not only due to the babbled utterances of infant HI-2. Also the significantly higher number of utterances with NoArtComPho in that group at the end of the first year (see Table 7.4) might have an influence on the number of syllables. During the last months studied many utterances with glottal interruptions were found in the HI group (especially HI-1, HI-3, HI-4). Thus, it seems that not only the NH group, but also the HI infants used syllabification during this period, although produced in a different way. While the NH infants used articulation to form separate syllables, the HI infants seemed to form the syllables more often by glottal obstructions than by supraglottal articulation movements.

To summarize: although in the first months the HI infants produce more utterances with only one syllable than the NH infants, it seems that both groups can produce utterances with several syllables. However, it seems that the NH infants tend to use another mechanism for syllabification compared to the HI infants. The NH infants tend to produce different syllable boundaries by articulating, especially during babbling. On the other hand, the HI infants tend to produce the syllable boundaries by phonation. This topic and its implications will be discussed more thoroughly in the discussion and in Chapter 9.

7.4 Discussion

We found differences between the NH infants and the HI infants with respect to both phonation and articulation. With respect to phonation we found differences between the two groups in number of non-articulated utterances with variegated and combined phonation, particularly in the later months of the period studied. The more complex types of phonation are significantly more often produced by the HI infants, than by the NH infants, when the utterance is not articulated. It seems that HI infants produce more utterances with a deviant phonation, such as rising intonation, with screaming, vocal fry or with other variations in phonation, as already discussed in Chapter 6.4. In another study (Giesbrecht, 2002) vocal fry was often found in a NH infant of four months of age, which suggests that this type of phonation might be typically produced at this early stage in NH infants. Variegated phonation might also be influenced by a lack of internal auditory feedback in HI infants and therefore the lack of fine control of the voice (Kent et al., 1987). Also more indirectly: the hearing loss might have resulted in a underdeveloped internal feedback system, needed for the voice controlling.

NH infants learn to control their phonation system by vocalizing, meanwhile training their internal feedback system. Not only the auditory feedback system but also the tactile and proprioceptive feedback and the interaction between them is trained via the production of their speech-like sounds (Fry, 1966, see also Chapter 3.2.5). This results in such a fine control that during the first year NH infants are able to produce intonation patterns which are influenced by their specific language background. Normally this influence starts to appear in the second half of the first year of life (e.g. De Boysson-Bardies et al., 1986, 1989, 1992; De Boysson-Bardies and Vihman, 1991; Whalen et al., 1991; Levitt and Utman, 1992). In HI infants we see not such an influence of the environmental language on their intonation patterns. The higher number of variegated utterances in the HI group might be the result of the lack of possible influence of the language background.

With respect to articulation we found on average no significant difference in the number of utterances with articulatory movements in the HI group compared to the NH group. In some previous studies, such as Kent et al. (1987), and Spencer (1993) more utterances with articulation were found for NH infants than for HI infants. We did not find such large differences between the two groups in terms of total number of articulations. This could be influenced by the fact that we studied somewhat younger children, but it could also be due to individual differences. One of the HI infants in our study produced only 2% articulated utterances from 6.5 months onwards. On average fewer utterances with articulation produced by HI infants were found in the last months studied (9.5-11.5).

Also the place and manner of articulated utterances could have had an influence on the different results between the present study and the previous studies. It should be noted that the SimArtNoPhon utterances, which were frequently produced by the HI group, were almost always produced with a voiceless back (velar, uvular) trill or fricative (Chapter 8.3.3). These segments were easily recognized by Dutch listeners as consonant-like since the voiceless velar fricative /x/ is a part of the sound system of Dutch. It is not unlikely that listeners with a language background not containing /x/ in the phonological system, perceive these sound productions as vegetative and exclude them from their data set. In that case, the low number of articulation movements in these previous studies might be an artifact.

The onset of babbling gave a sharp cut-off between HI and NH groups studied by Oller et al. (1985) and Oller and Eilers (1988). All of the NH infants in their study started babbling before ten months of age, while none of the HI infants started babbling before the age of 11 months. In our study, the HI infants obviously produced fewer babbling utterances within the age period studied than their NH peers. Five out of the six HI infants studied did not start babbling within the first year of life at all. Thus a more complex type of articulation, such as babbling, is produced more frequently by the NH infants than by the HI infants. The claim of Lenneberg et al. (1965) and Lenneberg (1967) that deaf infants start cooing and babbling during the first year like normally hearing infants is most probably incorrect (see also Chapter 3.3.5).

One HI infant in our group started to babble at 7.5 months of age, the period NH infants usually start babbling (Van der Stelt and Koopmans-van Beinum, 1986, see also Chapter 3.1). This subject (HI-2) frequently used articulatory movements for segmenting his utterances like NH infants do. This babbling decreased at 9.5 months, but in that period he had possibly an extra hearing loss because of otitis media. It is not totally clear why this child started to babble. His hearing was perhaps slightly better than that of the five other HI infants. According to Spencer (personal communication, 1994) babbling before about 11 months always implies usable residual hearing. Two other HI infants (HI-1 and HI-3) of the six HI infants in our study seem to have some residual hearing (see Chapter 4.2, Table 4.3) on the basis of audiometry. A relationship between the residual hearing and the starting to babbling might not be unlikely since the two children who did not start to babble before 30-36 months (HI-4 and HI-5) turned out to have no or hardly any usable residual hearing.

Infant HI-2 might have a usable residual hearing and was enrolled in a school for HI children instead of a school for deaf children, although his average hearing loss was over 90 dB. ABR and tone-audiometric tests (Chapter 2) cannot answer the question whether and to what extent the deaf infants make use of this residual hearing for perceiving and using auditory information. It is absolutely not evident why and in what cases residual hearing may indeed function as usable. We also have to consider factors like the functioning of the child with his/her hearing loss and hearing aids and the form of the audiogram, for instance a flat curve (so called continuing audiogram) or a steep audiogram with a high tone loss. Also the quantity and quality of parent-infant interaction should be considered (Chapter 3.2.1). At this moment it is not totally clear if the amount of babbling or of other vocalization forms can be used as a prognostic tool for speech development in HI children (for instance with CI). Further research with this respect would be useful. This topic will be discussed more thoroughly in Chapter 9.2.3 and 9.4.

In section 7.3.8 it was shown that HI infants produce a kind of syllabification, even if they do not babble (except HI-2). Also in other studies was shown that infants, produce rhythmic behavior in this age period (e.g. Thelen, 1981). The often cited study of Pepitto and Marentette (1990; 1991) indicates that deaf infants ‘babble’ with their hands by producing repetitive movements. Also, Takei (1998) found evidence for babbling in the manual mode by studying two Japanese signing infants. Ejiri (1998) concluded from her work that the appearance of canonical babbling might be closely linked with a more widespread rhythmicity of behavior whether manual or oral. The finding from the present study that also HI infants produced a kind of syllabification in the same period hearing infants usually babble, supports that view, even in the syllabification was not in the usual canonical form.

All twelve infants, both HI and NH, produced utterances with several syllables (see Table 7.11), indicating that hearing capabilities are not needed for syllabification in this period. Three of the six HI infants segmented the utterances into several syllables by simply interrupting the air stream (HI-1, HI-3, and HI-4). In this way series of syllables with glottals at the initial margin (boundary) of the syllable are produced. In a study of the utterance structures of the same infants as in the present study (except NH-6 and HI-6), between 12.5 and 17.5 months of age this finding was confirmed. It was found that the HI infants produced far more utterances with interrupted phonation without articulations than NH infants do (Koopmans-van Beinum and Doppen, 2003). This was interpreted as substitutions for the complex repetitive babbling movements that the NH infants produced. Thus HI infants seem to produce syllables, but produce them in a less complex way compared to NH infants.

Of one HI infant (HI-1) it is known from some video-recordings during the first year (see Chapter 4.3) that he produced utterances with mouth movements like in babbling, but without any voicing at the age of around eight months. Various terms are used for this voiceless, repetitive movements of opening and closing of the jaw: ‘silent babbling’, ‘silent mandibular oscillations’, ‘jaw wags’ or ‘mouthing’. In the study of Meier et al. (1997) it was found that although five out of seven hearing infants produced at least one jaw wag, the major portion of the jaw wags found were produced by HI infants.

To conclude, it seems that all infants, NH and HI infants have three basic components of canonical babbling at their disposal:

- syllabification: rhythmic, repetitive, movements on the phonation level (IntPho or ComPho) or on the articulatory level in the form of jaw wags
- voicing
- articulation movements, in particular in CV syllable structures

However, the coordination of these aspects into a simultaneous behavior is a highly complex skill, which also might require a well developed and well functioning internal auditory feedback system, which HI infants lack. Also it might be that not all CV structures are useful as a babbling component. It might be that specific place and manner combinations have to be developed in order to start the babbling stage. This topic will be discussed in Chapter 8.

Chapter 8[1]

Place and manner of articulation

8.1 Introduction

The present chapter will report on the differences between HI and NH infants with respect to place and manner of articulation in their vocalizations. The research questions with respect to this parameter were:

- Do deaf infants produce more or less variety of different articulation categories than hearing infants and from which age onwards?

- Do deaf infants produce different articulation movements than hearing infants with respect to place and manner of articulation and from which age onwards?

As described in Chapter 3.3.4, only few studies have been performed on place and manner of articulation of consonantal segments produced by deaf infants within the first year of life.

Firstly, a limited consonant repertoire in HI infants is reported in some of these studies (Stark, 1983; Stoel-Gammon, 1988; Stoel-Gammon and Otomo, 1986).

Secondly, with respect to manner and place of articulation, contradictory results have been described. One study has reported more stops and fewer fricatives in HI infants compared to NH infants (Kent et al., 1987), but others reported the opposite; fewer stops and more fricatives (Stoel-Gammon, 1988; Stoel-Gammon and Otomo, 1986). The same applies to place of articulation. On the one hand mainly velar articulations in the first three to six months of life have been found, followed by mainly central articulations at the end of the first year, for both HI infants and NH infants (Smith and Oller, 1981; Smith, 1982). On the other hand, more labials have been found for HI infants (Stoel-Gammon, 1988; Stoel-Gammon and Otomo, 1986). Previous studies of HI children after the first few years of life also conclude that labializing (fronting) of their speech sounds is quite common (e.g. Carr, 1953; Ryalls, 1993). An explanation might be that bilabials are not only more visual, but also acoustically/auditorily simpler than alveolars and velars, as well as relatively easy in articulatory movement (see also Chapter 3.3.4). From this point of view we might expect to find more front than central or back articulations for HI infants, also within the first year of life.

[1] Substantially extended and revised version of earlier publications (Clement et al., 1995, 1997).

Unfortunately, because studies discussed above on HI infants within the first year suffer from methodological problems, we were not able to use this previous research as a basis for hypotheses with respect to manner and place of articulation. However, we have reason to expect that differences in manner and place of articulation will be found between NH and HI infants within the first year of life.

It is reported in previous studies (see Chapter 3.1) that in the first months of life NH infants produce mainly fricatives and trills at the back place of articulation. It has also been suggested that, at the end of the first year, utterances of NH infants are influenced by the phonological consonant inventory of their environmental language (see Chapter 3.2.2). Dutch NH children of 1;3-1;8 years have already acquired front and central stops, front and central glides and front and central nasals, and they are able to produce them correctly in words (Beers, 1995, see also Chapter 3.3.4). It might be that NH infants are also able to produce these segments in their vocalizations already before early word production, even if their phonological development is only just starting. On the other hand, in HI infants we expect no influence of the phonological development on their vocalizations. From that point of view we expect that HI infants produce fricatives and trills articulations at the back place of articulation from the first months of life onwards.

Also, the fact that NH infants normally start to babble at the end of the first year and HI infants do not (see also Chapter 7.3.3) might result in a difference in manner and place of articulation between the two groups. In babbled utterances we expect segment types which are easily produced by opening and closing the jaw, such as front and central stops, front and central glides and front and central nasals (see Chapter 3.2.4).

Thus, we expect that, especially from the age NH normally start babbling:

- HI infants produce a smaller consonantal repertoire (less variety in place and manner categories)

- HI infants produce fewer stops, glides and nasals with respect to manner of articulation compared to the NH infants

- HI infants produce more back fricatives compared to the NH infants

- HI infants produce fewer fronts and centrals with respect to place of articulation compared to the NH infants if the environmental language has more influence via auditory speech and language processing on the vocalizations of the NH infants than on the vocalizations of HI infants.

or

- HI infants produce a same proportion or more front articulations compared to the NH infants because this place of articulation might be visual, acoustically and articulatory easier than other places of articulation.

8.2 Method

8.2.1 Classification in articulation movements

In Chapter 7.3.3 it was specified that in our material a total of 1880 utterances existed with one or more articulation movements (or consonant-like segments) in both groups of infants. In the present chapter these articulation movements are judged as to place and manner of articulation; voicing of the consonant-like segments was not taken into account in the analysis in this chapter (see also Chapter 4.4 for analysis procedure and definition of an utterance). The classification of place and manner of articulation movements was carried out by one trained phonetician (the author) on the complete data set, but also partly controlled by a second listener (see section 8.2.2). We choose a classification in categories which had been used in most of the previous studies on infant articulation movements, making it possible to compare our results with theirs (see also Chapter 3.3). The place and manner of the articulation movements per utterance were classified in the following way:

manner of articulation:

- fricatives and trills combined[2]
- stops
- glides ([j] or [w]-like)
- nasals
- laterals ([l]-like)

place of articulation:

- front (labial, labial-dental)[3]
- central (dental, alveolar, palatal)
- back (velar, uvular, pharyngeal)

For example, the articulation movement of a [ba]-like utterance was classified as a front stop. The three places of articulation could combine with the five manners of articulation. See Table 8.1 for all of the 15 possible combinations. These place and manner combinations were also called (articulation) categories.

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[2] Fricatives and trills were combined in this analysis, since it turned out to be very hard to distinguish one from the other. Also, a gradual transition from fricative to trill or vice versa at the same place of articulation was often heard, making it impossible to choose.

[3] A 'raspberry' produced with the tongue interlabially was also classified as front fricative/trill.

Table 8.1 The 15 possible categories (place and manner combinations) in vocalizations

		Manner of articulation				
		Stops	Fric/trills	Glides	Nasals	Laterals
Place of articulation	front	x	x	x	x	x
	central	x	x	x	x	x
	back	x	x	x	x	x

Just as in most studies of infant speech development, only supraglottal articulation movements have been analyzed. Neither voicing nor glottals were taken into account in the analysis presented in this chapter. Glottals were considered, in infants, as a special form of phonation (interrupted phonation), and not as a form of articulation (see also Chapter 7.2.1).

In many utterances two or more different articulation movements were found. The total of 1880 utterances with one or more articulation movements yielded 2725 articulation movements. However, not all articulation movements were included for analysis. First, if the same type of articulation movement occurred twice or even more often within the same utterance – like four times in the babble [bebababa] - it was counted just once. This was the case for 517 articulation movements in total during 194 utterances with babbling (151 in NH infants and 43 in HI infants). If all articulation movements of a babbled utterance were counted, rather than the number of *different* articulation movements in one utterance, the results would probably be influenced by the fact that all NH infants babbled, while only one HI infant did (see also Chapter 7). This would mean that the number of consonant-like segments that are likely to occur during babbling, such as front and central stops and front and central glides, would be found to be produced much more often by the NH infants than by the HI infants.

Moreover, in 155 utterances a stop was directly followed by a fricative/trill, glide or nasal or lateral at the same place of articulation, e.g. [apf], [bwa] or [dla]. Also in those cases the articulation movements were classified as one articulation. The manner of articulation was classified as fricative/trill, glide and lateral in these cases. In each of those combinations it was felt that the release of the stop ‘co-occurred’ in one movement with, for instance, a fricative. Moreover, it was found that during one recording for instance many affricates were heard while also many ‘plain’ fricatives/trills were produced, but hardly any “plain” stops. This gave us the indication that affricates were more related to fricatives/trills and less to stops. The vast majority of these stop-C combinations (86%) were affricates (133) utterances.

All other combinations of consonants in one cluster were classified separately. This held for instance for CVC sequences with different places and manners of articulation (e.g. [pak] or [baf]), combinations with different places of articulation (e.g. [bla]) and combinations of a fricative, glide or nasal, followed by a stop (e.g [amb] or [afb]. In the last case, both segments were classified separately, because the closure part of the stop after the first segment was perceived as the start of a new segment. Following this procedure, we classified in total 2053 articulation movements.

8.2.2 Verification of classification

Subsets of these data were also classified by a trained control listener. The second listener, a trained phonetician, classified 398 articulation movements of all utterances in 20 (out of 21) recordings at 8.5 and 9.5 months. This second listener followed the method described in 8.2.1 and her judgements were done completely independently from the first listener. The inter-judge agreement based on the 398 different articulation movements was 83.4% for place of articulation and 87.3% for manner of articulation. The main disagreement for place of articulation was between front and central articulation (38 out of 66 cases). The most common disagreement for manner was between stops and fricatives (15 out of 49 cases). Disagreement about both place and manner was found in only 4.3% of the articulation movements; the most common disagreement was between front glide and central lateral (6 times out of 17 cases). The agreement between the two listeners was sufficiently high to decide to use the judgments of only one listener for further processing, namely the judgments of the author.

8.2.3 Quantitative analysis

For each individual subject the number of articulation movements in each category was counted per month. If less than ten articulation movements were found in the data of that month, these data were not included for further analysis[4]. This was the case in 12 recordings in the NH infants, and 19 recordings in the HI infants (For number of recordings included in this analysis see Table 8.2). If ten or more articulations were produced the percentage of articulations in each category was calculated compared to the total number of articulations in that month for that

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[4] The exclusion of recordings with less than ten articulation movements was done to avoid that a specific category would have relatively too much weight relatively. This could be the case if only few articulation movements in the data of that month for a specific subject were found., since we calculated the percentages of each category before performing the statistical analysis.

particular subject. The statistic measurements were performed on the data in percentages.

Table 8.2. Number of recordings included in the analyses in this chapter per month.

Age (m)	NH	HI
2.5	2	0
3.5	5	1
4.5	3	2
5.5	5	4
6.5	4	4
7.5	6	5
8.5	5	4
9.5	5	3
10.5	5	4
11.5	6	3
Total	46	30

In Appendix Table A8.1 the results are shown per month and in total in absolute numbers and in percentages for each individual subject. For instance, subject NH-1 produced 18 articulation movements during 50 utterances at 4.5 months; 8 back stops and 10 back fricatives or trills. Thus, the percentage back stops was 44% and the percentage back fricatives/trills was 56% (see p. 238). We used percentages instead of the raw data for ease of comparison. Next, these individual percentages were then averaged over the subjects of each group per month. Although front and back laterals were possible, these articulation movements have not been found in our data set.

Firstly, the number of different articulation categories for both subject groups is presented in section 8.3.1. Next, the separate manners of articulation (stop, fricative/trill, glide, nasal, and lateral) are described in 8.3.2. In section 8.3.3 the place of articulation will be described in more details for the place of articulation. In the next section comparison with data of Dutch two-year olds and adults have been made. In section 8.3.5 the individual data is discussed. And finally, in section 8.3.6 the place and manner of articulation are reported of a special group of vocalizations; the babbled utterances.

8.3 Results

8.3.1 Number of different articulation categories

Due to the lack of hearing and spoken language input HI infants might have less variation in their sound productions than NH infants have. In order to get an indication of the variety of the infants with respect to their articulations, the number of categories is calculated. A category is defined as a specific combination of place and manner of articulation. The maximal number of categories was 15 (see Table 8.1), although front and back laterals were not found in our data set. Only the categories that were produced by an infant two or more times out of the 50 utterances per recording were taken into account to avoid incidental findings. It can be seen in Figure 8.1 and Table 8.3 that the number of categories is about similar in the first months studied, but clearly differs between the two groups from 7.5 months onwards. The HI group produced only less than 2 different categories from that age onwards, while in the NH group the number of different categories strongly increases. In answer to the first research question on this variable we see that the HI group produced clearly fewer different place – manner categories than the NH group, specially from 6.5 months onwards. This result is in accord with our expectations on this point.

The mean number of categories for the NH group was significantly higher ($p<0.001$ according to a t-test for matched samples) compared to the HI group (mean NH 3.4, sd=1.9, mean HI 2.0, sd=1.4). The means for each month were compared in a Mann-Whitney U test on the running averages (see also 5.3.1). After 6.5-8.5 months the NH infants produce significantly more categories than the HI infants.

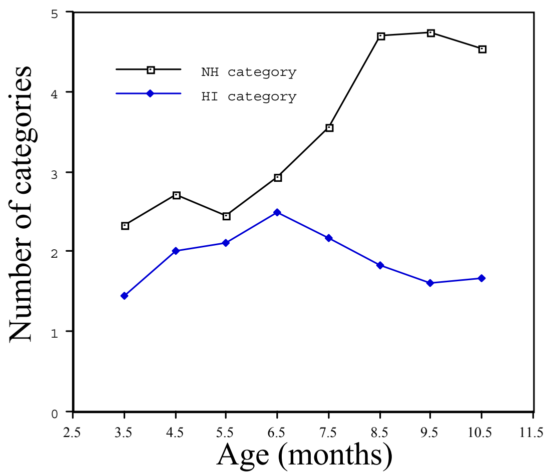

Figure 8.1 Mean number of categories per month (running averages), for the NH and HI group separated For N see Table 8.2. Significant differences were found from 6.5-8.5 months onwards.

The smaller amount of categories gives a strong subjective auditory impression of less variation between the utterances of the HI infants within one recording with respect to articulation. However, between subsequent recordings a shift from one very frequently produced type of articulation movement to another type can occur. For example, we found that HI-5 changed his most frequently produced category from back fricatives (42 out of 43 articulated utterances at 10.5 months) within one month to front fricatives (40 out of 45 articulated utterances at 11.5 months, see p. 243). The individual data with respect to the number of categories will be described in more detail in section 8.3.4. In the next sections the categories will be specified.

Table 8.3. Mean number of categories per month, and the running averages over three months each, for the NH and HI group separated, p is the p-value as result of Mann-Whitney U-tests comparing the NH and HI groups. (For N see Table 8.2).

Age (months)	NH	Running	HI	Running	p =
2.5	1.8		1.0		
3.5	3.0	2.3	2.0	1.4	ns
4.5	2.2	2.7	1.3	2.1	ns
5.5	3.0	2.5	2.8	2.2	ns
6.5	2.3	2.9	2.5	2.7	ns
7.5	3.3	3.6	2.7	2.3	p<.05
8.5	5.0	4.3	1.7	1.9	p<.001
9.5	4.7	4.3	1.3	1.6	p<.001
10.5	3.2	3.9	1.8	1.7	p<.001
11.5	4.0		1.8		
Mean	3.4		2.0		p<.001

8.3.2 Manner of articulation

In Table 8.4 the average and standard deviation of the percentages of each manner of articulation in total and in combination with each place of articulation is shown per month for both groups of children. Also the running averages and standard deviations over three months for both groups are shown. The p-value is the result of the Mann-Whitney U-tests on the running averages comparing the NH and HI groups. Also, for all place and manner combinations the mean percentages of the combined ten months are presented, as well as the results of t-tests for related samples.

Stops

In Table 8.4 and Figure 8.2 the percentage of stops can be seen in total. It can be seen that the NH infants produce more stops than the HI infants on average over the whole period studied (the NH group 41% and the HI group 19%). A t-test indicates a significant difference between the percentages of all months combined between the two groups (p<.001). The difference becomes significant from 6.5-8.5 months onwards, and is even highly significant from 8.5-10.5 months onwards, according to Mann-Whitney U-tests performed on the running averages. This result is in accord with our hypothesis with respect to stops (see section 8.1).

In Table 8.4 the averaged percentage of stops at front, central, and back articulation is shown. If all months were combined the HI infants produced a significantly smaller percentage front stops than the NH infants. From age 4.5-6.5 months onwards more utterances with front stops (e.g. [b]- or [p]-like) are produced by the NH infants than by the HI infants. The percentage decreases again for the NH group from 15% at 6.5-8.5 months to 8% at 9.5-11.5 months, but the percentage front stops stays significantly higher than for the HI group until the end of the period studied.

From age 8.5-10.5 months onwards significantly more utterances with central stops (e.g. [d]- or [t]-like) are produced by the NH infants than by the HI infants, although not if combining all months.

A gradual decrease of back stops (e.g. [g]- or [k]-like) is found for both groups from the beginning of the period studied. No significant difference is found if combining all months and only at 8.5-10.5 months significantly differences were found between the two groups for the back stops (more in the NH group compared to the HI group).

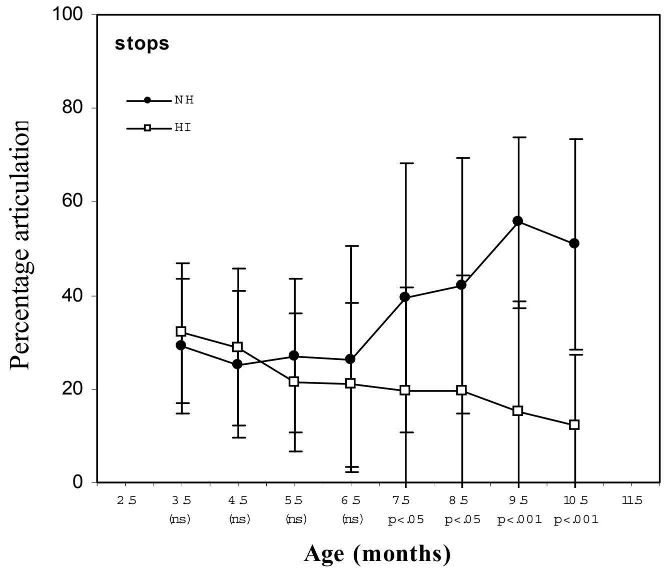

Figure 8.2. Mean percentage of stops (running averages) for both groups at the indicated ages.

Table 8.4. (see next page). Percentage of place and manner of articulation for the NH and HI group separately. For description see text.

Place	Manner	Stops									Fric/trill									Glides								
	Age (m)	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	0.0	0.0			na	na				1.5	2.1			na	na				2.3	3.2			na	na			
	3.5	1.3	3.0	1.7	2.8	0.0	na	0.0	0.0	ns	6.4	14.2	14.5	28.2	0.0	na	3.0	5.2	ns	13.3	17.1	7.5	13.1	0.0	na	2.7	4.6	ns
	4.5	3.4	3.1	3.7	5.0	0.0	0.0	3.0	6.0	ns	36.8	45.7	19.3	25.2	4.5	6.4	7.3	10.3	ns	1.4	2.4	7.1	11.4	3.8	5.4	2.7	3.5	ns
	5.5	6.2	6.6	7.2	7.5	5.3	7.4	3.8	6.4	ns	21.6	14.2	20.8	24.8	10.5	12.9	9.8	15.9	ns	4.5	3.7	9.8	20.5	2.7	3.1	3.0	3.7	ns
Front	6.5	11.1	10.0	13.5	22.9	4.4	7.4	4.8	7.1	ns	7.8	10.4	22.9	18.7	11.7	23.4	7.9	14.2	<.05	23.0	34.4	11.9	19.3	2.8	4.3	3.7	4.0	ns
	7.5	21.2	35.4	15.0	22.2	5.7	8.9	3.8	6.6	<.05	33.9	20.5	17.8	19.3	2.7	3.0	8.7	18.3	ns	10.7	13.0	13.1	19.0	5.1	4.6	2.8	4.1	<.05
	8.5	16.9	14.7	11.6	10.0	1.0	1.9	2.8	6.0	<.005	6.5	7.3	18.3	17.8	13.0	26.1	5.5	14.8	<.01	7.8	5.0	9.6	8.6	0.0	0.0	4.5	8.3	<.05
	9.5	11.4	6.9	11.6	9.9	0.0	0.0	0.4	1.2	<.001	11.1	3.3	7.7	7.1	0.0	0.0	5.6	15.7	<.05	10.1	6.0	9.5	8.4	9.3	16.0	6.1	11.5	<.05
	10.5	6.5	4.3	7.8	5.2	0.0	0.0	0.2	0.6	<.001	5.2	9.3	7.3	7.0	2.4	4.8	12.6	27.6	ns	10.8	13.7	11.5	9.1	9.6	13.5	7.7	11.5	ns
	11.5	5.9	3.2			0.7	1.3				6.1	6.9			38.4	44.0				13.3	8.0			3.3	4.0			
	mean	9.3	14.8			2.4	5.3			<.001	13.9	18.3			9.7	20.0			<.05	10.4	13.5			4.4	7.5			<.005
	Age (m)	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	0.0	0.0			na	na				0.0	0.0			na	na				0.0	0.0			na	na			
	3.5	0.9	2.0	1.4	2.4	5.6	na	4.7	4.2	ns	0.5	1.0	0.2	0.6	0.0	na	0.0	0.0	ns	1.1	1.5	0.5	1.1	0.0	na	2.7	4.6	ns
	4.5	3.1	3.1	1.5	2.5	3.8	5.4	5.1	6.2	ns	0.0	0.0	0.2	0.6	0.0	0.0	0.0	0.0	ns	0.0	0.0	3.2	5.2	3.8	5.4	1.1	3.0	ns
	5.5	1.3	2.8	2.5	4.6	5.5	7.9	4.3	6.3	ns	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ns	7.4	6.4	5.2	6.6	0.0	0.0	1.9	3.1	ns
Central	6.5	3.8	7.7	2.9	4.9	3.2	6.4	6.2	9.8	ns	0.0	0.0	0.4	1.5	0.0	0.0	0.0	0.0	ns	6.1	7.9	6.0	7.6	4.4	3.2	3.1	3.7	ns
	7.5	3.7	4.7	13.6	18.0	8.9	13.6	10.1	20.0	ns	1.0	2.4	0.4	1.5	0.0	0.0	0.0	0.0	ns	4.7	9.2	5.3	7.5	4.1	4.3	2.6	3.8	ns
	8.5	33.1	18.3	18.4	18.4	18.4	34.0	13.1	22.2	ns	0.0	0.0	1.5	3.3	0.0	0.0	0.0	0.0	ns	5.4	6.1	3.4	6.6	3.1	4.1	2.0	3.9	ns
	9.5	20.9	17.6	35.9	21.8	13.0	22.5	12.5	22.4	<.01	3.5	4.9	1.9	3.6	0.0	0.0	0.0	0.0	<.05	0.0	0.0	3.0	4.4	3.7	6.4	3.7	9.3	ns
	10.5	53.4	18.6	38.3	25.8	6.2	9.5	8.5	12.8	<.005	2.0	3.3	1.8	3.5	0.0	0.0	0.0	0.0	ns	3.6	3.4	3.8	4.5	7.5	15.0	3.8	9.5	ns
	11.5	40.1	30.6			7.2	7.7				0.0	0.0			0.0	0.0				7.1	4.9			2.6	4.4			
	mean	18.2	23.9			8.4	15.1			ns	0.8	2.3			0.0	0.0			<.05	4.0	5.7			3.7	6.2			ns
	Age (m)	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	36.4	0.0			na	na				51.5	4.3			na	na				0.0	0.0			na	na			
	3.5	24.2	14.8	25.9	15.3	38.9	na	27.7	17.1	ns	39.1	27.9	39.8	23.7	38.9	na	48.7	11.9	ns	1.3	3.0	0.7	2.2	0.0	na	0.0	0.0	ns
	4.5	22.3	22.2	19.9	15.1	22.0	20.3	20.9	15.2	ns	33.1	27.1	35.2	23.5	53.5	11.4	45.4	20.2	ns	0.0	0.0	0.5	1.9	0.0	0.0	0.9	2.3	ns
	5.5	14.5	12.7	17.3	14.5	15.8	13.4	13.4	12.1	ns	38.0	15.0	27.3	20.2	43.0	26.4	51.3	22.9	<.05	0.0	0.0	0.7	2.3	1.4	2.8	0.6	1.9	ns
Back	6.5	17.3	14.2	9.9	12.0	6.6	2.2	9.8	10.3	ns	15.9	11.1	21.6	16.8	58.8	25.6	49.5	24.9	<.01	1.9	3.8	1.1	2.8	0.0	0.0	1.4	3.6	ns
	7.5	1.1	1.7	8.9	10.7	7.4	11.0	5.7	7.3	ns	16.2	12.6	14.9	11.0	47.7	26.6	55.2	30.7	<.001	1.3	3.1	1.1	2.8	2.4	5.3	0.9	3.3	ns
	8.5	11.4	9.2	7.1	9.4	2.2	4.3	3.9	7.8	ns	12.6	11.1	14.0	11.2	61.3	44.7	56.9	38.5	<.005	0.0	0.0	0.9	2.4	0.0	0.0	1.0	3.5	ns
	9.5	9.9	12.8	8.3	9.4	0.0	0.0	2.4	3.9	<.05	12.9	12.0	9.7	10.3	66.7	57.7	65.1	41.2	<.005	1.2	2.6	0.4	1.5	0.0	0.0	0.0	0.0	ns
	10.5	3.4	4.8	4.9	8.0	4.3	4.3	3.4	5.2	ns	3.6	6.2	5.4	8.7	67.6	37.3	58.1	41.3	<.005	0.0	0.0	0.4	1.5	0.0	0.0	0.0	0.0	ns
	11.5	1.9	3.1			5.9	8.3				0.6	1.5			36.7	35.7				0.0	0.0			0.0	0.0			
	mean	11.8	13.5			8.5	11.3			ns	18.9	20.1			53.9	32.1			<.001	0.6	2.1			0.6	2.4			ns
	Age (m)	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	36.4	0.0								53.0	2.1								2.3	3.2							
	3.5	28.7	15.9	29.2	14.5	44.4		32.1	15.0	ns	48.3	27.8	54.6	24.7	38.9		51.6	11.6	ns	13.0	16.1	8.7	13.3	0.0		5.1	8.9	ns
	4.5	41.5	29.5	25.3	15.8	25.9	14.8	28.9	16.9	ns	57.4	29.2	56.7	23.7	58.0	4.9	52.7	18.3	ns	1.0	2.0	10.9	12.3	7.7	10.9	4.5	6.4	ns
	5.5	21.9	17.0	27.1	16.5	26.5	20.1	21.5	14.9	ns	59.6	17.5	50.2	25.8	53.5	24.1	61.2	17.2	ns	11.9	8.9	15.7	20.4	4.1	5.3	6.1	5.8	ns
Total	6.5	45.8	33.9	26.3	24.1	14.2	8.2	21.0	17.5	ns	18.9	19.0	46.6	24.9	70.5	9.9	57.5	21.5	ns	24.8	29.1	18.9	19.5	7.3	4.8	7.9	6.5	ns
	7.5	26.0	34.0	39.5	28.7	22.0	22.1	19.5	22.3	<.05	51.0	25.9	33.1	24.1	50.4	25.1	63.9	26.9	<.001	16.6	17.6	19.3	19.3	11.6	7.5	7.6	6.5	<.05
	8.5	61.5	16.5	42.2	27.2	21.5	34.9	19.6	24.9	<.05	19.1	11.3	33.7	22.0	74.4	38.2	62.5	36.8	<.05	13.2	8.0	13.9	11.6	3.1	4.1	9.1	11.7	ns
	9.5	42.3	14.2	55.7	18.3	13.0	22.5	15.2	23.4	<.001	27.5	9.6	19.2	13.1	66.7	57.7	70.7	38.7	<.005	11.2	5.6	12.9	8.0	13.0	22.5	10.9	16.5	ns
	10.5	63.3	18.9	50.9	22.6	10.5	13.6	12.2	15.0	<.001	10.9	14.5	14.5	13.4	70.0	35.9	70.5	37.5	<.005	14.4	11.2	15.6	10.1	17.1	20.3	12.5	17.0	ns
	11.5	47.8	29.0			13.8	14.7				6.7	6.4			75.2	31.8				20.4	11.7			5.9	8.3			
	mean	41.4	25.8			19.3	19.3			<.001	33.7	26.3			63.5	29.2			<.001	14.0	14.4			8.5	11.2			<.05

Place	Manner	Nasals									Laterals									Total								
Front	**Age (m)**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**										**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	0.0	0.0			na	na													3.8	1.1			na	na			
	3.5	4.2	5.5	2.1	4.2	0.0	na	0.0	0.0	ns										21.0	19.8	25.8	29.3	0.0	na	5.6	4.9	ns
	4.5	0.0	0.0	1.6	3.8	0.0	0.0	0.7	1.9	ns										36.1	40.6	31.7	25.4	8.4	1.0	13.7	17.3	ns
	5.5	0.0	0.0	0.5	1.7	1.3	2.6	0.5	1.6	ns										32.2	17.4	38.3	30.7	19.8	21.6	17.2	18.5	ns
	6.5	1.6	3.2	1.0	2.7	0.0	0.0	1.3	3.5	ns										54.8	41.3	49.2	27.2	18.9	22.4	18.0	16.3	<.005
	7.5	1.5	3.7	1.2	2.7	2.4	5.3	0.9	3.3	ns										67.3	16.6	49.1	27.2	15.9	7.9	16.2	17.7	<.005
	8.5	0.6	1.4	4.1	7.8	0.0	0.0	1.9	4.5	ns										31.8	16.7	48.7	21.1	14.0	25.5	14.5	17.1	<.001
	9.5	10.9	11.3	3.8	8.0	3.7	6.4	1.0	3.3	ns										43.5	12.0	32.6	17.4	13.0	22.5	13.0	19.9	<.01
	10.5	0.0	0.0	8.8	12.0	0.0	0.0	1.1	3.5	<.05										22.5	18.8	35.5	21.5	12.0	18.0	21.4	29.4	<.05
	11.5	14.4	14.5			0.0	0.0													39.6	27.1			42.5	44.1			
	mean	3.9	8.2			0.9	3.0			<.05										37.6	27.2			17.4	21.6			<.001
Central	**Age (m)**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	0.0	0.0			na	na				3.0	4.3			na	na				3.0	4.3			na	na			
	3.5	0.6	1.4	0.3	1.0	0.0	na	0.0	0.0	ns	4.5	2.6	2.9	3.1	5.6	na	5.0	4.6	ns	6.2	4.2	5.3	3.7	11.1	na	11.9	3.2	ns
	4.5	0.0	0.0	0.8	2.3	0.0	0.0	4.4	8.0	ns	0.0	0.0	3.4	5.2	4.5	6.4	4.9	3.6	ns	2.3	2.9	9.2	7.7	12.2	4.5	15.4	13.8	ns
	5.5	1.7	3.7	0.7	2.3	7.9	9.8	4.8	6.6	<.05	4.3	7.9	2.8	5.4	4.7	3.4	4.2	5.0	ns	14.6	9.8	11.2	10.6	18.1	18.8	15.7	11.9	ns
	6.5	0.0	0.0	0.5	2.1	4.1	2.8	6.5	10.4	<.005	3.1	3.8	4.2	6.2	3.4	6.8	4.8	5.7	ns	10.4	13.3	14.0	9.5	15.2	7.0	20.3	19.6	ns
	7.5	0.0	0.0	0.2	0.8	7.4	15.5	4.2	9.6	<.05	4.8	7.1	4.5	4.8	5.8	7.1	3.6	5.8	ns	14.2	7.9	23.9	19.3	26.2	27.9	21.6	25.2	ns
	8.5	0.6	1.3	1.8	4.0	0.0	0.0	3.6	10.0	ns	5.1	2.4	4.4	5.1	1.0	1.9	3.3	5.1	ns	44.2	17.7	29.3	18.9	22.5	36.8	23.5	29.8	ns
	9.5	5.2	6.1	4.7	6.9	1.9	3.2	0.5	1.8	<.05	2.9	5.1	3.9	3.7	1.9	3.2	1.4	2.4	ns	32.6	17.9	49.0	24.5	20.4	35.3	19.2	29.7	<.05
	10.5	8.0	9.3	8.0	9.0	0.0	0.0	0.6	1.9	<.005	3.4	3.2	2.3	3.5	1.3	2.5	1.9	3.1	ns	70.4	23.1	53.9	26.6	14.9	26.8	15.8	24.2	<.005
	11.5	10.2	11.1			0.0	0.0				0.6	1.5			2.6	4.4				58.0	26.3			12.3	16.3			
	mean	3.1	6.5			3.0	7.5			ns	3.2	4.5			3.3	4.6			ns	27.5	27.3			18.2	22.2			ns
Back	**Age (m)**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**										**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**
	2.5	5.3	1.1			na	na													93.2	3.2			na	na			
	3.5	2.7	6.0	3.2	3.1	11.1	na	6.3	5.7	ns										72.8	20.9	68.9	29.5	88.9	na	82.5	6.0	ns
	4.5	0.0	0.0	1.2	3.6	3.8	5.4	3.9	4.9	ns										61.6	41.8	59.1	24.6	79.4	3.5	70.9	16.9	ns
	5.5	0.6	1.4	3.0	9.5	2.0	4.0	1.8	3.3	ns										53.1	12.5	50.5	27.9	62.1	17.6	67.1	19.2	ns
	6.5	8.3	16.7	2.4	8.5	0.5	1.1	1.0	2.3	ns										34.8	32.9	36.7	23.5	65.9	25.6	61.7	23.5	<.05
	7.5	0.0	0.0	2.2	8.5	0.5	1.1	0.4	1.0	ns										18.5	12.4	27.0	20.3	57.9	30.1	62.1	30.5	<.001
	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	ns										24.0	12.4	21.9	15.7	63.5	42.6	62.0	38.0	<.05
	9.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.5	ns										24.0	23.6	18.4	16.8	66.7	57.7	67.8	39.3	<.005
	10.5	0.0	0.0	0.0	0.0	1.2	2.4	1.3	2.8	ns										7.1	6.7	10.6	16.0	73.0	32.4	62.8	39.0	<.005
	11.5	0.0	0.0			2.6	4.4													2.5	3.8			45.2	35.0			
	mean	1.3	5.3			1.5	3.1			ns										34.9	32.0			64.4	30.5			<.001
Total	**Age (m)**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**	**NH**	**sd**	**run**	**sd**	**HI**	**sd**	**run**	**sd**	**p=**									
	2.5	5.3	1.1								3.0	4.3			na	na												
	3.5	6.2	10.4	4.8	8.2	11.1		6.3	5.7	ns	3.7	3.0	2.9	3.1	5.6	na	5.0	4.6	ns									
	4.5	0.0	0.0	3.8	7.5	3.8	5.4	9.1	7.7	ns	0.0	0.0	3.4	5.2	4.5	6.4	4.9	3.6	ns									
	5.5	2.3	3.6	4.3	9.6	11.2	9.1	7.1	6.9	ns	4.3	7.9	2.8	5.4	4.7	3.4	4.2	5.0	ns									
	6.5	8.0	14.5	4.0	8.7	4.7	3.5	8.8	10.1	<.05	2.5	3.6	4.2	6.2	3.4	6.8	4.8	5.7	ns									
	7.5	1.5	3.7	3.7	8.7	10.3	14.6	5.4	9.7	ns	4.8	7.1	4.5	4.8	5.8	7.1	3.6	5.8	ns									
	8.5	1.2	1.6	6.0	10.4	0.0	0.0	5.7	10.7	ns	5.1	2.4	4.4	5.1	1.0	1.9	3.3	5.1	ns									
	9.5	16.1	14.2	8.4	11.1	5.6	9.6	2.0	5.1	<.05	2.9	5.1	3.9	3.7	1.9	3.2	1.4	2.4	ns									
	10.5	8.0	9.3	16.7	15.0	1.2	2.4	2.9	5.5	<.005	3.4	3.2	2.3	3.5	1.3	2.5	1.9	3.1	ns									
	11.5	24.6	17.0			2.6	4.4				0.6	1.5			2.6	4.4												
	mean	7.8	12.1			5.4	8.1			ns	3.1	4.4			3.3	4.5			ns									

Fricatives/trills

The percentage of utterances with fricatives/trills articulations also differs significantly between the two groups. As can be seen in Table 8.4 and Figure 8.3 the HI infants produce significantly more fricatives and/or trills than the NH infants (64% and 34% on average over all months) especially in the last months studied. The percentage fricatives/trills increases slightly during the first year of life in the HI group. The significant difference between the HI and NH infants for fricatives/trills is mainly caused by the higher number of back fricatives produced by the HI group. As can be seen in Table 8.4 the averaged percentage of fricatives/trills at front, central, and back articulation was significantly different between the groups if combining all months. For all months combined and at 5.5-7.5, 7.5-9.5 and 8.5-10.5 months (running averages) the HI infants produced significantly fewer utterances with front fricatives/trills (e.g. (inter)labial raspberries, [v]- or [f]-like segments) than the NH infants as shown in Table 8.4. Next, for all months combined and at 8.5-10.5 months the HI infants produced a significantly lower percentage of utterances with central fricatives (e.g. [r]-, [s]-, [z]-like segments) than the NH infants.

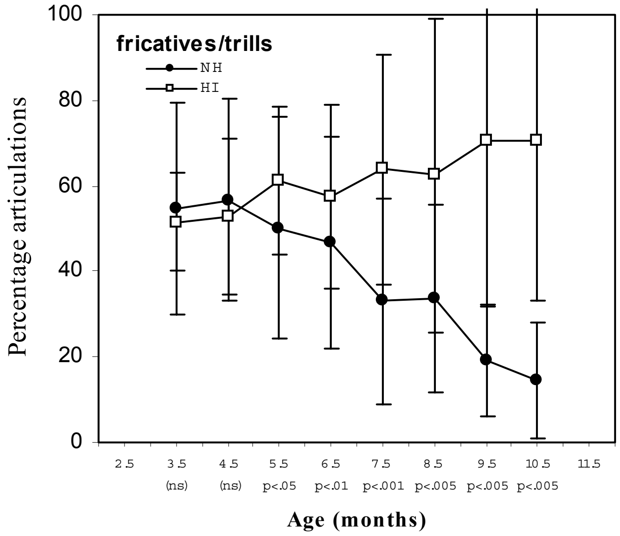

Figure 8.3. Mean percentage of utterances with fricative/trill-articulations per month for the NH and HI group separately.

Back fricatives/trills (e.g. [χ]- or [Я]-like) are produced more often by the HI infants than by the NH infants for all months combined and already from 4.5-6.5 months onwards. As can be seen in Figure 8.4 the percentage of utterances with back fricatives decreases strongly with age in the NH group (from 40% at 2.5-4.5 months to 5% at 9.5-

11.5 months). In the HI group a more or less consistent percentage around 50% is found for all months studied. This result is in accord our hypothesis described in section 8.1.

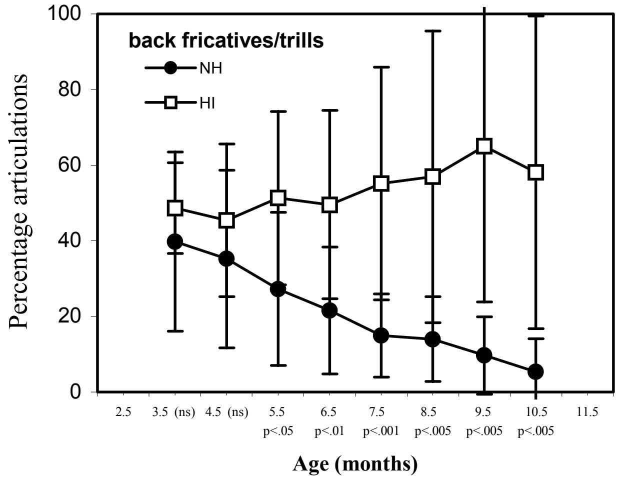

Figure 8.4. Mean percentage fricatives and trills at back place of articulation on average for both groups.

Glides

The percentage of utterances with glides in the NH and HI infants can be seen in Table 8.4 and Figure 8.5. Conform our hypothesis the NH infants produce more glides than the HI infants, which is true for all months combined (14% for the NH infants and 9% for the HI infants on average. Significant differences are also found at 6.5-8.5 months ($p<.05$).

The percentages of glides at back, central, and front place of articulation are also shown in Table 8.4. There it can be seen that the difference between the NH and HI infants is mainly found at the front place of articulation. The percentage of front glides is smaller in the HI group than in the NH group from 6.5-8.5 until 8.5-10.5 months. No significant differences were found for central glides and back glides for the months combined or any month studied.

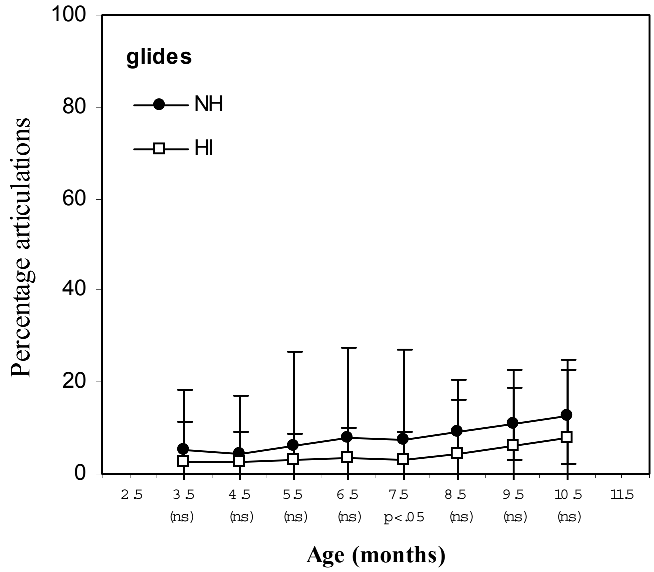

Figure 8.5. Mean percentage of utterances with glides per month, for the NH and HI group separately.

Nasals

On average for all months the NH group produced 8% nasals and the HI infants 5% on average (see Table 8.4 and Figure 8.6). This average was not significantly different between the groups, which was not expected according to our hypothesis. In the first period studied, however, more nasals are produced by the HI subjects (significant at 5.5-7.5 months). At 8.5-10.5 and 9.5-11.5 months the opposite was found; the NH infants produced significant more nasals compared to the HI infants. This topic will be discussed in more detail in section 8.4.

The smaller number of nasals for the HI infants are produced at front position (significant for all months combined and 9.5-11.5 months). The central place of articulation is produced more often by the HI infants at 4.5-6.5 until 6.5-8.5 months, but also more often by the NH infants at later months (8.5-10.5 and 9.5-11.5 months). Nasals at back place of articulation are not significantly different between both groups.

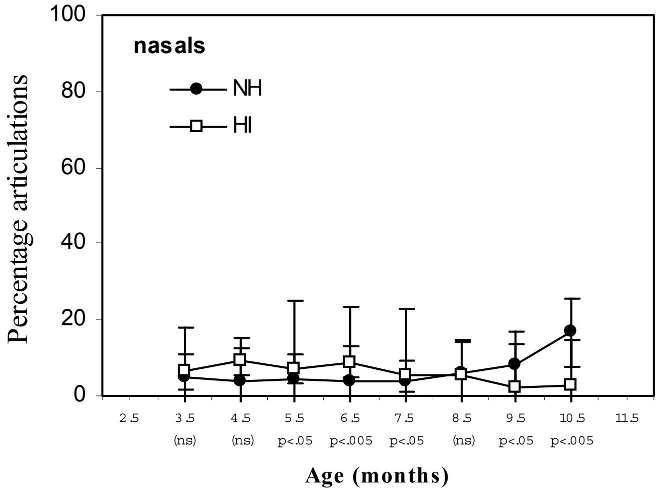

Figure 8.6. Mean percentage of utterances with nasal articulations per month, for the NH and HI group separately.

Laterals

In Table 8.4 and Figure 8.7 the percentages of laterals for both groups are shown. No difference is found between the two groups when combining the data of the whole period studied. Laterals were uncommon in both groups (3% in both groups) and not significant different in any month studied or for all months combined.

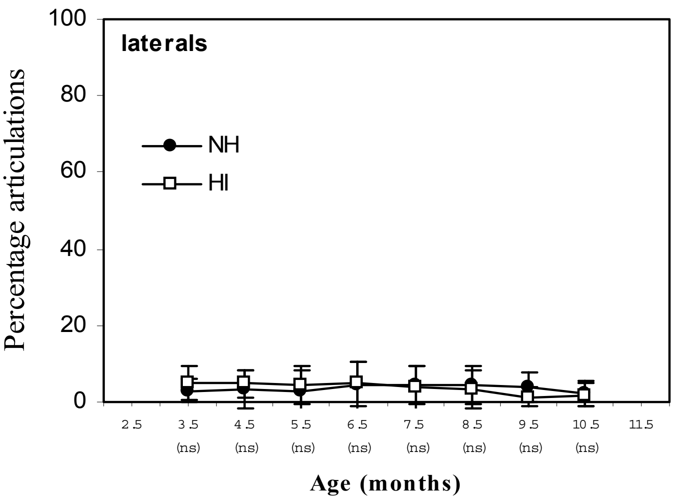

Figure 8.7. Mean percentage of utterances with laterals per month, for the NH and HI group separately.

8.3.3 Place of articulation

In this section the place of articulation will be discussed (combining all manners of articulation). In the first months both NH and HI group produced mainly articulations in the back part of the vocal tract as shown in Table 8.4. Almost 69% of the articulations at 2.5-4.5 months were produced with a back articulation. However, in the NH groups the percentage of back articulations decreased gradually (from 69% at 2.5-4.5 months to 11% at 9.5-11.5 months), while this was not the case for the HI group. In the HI group the percentage back articulations stayed above 60% until the end of the first year. The differences between the two groups were significant from 5.5-7.5 months onwards as can be seen in Table 8.4 and Figure 8.8.

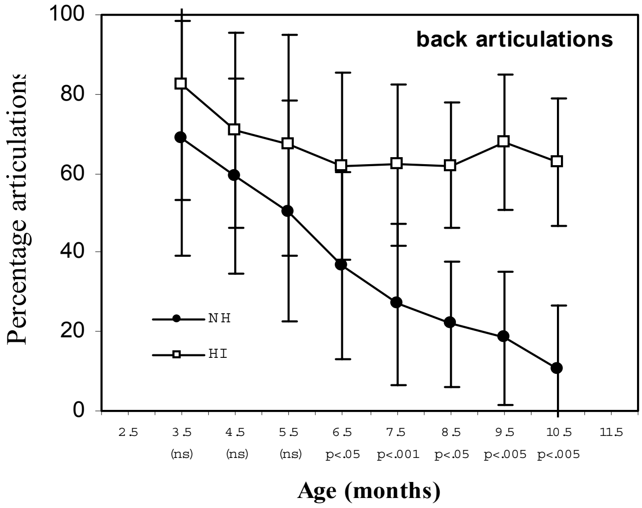

Figure 8.8. Mean percentage of utterances with back place of articulation per month, for the NH and HI group separately.

Until 8.5 months about the same proportion of central articulations was produced in both groups. However, the NH group produced gradually more centrals in the last months studied as can be seen in Table 8.4 and Figure 8.9. At the end of the first year - 9.5-11.5 months- central articulations were produced in over 50% of the utterances on average (even 70% at 10.5 months - not running) by the NH infants, but only in 16% of the utterances by the HI infants. This difference was significant at the ages 8.5-10.5 and 9.5-11.5 months.

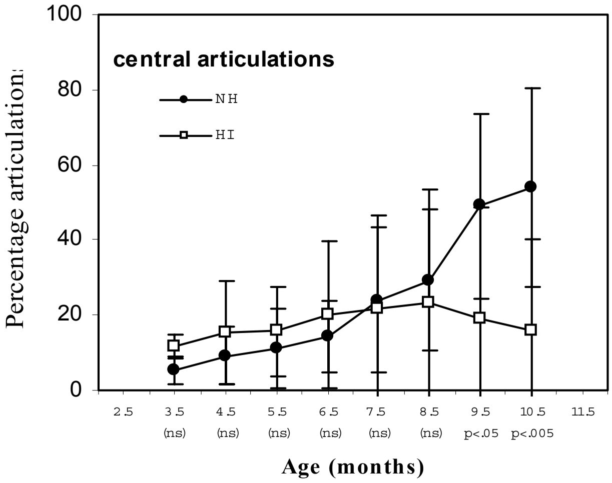

Figure 8.9. Mean percentage of utterances with central place of articulation per month, for the NH and HI group separately.

In the NH group we see a gradual increase and then decrease in front articulations during the period studied as can be seen in Table 8.4 and Figure 8.10. Around six months of age over 50% of the articulations were produced at the front position with a peak of 67% at 7.5 months by the NH infants. On the other hand, the HI infants produced only around 15% for the whole period from 3.5-5.5 months until 8.5-9.5. This difference resulted in a significant difference between the two groups from 5.5-7.5 months onwards. In the HI infant group a clear increase of the front articulations could be seen at 9.5-11.5 months (21%), probably due to a high percentage at 11.5 months (43%).

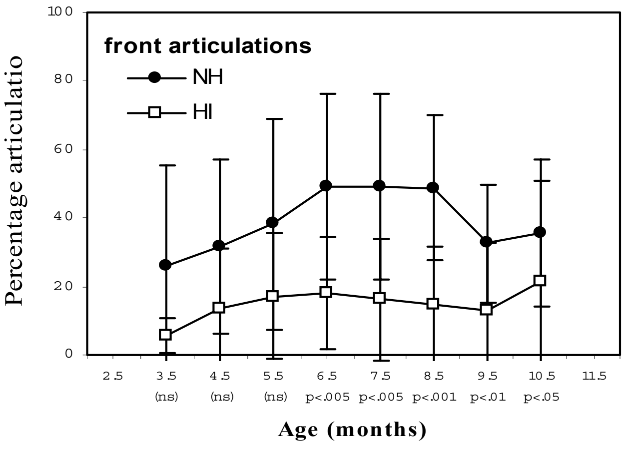

Figure 8.10. Mean percentage of utterances with front place of articulation per month, for the NH and HI group separately.

The back articulations produced by the HI group were mainly back fricatives and trills, which the HI infants kept producing very frequently (around 50% on average, see also Table 8.4) during the whole first year, while in the NH group the percentage back fricatives gradually decreased (see also section 8.3.2). In Appendix A8.1 the place of articulation is shown for each subject separately.

The high percentage of central articulations produced by the NH group at the end of the first year were mainly central stops and central nasals as can be seen at Table 8.4. The high number of front articulations produced by the NH group around 6.5 and 7.5 months were produced in all type of manners possible.

Thus, it seems that in the NH infants -as a group-, the most frequently produced place of articulation changes over time during the first year of life: from back to front to central, while this is not the case for the HI infants. The HI infants produced mainly back articulations during the whole period studied.

In section 8.1 we discussed two hypotheses with respect to place of articulation. We might expect that vocalizations of NH infants are influenced by the phonology of the spoken environmental language, especially at the end of the first year, while we expect less effect of the spoken environmental language on the vocalizations of HI infants. In that case we expect that HI infants produce fewer fronts and centrals and more back articulations compared to the NH infants.

On the other hand we might expect that HI infants produce a same proportion or even more front articulations compared to the NH infants because this place of articulation might be visual, acoustically and articulatory easier than other places of articulation.

Although also other explanations are possible, our data give some evidence for this second hypothesis. The HI infants might show a tendency at the end of the first year to produce more front articulations compared to the previous months which might be influenced by, for instance, visual aspects of the spoken language input. This topic will be discussed in detail in section 8.4. A study of vocalizations of HI infants *after* the first year of life might answer the question whether this possible trend continues also in later periods.

However, our results give stronger evidence for the first hypothesis. We found that back articulations were clearly more often produced and that front and central articulations were less often produced in the HI infants compared to the NH infants. Thus it might be that the environmental language has more influence via auditory speech and language processing on the vocalizations of NH infants than of HI infants. This topic will be discussed further by comparing our data with data of Dutch older children and adults in section 8.3.4.

8.3.4 Comparisons with data of Dutch two-year-olds and adults

From other studies we know that the influence of the environmental language can be noticed in the frequency of occurrence of consonantal features of the vocalizations of NH infants at the end of the first year. English, French, Japanese and Swedish were the languages studied (e.g. De Boysson-Bardies et al., 1992, see also Chapter 3.2.1). Therefore, we might also expect in case of Dutch as input language that certain phonological features of that language will appear in the vocalizations of NH infants at the end of the first year of life. We assume that this effect will be more clearly the case in NH infants and less in HI infants.

In our study, we saw in the previous sections that Dutch NH infants produce their place and manner of articulation differently from HI infants already within the first year of life. We can assume that the difference is caused by the hearing loss. We expect that the HI infants are not influenced by the spoken language input via the auditory channel, while the NH infants are. To check this hypothesis, we can examine whether the six NH infants studied show a similar distribution of articulation as compared to Dutch speaking adults. The expectation is that NH infants produce some places or manners of articulation that are relatively common in the spoken language input, more than HI infants. And conversely: the NH infants produce some uncommon places or manners of articulation in the spoken language input, less often than the HI infants. We will discuss this hypothesis more thoroughly in the discussion of this chapter.

We can also double check this idea by looking at the place and manner of articulation of Dutch children of for instance two or three years old, as well. We assume that these children are still in the process of acquiring the Dutch phonology system, since it is on average not before the age of eight years until all segments and consonant clusters used in Dutch are produced correctly (Beers, 1995). We expect to find percentages of places and manners of these young children more or less in between those of the NH infants and the adults.

Dutch adults

We calculated the percentages of place and manner of articulation of Dutch adults, based on frequency of occurrence of the consonants and consonant clusters in one million Dutch written words[5] of the CELEX database. This was done with help of the CELEX, the Dutch expertise center for lexical information, in Nijmegen, the Netherlands. The one million words are derived from written texts and phonetically transcribed by CELEX. The frequency of occurrence of the 22 Dutch consonants (including /h/) is shown in Table 8.5.

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[5]At the moment this part of the study was performed no spoken database for Dutch was available.

Table 8.5. Frequency of occurrence of all Dutch consonants in adult written language, based on the CELEX database for written Dutch.

Consonant	Percentage	Consonant	Percentage	Consonant	Percentage
/n/	18.3	/m/	4.1	/ŋ/	1.5
/t/	12.0	/x/	3.7	/j/	1.3
/d/	11.1	/z/	3.3	/f/	0.8
/r/	10.2	/w/	2.8	/ʃ/	0.09
/s/	7.1	/b/	2.3	/ʒ/	0.03
/l/	5.9	/p/	2.3	/g/	0.01
/k/	4.6	/h/	2.2		
/v/	4.3	/χ/	2.0	Total	100%

In Table 8.6 each phoneme for Dutch is shown in phonetic symbols related to each possible place and manner combination for Dutch to be able to compare the adult data with the data of the infants. From the frequency of occurrence of consonants and consonant clusters, the frequency of occurrence of place and manner of articulation was derived, following the same rules as for the infants (see 8.2.1). For example: a stop + fricative/trill (affricate) cluster on the same place of articulation, became a fricative/trill. Thus the syllable final cluster in [kats] was classified as a central fricative. In most consonant clusters, e.g. [ast], both consonants are classified separately, thus as central fricative and central stop respectively.

Table 8.6. All possible place and manner combinations for Dutch.

manner place	stops	fricatives /trills	glides	nasals	laterals
front	/b/, /p/	/v/, /f/	/w/	/m/	
central	/d/, /t/	/z/,/s/,/ʒ/,/ʃ/,/r/	/j/	/n/	/l/
back	/g/, /k/	/χ/		/ŋ/	

The percentage of each place and manner combination, compared to the total number of consonants out of one million words, is shown in Table 8.7. The laryngeal /h/ is excluded here, since the glottals are also excluded from the data of the infants, causing small differences in the percentages with Table 8.5. In Table 8.7 all five manners of articulation are combined with all three places of articulation, while also the total for each place and manner of articulation is shown. It can be seen that the central place of articulation is by far the most frequent (in total 70.8%); the frequency of occurrence of stops and fricatives at the central place of articulation together adds up to almost 45%. The six most often occurring consonants in Dutch - /n/, /t/, /d/, /r/, /s/, /l/ - are all produced at the central place of articulation. Before we compare these data with the data of infants we will also take a look at data of Dutch two-year-olds.

Table 8.7. Frequency of occurrence of place and manner of articulation for Dutch adults, based on one million written words.

manner / place	stops	fricatives /trills	glides	nasals	laterals	Total
front	4.8	5.2	2.9	4.2		17.1
central	23.7	21.2	1.3	18.7	6.0	70.8
back	4.7	5.8		1.5		12.0
Total	33.2	32. 3	4. 2	24.3	6.0	100

Two-year-olds

In Table 8.8 the place and manner combinations are given on average for nine Dutch, phonologically normally developing and NH children of 24 months of age. The data are based on recordings of spontaneous speech, collected from nine monolingual NH children from native Dutch parents in a familiar environment for the children (Jansonius-Schultheiss, 1999).

Table 8.8. Frequency of occurrence of place and manner of articulation, of all produced consonants for 9 Dutch children of 24 months of age with normal developing phonology (based on data of Jansonius-Schultheiss, 1999).

manner / place	stops	fricatives /trills	glides	nasals	laterals	Total
front	19.3	4.1	3.4	6.8		33.6
central	22.2	10.4	3.9	10.5	4.7	51.7
back	10.0	4.6		0.1		14.7
Total	51.6	19.1	7.3	17.4	4.7	100

The data was analyzed (as much as possible) in similar way as the data of the infants (see 8.2.1). The same rules were applied and the laryngeals were excluded. All consonants produced by the children are included, which could be either correctly produced, or produced as a substitution for another phoneme. That is, if the child pronounced /kIk/ instead of the target word /kIp/ (chicken) /k/ was counted twice, even though the final /k/ is incorrect. In this way we make the speech production of these nine children more comparable with that of the six NH infants studied here. In our study the productions cannot be defined as ‘correct’ or ‘incorrect’, since we did not study whether the utterances contained meaning or not. Next, the percentage of each place and manner combination was calculated by comparing it to the total number of articulations found per child. Finally, the mean percentages were calculated for the whole group.

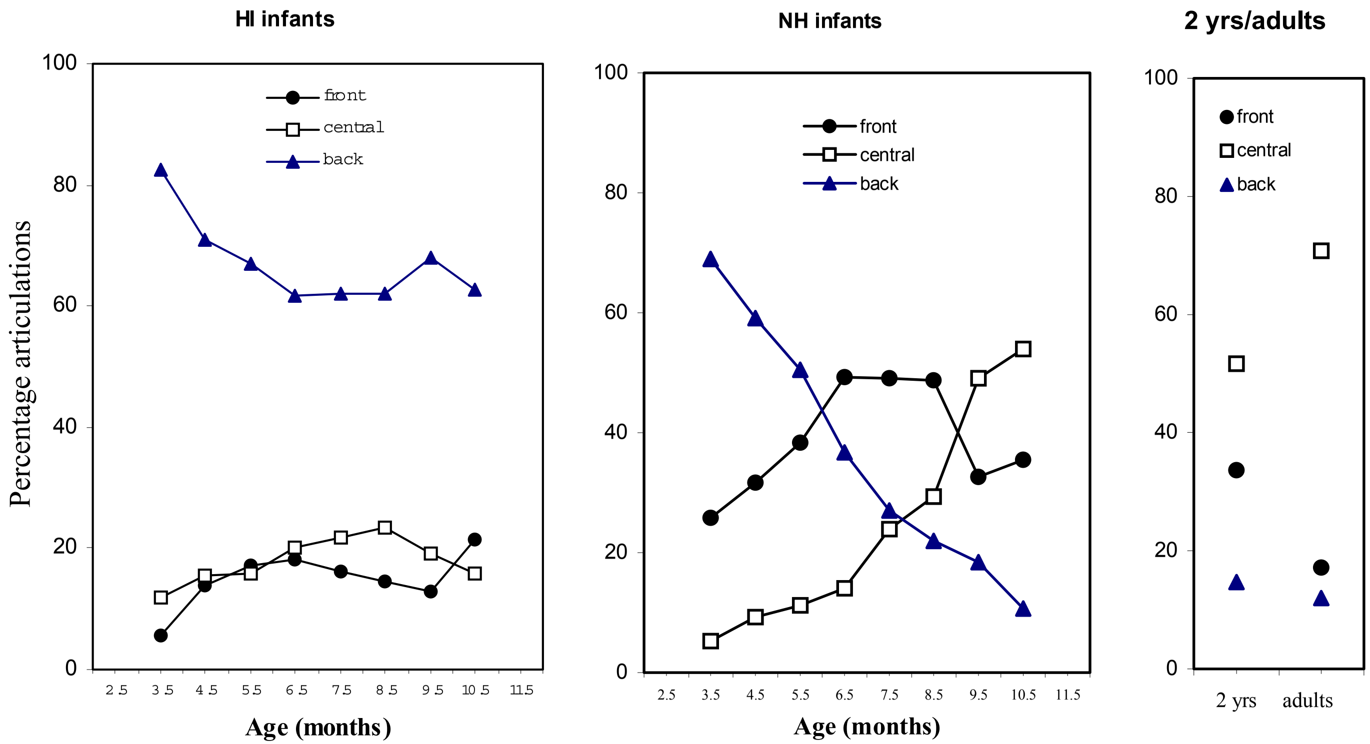


Figure 8.11. Mean percentage of place of articulation per month for the NH and HI group (N: see Table 8.2), as well as for NH children at 2;0 years and for Dutch adults (N: see text).

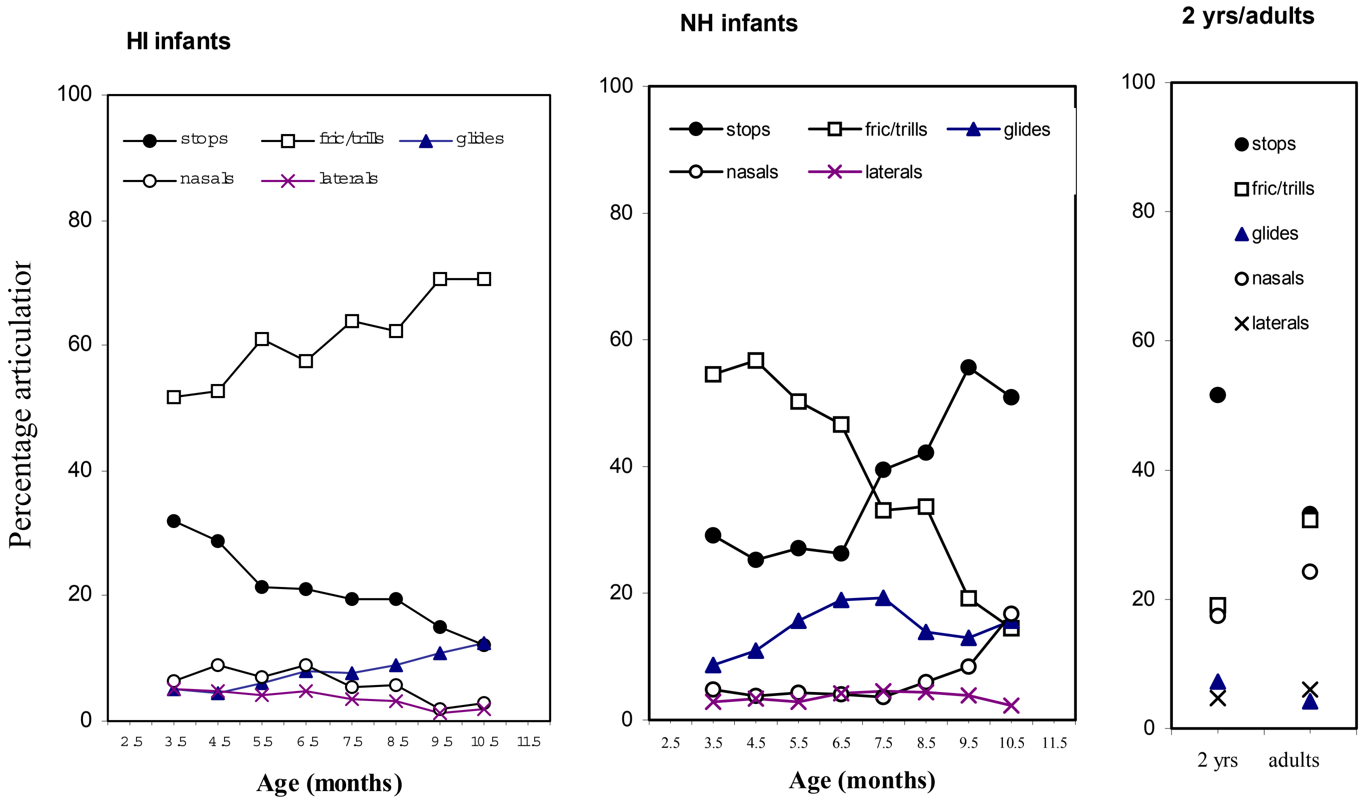


Figure 8.12. Mean percentage of manner of articulation per month for the NH and HI group, as well as for NH children at 2;0 years and for Dutch adults (N see Table 8.2).

Data of infants, children and adults compared

In Figure 8.11 the mean percentage of utterances with back, central, and front place of articulation is shown per age for the NH and HI groups, combined with the data of 2.0-year-old children and adult Dutch speakers. As described in 8.3.3 and 8.3.4 it can be seen, that the HI infants produced mainly back articulations during the whole first year. The NH group has the tendency to produce the main place of articulation in a certain fixed order; during the first months mainly back articulations and halfway the first year more front, and at the end of the first year more centrals. At 10.5 months the centrals were most common, followed by front and back articulations as least common place of articulation.

It can be seen that also the adult speakers produced the central place of articulation most often, followed by front place, while the back place was produced least frequently. Children of 2.0 years of age show also the same distribution. The percentages seem to be similar to the infants at the end of the first year, as we expected. In the two-year-olds the percentage back articulations is lowest as in the two other age groups and the percentage centrals is highest. To summarize, it seems that already at the end of the first year, the distribution of place of articulation for hearing infants is similar to that at the adult age and at the age of two years. This shows a developmental process with respect to place of articulation in the direction of a complete phonological language system at later age. This starts already before the end of the first year of life.

Clear differences between the HI group and the other groups with respect to place of articulation can be seen in Figure 8.11 (see also 8.3.3). The HI group produces about the same distribution from the first months until the end of the first year, namely with the back place of articulation as the far most produced place. This topic will be discussed in more detail while presenting the individual data in the next section.

In Figure 8.12 the mean percentage of articulation for the five manners of articulation are shown for both groups of infants, combined with the data of the 2;0-year-olds and adults. The differences between the HI and NH infant groups become more clear from six months on as described in section 8.3.1 The HI infants produce mainly fricatives/trills during the whole period studied. As can be seen in Figure 8.4, in the last three months (9.5-11.5 months) the NH infants produced mainly stops, followed by nasals, glides and fricatives and trills, whereas laterals were quite uncommon. The Dutch children at 2;0 years show overall a frequency of occurrence of the manner of articulation which is similar to the last months of the NH infants and the adults. The high percentage of stops in the last months of the NH group is also seen in the two-year-olds. Also, the percentage of fricatives/trills, nasals and laterals is similar. Only the relatively high percentage of glides of the NH infants decreases in the two-year-old group. Looking at the data of the adult speakers in Figure 8.12 and Table 8.7 it can be seen that also in this group stops occur most frequently. However, more than half of the consonants of the children are stops, compared to only one third for the adults. In the adult group the stops were directly followed in percentage by

fricatives/trills. The percentage of fricatives/trills is smaller in the NH infants and the two-years-olds compared to the adults.
Looking in more detail (see Table 8.7 and Table 8.8), it turns out that the fricatives/trills of the adults are produced four times more often centrally than at the front or back. The NH infants hardly produce central fricatives/trills (Table 8.4), whereas the two-year-olds produce the central fricatives/trills already more often than front or back fricatives/trills. This means that between one and two years of age more central fricatives/trills appear, leading to a more adult-like consonantal production. The adults produced the nasals relatively more often than the children, but the laterals and glides are produced in a percentage similar to that of the two-year-old group. In some place and manner combinations, such as the central nasals, we see clearly an increase starting already at 9.5 months, leading to a distribution similar to the adults and the two-year-olds. In other combinations such as the back fricatives/trills we hardly see any changes between the three groups. Moreover, the percentage back stops was equal in the last months of the first year to that of the adults, whereas the two-years-olds produced relatively more back stops compared to both other groups. Possibly back stops are not likely to be used much during babbling, whereas they occur more frequently during the production of the first words of young children for unknown reasons.

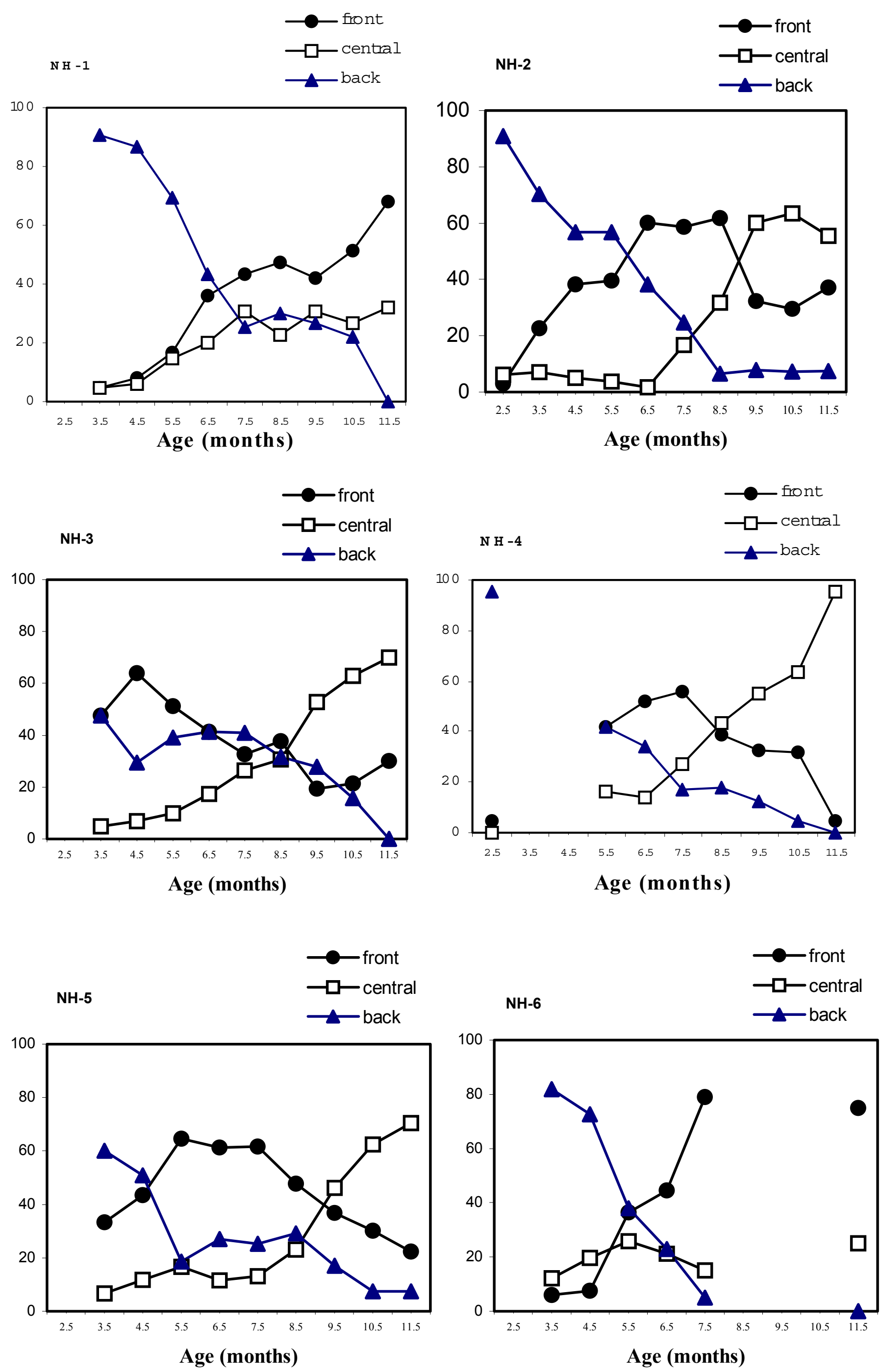
From this data we can conclude that for both place and manner of articulation the NH infants already at the end of the first year of life show tendencies toward an adult-like production of consonantal features. Especially for place of articulation we see influences of the auditory language input on the vocalizations of the NH infants. In section 8.4 we will discuss further the implications of these findings.

Clear differences between the HI group and the other groups were found with respect to manner of articulation can be seen in Figure 8.12 (see also 8.3.2). While the percentage of stops is the highest in the two-years olds, the adults and the NH infants at the end of the first year, the HI group produces much more fricatives/trills than stops. This topic will be discussed in more detail while presenting the individual data in the next section.

8.3.5 Individual subjects

In section 8.3.1 we found that the NH infants clearly produced more different place and manner categories than HI infants. To see if these group differences also hold for the individual subjects, the data of the twelve subjects will be described also individually. In Table 8.9 the number of categories of the individual infants are shown per month and averaged over the period between 5.5 and 11.5 months, thus the period in which recordings from all HI infants were available.

Also the total number of different categories produced by each subject was calculated within that period (maximal 15, see also Table 8.1). Although in section 8.3.1 only place and manner combinations that were produced at least twice per recording were included to define a category, in this section for individual data also combinations that were produced once (during a single recording), but during four or more different recordings, were included in the total number of categories per subject.


NH-1
front
central
back
Age (months)
NH-2
front
central
back
Age (months)
NH-3
front
central
back
Age (months)
NH-4
front
central
back
Age (months)
NH-5
front
central
back
Age (months)
NH-6
front
central
back
Age (months)

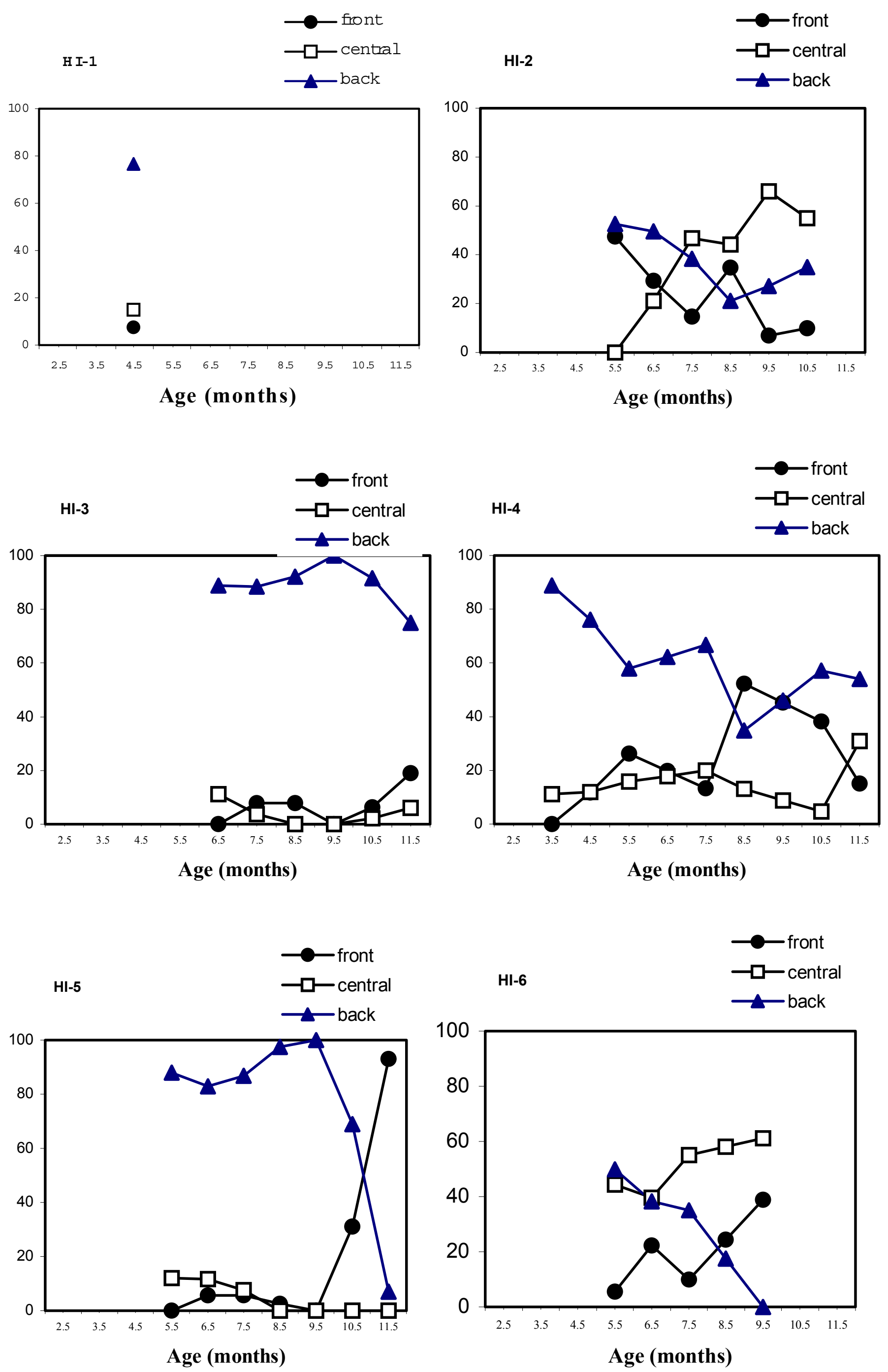


Figure 8.13. The percentage of front, central, and back place of articulation per month is shown per subject. The curves are based on the running averages, while the data at the outer parts of the curves (normally at 2.5 and 11.5 months) are the percentages for only those months.

In the NH group the smallest number of categories (7) was produced by subject NH-6 but she had an incomplete data set at 9.5 - 11.5 months[6]. In the HI group a maximum of eight different categories was found, produced by subjects HI-2 and HI-6. According to a Wilcoxon Signed Rank test the HI subjects produced fewer different categories in total between 5.5 and 11.5 months, compared to the NH infants ($p=<0.05$, mean 9.8 sd 1.5 for the NH group and mean 5.8 sd 2.6 for the HI group).

Table 8.9. The number of articulation categories per month from 5.5 months onwards, the mean number of categories, as well as the total number of different categories produced between 5.5 and 11.5 months per subject. For calculation of the total number of categories: see text.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	Mean	HI1	HI2	HI3	HI4	HI5	HI6	Mean
5.5	4	3	2	3	4	2	3.0	1	4	3	2	3	4	2.8
6.5	3	4	4	0	3	0	2.3	0	2	1	3	4	5	2.5
7.5	2	2	5	5	4	2	3.3	0	5	4	2	2	3	2.7
8.5	8	4	7	4	5	2	5.0	0	2	1	4	1	2	1.7
9.5	5	6	5	5	7	na	4.7	0	1	1	1	1	4	1.3
10.5	4	4	3	3	5	na	3.2	0	5	1	3	1	1	1.8
11.5	4	8	4	1	4	3	4.0	0	1	2	3	2	3	1.8
Mean	5.6	5.9	5.9	4.6	6.0	2.4	3.9	0.3	4.0	2.9	3.4	2.9	4.1	2.1
Total n.of categories	*9*	*10*	*11*	*11*	*10*	*7*	*9.8*	*1*	*8*	*7*	*6*	*6*	*8*	*5.8*
sd							*1.5*							*2.6*

With respect to place of articulation the data is specified for the individual subjects (see Appendix Table A8.1). Figure 8.13 shows the percentage of front, central and back place of articulation per month per subject. It can be observed that in the first two or three months studied (if data available) all NH infants produced more utterances with back articulation movements than with front and central articulations. After this period all subjects showed a decrease in the percentage of back articulations. At the same time, the percentage of utterances with front articulations showed a clear increase and became the most common place of articulation, approximately halfway the first year for all NH subjects. For NH-1 front became the main place of articulation relatively late at 7.5 months, for NH-3 and NH-5 relatively early at 4.5 months, and for the other NH infants at 5.5 or 6.5 months (see Figure 8.13). After this period, the percentage front articulations decreased again for four NH infants (NH-2, NH-3, NH-4 and NH-5), while the percentage of utterances with central articulations increased. From 9.5 months onwards the central articulations were produced more often than the back and front articulations for NH-2, NH-3, NH-4 and NH-5. NH-1 was an exception in producing a high percentage of front articulations during the whole second half of the first year. For NH-6 not enough data were available from 9.5 months onwards to judge on the development of the place of articulation in that period.

[6] No data was available at 9.5 and 10.5 and an incomplete data set at 11.5 months.

As shown in section 8.3.3 significant differences with the NH group for all months combined were found with respect to place of articulation. None of the HI infants seems to follow exactly the characteristic pattern for the NH infants after the first months (see Figure 8.13), although during the first months (2.5-4.5 months) the subjects in both groups produced mainly back articulations in the few recordings with at least 10 articulations per recording available at that early age (see section 8.2.3 for method description). HI-1 produced only ten articulations or more at 4.5 months of age. For HI-4 the front articulations were the main place at 8.5 months, and for HI-5 at 11.5 months, which was much later and in fewer recordings than for the NH infants.

Only in case of HI-2 and HI-6 the centrals became the main place at the end of the first year, just as in four of the NH infants. HI-2 produced the centrals as the main place of articulation at 7.5-9.5 months, which is the period he started babbling[7]. Overall, the back articulations were produced far more frequently than central and front articulations. Two HI infants produced the back place most often at the end of the first year (HI-3, HI-4). HI-5 used mainly back articulations until 11.5 months when he produced mainly fronts. In Appendix A8.2 and A8.3 oscillograms of examples of utterances of NH infants and HI infants at different months of age are shown.

Looking at the percentage of front stop articulations specifically, the two groups seem to differ also at the individual level. The NH infants produced significantly more front stops than the HI infants from 6.5-8.5 months onwards (see Table 8.4). In Table 8.10 the percentage front stops is shown per subject, the mean percentage per month and averaged between 5.5 and 11.5 months, since this is the period in which recordings for all infants were available. The individual NH subjects produced between 4% and 27% of their articulations as front stops, while two HI infants did not produce them at all and three HI infants only 1% or 2%. However, it is striking that the only babbling HI infant (HI-2, see also Chapter 7.3.6) produced also a high percentage of front stops (11%), just like some of the NH infants. This point will be discussed more thoroughly in section 8.4 and Chapter 9.2.3.

Table 8.10. Percentage of front stop articulations per subject. na= no data or not enough articulations available.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	Mean	HI1	HI2	HI3	HI4	HI5	HI6	Mean
5.5	3	3	na	8	17	0	6	na	16	na	5	0	0	5
6.5	8	24	0	na	13	na	11	na	15	0	na	0	2	4
7.5	0	92	8	4	18	5	21	na	21	0	0	3	5	6
8.5	12	36	9	0	27	na	17	na	4	0	0	0	na	1
9.5	11	21	6	4	15	na	11	na	na	0	na	0	0	0
10.5	7	0	11	5	10	na	6	na	0	0	0	0	na	0
11.5	5	11	5	2	4	8	6	na	na	0	0	2	na	1
Mean	7	27	6	4	15	4	11	na	11	0	1	1	2	2

[7] Individual variation and possible explanations for individual variation will be discussed in more detail in Chapter 9.2.3.

8.3.6 Babbling and place and manner of articulation

In Chapter 7.3.3 we found that all NH infants produced babbled utterances while only one HI infant did (HI-2) (see Chapter 7.2.1 for definition of babbling and see Table 7.3 for the number of babbled utterances per infant and per month). In this section we describe the place and manner of articulation of the babbled utterances.

The mean percentage of place and manner combinations of the 160 articulation movements during 151 babbled utterances of the NH infants and the 56 articulation movements during 43 babbles of infant HI-2 are shown in Table 8.11. All classified articulations of the babbled utterances are included in the table, that is also non-repeated consonants, e.g. the final fricative in [babababaf] (see also section 8.2.1 for description of the method). The class of central stops was the most frequently produced category in both the NH group (38%) and subject HI-2 (57%). All NH subjects used four to seven different categories to babble (between 5.5 and 11.5 months), and several NH infants produced up to five different categories during one recording for the babbled utterances. On the other hand some NH subjects produced just one category while babbling during a single recording.

Table 8.11. Mean percentage of place and manner combinations of the babbled utterances of all NH infants (N=160) and of the HI infant HI-2 between 5.5-11.5 months (N=56). no=no observations.

5.5-11.5 NH	stops	fric /trills	glides	na-sals	late-rals	Total
front	20.6	1.9	10.0	6.3	no	38.8
centr	38.1	0.6	3.8	8.8	1.9	53.1
back	6.9	0.6	0.6	0.0	no	8.1
Total	65.6	3.1	14.4	15.0	1.9	100

5.5-11.5 HI-2	stops	fric/ trills	glides	na-sals	late-rals	Total
front	12.5	0.0	7.1	0.0	no	19.6
centr	57.1	0.0	7.1	0.0	12.5	76.8
back	3.6	0.0	0.0	0.0	no	3.6
Total	73.2	0.0	14.3	0.0	12.5	100

In the age period when the NH infants babbled (from about 5.5 onwards, see also Chapter 7.3.3), they produced significantly more front stops (from 5.5-7.5 months onwards) and central stops (from 8.5-10.5 months onwards) than the HI infants (see also Table 8.3.b). The mean percentage was 26 % for the NH group and only 8% for the HI group for the central stops and front stops combined (see Table 8.3.b). Thus, it seems that front and central stops are often produced in the same period as the babbling stage starts. Although not all of the front and central stops occur in babbled utterances of the NH infants, most of the articulation movements in the babbled utterances are produced with front or central stops (59%, see also Table 8.11). Furthermore, the only babbling HI infant (HI-2, see also Chapter 7.3.3) produced not only a high percentage of central stops, but also of front stops in his utterances, as the only infant from his subject group (see also Appendix A8.1). These results suggest that babbling is related to the capacity to produce front or central stops.

The babbling HI infant HI-2 produced babbles that were quite similar to those of the NH infants with respect to articulation. The main category was also central stop

(57.1%), followed by a cluster of front stops and central laterals ([bla], 12.5%), front and central glides (7.1%). However, striking is his complete lack of nasals in his babbled utterances compared to the NH infants (15.0%). In contrast, it was found that all NH infants produced at least some front or central nasals in their babbled utterances, but only from 9.5 months onwards (see Table 8.12). In the period between 5.5 and 8.5 months onwards no babbled utterance was produced with nasals at all, while between 9.5 and 11.5 months 32.1 babbles were produced in total. If combining the data of all months a t-test for paired samples shows a significant difference (p<.01). A Mann-Whitney U test on the running averages showed significant differences between the two groups at 9.5 months (p<.05) and 10.5 months (p<.001), but not in the previous months. This seems to justify to split up the age period in which the NH babble, into two parts: babbling stage 1 (5.5-8.5 months) and babbling stage 2 (9.5-11.5 months).

Table 8.12. Number of babbled utterances with nasals per month and per subject and in total over 5.5 to 11.5 months. Between 2.5 and 5.5 months no babbling was found and these months were therefore excluded in this table.

Age (m)	NH1	NH2	NH3	NH4	NH5	NH6	Mean	HI1	HI2	HI3	HI4	HI5	HI6	Mean
5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	3	0	2	3	nd	1.6	0	0	0	0	0	0	0
10.5	0	0	0	0	3	nd	0.6	0	0	0	0	0	0	0
11.5	3	1	1	1	7	8.1[8]	2.6	0	0	0	0	0	0	0
Total babbles with nasals	3	4	1	3	13	8.1	32.1	0	0	0	0	0	0	0

The place and manner combinations of the babbles of the NH infants are shown in Table 8.13 for babbling stage 1 (78 articulation movements during 70 babbled utterances) and babbling stage 2 (82 articulation movements during 81.3 babbles). It can be seen that the babbles with front and central nasals are produced in the secondary babbling stage in the last months of the first year of life. The high percentage of nasals in the babbles during babbling stage 2 might be influenced by the environmental language. In Dutch adults the percentage nasals was 24.3% (see Table 8.7), while most nasals were produced at central place of articulation (18.7%). An influence of the environmental language on the vocalizations is not unlikely at the end of the first year as described in previous studies (see also Chapter 3.2.1).

The data shown in Table 8.12 suggests that the babbling HI infant did not seem to 'reach' this babbling stage 2 within the first year. Thus, HI-2 started babbling despite his hearing loss of over 90 dB, but the content of his babbled utterances was different from that of the hearing infants at the end of the first year.

[8] Corrected data, since the number of utterances in this recording was only 31 instead of 50.

Table 8.13. Percentage place and manner of babbled utterances of NH infants in babbling stage 1 (5.5-8.5 months, N=78) and babbling stage 2 (9.5-11.5, N=82).

5.5-8.5 NH	stops	fric /trills	glides	na-sals	late-rals	Total
front	26.9	2.6	11.5	0.0		41.0
centr	37.2	0.0	5.1	0.0	2.6	44.9
back	11.5	1.3	1.3	0.0		14.1
Total	75.6	3.8	17.9	0.0	2.6	100

9.5-11.5 NH	stops	fric /trills	glides	na-sals	late-rals	Total
front	14.6	1.2	8.5	12.2		36.6
centr	39.0	1.2	2.4	17.1	1.2	61.0
back	2.4	0.0	0.0	0.0		2.4
Total	56.1	2.4	11.0	29.3	1.2	100

It should be noted that we could not relate this babbling stage 2 to the stage, mentioned in the literature, with non-reduplicated, or variegated babbling (e.g. Stark, 1980; Oller, 1980, see also Chapter 3.1) characterized by the use of different consonants and vowels within a series and occurring normally at the end of the first year. All NH infants, except NH-4, produced one or more babbled utterances with two or more categories before 9.5 months of age and we did not see a clear increase of this type of babbles towards the end of the first year in this group.

8.4 Summary and discussion

As discussed in Chapter 7.4 the coordination of several aspects of the vocalization development into a simultaneous behavior is a highly complex skill. Moreover, it might require a well developed and well functioning internal auditory feedback system, which HI infants lack. The production of certain consonantal segments might be relatively complex, since it requires the cooperation of several articulators, such as the jaw, glottis, lungs, velum, etcetera. From that point of view we expected a smaller consonant repertoire in HI infants, than in NH infants.

A limited consonant repertoire for the HI infants, as found by Stoel-Gammon and Otomo (1986) is also found in the present study (see Figure 8.1) conform to our hypothesis. We found that overall the HI infants produced significantly fewer different categories of articulations than the NH infants from 6.5-8.5 months onwards. Measured in the period between 5.5 and 11.5 months, the NH infants produced on average in total 9.8 different categories (of the 15 possible) compared to only 5.8 by the HI infants. In Figure 8.1 we see that the number of categories strongly increases in the NH infants from 6.5-8.5 months onwards, whereas this is not the case in the HI group. The increase in categories in the NH infants can be explained by the production of several new categories at that period (such as central stops) while also earlier categories (such as back fricatives) are still produced. In the HI infants we found clearly less variation; as can be seen in Table 8.9 only a single type of category is produced in many recordings whereas they produced only a few new categories in the second half of the first year. Thus a lack of auditory input and feedback might seem to effect the number of different place and manner combinations of HI infants already around the age of six months.

However, unlike the other HI infants, HI-2 also produced a high amount of different categories (8), just like the NH infants did. Beside this high number of categories he also produced other places and manners of articulation compared to the other HI infants as will be discussed later in this section.

Looking in more detail at the place and manner of the articulation movements (sections 8.3.2 and 8.3.3) we concluded that the group of NH infants and the group of HI infants differ with respect to place and manner of articulation within the first year of life. The finding here, that HI infants differ from NH infants in phonetic properties of their vocalizations, is in agreement with Oller et al. (1985), Stoel-Gammon and Otomo (1986), Stoel-Gammon (1988), and Kent et al. (1987). In our study substantial differences in both place and manner of articulation were found from a very early age, and even earlier than found in the studies mentioned above.

With respect to the place of articulation we could observe a specific pattern for most NH infants. NH infants produce around 2.5 and 3.5 months of age mainly back articulations, mainly back fricatives/trills and back stops (see also section 8.3.3). Halfway the first year we find an increase of the percentage of utterances with front articulations up to 7.5 months, namely front fricatives/trills, front stops, and front glides, while back stops and back fricatives/trills decrease. The central articulations increase dramatically at the end of the first year. After 8.5 months the percentage of stops was much higher than of fricatives/trills. At the end of the first year a high percentage of central articulations can be found (54%), mainly in the form of central stops. Similar results with respect to place of articulation were found by Smith (1982) in his study of vocalizations of normal children, but strikingly also for the HI infants in his study. At the end of the first year he also found that centrals were the main place of articulation for the HI subjects.

In contradiction to the study of Smith (1982), in our study the HI infants were found to produce more back than front or central articulations until the end of the period studied. In the first months of the HI group we see also, as in the NH group, a high percentage of back fricatives/trills and back stops. The percentage of back stops decreases, while the percentage of back fricatives/trills stays relatively very high during the whole period studied. The percentage of front articulations increases only at the end of the first year, mainly in the form of front fricatives/trills. At the end of the first year, at 8.5-10.5 month and 9.5-11.5 months, significantly fewer central articulations are produced by the HI infants (16%) than by the NH infants. An explanation for the contradiction in results between the Smith study and ours can be that the infants in his study had a wide variety of hearing losses (moderate to profound hearing losses), while in our study all infants had severe losses (90 dB or more).

Also the HI infant from the study of Kent et al. (1987) produced many more alveolars (comparable with the central articulations from our study) compared to his hearing twin brother. This child had a severe to profound loss unaided, and a loss of about 48 dB with a hearing aid. Moreover, two infants studied by Stoel-Gammon

(1988) with an aided loss of 15 and 25 dB respectively, produced dentals (including alveolars and palatals, thus comparable with our class ‘central’) within the first year. In six other infants with a more severe loss, no dentals were found before 20 months, except in one sample. Thus, the ability to produce dentals or central articulations seems to be related with the hearing status of the HI infants. However, in our study, no clear relation was found between the audiograms of the HI infants and the percentage of dentals, although the infant with probably best hearing according to his audiogram (HI-2) produced not only more different categories, but his articulations were also different from the articulations of the other HI subjects with respect to place and manner of articulation. HI-2 produced relatively more centrals and stops at the end of the first year in a more or less similar way as NH infants do. The data of this subject will be discussed in Chapter 9.2.3, related to his data discussed in the previous chapters.

A high percentage of stops was produced by the NH infants at the end of the first year. Unlike NH infants the HI infants produced a higher percentage of fricatives/trills than of stops during the whole period studied. Also Stoel-Gammon (1988) found in her study a lower proportion of stops by HI infants than by NH infants. On the other hand, the HI infant from the Kent et al. study (1987) produced more stops compared to his hearing twin brother, although it was mentioned that they were ‘typically frictionalized’. It might be possible that the productions of the HI infant in their study would have been classified as affricates or fricatives/trills in our classification system (see section 8.2.1); this might explain the different results.

Within the higher percentage of back articulations we found that especially the back fricatives/trills were produced significantly more often by the HI infants than the NH infants. This type of articulation movement is typically produced by NH infants in the first months of life similar to results in previous studies on NH infants as described in section 3.1 (40% at 2.5-4.5 months in our study). In the period from 4.5-6.5 onwards, the HI infants produced significantly more back fricatives than the NH infants. One explanation might be that this type of articulation is a specific feature found in HI infants. As described already in Chapter 7.3.6, it seems that the utterances of the HI infants share the feature of high tension in the muscles of the back part of the vocal tract. One of the ways this tension is produced is by a constriction created at the level of the velum, uvula or pharynx, resulting in a high percentage of back fricatives/trills. This topic will be discussed in more detail in Chapter 9.2.2.

On the other hand, it might also be the case that the HI infants simply continue producing this specific category, while the NH infants decrease the percentage of back fricatives/trills, meanwhile making place for other categories, such as front stops and central fricatives (see also Section 8.3.2). As described above this might result in a higher number of different articulation categories in the NH infants, which was not the case in the HI infants. This difference in vocalization development might be related to the development of the vocalization stages as described in Chapter 3.1 and will be discussed fully in Chapter 9.1 and 9.2.

In the HI group we could see that the percentage of utterances with a certain place or manner of articulation changed slightly during the first year of life. For instance, the percentage back fricatives and trills increases slightly for the HI infants during the first year of life. The spoken language input can not be responsible for those changes, but rather factors such as anatomical and neurological development also influence the development of the vocalizations can (see also Chapter 3.2). This type of changes can also be expected in the NH group, but is probably overruled by the effect of the hearing, including the input of the environmental language and other factors that are probably affected by hearing. For instance, the low percentage of centrals for the other HI infants compared to the NH infants at the end of the first year is probably influenced by the lack of hearing. One possible explanation might be the effect from the environmental language on the vocalizations of the NH infants already at this early age, whereas this is not the case in HI infants. It was suggested by e.g. studies of De Boysson-Bardies et al. (1992) that the utterances at the end of the first year of infants of four different language backgrounds differ in the same way as the productions of adult speakers of those language environments do. They concluded that at the end of the first year the place and manner of articulation of the vocalizations of infants is influenced by the environmental language (see also Chapter 3.2.2). By comparing our data with data of two-year-olds and adults we concluded that for both place and manner of articulation at the end of the first year of life the NH infants have tendencies toward an adult-like production of consonantal features. Especially for place of articulation we see a clear influence of the auditory language input. In the Dutch adult speech the central position was the most common place of articulation, just like in the NH infants in the last months studied, indeed suggesting influence from the language input on the vocalizations which is not the case in HI infants (see Figure 8.11).

On the other hand, the NH infants produced the stops as most often produced manner of articulation at 9.5-11.5 months (51%) whereas the Dutch adults produced almost as many fricatives as stops (32% and 33%, see Figure 8.12). This indicates that in our study the manner of articulation is probably not much influenced by the specific language environment, but more by other influencing factors.

Also some other significant differences between the groups can not be explained totally by the influence of the spoken environmental language. For instance, several NH infants produced significantly more front articulations compared to the HI infants, in the period between 5.5-7.5 onwards. Almost all possible manners at the front place of articulation, namely front stops, front fricatives/trills, and front glides, were produced significantly more often by the NH infants than by the HI infants. Since the front position is not very common as place of articulation by adults (only 17%), we can not explain these higher percentages by the NH infants only by the influence of the environmental language on their articulations. Therefore we expect that the high amount of front articulations in NH infants at this early age is also influenced by other factors such as anatomy and physiology (see also Chapter 3.2). On the other hand, we can not explain the high percentage of front articulations in the NH infants by those factors alone, since HI infants do not produce them in the same way. Therefore it is probably true that this part of the vocalization development is influenced both by aspects such as anatomical, physiological, and neurological development (which are probably similar in both infant groups) and hearing. Hearing might affect the moment that the effect of these other aspects appears.

We found that three of the six individual HI subjects produced front articulations as main place of articulation during one or more months –just as the NH infants did-, but at a relatively late period. HI-5 started front articulations even at 11.5 months. It might be the case that after the first year of life this trend continues for the HI group as suggested by studies of older HI infants (see also Chapter 3.3.4). One explanation might be that at the end of the first year aspects such as visual features of the environmental language might start to influence vocalizations of HI infants.

On the other hand, this increase in front articulations in some of the HI infants might indicate a delay in the vocalization development compared to the NH infants. Several phonological processes heard in the speech of older HI children are comparable to those in younger NH children, such as gliding, devoicing of final obstruents, cluster reduction, stopping of fricatives, fricativization of other stops, and vowel substitutions (Oller and Kelly, 1973; Abberton et al., 1990; Beers and Baker, 1997). From that point of view we might expect an equal development compared to NH children, but slower. In that case we also might expect a longer period with back articulations and a delayed period with front articulation for the HI infants during the first year of life. If this hypothesis is true, we might also expect a delayed production of the central articulations for the HI infants, after the first year of life. This period is beyond the scope of this thesis, but could possibly be an interesting topic of further research.

We don't know exactly whether the number and type of articulation categories are influenced by the fact that the NH infants started babbling and the HI infants (as a group) not. As described in Chapter 7.3.3 all six NH infants babbled. The babbled utterances were produced mainly with front and central stops, front glides and central nasals (see Table 8.11). In the age period when the NH infants babbled (from about 5.5 onwards, see also Chapter 7.3.3) the NH infants produced significantly more front stops (from 6.5-8.5 months onwards) and central stops (from 8.5-10.5 months onwards), front glides (at 6.5-8.5 until 8.5-10.5 months) and central nasals (from 8.5-10.5 months onwards) than the HI infants did (see also Table 8.4). Especially the front stops seemed to differ highly significantly between the two groups. The mean percentage (between 5.5 and 11.5 months) for the NH group was 11% of the articulated utterances for the NH group and only 2% for the HI group for front stops (see Table 8.10). The only babbling HI infant (HI-2) produced also a high percentage of front stops, namely 8%, which was comparable with the average percentage of front stops of the NH group.

These results might indicate a relationship between this category of articulation and the start of the babbling stage. It might be the case that there is an underlying reason why infants (both NH or HI) start babbling, as well as producing front stops. It has been suggested by several researchers (e.g. MacNeilage, 1998; MacNeilage and Davis, 2000, 2001) that front articulations are relatively easy to produce and therefore are a good "starting point" in a new stage in early speech development, such as babbling. Since babbling is produced by opening and closing the jaw it is likely that the result is a stop at front or central position (see also Chapter 3.2.5). Therefore it might be the case that front stop articulation is a precursor or even a precondition for the start of babbling in both NH and HI infants. More research is necessary to study this hypothesis.

It was seen in Table 8.11 that the category of central stops was the most frequently occurring category in the babbled utterances of both HI-2 and of all NH infants. However, at the end of the first year, also nasals emerged in the babbled utterances of the hearing infants, but not in those of the HI infant. This suggests a developmental effect in the babbled utterances of NH infants, which was not present in the babbling of the HI infant. That nasals emerge during babbling in the NH infants at a later stage than the babbling without nasals, is probably influenced by the fact that the velum muscles are more able to actively lift up and pull the velum from that age on, prior to the actual onset of word productions (see also Chapter 3.2.5). Thus, HI infant HI-2 could babble with the type of babbles in stage 1 but not in stage 2. This lack of the second babbling stage in the HI-2 might also be related to his small number of babbled utterances between 9.5 and 11.5; HI-2 produced only 6 babbled utterances at 10.5 and 11.5 month of age combined and the babbled utterances were totally absent at 11.5 months of age (see Chapter 7.3.3). We suggest that more research be done on this topic.

Chapter 9

Discussion and conclusions

In this chapter we will summarize the findings of Chapters 5, 6, 7 and 8 with respect to both NH and HI infants. First, in section 9.1 our findings will be discussed for the NH infants and compared to the results of previous studies. Next we will search for explanations for the patterns found in the NH infants. We will discuss our findings with respect to the expectations based on the proposed model for vocalization development (see section 3.4.3). The results for the NH infants are used as a basis for a proposal of a new model at the end of section 9.1.

Next, in section 9.2 we will discuss the results of the vocalizations of the HI infants in relation to the same vocalizations stages. Based on these findings we will re-evaluate the proposed model and discuss the implication of our results of the HI infants for this model in section 9.3. Finally we will discuss the practical implications of our findings (section 9.4) and give recommendations for further research (section 9.5).

9.1 Vocalization development in normally hearing infants

In Chapters 5, 6, 7 and 8 we presented our findings with respect to number of utterances, duration, phonation and articulation types, place and manner of articulation, utterance structure and number of syllables of the NH and HI infants per month. In this section we will discuss the NH data, whereas in section 9.2 the HI data will be discussed. From the combined results of these chapters it appears that the six NH infants studied showed patterns in their vocalizations in specific periods. Especially within the first months the six infants produced very similar types of utterances. In a later period more variation was found within the NH group, but several overall patterns could still be found.

In certain months the NH infants produced a new pattern that had not been produced earlier; this can probably be related to the onset of a new stage. As discussed in Chapter 3.1, several studies have described stages in the vocalization development of NH infants within the first year of life. In Chapter 3.1 we compared three different stage models (Stark, 1980; Oller, 1980; Koopmans-van Beinum and Van der Stelt, 1986). It was concluded that clear similarities were found between the three models with respect to most stages, such as cooing and babbling, and that all NH infants seem to undergo the same stages roughly at the same ages. Our findings from the six NH infants studied, between the ages of 2.5 months and 11.5 months, confirm the existence of several development stages in the vocalization development of NH infants. After discussing the findings for each stage as described in our study, we compare our findings to the descriptions of a similar stage in the three stage models of Stark, (1980), Oller (1980) and Koopmans-van Beinum and Van der Stelt (1986). We will discuss our findings with respect to both group results as well as related to patterns in the individual data in order to determine the vocalization stages. Monthly individual data gives an indication of the onset and duration of each stage in the six individual NH infants[1].

Initial stage

Four NH infants (NH-1, NH-3, NH-5 and NH-6) appear to be in the same stage at 2.5 months (two infants produced the next stage already at that age). A relatively small amount of utterances was found, as well as a small amount of utterances with articulation (4.8 articulation movements on average for these four infants, see Appendix A8.1 and A9.1), and a maximum of two different articulation categories were produced (see Table 8.9). The utterances are relatively short (532 ms on average for these four infants at 2.5 months, see Table 6.2 and Appendix A9.1) and almost no utterances with a duration of more than 2000 ms are found (see Table 6.3). The highest numbers of utterances with simple, uninterrupted (NoArtSimPho) phonation and interrupted phonation (NoArtIntPho) are both found in our data in this month (see also Table 7.4).

Stark (1980) and Oller (1980) found one stage between birth and this age (called ‘reflexive’ and ‘phonation stage’ respectively), wheras Koopmans-van Beinum and Van der Stelt (1986) found two separated stages between birth and 2.5 months of age (see Chapter 3.1) From our data set it is not possible to separate out two separate stages, possibly because we have no data available from earlier months. Therefore we call this stage the initial stage.

Cooing stage

The following stage, which we called the ‘cooing stage’, starts between 2.5 (in NH-2 and NH-4) and 3.5 months of age (in NH-1, NH-3 and NH-6). In this stage clearly more utterances were produced overall and more utterances with articulation were found (see Appendix A8.1 and A9.1); the average number of SimArtTotal utterances at 3.5 months was almost double compared to 2.5 months of age (see Table 7.4). The articulation movements are produced almost only at the back (at least 70%) and the percentage front and central is still under 15% (see Appendix A8.2 and Appendix A9.1). Only a small number of different categories are produced (see Table 8.9 and Appendix A9.1), mainly

[1] In Appendix A9.1 an overview is shown of the results of several aspects in the vocalizations of the six individual NH subjects, as shown in Tables 5.5 (number of utterances), 6.2 (utterance duration), 6.4 (F0), 7.7 (VarPho and ComPho), A8.1 (number of articulated utterances), A8.2 (place of articulation), 7.7 (number of babbled utterances) and 8.12 (number of babbled utterances with nasals).

back fricatives and back stops (see also Table 8.4). Utterances with several syllables are also found in this period, although utterances with only one syllable are still most common (see also Chapter 7.3.8).

In this period variegated phonation also starts (see also Table 7.4). Variegated phonation at this age was also found by Giesbrecht (2002), who described that one specific type of phonation, namely vocal fry, occurred more often at four months of age compared to three months of age. This vocal fry was often produced in combination with a long utterance duration. We also observed vocal fry in our data of NH infants at 3.5 months of age, although we did not specify this specific type of variegated phonation in our data analysis (see Chapter 7.2).

Moreover, during the cooing stage, we found long utterance durations in the data resulting in a duration peak at 3.5 months in five NH infants and 4.5 months in NH-1 (see also Chapter 6.3.1). Such a peak seems to be a feature of this stage. We found also, however, some contradiction to this assumption and this will be discussed in detail in section 9.2.2.

The large amount of back articulations was also described by Stark (1980), Oller (1980) and Koopmans-van Beinum and Van der Stelt (1986). We decided to call this stage the 'cooing stage', using the same term as in previous studies (e.g. Stark, 1980; see also Chapter 3.1). The term 'one articulatory movement' (Koopmans-van Beinum and Van der Stelt, 1986) seemed somewhat unclear, since we found especially articulations at the back place of articulation it this stage. At later stages the utterances with one articulation movement were produced mainly at front or centrally.

NH-5 did not seem to show a cooing stage in his data and in NH-3 the cooing and variegated stages seem to start simultaneously at 3.5 months (see also Appendix A9.1). This might be an artefact of our methodology since we analysed recordings at monthly intervals. This interval may have been too long. In the first months the stages of the NH infants seem to be short and follow each other fast. Perhaps the cooing stage (without features of the variegated vocalization stage) was produced in between the recordings of 2.5 and 3.5 months in these two infants.

Variegated vocalization

The next stage shows more variation in types of vocalization and is produced from 3.5 months onwards in NH-2, NH-3, NH-4 and NH-5, from 4.5 months onwards in NH-6 and at 5.5 months in NH-1. Still many back articulations are found, but the percentage falls below 70% in all NH infants before or at 5.5 months of age. In the same period more front or central articulations start to appear (at least 15%, see Appendix A8.2 and Appendix A9.1) and with that the number of different articulation categories increases (see Table 8.9 and Appendix A9.1). We find still a great deal of variegated phonation: the VarPho type of utterance was common in this period (around 20%, see Table 7.4 and

Appendix A7.1). Moreover, a high median F0 (Table 6.4) and the highest F0 range and standard deviation within the utterance were both found at 4.5 and 5.5 months (see Table 6.7), as well as the highest standard deviation between utterances (see Table 6.6). A high percentage of the utterances with variegated phonation were produced without articulation (for instance 16% at 4.5 months in our data set, see Appendix A7.1). A shorter utterance duration (<1000 ms) was also found in this period, especially at 4.5 months for four NH infants and at 5.5 months (in NH-1) compared to previous months (see also Chapter 6.3.1 and Appendix A9.1). A higher number of vocalizations (see Chapter 5.3.1) was found at 4.5 months in four NH infants and in NH-5 and NH-6 at 3.5 months. This might be related to the start of the turn-taking process of infants and their mothers (see Chapter 3.2.2 and section 9.2.2 for a discussion on this topic).

The variation in the vocalizations is also mentioned in the three other models at a similar age. Koopmans-van Beinum and Van der Stelt (1986) emphasize variegation in phonation, while Stark (1980) emphasizes variegation in articulation and Oller describes both. Since a great deal of variation was found in our data with respect to both phonation and articulation movements, we decided to use the term 'variegated vocalization' for this stage.

In our data (see also Appendix A9.1), however, we found two different patterns for the individual NH infants in this stage. In some infants we found more variation with respect to articulation (more articulation categories and a clear decrease in back articulation). For instance, NH-1 and NH-2 started more variation with respect to articulation at 5.5 and 4.5 months respectively. In other infants we found more variation with respect to phonation (for instance, a high median F0 and more VarPho utterances), while their number of articulations within the utterances clearly decreased. Also the total number of utterances decreased in some infants. These types of vocalizations were produced by, for instance, NH-4 at 3.5 and NH-5 and NH-6 at 4.5 months. We used the term 'variegated articulation' (VArt) and 'variegated phonation' (VPho) to indicate these two patterns, both being part of the variegated vocalization stage. We did not find evidence for a certain order of emergence of these two patterns. In some infants only one of these patterns was found in the period studied. NH-1 and NH-3 produced only the VArt pattern and NH-6 produced mainly VPho pattern. On the other hand, in three cases we found a simultaneous production of these patterns (NH-2 at 6.5 months, NH-5 at 7.5 months and NH-6 at 5.5 month). In NH-4 and NH-5 an alternation of the two patterns was found within three months. We therefore concluded that there was no basis for separating these patterns out into two stages. In five NH infants one of these patterns started at 3.5 of 4.5 months and in NH-1 at 5.5 months.

Babbling stages 1 and 2

As argued in Chapter 8.3.6, we found two babbling stages in the NH infants. Babbling stage 1 starts at 5.5 to 7.5 months in all NH infants studied (see also Chapter 7.3.6). Most utterances are produced with front articulations (>50% in all infants at 7.5), but also central stops appear (>15%, see also Table 8.4), while the back articulations clearly decreased (<50%). A higher number of different articulation categories starts in this period with even 8 different articulation categories in some NH infants (see Table 8.9). With respect to phonation a high number of voiceless articulations was found for four NH infants at 7.5 and 8.5 months (see also Appendix A7.1 and Chapter 6.3.5). Also Stark (1980), Oller (1980) and Koopmans-van Beinum and Van der Stelt (1986) describe the onset of a babbling stage at a similar age as found in our data.

In our data set we found a second stage that we called babbling stage 2 starting between 9.5 and 11.5 months, as discussed in Chapter 8.3.6. In this period babbling with nasals (both front and central) starts. In this period most of the utterances are produced with central articulation movements (>50%) as well as the simple phonation type. Almost no voiceless articulations are found in this stage. In our data five infants started the babbling stage 2. NH-3 produced only one babbled utterance with nasals (at 11.5 months).

We do not know exactly what factors influence the onset of this babbling stage 2 (see also 8.4). For instance, anatomical and physiological development probably has an influence on the production of nasals (see Chapter 3.2.5). It might also be the case that spoken language input and auditory speech and language processing have an influence on this babbling stage at the end of the first year. As discussed in Chapter 8.3.6 we concluded that for both place and manner of articulation the NH infants show tendencies toward an adult-like production of consonantal features of Dutch at the end of the first year of life. Especially for place of articulation we found an influence of the auditory language input on the vocalizations of the NH infants in this babbling stage 2 (Chapter 8.3.4). Also we expect an influence from (auditory) internal feedback, in order to be able to coordinate the complicated articulatory movements in this stage. The influence of neurology and cognition is not clear with respect to the onset of this stage.

This babbling with nasals was not -to our knowledge- mentioned in previous literature on vocalization development and we did not predict this stage in our model in Chapter 3.4.3. As discussed in Chapter 8.3.6 and similar to Koopmans-van Beinum and Van der Stelt (1986) we did not find evidence for a stage with non-reduplicated or variegated babbling as described by Stark (1980) and Oller (1980), characterized by the use of different consonants and vowels within a series at the end of the first year. All NH infants, except NH-4, produced one or more babbled utterances with two or more categories before 9.5 months of age, but we did not see a clear increase of this type of babbles towards the end of the first year.

To establish whether a subject produced a certain pattern related to a vocalization stage within a specific month we used several criteria based on our stage descriptions. These criteria are shown in Table 9.1 per stage. There were at least one criteria (babbling stage 1 and 2) and at most five criteria (e.g. initial stage) available to observe patterns related to the stages. To establish a certain pattern the vocalizations had to meet at least four out of five criteria or three out of four criteria or the single criterion for the babbling 1 and babbling 2.

Table 9.1. Criteria for the vocalization stages of the six individual NH infants in order to indicate patterns related to vocalization stages per recording. See text for explanation of the terms used for the stages and for a description of the criteria for each stage.

	Max crit	Nr of utt.	Phonation			Articulation				Babb-ling
Criteria			Mean duration (ms)	Mean F0 (Hz)	Nr of VarPho /ComPho utt.	Nr of articulations	Nr of categories	Place (%) Back	Front /Central	Nr of babbl. utt.
Initial	5	≤80	≤800	≤350	-	≤10	0-2			
Cooing	5	≥80			-	≥10	≤3	≥70	≤15	
Variegated Articulation	4	≥80					≥4	≤50	≥15	
Variegated Phonation	4 (5)[2]	≥80		≥350	(≥10)[2]	≤10	0-1			
Babbling 1	1									≥ 2 babbles
Babbling 2	1									≥ 2 babbles with nasals

[2] Data for this aspect were only available from 7.5 months onwards due to technical reasons.

In Appendix Table A9.1 the individual data for number of utterances, utterance duration, mean F0, number of utterances with variegated and combined phonation, number of utterances with articulation movements, number of consonant-like categories, percentage back, central and front place of articulation, number of babbled utterances and number of babbled utterances with nasals, is shown per month. The pattern most often produced is shown in this table, as well as the number of the criteria met for this pattern. In most cases the patterns met the minimal number of criteria as can be seen in Table A9.1 and in some cases the criteria for two patterns were met.

The most often produced patterns in the individual subjects as shown in Table A9.1 were also presented in Table 9.2 per month. It can be seen that patterns in the vocalizations related to the stages were produced by all NH infants, except the cooing stage in NH-5. NH-1 and NH-6 produced all five described stages. In NH-2 and NH-4 the initial stage was not found. Vocalizations related to cooing were produced at 2.5 months and the initial stage was probably produced before that age in these infants. In NH-3 the cooing stage was not found as we already discussed. NH-3 did not reach babbling stage 2, since he produced only one babble with nasals. Note that once the subjects produced vocalizations related to babbling 1 and 2, they did not produce (nasalized) babbles in all subsequent months.

Table 9.2. Patterns in vocalizations related to the stages of the six individual NH infants. Each cell indicates the most produced pattern related to a stage in that month. I=initial stage, C=cooing stage, VArt= variegated articulation, VPho=variegated phonation, B1= babbling stage 1, B2=babbling stage 2, na = no observations in data. See text for explanation of the terms used for the stages and Appendix A9.1 for the criteria for each stage.

Age (months)	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
2.5	I	C	I	C	I	I
3.5	C	VArt	C/VArt	I/VPho	VArt	C
4.5	C	VArt	VArt	VPho	VPho	VPho
5.5	VArt	VArt	B1	VArt	VArt	VArt/VPho
6.5	B1	VArt/VPho	VArt	VPho	B1	VPho
7.5	VArt	B1	VArt	B1	VArt/VPho	B1
8.5	B1	B1	B1	B1	B1	VPho
9.5	VArt	B2	B1	B2	B2	na
10.5	VArt	VArt	B1	B1	B2	na
11.5	B2	B1	B1	B1	B2	B2

We defined the onset of a stage as the first month in which vocalizations related to a new stage were produced. Similarly to the stage models of Stark, (1980), Oller (1980) and Koopmans-van Beinum and Van der Stelt (1986) we expect that the stages in NH infants are formed hierarchically, that is, once a new pattern is produced, a new stage has been entered. In Figure 9.1 we summarize the emergence and duration of the stages in the six NH infants studied. It can be seen that the vocalization stages are found in the same order in all NH subjects. Moreover, although the onset of the stages are not exactly at the same month for the individual subjects, no large differences are found between the individual subjects in onset of the different stages.

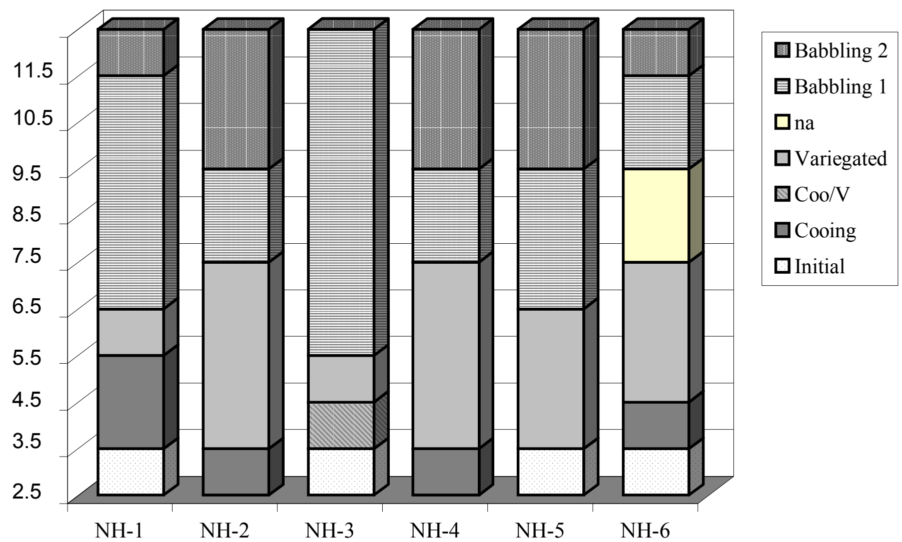


Figure 9.1 Onset of the vocalization stages in the six individual NH infants, based on Table 9.2. Onset was defined as the first month a pattern related to a new stage emerged. Coo/V=combination of the Cooing and Variegated vocalization stage. na=not available.

In Table 9.3 the comparison between the onset and duration stages found in our study and the three stage models of Stark (1980), Oller (1980) and Koopmans-van Beinum and Van der Stelt (1986) is summarized. Although there are also some differences with respect to the exact ages of onsets and description of the content of the stages, several similarities can be found between our results and these three models, confirming the existence of several development stages in the vocalization development of NH infants. Differences can be explained by differences in methodology. Note that the duration of each stage cannot be exact in our study, since we have collected data at monthly intervals. Moreover, we cannot be exact about the onset of the initial stage in our study, since we analysed data in the NH infants from 2.5 months only.

Table 9.3 Overview of the three stage models compared with the stages found in the NH infants in this study.

Stark (1980)	Oller (1980)	Koopmans/v.d. Stelt (1986)	This study
Reflexive 0- 1.5 months	Phonation 0-2 months	Uninterrupted phonation 0-1.5 months	Initial stage ≤ 2.5 months ▪ 2.5 months in 4 NH infants
		Interrupted phonation 1.5 – 2.5 months	
Cooing 1.5 – 3 months	Gooing 2-4 months	One articulatory movement 2.5 – 4.5 months	Cooing ≤ 2.5– 3.5 months ▪ 2.5 months in 2 NH infants ▪ 3.5 months in 3 NH infants ▪ not found in 1 NH infant
Vocal play 4 – 7 months	Expansion 4-6 months	Variegated phonation 4.5 - 6 months	Variegated vocalization 3.5 – 5.5 months ▪ 3.5 months in 4 NH infants ▪ 4.5 months in 1 NH infant ▪ 5.5 months in 1 NH infant in two different patterns[3]: ▪ Variegated Articulation ▪ Variegated Phonation
Reduplicated babbling 7-10 months	Canonical babbling 7-10 months	Babbling 7 – 12 months	Babbling stage 1 5.5 - 7.5 months ▪ 5.5 months in 1 NH infant ▪ 6.5 months in 2 NH infants ▪ 7.5 months in 2 NH infants ▪ unknown in 1 NH infant
Non-reduplicated babbling 10-14 months	Variegated babbling 10-12 months		Babbling stage 2 9.5 –11.5 months ▪ 9.5 months in 3 NH infants ▪ 11.5 months in 2 NH infants ▪ not found in 1 NH infant
First words	First words	First words	Not found in our data

3 We did not find evidence for a specific order of emergence of the VArt and VPho patterns. The patterns were therefore combined in this table to one stage; the variegated vocalization stage (see also p. 178).

In search for explanations for the onset of the vocalization stages, we discussed in Chapter 3.4 the expectation that several developmental aspects, such as anatomy, parent-infant interaction and spoken language input, have an influence on the onset of the vocalization stages. We presented our expectations in a model in Chapter 3.4.3. Our findings for the NH infants in this study require a few small changes compared to the model presented in Figure 3.2. First, the terms used to indicate the stages have changed and second, babbling stage 2 is added.

In Figure 9.2 we show the model adjusted to our findings here. As in Figure 3.2, the bottom layer of the cells of the bottom layer in Figure 9.2 represent the influence of the factors on the vocalization development stages. The cells of the upper layer represent the influence of hearing (loss) on the vocalization stages via these factors. Transparent cells mean that no effect is expected, dark grey represent an assumed effect and light grey is an uncertain effect. Dashed arrows represent an indirect effect of hearing on the factor and a question mark indicates an unclear effect.

Babbling stage 2 was not discussed in Chapter 3, but, as can be seen in Figure 9.2, we expect that several factors influence this stage. Probably anatomical and physiological development influence the production of nasals produced in this stage. On the other hand also auditory speech and language processing, language input and internal feedback might have influence on this stage (this section). Since hearing has an influence on auditory speech and language processing, language input and internal feedback (see Chapter 3.4.1) we expect that this stage is influenced by hearing, especially with respect to segmental aspects.

In section 9.2 we will discuss our results for the HI group in comparison with the NH infants and in section 9.3 we will discuss the implications of these findings for the model.

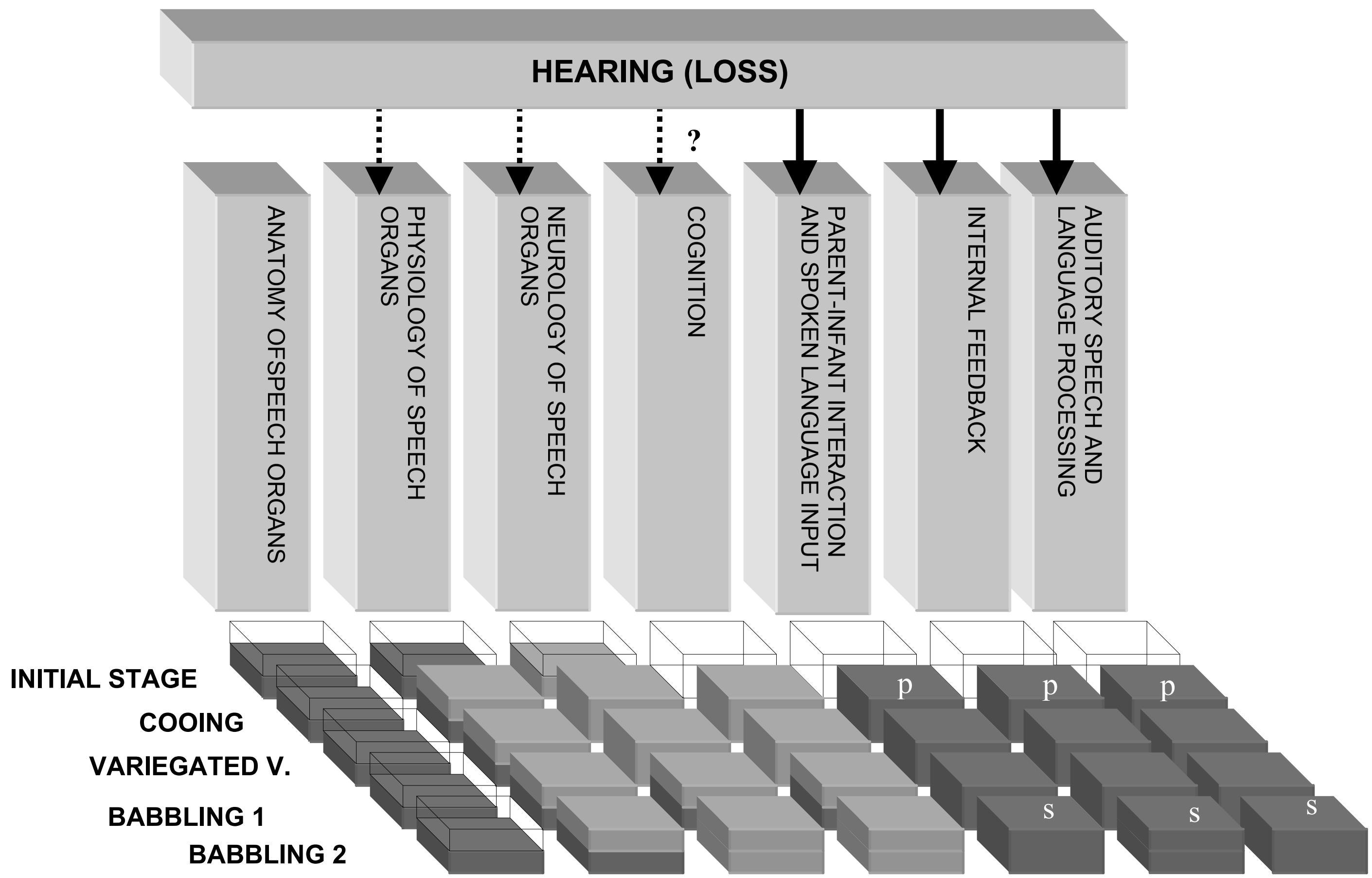


Figure 9.2. Adjusted model (see also Figure 3.3): Model of factors influencing the vocalization stages.
The cells of the bottom layer represent the influence of the factors on the vocalization development stages. The cells of the upper layer represent the influence of the hearing on the vocalization stages via these factors. Transparant=no effect, dark grey is assumed effect, light grey is uncertain effect. Dashed arrow is indirect effect and ?=unclear effect. p=prosody, s=segmental aspects

9.2 Vocalization development in deaf infants

9.2.1 Patterns in vocalization development of deaf infants

In Chapter 3.4 we stated that the influence of hearing on vocalization development can be evaluated by studying the vocalizations of HI infants and comparing them with the vocalizations of NH infants. In Chapters 6, 7, 8 and 9 we studied several parameters and the results of these chapters will be discussed in this section in two different ways. First, the results of both groups will be discussed related to age followed by the results of the individual subjects related to the vocalization stages as defined in section 9.1.

We assume that the anatomical development of both NH and HI infants is similar and not influenced by hearing (see Chapter 3.4.1). We also discussed the assumption that the anatomical development has an influence on the vocalization stages (see Chapter 3.2.2), but that the vocalization development itself has no influence on anatomy (see Chapter 3.4.2). Therefore we expect an influence of anatomy on the vocalization development at the same age in both groups. Differences between the two groups at the same ages cannot be attributed to anatomical development, but reflect the influence of hearing. In case hearing influences the vocalization development stages, we expect that the stages produced by HI infants, might be absent, delayed or produced differently as compared to the six NH infants.

A summary of the group results is presented in Table 9.4 at monthly intervals for most aspects studied. We can see that both differences as well as similarities are found between the two groups at the same ages. In the first months studied mostly similarities are found, while at the end of the first year several aspects of vocalization development are different. The first differences to appear are in number of utterances, number of utterances with one syllable (at 4.5 months) and duration (at 3.5 months). As discussed in Chapter 3.4.1 number of syllables and duration are prosodic aspects that we expected to be influenced by hearing before segmental features.

In order to explain the similarities and differences between the two groups we will first discuss whether the HI infants produced the vocalization stages in a similar way and at the same age as NH infants do. In Appendix A9.2 an overview is shown of the patterns in the vocalizations of the six individual HI subjects and in Table 9.5 a summary is shown of these patterns.

In the initial stage the HI infants produced types of vocalizations that were very similar to those of the NH infants (see section 9.1) and at approximately the same time. This type of utterances was found at 2.5 months in HI-1 and at 2.5 in HI-4. At 3.5 months the initial stage was also found, but combined with VPho pattern (see section 9.1 for the description of this pattern), in HI-1 and HI-5. We found in both groups a small amount of utterances, few articulation movements and few categories in the initial stage. HI-1 and HI-4 (the only two HI infants we could study at this early age) produced the initial

Table 9.4. Overview of the similarities and differences between the NH group and HI group per month and for all months combined (based on the results of Chapters 5, 6, 7 and 8). Dark grey=more often produced by HI infants, light grey=more often produced by the NH infants, ns=no significant difference between the two groups.

Age (months)	Numb. of utt.	Utt. Dura-tion	F0 mean	F0 st.dev.	F0 Range	Nr Voice-less utt.	VarPho NoArt	Nr.utt one Syllabl	C Struct.	Articu-lations	Sim Art	Babbl.	Babb. Nasals	Art Cate-gories	Back	Back fric/tri	Central	Front
2.5		ns	ns	ns	ns	ns												
3.5	ns	NH>HI	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
4.5	HI>NH	ns	ns	ns	ns	ns	ns	HI>NH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
5.5	HI>NH	HI>NH	ns	ns	ns	ns	ns	HI>NH	ns	ns	ns	ns	ns	ns	ns	HI>NH	ns	ns
6.5	HI>NH	ns	ns	ns	ns	ns	ns	HI>NH	ns	ns	ns	ns	ns	ns	HI>NH	HI>NH	ns	NH>HI
7.5	HI>NH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	NH>HI	ns	NH>HI	HI>NH	HI>NH	ns	NH>HI
8.5	HI>NH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	NH>HI	ns	NH>HI	HI>NH	HI>NH	ns	NH>HI
9.5	HI>NH	ns	HI>NH	ns	ns	ns	ns	ns	HI>NH	ns	ns	NH>HI	NH>HI	NH>HI	HI>NH	HI>NH	NH>HI	NH>HI
10.5	HI>NH	ns	HI>NH	ns	ns	ns	HI>NH	ns	HI>NH	NH>HI	ns	NH>HI	NH>HI	NH>HI	HI>NH	HI>NH	NH>HI	NH>HI
11.5		ns	HI>NH	ns	ns	HI>NH												
Mean	HI>NH	ns	HI>NH	HI>NH	HI>NH	HI>NH	HI>NH	na	na	ns	ns	NH>HI	NH>HI	NH>HI	HI>NH	HI>NH	NH>HI	NH>HI

stages at 2.5 months, thus in the same period as most NH infants did. We will tentatively conclude that the onset of the initial stage is the same in both groups. In section 9.3 we will discuss explanations for this finding.

Table 9.5. Patterns in vocalizations related to the stages of the six individual NH infants. Each cell indicates the most produced pattern in that month. I=initial stage, C=cooing stage, VArt= variegated articulation, VPho=variegated phonation, B1= babbling stage 1, na = no available observations in data. See section 9.1 for an explanation of the terms used for the stages and the criteria for each stage.

Age (months)	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
2.5	I	na	na	I	na	na
3.5	I/VPho	na	na	C	I/VPho	na
4.5	C	na	na	C	VPho	na
5.5	VPho	VArt	VPho	C/V[4]	C	VArt
6.5	VPho	C	C	VPho	VArt	VArt
7.5	VPho	B1	VArt	VArt/VPho	C	VArt
8.5	VPho	B1	C/VPho	VArt	C	VPho
9.5	VPho	VPho	C/VPho	VPho	C	VArt
10.5	VPho	B1	C/VPho	VArt/VPho	C	VPho
11.5	VPho	VPho	C/VPho	VArt	VArt	VPho

Patterns related to the cooing stage (C, starting at ≤ 2.5– 3.5 months in the NH infants) can be found in five HI infants (see Appendix A9.2 and Table 9.5) and are produced in a way similar to the NH infants studied. We could not establish the exact onset of the cooing stage in HI-2, HI-3 and HI-6 since no data was available before 5.5 months of age. However, the onset of the cooing stage could be established in HI-1, HI-4 and HI-5, the three HI infants studied at this early age. According to our criteria (see section 9.1) HI-4 produced this stage from 3.5 months onwards, which is a normal age compared to the NH infants. On the other hand, HI-1 started cooing at 4.5 and HI-5 at 5.5 months, which is delayed compared to the NH infants.

Moreover, we found characteristics of the cooing stage in the data of four HI infants at 5.5 months of age or even later, whereas all NH infants had started the variegated vocalization stage or even babbling 1 by that age (see section 9.1). For instance, cooing

[4] In HI-4 characteristics of both the VArt and the VPho patterns were found in combination with cooing at 5.5 months. Therefore the exact V pattern could not be established.

was still found in HI-4 at 5.5 months, HI-5 at 10.5 and HI-3 even until 11.5 months combined with the VPho pattern. Thus, the cooing stage is prolonged in several HI infants studied.

HI-4 started the cooing stage at the same age the NH infants did. However, he did not produce exactly the same type of vocalizations in this stage as the NH infants. As described in Chapter 6.3 HI-4 (similarly to HI-1 and HI-5) did not produce the duration peak at 3.5 months that all NH infants produced at that age. In section 9.2.2 we will discuss whether the duration peak is a characteristic of the cooing stage or should be treated as a specific phenomenon in HI infants independent of a specific stage.

All HI infants produced the variegated vocalization stage (V, VArt, VPho) in the same period as the NH infants (3.5-5.5 months of age). We found patterns related to the variegated vocalization stage from 3.5 months onwards in HI-1 and HI-5 (in combination with the initial stage) and at 5.5 and 4.5 months respectively more clearly (no combination). HI-4 started the variegated vocalization stage at 5.5 months (combined with cooing). This is relatively late, but still within the normal range compared to the NH infants (NH-1 also produced this stage at 5.5 months). In HI-2, HI-3 and HI-6 we cannot establish the exact onset of this stage since the recordings started at 5.5 months and they already appear to be in this stage. This is within the normal range.

However, we found differences between the two groups with respect to the way this stage was produced. Similar to the NH infants we found two different patterns in the variegated vocalization stage. The HI infants produced, however, more often the VPho pattern compared to the NH infants. The HI infants produced 24 times the VPho pattern and 12 times the VArt pattern (see Table 9.5), while the NH infants produced the VArt pattern more often (18 times) than the VPho pattern (10 times) (see Table 9.2). In all HI infants we found the VPho pattern in several months, which was not the case in the NH infants (see section 9.1). Especially HI-1 produced utterances with a small percentage of articulation movements and with variegated phonation (often with vocal fry) and HI-3 produced the VPho pattern during five of the seven months studied (mainly in combination with cooing).

One of the main characteristics of the VPho pattern, the production of variegated phonation, was found more often in the HI infants (at the end of the period studied and for all months combined) compared to the NH infants (see Chapter 7.3.4). The production of this specific type of utterance in HI infants will be discussed in more detail in section 9.2.2.

Strikingly, we found that HI-1, HI-2, HI-3 and HI-5 still produced characteristics of the cooing stage, after the variegated stage had started already. This resulted in an alternation of the cooing and variegated vocalization stage in HI-1, HI-3 and HI-5 (see Table 9.5). In HI-3 and HI-5 characteristics of the cooing stage were still present even until the end of the period studied. Moreover, a combination of the cooing stage and the variegated vocalization stage was found in HI-3 during several months. A combination of these stages is possible, since the cooing stage has more effect on the articulatory domain, whereas the variegated phonation has more effect on the voicing domain of vocalization. This combination of the cooing stage and variegated phonation was scarcely found in any of the NH infants studied (only NH-4 possibly produced this combination at 3.5 months, see section 9.1). The production of cooing after the variegated vocalization stage had been started already, was not found in any of the NH infants studied and it gave an impression of a decline in vocalization development in these HI infants.

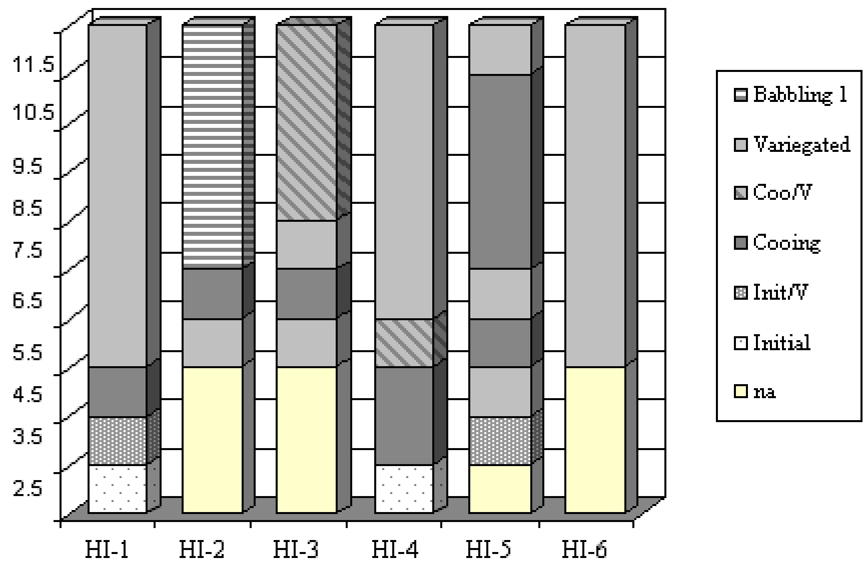


Figure 9.3. Onset of the vocalization stages in the six individual HI infants. Init=Initial, Coo=Cooing, V=Variegated stage.

In HI-2, HI-3 and HI-6 we could not establish the exact onset of the cooing stage and the variegated vocalization stage since we could not collect data before 5.5 months. In HI-6 only the variegated stage was found in the period studied. However, the onset of the cooing stage and the variegated vocalization stage could be established in HI-1, HI-4 and HI-5. Strikingly, HI-1 and HI-5 produced characteristics of the variegated vocalization stage (partly in combination with the initial stage) before the cooing stage. Therefore it seems that HI infants do not produce these two stages necessarily in the same order as NH infants do. Only HI-4 produced the initial, cooing and variegated stage in the same order as the NH infants do. The order of the cooing stage and variegated vocalization stage can also be seen in Figure 9.3, that gives an overview of the stage onsets in the six HI infants. The order of these stages will be also discussed in more detail in section 9.3.

Moreover, in several HI infants (HI-1, HI-3, HI-4 and HI-5) a high amount of voiceless utterances was found during their (combined cooing and) variegated vocalization stage (see Chapters 6.3.5 and 7.3.5). We found also voiceless utterances in HI-2 at 7.5 months of age during his babbling stage. The high amount of voiceless utterances in the HI infants will be discussed in detail in section 9.2.2.

Only subject HI-2 started babbling stage 1 (at 7.5 months, see also Figure 9.3), thus at the normal age compared to the NH infants (5.5-8.5 months). None of the other HI infants started the babbling stage and thus by implication their variegated vocalization stage was extended. The babbles of HI-2 turned out to be quite similar to those of the NH infants (see also Chapter 8.3.6). He also produced a high number of different articulation categories (see Chapter 8.3.5), produced front articulations as main place of articulation at 5.5 months of age and produced central stops (>15%) from 7.5 months onwards, which seems to be similar compared to the NH infants in the same period. HI-2 did not produce babbles in all recordings in the months after the babbling stage had started. This was not seen as abnormal behaviour since this also occurred in two NH infants. Although HI-2 produced babbling stage 1 at the same age as the HI infant he did not progress, however, to the babbling stage 2 within the first year of life, while five of the six NH infants did between 9.5 and 11.5 months (see also Figure 9.3). The findings for this specific subject, HI-2, will be discussed in more detail in section 9.2.3.

In Table 9.6 the stage onsets of the HI group and NH group are summarized and compared. In case a stage onset is similar between both groups we also compared the quality of the type of vocalizations in that stage.

Table 9.6. Summary: onset of the vocalization stages compared between the NH infants and HI infants.

Stage	Onset stage NH infants	Onset stage HI infants	Similar in quality?
Initial stages	≤ 2.5 months	HI-1 and HI-4 at normal age	Yes
Cooing	≤ 2.5 – 3.5 months	HI-4 at normal age HI-1 and HI-5 delayed	No: shorter duration at 3.5 months
Variegated vocalization	3.5 – 5.5 months	All HI infants at normal age	No: more VPho pattern
Babbling stage 1	5.5 - ≥ 7.5 months	HI-2 at normal age Absent in other HI infants	Yes
Babbling stage 2	9.5 - ≥ 11.5 months	Absent in all HI infants	

It can be concluded that

with respect to the stage onsets:

1. HI infants undergo similar stages in their vocalization development as NH infants do.
2. The initial stages are produced similarly in both groups.
3. The onset of the cooing stage can be at a normal age in HI infants (one infant) but can also be delayed (two infants) compared to NH infants.
4. The onset of the variegated vocalization stage of the HI infants is at a normal age (six infants) compared to HI infants.
5. The onset of the babbling stage 1 can be at a normal age in HI infants (one infant), but is more likely to be delayed or absent (five infants) compared to NH infants.
6. It is unclear if HI infants reach babbling stage 2. One HI infant went through the variegated and babbling stage at the same age as NH infants did, although the babbling stage 2 was not found in his data.
7. Characteristics of the cooing stage can be seen after the variegated vocalization stage started already (four HI infants) and a combination or alternation of the cooing and variegated vocalization stage can exist (three HI infants).
8. Characteristics of the variegated vocalization stage (VPho) can be found before the cooing stage (two infants), but the stages can also be produced in the same order as NH infants do (one infant)

with respect to the quality of the stages:

1. HI-4 did not produce the duration peak during the cooing stage (that he produced at normal age).
2. The pattern VPho is produced more often than the VArt pattern in HI infants, while NH infants produce the VArt pattern more often than the VPho pattern.

The implication of these results for the model will be discussed in section 9.3.

From the discussion above it is clear that the HI infants, with the exception of HI-2, were delayed in the onset of several stages. On the other hand, we also found differences between NH and HI infants that do not seem to be totally imbedded in the vocalization stages, namely:

- a higher number of utterances by the HI infants
- differences in utterance duration by the HI infants
- more voiceless utterances by the HI infants

Moreover, we found a higher number of the VPho pattern within the variegated vocalization stage produced by the HI infants compared to the NH infants. These four phenomena will be discussed specifically in section 9.2.2.

9.2.2 Specific phenomena in vocalizations of deaf infants

Utterance duration at 3.5 months

The main characteristics of the cooing stage (for instance, a high number of utterances with articulation and articulation at the back) were present in both groups. Also a relatively long utterance duration was found in both groups, although it was no criterion for the cooing stage. At a later age we found a long utterance duration during their cooing stage in several of the HI infants, but not in all (for instance HI-1 and HI-4 at 4.5 months and HI-5 at 5.5 months of age). On the other hand, NH-1, who clearly was still in the cooing stage at 4.5 months, produced an average utterance duration of 1217 ms at the same age (see Appendix A9.1). These findings lead us to explore whether there is a relationship between the cooing stage and a long utterance duration.

At 3.5 months the utterance duration was very long (1441 ms on average, see Table 6.1) in the NH infants. As was discussed in Chapter 3.2.5, utterance duration can be controlled better from three months onwards in NH infants. Developmental changes in anatomy, such as restructuring of the rib cage and descending of the larynx, lead to the possibility of increased control of the air flow. From that age onwards the lungs are able to create a higher or lower sub-glottal air pressure resulting in longer or shorter utterance durations (see Chapter 3.2.4). Interestingly, NH-4 started to produce all characteristics of the cooing stage already at 2.5 months, but with a short utterance duration (see Appendix A9.2). No utterances with a duration longer than 2000 ms were found in his data at 2.5 months, but 18 such utterances at 3.5 months (see Table 6.3). Although NH-4 at 2.5 months is in this stage with respect to the number of utterances and articulatory characteristics, it is plausible that he does not yet have the motor ability to produce long utterances. Anatomical development is thus assumed to be crucial in the production of long utterance duration.

On the other hand, both groups of infants most probably undergo this anatomical development at the same age, but they differ with respect to utterance duration at 3.5 months of age. The average utterance duration was significantly shorter in the three HI infants studied at this early age compared to the NH infants (see Table 6.2). Only very few utterances with a duration over 2000 ms were found in the HI infants at this age (see Table 6.3). We therefore concluded in Chapter 6.4 that the utterance peak at 3.5 months in the NH infants cannot be explained by motor aspects alone, but also by hearing. HI-1 and HI-4 produced a short utterance duration (868 ms and 772 ms) while still being in the initial stage at 3.5 months (see Appendix A9.2). The absence of the long utterances (see Table 6.3) therefore seems to be related to a delayed onset of the cooing stage in these two infants. On the other hand, a short average utterance duration (885 ms) and only one utterance with a duration longer than 2000 ms were also found in HI-4, whereas he clearly produced all other characteristics of the cooing stage in his vocalizations at this month (similar to NH-4 at 2.5 months) (see Appendix A9.2). Thus, interestingly, in HI-4 hearing affects the utterance duration at 3.5 months, while other factors seem to be responsible for the onset of the cooing stage at a normal age with respect to number of utterances and articulatory aspects.

Aspects influenced directly by hearing are internal auditory feedback, auditory speech and language processing and turn-taking during parent-infant interaction (see Chapter 3.4.1). It was described in section 3.2.2 that a normal development in auditory speech and language processing explains results from previous studies that NH infants are sensitive to the perception of the prosodic features (such as utterance duration and F0) of their own language already within the first months of life. Moreover, it has been found that the perception of prosodic features influences the production of prosodic features of NH infants from a few months of age onwards (see section 3.2.2), implying a development of voicing control at that age.

We expect that a well developed and functioning internal auditory feedback system is required to coordinate the production of certain types of vocalizations and to produce them intentionally (Koopmans-van Beinum, et al., 2001). Coordination of different aspects into simultaneous vocalization behaviour is a complex skill (see Chapter 7.4) and in order to produce the typical articulated vocalizations during the cooing stage in combination with the long utterance duration, a well developed coordination system seems required. Lack of internal feedback might therefore affect the prosodic features of vocalizations in HI infants, such as utterance duration (see section 3.3.2), while the articulations are not affected in the cooing stage of HI-4.

We can conclude that, although a long utterance duration seems to co-occur with specific types of vocalizations during the cooing stage, the production of the duration peak is not totally related to the onset of this stage. For the production of long utterances, as found in NH infants at 3.5 months, both anatomical development corresponding to that age as well as hearing are involved.

Variegated and voiceless phonation

Not only utterance duration seems to be affected in the HI infants. Lack of voicing coordination and lack of coordination of the simultaneous production of articulation and phonation also seems to affect the types of utterances produced: resulting in more utterances with articulation without phonation (voiceless utterances) and more utterances with phonation without articulation, as discussed in Chapter 7.4.

The voiceless utterances with articulation (SimArtNoPho) were produced significantly more often by the HI infants than by the NH infants (see also 7.3.5). In the NH group voiceless utterances are mainly produced at 7.5 and 8.5 month of age, thus during the babbling stage 1 (see also 6.3.5 and Table 7.4). Also the HI infant who started babbling, HI-2, produced voiceless utterances in the same month. On the other hand, the other HI infants also produced voiceless utterances at 7.5 months of age or at a somewhat later age (see Table 7.8). These utterances were obviously not produced during a babbling stage, but mainly during the (combination of the cooing stage and) variegated vocalization stage (for instance, HI-3 at 10.5 months of age, see Table 7.8 and Appendix A9.2). In the study of Meier et al. (1997) it was also found that a special type of voiceless utterances, jaw wags (repeated articulation movements without phonation), were produced more often by HI infants compared to NH infants (see also Chapter 7.4). Voiceless utterances might indicate an insufficient coordination of articulation and phonation as discussed in Chapter 7.4.

As described in section 9.2.1 we found a similar age of onset of the variegated vocalization stage for both groups. One the other hand, we also found a higher production of the VPho pattern during the variegated vocalization stage of the HI infants. Typically produced in this pattern is a high amount of utterances with variegated phonation (see section 9.1). Utterances with phonation but without articulation, NoArtVarPho and NoArtComPho utterances, with a variegated phonation such as vocal fry and glottal sequences were produced more often by the HI infants than by the NH infants at the end of the period studied (and also for all months combined in the case of NoArtVarPho, see Chapter 7.3.2). Moreover, we found more variation with respect to voicing in the HI infants compared to the NH infants with respect to F0 (range and standard deviation within the utterance, see Chapter 6.3.3). The majority of the NoArtVarPho and NoArtComPho utterances were produced by four HI infants, HI-1, HI-2, HI-3 and HI-4. As described in Chapter 7.3.5 the way the NoArtVarPho and NoArtComPho utterances were produced, however, differed per subject. HI-2 produced in the last three months many very high pitched, short utterances, although he started the babbling stage before producing these high pitched utterances. HI-1 produced mainly long utterances with vocal fry, often with glottal stops producing some kind of syllabification. HI-3 produced utterances typically with a fast alternation of rising and falling intonation often with glottal stops producing very short syllables and HI-4 made often the NoArtComPhon utterances with a 'coughing-like sound'. Also Oller (2000, pp. 139-141) described a very high number of sequences with glottal stops without articulation in the vocalizations of an HI infant at the end of the first year.

As discussed in section 9.2.1 we found that the VPho pattern also was produced in combination with the back fricatives/thrills, typically produced during the cooing stage. A combination of these stages is possible, since the cooing stage has more effect on the articulatory domain, whereas the variegated phonation has more effect on the phonation domain (see 9.2.1). We might assume that these three types of utterances, NoArtVarPho, NoArtComPho and back fricatives/trills, are all related to the use of considerable tension in the muscles of the back part of the vocal tract, which could be heard in five of the six HI infants studied. A constriction can be created at the level of the velum, uvula or pharynx (a high percentage of back fricatives and trills, see Table A8.2), possibly but not necessarily combined with voicing. It can also be created somewhat lower at the glottis or false vocal cords (resulting in NoArtVarPho and NoArtComPho utterances). In some HI infants (e.g. HI-4 at 5.5 months) it was even hard to identify whether the constriction was made supralaryngeally, resulting in an articulated utterance with back fricatives/trills, or glottally resulting in non-articulated variegated or combined phonation (as discussed in Chapter 7.2.2). One explanation for the high amount of these types of utterances, is that HI infants compensate their lack of auditory input by tactile or kinesthetic stimulation (Oller, 2002), as also discussed in Chapter 7.3.5 and 8.4.

A second explanation for the high amount of NoArtVarPho and NoArtComPho related to the residual hearing in some HI infants will be discussed in section 9.2.3.

Turn-taking, utterance duration and number of utterances

As discussed above, good coordination is necessary, for instance, in order to control voicing making it possible to lengthen (from 3.5 months of age onwards) or shorten the utterance duration more or less intentionally (see also Chapters 3.2.4, 3.2.5 and 6.4). Such intentional control of duration is important, also in the development of turn-taking between infants and parents.

The age that NH infants start turn-taking is around 3.5-4.5 months according to previous studies (see Chapter 3.2.1). Pauses allow the conversation partner to speak, thus creating an alternation of speaking and listening turns with their mothers (see also Chapter 6.4). Especially shortening of the utterances might be a skill needed to create pauses in their vocalizations. Besides the shorter utterance duration, also the number of utterances might be affected by the onset of turn-taking in the NH infants. Because of the alternation between infant and mother utterances during turn-taking, we might also expect an increase of the number of utterances in both infants and mothers.

Although we did not study the start of the turn-taking process specifically, some of our data seem to confirm that the NH infants started turn-taking around the age mentioned in previous studies. At 4.5 months three infants (NH-2, NH-3, NH-4) produced a shorter utterance duration (Table 6.2), and their number of utterances clearly increased (see Table 5.3), together with the number of utterances produced by their mothers (see Table 5.4) compared to 3.5 months[5]. At 5.5 months the number of utterances decreased again for both NH infants and their mothers (see also Chapter 5.3.1).

We do not see such behaviour in the HI infants and their mothers. Shorter utterance duration or an increase in number of utterances are not found in the data of the HI infants at 4.5 months of age. Also in later months -in contrast to the NH subjects- we did not find a combination of a decrease of utterance duration, increase of infant utterances and increase of mother utterances. These results indicate that lack of hearing delays the onset of the turn-taking process overall, since a HI child is not able to hear the pauses in his parents' speech that indicate his turn to vocalize (see section 3.4.1). The control of utterance duration necessary for turn-taking might however also be affected by the lack of hearing.

In the HI infants we found an increase in utterance duration from 4.5 months onwards (significantly longer than NH infants at 5.5 month of age, see Chapter 6.3.1 and Figure 6.3). We also found an increase in the number of utterances starting at 3.5 months, resulting in a significantly higher number of utterances compared to the NH infants from 5.5 months of age onwards (see Chapter 5.3.1). Combining these results, it is obvious that the HI infants produced a higher total number of vocalizations compared to the NH infants.

The total number of utterances (for infants and their mothers combined) was found to be similar in both groups (see Table 5.2). Around 250 utterances were produced in total in ten minutes for both groups and for all months studied. Combining this finding with a large total amount of vocalization production found in the HI infants it becomes more clear why the mothers of the HI infants produced significantly fewer utterances compared to mothers of NH infants from 6.5 months onwards (see also Chapter 5.4 and Figure 5.5). If the mothers aim at a normal turn-taking process with their infants, they will prevent too much overlap with the utterances of their infants, thus leading to fewer utterances on their part. It also might be the case that mothers of HI infants do not talk to their infants, unless they have eye contact with their child. This might also reduce the amount of spoken language directed to the child (see also Chapter 5.4). We suggest that more research should be done on this topic, including a study of the nonverbal turn-taking behaviour of HI infants and their mothers.

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[5] If the NH infants at 4.5 months of age produce shorter utterances to create enough pauses for the turns of their mothers, we expect that also the mothers' utterances are shorter for the same reason. Unfortunately no duration measurements were performed on the mother utterances in our study.

Thus, we can conclude that some special phenomena are found in HI infants, such as a shorter duration at 3.5 months, more utterances overall and more voiceless articulation. We also found a very high amount of variegated phonation related to the variegated vocalization stage and often combined with cooing. These types of vocalizations can be explained by several effects of hearing loss, such as delayed turn-taking, lack of voicing control, more tactile and kinesthetic stimulation or the influence of residual hearing.

9.2.3 Individual variation

As mentioned in the previous sections of this chapter, the HI infant group showed some similarities in their behaviour but also showed a great deal of individual variation. HI-2 was a clear exception: his vocalization development was strikingly similar to that of the NH infants. Not only did the variegated vocalization and babbling stage 1 start at the same age as the NH infants, but also several other aspects of his vocalization development were similar. For instance, in his babbling stage 1 similar articulation categories were produced compared to the NH infants (Table 8.11). His number of different articulation categories increased in the second half year of life and he also produced some voiceless utterances at 7.5 months, like the NH infants. These were all aspects related to the babbling stage 1 in the NH infants (see also section 9.1). No other HI infant was so like the NH infants.

On the other hand, some other aspects of HI-2's vocalizations were different compared to the NH infants. In these specific aspects HI-2 seemed to behave more similar to the other HI infants. His number of utterances was, averaged over 5.5 months[6] until 11.5 months, significantly higher than in most of the NH infants, except NH-1 by means of Wilcoxon Signed Ranks test ($p \leq .05$, see also Table 5.3). Moreover, HI-2 produced on average over the whole period an utterance duration longer than any NH infant (see also Table 6.2), although not significantly different by means of a Wilcoxon Signed Ranks test. He also produced a high number of NoArtVarPho utterances in terms of a very high F0 in the last months studied (see also Table 6.5, significantly different from NH-2 and NH-6 by means of a Wilcoxon Signed Ranks test). We also found some differences with respect to articulation. Although he produced a relatively high percentage of front articulations at 5.5 months, he did not produce front articulations as the main place of articulation whereas all NH infants did during one or more months (see also Appendix A8.1).

The aspects in which HI-2 behaved more similarly to the other HI infants than to the NH infants were mainly those aspects that we could not relate clearly to the vocalization stages, such as utterance duration and number of utterances, confirming our assumption that these specific aspects were not related to the vocalization stages and have their own developmental path (section 9.2.2).

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[6] From 5.5 month of age onwards the vocalizations of HI-2 were analysed.

It might be assumed that residual hearing had some influence on the vocalizations of HI-2. The similarities compared to NH infants, for instance age of onset of babbling stage 1, might be related to his residual hearing as discussed already in Chapter 7. He had slightly more residual hearing than the other HI infants (according to the audiometric measurements, see also Table 4.3). His hearing loss was 93 dB PTA unaided and 55 dB PTA when using hearing aids. Possibly HI-2 could use the residual hearing, with help of hearing aids, sufficiently to be able to enter the babbling stage 1 and to produce vocalization types related to that stage. Also the form of the audiogram could have had an influence. HI-2 had a steep audiogram with a high tone loss (see also Appendix Figure A4.1). It might be that he could hear lower frequencies well enough to have auditory access to some of the prosodic features of his environmental language, such as syllable duration. Also, it should be mentioned that his social environment was observed to be almost ideal; his mother was an educated pre-school teacher and clearly stimulated HI-2's communication skills as much as possible (Chapter 4.1).

In the other HI infants, however, we did not find a clear relationship between the amount of residual hearing (see Table 4.3) and the age of onset of the vocalization stages, number of utterances, voiceless utterances or utterance duration. We divided the HI infants into two groups of infants depending on their residual hearing, in order to explore any influence from residual hearing. The infants HI-1, HI-2, and HI-3 have a hearing loss (tested with hearing aids) less than 65 dB PTA in the best ear (see also Table 4.3). Infants HI-4, HI-5, and HI-6 have a hearing loss of more than 100 dB PTA with or without hearing aids. HI-1, HI-2, HI-3 and HI-6 used hearing aids, while this was not the case in HI-4 and HI-5 (not regularly) (see Table 4.3). Although the group sizes are very small here, the results give an indication of possible effects.

As discussed in section 9.2.1 in several HI infants we found a delayed onset of the cooing stage. We did not find evidence for a greater delay in HI-1 and HI-3 (with more residual hearing) compared to the three infants with less residual hearing as described in section 9.2.1 (Figure 9.2). For instance, HI-4 (the infant with the smallest amount of residual hearing) started his cooing stage at a normal age, whereas this stage was delayed in HI-1 (more residual hearing). Also with respect to the onset of the variegated vocalization stage we found no clear influence of residual hearing. The subgroups with more residual hearing or less residual hearing both started this stage at 5.5 months or earlier. Also no relationship between residual hearing on the amount of voiceless utterances was found. The two infants with a large amount of SimArtNoPho utterances (HI-3 and HI-5) differed with respect to residual hearing.

Also no clear influence was found of residual hearing on the number of utterances. HI-1, HI-2 and HI-3 produced on average 145.3 utterances (sd 58.0) and HI-4, HI-5 and HI-6 on average 125 utterances (sd 60.2) if the data are combined between 5.5 and 11.5 months (as shown in Table 5.4). This is not a significant difference according to a

Wilcoxon Signed Rank test. Therefore we conclude that within the HI group the residual hearing does not seem to be a strong factor in explaining differences in the number of utterances. Residual hearing also had no clear effect on utterance duration (see also Table 6.2). The three infants with some residual hearing (HI-1, HI-2 and HI-3) had on average a longer utterance duration (1134 ms, sd 322), compared to HI-4, HI-5 and HI-6 (781, sd 172) combining the data between 5.5 and 11.5 months. This difference was not significant by means of a Wilcoxon Signed Ranks test[7].

Residual hearing seems to affect the number of NoArtVarPho and NoArtComPho within the HI group. The three infants with some residual hearing (HI-1, HI-2 and HI-3) produced these utterances significantly ($p<.005$) more often (19.0, sd 8.5) than HI-4, HI-5 and HI-6 (8.3, sd 7.4) by means of a Wilcoxon Signed Ranks test (combining the data between 7.5 and 11.5 months, see also Table 7.8).

The higher number of such utterances in the three infants with more residual hearing might be the result of some auditory feedback (possibly influenced by the wearing of hearing aids at an early age). This may in turn lead to the production of special types of VarPho utterances, such as vocalizations with screaming or a high pitch, that fall within the hearing range. For instance, HI-2 often produced high pitched NoArtVarPho utterances (see Chapter 6.3.5 and section 9.2.2), which he could possibly just hear. Unfortunately we did not classify the NoArtVarPho utterances into further subcategories. More research into NoArtVarPho utterances in terms of subcategories is therefore recommended.

Finally, our data do not suggest that the language method used by the parents (Oral Method, sign supported speech, Sign Language of the Netherlands or bilingual input, see Chapter 2.4) had any influence on vocalization development. For instance, when comparing the number of utterances of the HI subjects using the three different language methods, we find no clear differences in either mothers or infants in this age period. It should be remembered that all HI infants, except HI-2, have an older deaf brother or sister. Thus, the mothers were already used to communicate with the language method chosen. Although one might expect fewer spoken utterances of signing mothers compared to ‘oral’ and ‘total communication’ mothers, this was only found for mother HI-4, when considering all recordings. However, when averaging over the recordings from 5.5 months she produced *more* speech utterances than mother HI-1 and HI-2 (see Table 5.3). The other mother using Sign Language of the Netherlands, HI-5, actually produced the highest number of speech utterances of all mothers in the HI group. There seems to be no relationship between the number of infant utterances and language method in this early age period. One of the two infants raised with Sign Language of the Netherlands, HI-4, produced the smallest number of spoken utterances, but the other, HI-5, produced more utterances than three other HI infants (see Table 5.4). No other aspects

[7] Unfortunately no statistical analysis could be performed on the duration data of each collection of the 50 utterances for technical reasons.

studied seemed to be influenced by the language method either. On the other hand, we should remember that the number of subjects within the subgroups is small.

Thus we can only conclude that the differences found within the HI group are not easy to explain. Language method used seems to have no influence. Residual hearing seems to have some influence, even within a group of HI infants with losses more than 90 dB PTA (unaided). The onset of the cooing stage and the variegated vocalization stage, number of utterances, number of voiceless utterances and utterance duration could not, however, be explained by differences in residual hearing, but the larger number of NoArtVarPho utterances seemed to be related. Moreover, the vocalization development of the infant with most residual hearing (HI-2) was most similar to the vocalization development of NH infants, more than any other HI infant studied. We suggest that in the future this topic is studied with larger subject-groups.

9.3 Influence of hearing on vocalization development and implications for the model

As described in Chapter 3.2 we argued that developmental aspects, such as interaction and language input, auditory speech processing, internal feedback, physiology, neurology and maybe cognition and anatomy, affect the onset of the vocalization stages. We expected these factors to affect various stages.

Second, we argued that hearing influences all these aspects, directly or indirectly, with the exception of anatomy (see Chapter 3.4.1). Combining this information we predicted that hearing loss has a minor effect on the initial stage. Hearing loss has more effect on the cooing stage, the variegated vocalization stage and the babbling stages (see section 9.1 for definition of terms). We therefore predicted a delay in these stages or different types of vocalizations under the influence of hearing (see Chapter 3.4.3). Our predictions were summarized and visualized in a proposed model in Figure 3.2. After discussing our results of the six NH infants we proposed a somewhat adjusted model (Figure 9.2) with respect to the terms used for the vocalization stages.

To evaluate the model we analysed the vocalization development of HI infants. It can be concluded from section 9.2 that hearing affects vocalization development. The effects of hearing loss can be summarized as follows:

<u>delay or absence of vocalization stages up to the age of 12 months</u> (see section 9.2.1)

- delay in onset of the cooing stage (in two out of three HI infants)
- normal onset of the variegated vocalization stage (in all six HI infants)
- absence of babbling 1 (in five out of six HI infants)
- absence of babbling 2 (in all six HI infants)

<u>specific phenomena</u> (see section 9.2.2)

- no long utterance duration at 3.5 months
- more utterances overall
- more variation in phonation (more variegated phonation types with or without interruption of the phonation, more F0 variation)
- combination of cooing and variegated phonation
- more voiceless utterances

<u>influence of residual hearing in HI-2</u> (see section 9.2.3)

- no delay in variegated vocalization stage and babbling 1
- production of specific phenomena

<u>possible influence of residual hearing in HI-1, HI-2 and HI-3 (see section 9.2.3)</u>

- more variegated phonation

We shall return to the proposed model to evaluate the implications of these findings for the model. First of all, we will discuss the effect of hearing loss on some of the developmental aspects although this was not the major topic of this study. In Chapter 3.4.3 we discussed the possibility of a direct influence from hearing (loss) on some aspects and an indirect influence on other aspects (the effect of abnormal types of vocalizations or absence of types of vocalizations).

First of all, the influence of hearing loss of infants on parent-infant interaction and spoken language input of their mothers was not totally clear from previous studies (see also Chapter 3.2.1). Although we did not study the language input of mothers of HI infants fully, we found in our data evidence for an effect of the hearing loss in infants on the number of utterances of their mothers. We found differences with respect to the number of utterances between the mothers of the NH infants and the mothers of the HI infants (see Chapter 5.3.1). The mothers of the NH infants produced on average more utterances than the mothers of the HI infants (significant from 5.5-7.5 months onwards). The mothers of the NH infants produced even twice as many utterances as their children, which was not the case for the mothers of the HI infants. We interpret this as being due to the fact that the HI infants cannot hear their mothers and are not aware of the other taking a turn; the mothers then adapt to their infants[8]. This result shows that direct or indirect influence from hearing of the infants on the spoken language input from their mothers is clear with respect to the number of maternal utterances. Therefore it seems

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[8] Explanations for the effect of hearing loss of the infants on the maternal utterances were discussed in Chapter 5.4 and section 9.2.2.

likely that our model is correct with respect to the influence of hearing of infants on the parent-infant interaction and language input from their mothers.

With respect to cognition and to physiology and neurology of the speech organs we did not expect direct influence from hearing (see Chapter 3.4.1). An indirect effect, however, could not be excluded (see Chapter 3.4.2). In our data we found no evidence for a delayed (non-verbal) cognitive development in the HI infants. The six infants studied showed no major delay in their cognitive development according to the Bayley Developmental Scales (Bayley, 1969, 1993; see Chapter 4.1). Moreover, no deviant motor development of the mouth (expected to be influenced by physiology and neurology of the speech organs) was found in any of the six HI infants studied (see Chapter 4.1). However, it should be kept in mind that normal cognitive development and mouth motor development were subject selection criteria in our methodology (see Chapter 4.1). Therefore we cannot totally exclude these factors as possibly being indirectly affected by hearing loss.

The model predicts that the vocalization stages are influenced by hearing from the cooing stage onwards (see Chapter 3.4.3). Our data partly confirm this expectation.

The model predicts that the cooing stage is influenced by the hearing (see Chapter 3.4.3) and therefore we expected that the onset of this stage would be delayed or that the stage would be slightly different in HI infants. Hearing is assumed to affect especially the prosodic features of vocalizations during this stage.

We concluded in section 9.2.1 that in our data one HI infant produced the onset of the cooing stage at the normal age (3.5 months of age), and two infants were delayed. In the infant who produced the cooing stage at normal age compared to the NH infants (HI-4) we found a clear difference with respect to prosody. He did not produce a duration peak as found in all NH infants at 3.5 months (discussed in section 9.2.2). Therefore we conclude that the model is correct with respect to both onset as well as the type of utterances produced during this stage.

The initial stage is not expected to be influenced by hearing. In our data we find clear similarities between NH and HI infants with respect to the initial stage, probably mainly influenced by a similar anatomical, physiological and neural development. Therefore the model seems to be correct for this stage, at least on the basis of the data from the two HI infants we could study at this early age.

Our model predicts that the onset of babbling stage 1 is delayed in HI infants. For the babbling stage 1 all factors are important: auditory language processing, internal feedback, physiology, neurology, cognition and anatomy (see Chapter 3.2). We expect that hearing loss affects most of these factors directly and indirectly. For the onset of babbling anatomy might be important, but anatomy is not expected to be influenced by hearing loss. If anatomy is the main influence on babbling onset, babbling should start in HI infants at a normal age. If other factors (influenced by hearing loss) are more important, babbling onset would not be expected in the HI infants at the normal age.

Our data show that only one subject, HI-2, started the babbling stage 1 at the normal age compared to the NH infants (see also Table 9.4 and 9.5). None of the other HI infants started babbling within the first year of life. Since five infants did not babble, it is likely that hearing, via several factors, influences the onset of the babbling stage. Normal anatomy, cognition, neurology and physiology probably also influence the babbling onset stage (see also Chapter 3.2.4, 3.2.5 and 3.2.6), but beside these factors certainly (enough residual) hearing is important (influencing auditory speech processing, internal feedback or parent-infant interaction). Therefore it can be concluded that the onset of the babbling stage is preconditioned by both hearing as well as normal development of several other aspects and that the model is correct with respect to the onset of the babbling stage. As discussed in section 9.2.3, we assess the residual hearing and form of the audiogram of HI-2 as sufficient to enter this babbling stage, although we do not have proof. We therefore suggest that more research should be done to investigate the onset of babbling in HI infants with or without residual hearing.

At the end of the first year we found a second babbling stage in the NH infants, as discussed in section 9.1. We expected that hearing has an influence on this stage (section 9.1). Neither HI-2 nor any other HI infant studied entered this stage within the first year of life (see also Table 9.4 and 9.5). We therefore conclude that hearing has an influence on the onset of this stage. Moreover, we expect that this stage can only begin once babbling 1 has started. We suggest that more research should be done to investigate this specific babbling type in both NH and HI infants.

Thus, we conclude that the model presented in Figure 9.2 is partly correct with respect to the influence of hearing on the vocalization stages of infants within the first year of life. The cooing stage, babbling 1 and babbling 2 are most probably affected by hearing and the initial stage is not influenced by hearing as expected.

According to the model we also expected an influence of hearing on the variegated vocalization stage (see also Chapter 3.4.3); we expected that the onset of this stage is delayed in HI infants. Our data did not confirm this expectation (see section 9.2.1). We could establish that the six HI infants started this stage at the normal time compared to the NH infants (3.5 – 5.5 months). There was also no relationship between residual hearing and onset of this stage and so hearing does not seem to play a crucial part here (see section 9.2.3). Therefore we conclude that the model is not correct with respect to the onset of the variegated vocalization stage and that hearing has a minor influence on the onset of this stage. This finding suggests that in HI infants the cooing stage and variegated stage might develop independently from each other and that (partly) different factors influence the onset of these two stages.

This can be confirmed by several findings:

- HI-1 and HI-5 produced characteristics of the variegated stage (VPho), at 3.5 months, and at 3.5 and 4.5 months respectively, although they did not produce the cooing stage yet (see section 9.2.1).
- Also in HI-2, HI-3 and HI-4 we saw that they first produced characteristics of the variegated vocalization stage (VPho) and at later months the cooing stage (also in combination)[9]. This gives the impression of decline in vocalization development in these infants (see section 9.2.1).
- We found often a combination of the cooing stage and the variegated phonation stage during several months or alternation of the cooing stage and the variegated vocalization stage in several HI infants (see sections 9.2.1 and 9.2.2).

Such lack of interdependence between the cooing and the variegated stage is plausible. During the cooing stage mainly a development of articulatory aspects can be seen (more articulations and more back articulations), whereas during the variegated vocalization stage a development of the phonation domain is found where the VPho pattern is produced (see 9.2.1). It might therefore be the case that hearing has more influence on the development of articulation and less on the development of the phonation path during these stages. We can not explain why HI-2 first produced more characteristics of the VArt pattern at 5.5 months and more characteristics of the cooing stage at 6.5 months[8].

One of the main characteristics of the variegated vocalization stage in NH infants is variegated phonation (see section 9.1). In the HI infants a larger amount of this type of utterance is found at the end of the first year and for all months combined during the variegated vocalization stage (see section 9.2.1). In section 9.2.2 several explanations for that phenomenon were discussed, such as lack of voicing coordination, kinesthetic and tactile stimulation. It is unclear whether such explanations also clarify the onset of such vocalizations in NH infants. Moreover, we expect that residual hearing has an influence on the amount of this specific type of vocalization (see section 9.2.3). It is unclear, however, whether residual hearing affects the onset of this type of vocalization. We suggest that more work should be done on the onset of the cooing and variegated vocalization stages, especially with respect to the VPho pattern in both NH and HI infants.

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[9] HI-2 and HI-3 were studied from 5.5 months onwards. It is therefore not possible to establish the exact onset of the cooing stage and the variegated vocalization stage in these infants.

We have also described other special phenomena of the HI infants (see section 9.2.2). A higher number of utterances, more voiceless utterances and a different utterance duration (shorter at 3.5 months and longer at 5.5 months) compared to the NH infants were aspects obviously influenced by hearing, but not related to the vocalization stages in HI infants. In section 9.2.2 we discussed several factors that possibly affect these special phenomena.

Therefore we propose a new model based on our findings (see Figure 9.4). In this new model it can be seen that hearing affects most vocalization development stages. The cells represent the onset of the stages, while the text in the cells gives information about the quality of the stages.

We concluded that hearing affects:

- onset and quality of the cooing stage (prosody: duration)
- onset of the both babbling stages[10]
- quality of the variegated stage (more VPho pattern)
- some special phenomena (independently of the stages)

Hearing does not affect

- quality of the initial stage
- onset of the variegated stage

The independent order of the cooing stage and variegated vocalization stage is expressed with an arrow between these two stages. Moreover, specific phenomena (see section 9.2.2) such as the higher number of utterances in the HI group, are added in this model. Since it is not exactly clear which aspects have an influence on these specific phenomena, we called them 'various factors'. In order to evaluate our model more thoroughly more research is clearly necessary. In section 9.5 suggestions are put forward for further research.

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[10] In HI-2 the onset and quality of babbling stage 1 was normal compared to the NH infants, but we cannot generalize this finding since he was the only babbling HI infant within the period studied.

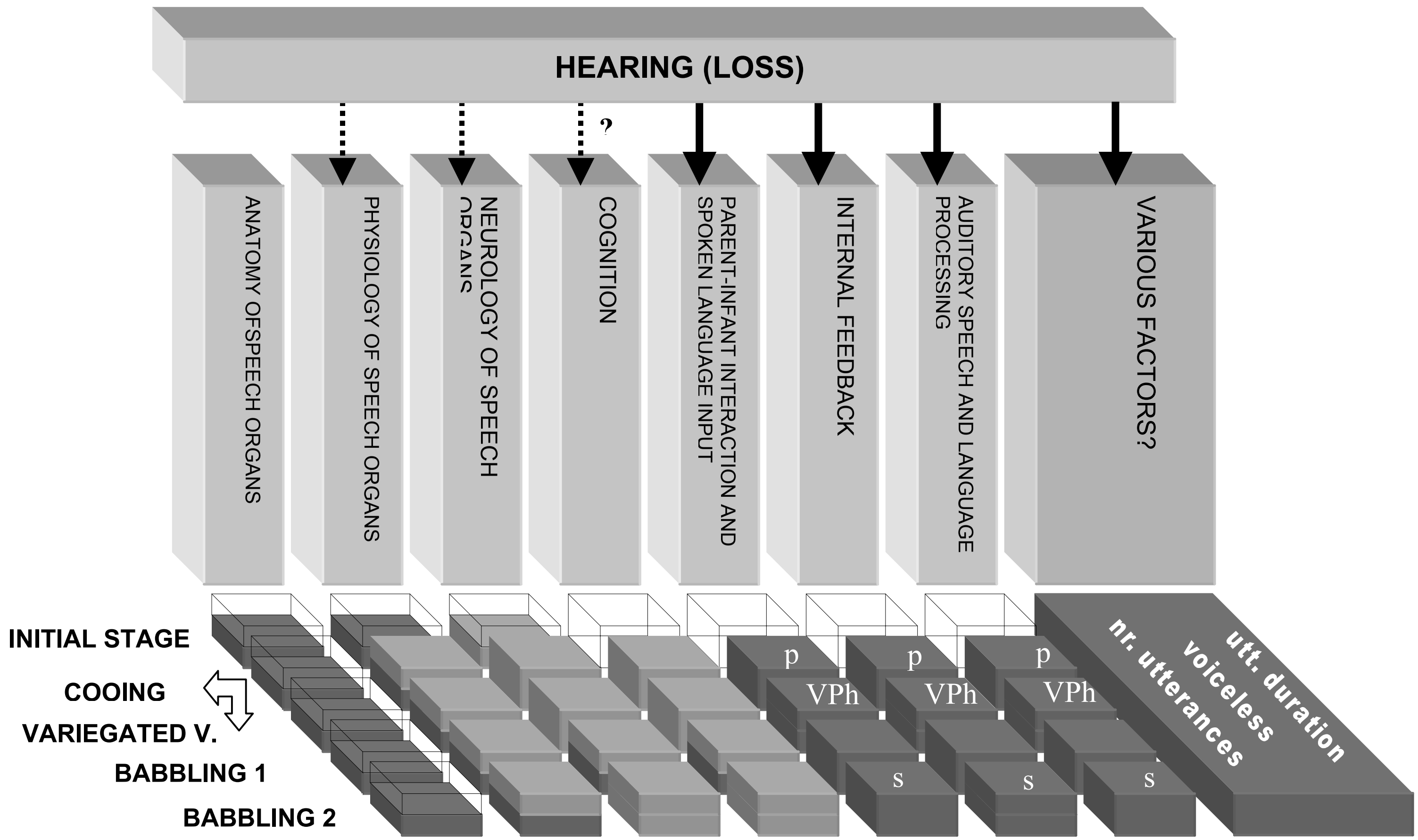

Figure 9.4. Adjusted model (see also Figure 9.2): Model of factors influencing the vocalization stages.

The cells of the bottom layer represent the influence of the factors on the vocalization development stages. The cells of the upper layer represent the influence of the hearing on the vocalization stages via these factors. Transparant=no effect, dark grey is assumed effect, light grey is uncertain effect. Dashed arrow is indirect effect and ?=unclear effect. p=prosody, s=segmental aspects, VPho=variegated phonation. Some special phenomena (utterance duration, voiceless utterances and number of utterances) are effected by hearing (via various factors), but independently of the vocalization stages. Hearing has an influence on the onset of the cooing stage and the babbling stages, but not on the onset of the initial stage and variegated stage.

9.4 Practical implications of this study

The clear differences in vocalization development between NH and HI infants in the first year have several practical implications. In the Netherlands far most newborns will be screened for hearing loss in the near future (see also Chapter 2.3.2). More HI infants are expected to be diagnosed and enrolled in early intervention programs already within the first months of life (see also Chapter 2.4). Therefore we will discuss the implications of our study on diagnostic and prognostic tools (section 9.4.1) and on intervention programs (section 9.4.2) for HI infants within the first year of life.

9.4.1 Diagnostic and prognostic tools

For HI infants precise information concerning their speech and language development needs to be collected as early as possible in order to be able to follow their progress as a basis for intervention. Moreover, diagnostic tools might help to predict later speech and language development problems. Unfortunately, no such tool for vocalization development in HI infants and young HI children yet exists. A prognostic tool for speech and language development of HI children between three and five years of age has been developed to predict the speech and language development at age 11-16 years (Geers and Moog, 1987, 1989), but this of course does not involve vocalization development in infants and toddlers. For older normally hearing children several diagnostic tools have been developed for language including phonology. For Dutch children there are general tests, for example the Schlichting test for lexical and syntax production development (Schlichting, Van Eldik, Lutje Spelberg, Van der Meulen and Van der Meulen, 1995) and the Reynell language comprehension test (Reynell, 1987; Van Eldik, Schlichting, Lutje Spelberg, Van der Meulen and Van der Meulen, 1997) are developed for (NH) children between 18 months and six years of age. For phonology there is the FAN analysis (Beers, 1995) for children between one and four years. However for the first year of life there are only general communicative measures and no tests for features of early speech.

A prognostic tool based on vocalization development is only useful if vocalization development is related to later speech and language development. We have no reason to doubt such development. In several studies comparing vocalizations with later speech and language development of hearing children a positive relationship was found (see also Chapter 1.1). For instance, a late onset of babbling might be an important predicting factor for later developmental disabilities, including problems in speech, language, and reading, as suggested by Oller et al. (1998; see also Chapter 1.1). In HI infants who had been implanted with a Cochlear Implant (CI) a relationship between age of onset of babbling and age of onset of first words has been suggested (Gillis et al., 2002; Schauwers et al., in press). In these studies the CI had been implanted in infants between

6 and 18 months of age. It was shown that nine CI infants studied start to babble only a few months after activation of the device and that spoken words followed several months after canonical babbling in most of these infants. As yet it is unknown whether their later language development is normal. Possibly canonical babbling is a good predictor of speech and language development. This should be an interesting topic for further research.

Recently Fell, MacAuslan, Ferrier, Worst and Chenausky (2002) studied the possibilities for creating such a diagnostic/prognostic tool for vocalization development as early as within the first year of life in typically developing infants (motor, neurological and cognitive delays) and their results seem promising. We strongly suggest that a tool for early language development of (HI) children be developed in the nearby future. We expect that our findings can be used as a base for the development of such a tool.

For children implanted with CI at an early age a diagnostic and prognostic tool for vocalization development and early language development is also very important. In some children who had been implanted with a CI device at an early age, an unsatisfactory speech development was found (Richter et al., 2002, see also Chapter 2.4); in such cases the intervention program might need adjustments. If the choice had been made for an oral programme only, then a problem with speech could imply a transition to a bilingual programme using both oral and manual communication. Such a change should take place as early as possible in order to promote a normal language development in at least one language. If speech and language development is not measured until, for instance, two or three years of age, it is relatively late for the transition to another type of intervention program.

All our HI infants studied were followed up by yearly interviews with parents and the Audiology Centers until 1998, when the oldest child was six years of age, and the youngest child three years of age. It was thus possible to compare the early vocalization development with a very general impression of speech and language development. As described in section 9.2.3, in our study, one infant (HI-2) differed from the other subjects in his group with respect to several vocalization development aspects, although it should be mentioned that his vocalization development was not totally similar to that of the NH infants with respect to some other aspects, such as F0 in the last months and no babbling with nasals. He turned out to be the infant with most utterances, and started the vocalization stages, variegated vocalization and babbling, at a normal age. Also his number of categories and the place and manner of his articulations were strikingly normal compared to the NH infants. HI-2 also became the child with the best speech- and (spoken) language development compared to the other five HI children. Similarly, Oller and Eilers (1988) mention that the most verbal HI infant in their study, became by far the most verbal child at later age (six years), compared to the other eight HI children, although it was not the infant with the smallest hearing loss. In our study the infant with the most profound hearing loss (HI-4), produced the least number of utterances, and did not start babbling nor talking at 3 years of age (the latest age we recorded him). Unfortunately we have no data after that age, thus we do not know if (and if so at what age) he started babbling or talking. We also did not collect data of his sign language (see Chapter 1.2).

Although the sample might be too small to draw clear conclusions, our study seems to indicate a relationship between the number of vocalizations and the onset of the vocalization development stages on the one hand and speech and language development at later age on the other.

Therefore we can conclude that number and type of vocalizations might be useful as part of a diagnostic and prognostic tool for later speech and language development in HI infants. More research is necessary to study the possibility of using the vocalization development as a basis for such a tool.

9.4.2 Intervention

It is most probable that in the nearby future a larger group of infants will enrol in early intervention programs in The Netherlands (see Chapter 2.3.2 and 2.4). This implies that the existing early intervention methods possibly need adjustment to this new development (Brienesse, Van der Stege, Meijs, and Nieuwmans, 2003). An important part of the early intervention programs concerns the stimulation of the communication skills, speech and language development and auditory development (see Chapter 2.4), but the stimulation of the vocalization development is an almost unexplored area.

We expect that the development of vocalizations is important for several reasons. It is possible that the development of vocalization stages affects the later speech and language development in both NH and HI infants. As discussed already in Chapter 1.1 it seems that infants vocalize for several reasons as part of their development, such as training of the internal feedback. At the end of the first year NH infants are able to produce articulation movements that seem to be influenced by their environmental language. This part of the phonetical and phonological development probably needs to be trained in order to produce the first words and even later speech and language development (see Chapter 1, 3 and 8). Moreover, vocalizations also play an important role in parent-infant interaction (see also Chapter 1.1 and 3.2.1).

The high number of utterances of the HI infants within the first year of life (Chapter 5) seems to confirm that part of the vocalization production probably has the same aims as in NH infants, such as training of internal feedback and parent-infant interaction and bonding. Therefore we may conclude that also in HI infants vocalization development is very important for several aspects of their development.

In HI infants we see that several aspects of their vocalization development are influenced to a large extent by their lack of hearing (see sections 9.2 and 9.3). We found, for instance, no babbling in five HI infants (see Chapter 7.3.3), less front and central consonantal articulation (see Chapter 8.3.3), more variegated phonation and voiceless phonation (Chapter 6.3.3 and 6.3.5), more utterances with only one syllable and fewer syllables with supraglottal consonants at syllable boundaries (7.3.8), compared to NH infants.

Moreover, we expect that several aspects of the development (such as auditory feedback and neural and physiological development of the speech organs) might be influenced in case of deviant vocalization development (see also Chapter 3.4.2). For instance, if a mother realizes that her child does not respond with communication skills, such as turn-taking, in the way she expects, she might decrease her spoken language input (see Chapters 5 and 9.2.2). This might affect the spoken language development in turn. Therefore it is useful to investigate whether stimulation of the vocalization development within the first year of life in HI infants also stimulates the later speech and language development and perhaps even other aspects of the development of HI infants.

There is some evidence that vocalization development of infants *can* be stimulated during an early intervention program. Only in very few studies some researchers mention therapies in which vocalization production, mainly babbling, is stimulated during the first year of life in infants with a deviating vocalization development, although no work is done on HI infants yet (Ertmer and Galster, 2001; Cress, 2001). Very recently Fell, Cress, MacAuslan and Ferrier (submitted for publication, personal communication, 2004) explored possibilities for the stimulation of the vocalization development with a visual feedback pc-program: VisiBabble. This tool was tested on a-typically developing NH infants. It turned out that the overall number of utterances, number of syllables and variety of syllable production increase after several sessions with the VisiBabble program. Although there is no direct evidence yet that this vocalization stimulation has also positive effect on the start of word production, it is not unlikely that early word production is effected by babbling (see Chapter 1.1). We suggest that the development of such tool also will be investigated for HI infants[11].

In that case we can imagine that the vocalization development of HI infants are stimulated with help of visual feedback to produce for instance:

- more front and central articulations
- more syllables with supraglottal consonants
- up and down jaw movements (to start babbling at an earlier age)
- more voicing control (more controlled utterance duration and pitch)

[11] First contacts were made with Prof. Fell in order to investigate possibilities for cooperation in the future.

- better combined articulation and phonation coordination (fewer voiceless utterances and babbling at an earlier age)
- turn-taking

We strongly suggest that further research be done in order to explore possibilities for early stimulation of the pre-verbal vocalization development and its possible result on later speech and language development. In that case our findings can be used as a base for such an early intervention program focussed on vocalization development.

9.5 Further research

In order to test our model more thoroughly, more research is clearly necessary. In this study we analysed the vocalization development of only six HI infants: there were practical reasons for this. It was very hard to find enough subjects fulfilling all our criteria within the first half year of life, using the audiometric possibilities at that time. Secondly with the restrictions of a Ph.D. project there is a limit to the amount of data that can be collected and analysed. It was also not possible to find a subject group in which all possible factors were controlled for. For instance, we have here suggested that residual hearing (with hearing aids) and form of the audiogram influence vocalization development, also in hearing losses (unaided) over 90 dB PTA. An investigation with an even more controlled and larger subject group (for instance both with some residual hearing as well as without any residual hearing) would make the effects clearer. In the near future early screening methods will be available for almost all Dutch newborn infants (see Chapter 2.3.2), which can make the selection of such a subject group possible.

Next, in this study the data of only two HI infants could be collected at 2.5 months, and of three infants at 3.5 months of age. It might be useful to retest our model with more HI infants especially within the first 5 months of age, with respect to the first vocalization development stages. Also with respect to this point, early screening methods within a couple of weeks after birth should make such study possible.

We analysed every monthly recording of all subjects. Although it was not possible to analyse more data within our study, we suggest that it would be useful to analyse vocalizations of NH infants and HI infants collected over smaller time intervals. Studying the data every two weeks would reduce the chance of "missing" important steps in vocalization development.
We concluded that several vocalization stages are delayed in most HI infants. Since we analysed data of HI infants only until 11.5 months of age we are not able to know whether all stages started in all infants. From information collected after the first year of life (audio recordings until 17.5 months, video-recordings until three years and interviews with the parents and audiology centres until the children were three to seven

years old) we were able to indicate the age the infants started babbling (except the precise age for HI-4). More research is needed in order to be able to confirm the hypothesis whether both babbling stages start after the first year or are absent in some HI infants.

Moreover, some work is done on the data of ten of the twelve infants studied in this thesis, but *after* the first year of life (Dikkenberg-Pot et al., 1998). Data of the infants between 12 and 18 months show that after the first year of life both groups of infants produced similar number of utterances, in contrary to the first year of life, see also Chapter 3.3.1). It was also concluded that the utterance duration was longer in the HI group compared to the NH group for almost all months studied between 12 and 18 months, thus different from the results of the first year of life (see also Chapter 3.3.2). The results also revealed e.g. that the HI infants produced significantly more variegated phonation without articulation (NoArtVarPho and NoArtComPho) between 12 and 18 months, similarly to the age of 9.5-11.5 months in the present study (Dikkenberg-Pot et al., 1998).

We suggest that the data of the infants after the first year will be analysed with respect to several other aspects also, such as place and manner of articulation and number of syllables. Next, we also propose that these results will be related to the vocalization stages and to the model as proposed in section 9.3.

In our study a choice was made to analyse the data with respect to several possible aspects of vocalization development, such as duration, F0 and place and manner of articulation. Beside these aspects also other aspects can be studied. At this moment the production of vowels-contrasts of the same infants as described in this thesis, is studied with help of spectral analysis. The first results show that the vowel space is smaller in the HI infants (Van der Stelt et al., 2003a and 2003b). Also it would be interesting to study the spoken parent-infant interaction more thoroughly. For instance the utterance duration of the mother's utterances and the overlap in utterances of mother and infant, would give more insight in the turn-taking process of NH infants and HI infants and its effect on number of utterances and utterance duration.

One of the practical implications of the results of our study is that these results can be used as a base for an intervention program for vocalization development. As discussed in section 9.4 we suggest that further research should be done on the possibility to develop such program. Finally we suggest that further research is carried out investigating the possibilities of creating diagnostic and prognostic tools. In that case our study can be used as a basis for such tools.

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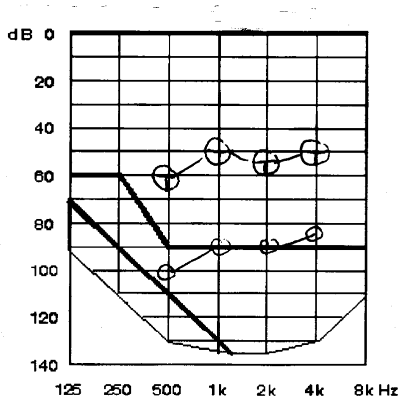
Appendices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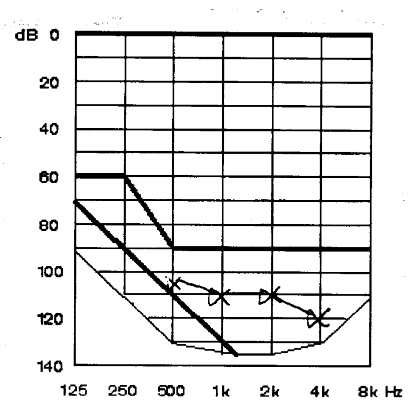
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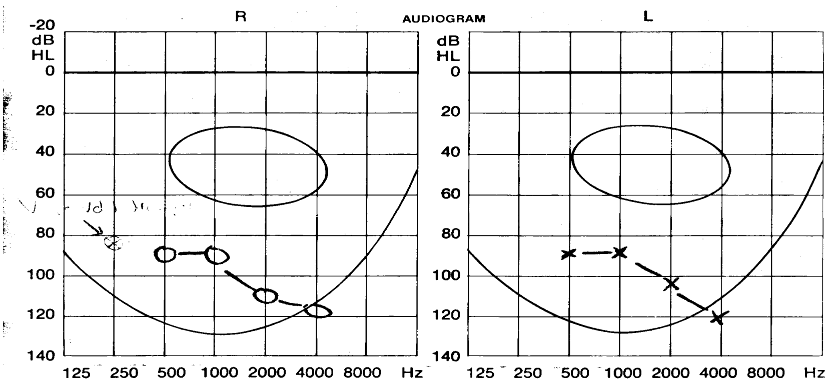
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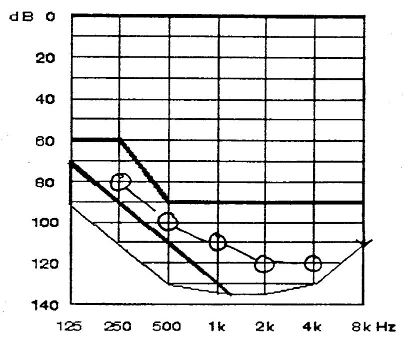
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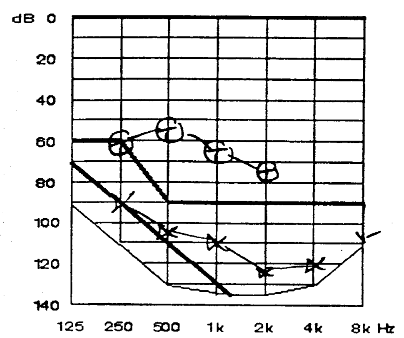
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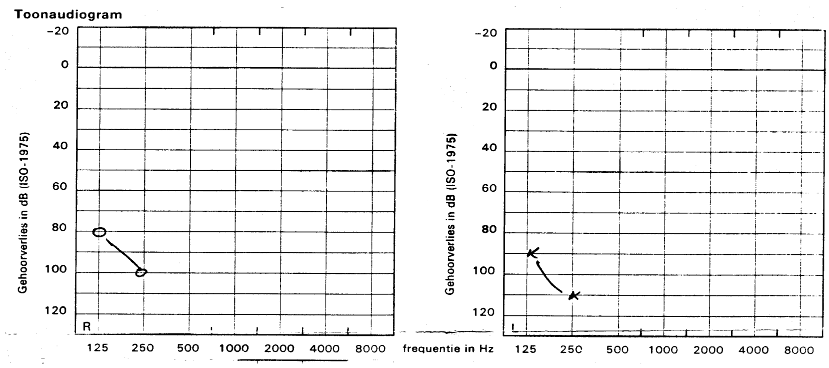

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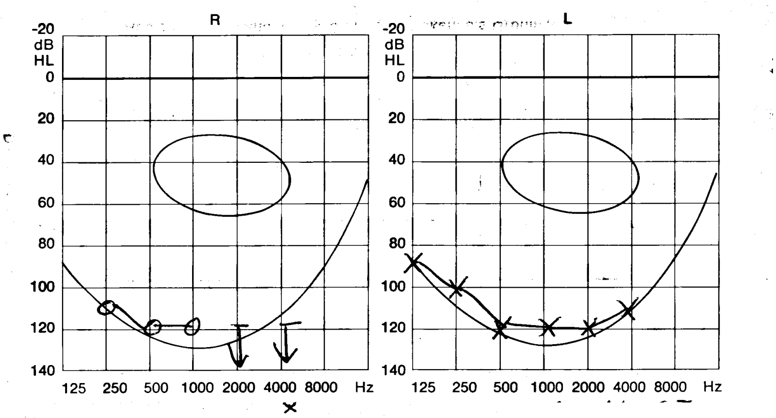

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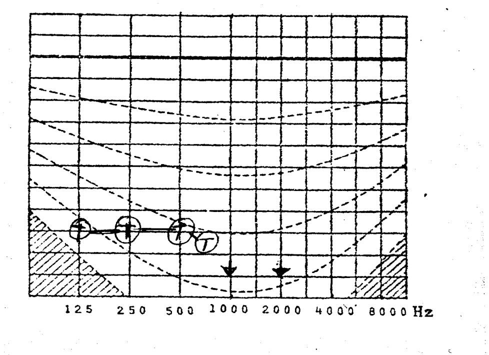
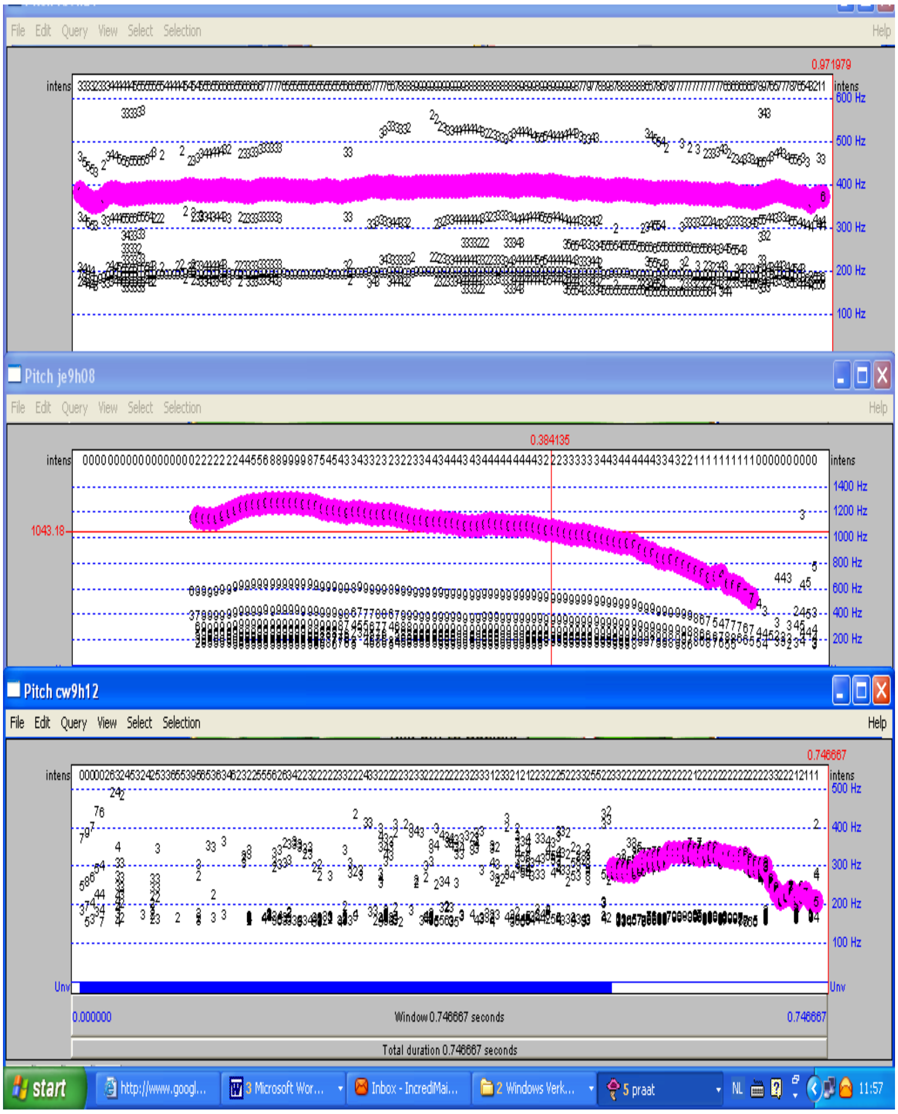


HI-6

Figure A4.1 Copies of the original audiograms of both ears (if possible) of the hearing impaired subjects

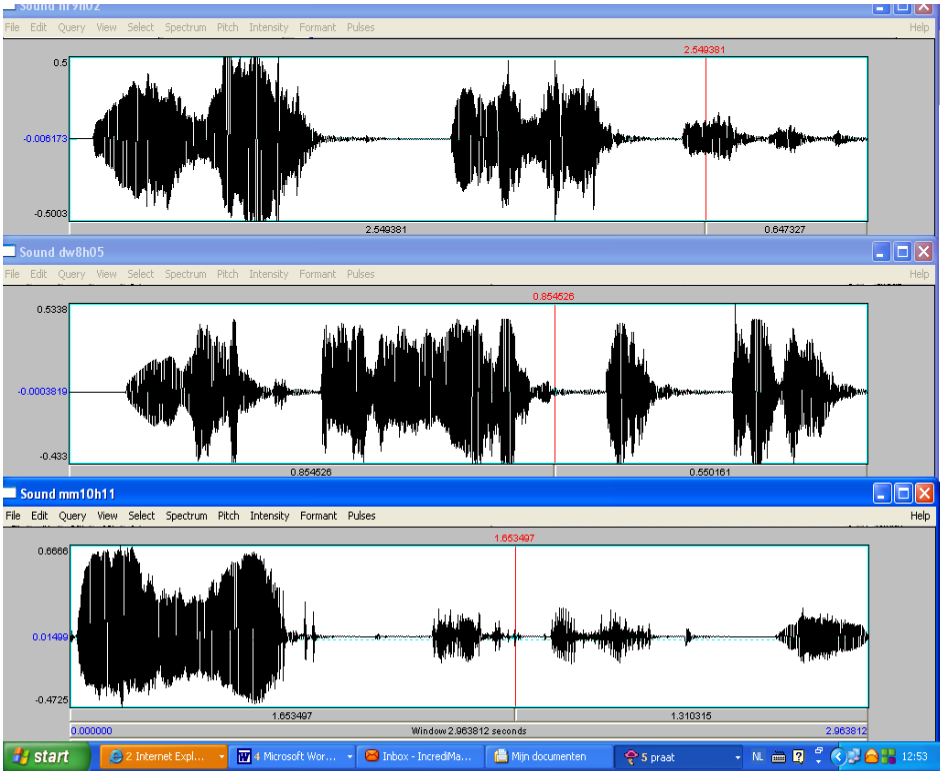


Utterance with average F0, produced by NH-4 at 9.5 month of age

Utterance with high F0, produced by HI-2 at 9.5 month of age

Utterance with low F0, produced by HI-4 at 9.5 month of age

Appendix Figure A6.1. Examples of F0 of utterances of three infants studied at 9.5 months of age.

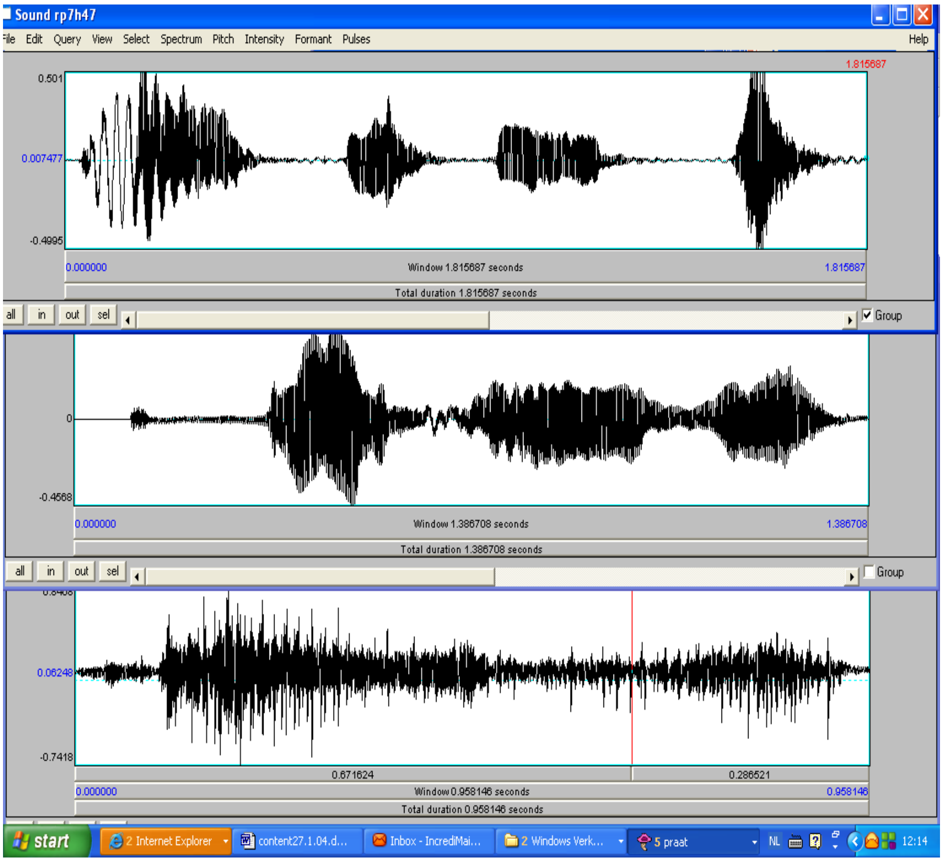


Utterance of HI-1 at 9.5 months

Utterance of HI-3 at 8.5 months

Utterance of HI-5 at 10.5 months

Appendix Figure A7.1 Examples of NoArt ComPho utterances of three HI subjects



Babbled utterance of NH-2 at 7.5 months of age (Babbling IntPho)

Babbled utterance of HI-2 at 7.5 months of age (Babbling SimPho)

Voiceless utterance of HI-4 at 7.5 months of age (SimArt NoPho)

Appendix Figure A7.2 Examples of Babbling utterances two NH infants and a voiceless utterance of one HI infant all studied at 7.5 months of age.

Appendix Table A8.1 (next page). Place and manner of articulation for each individual subject shown per month and in total, in absolute numbers and in percentages.

H-1		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
front	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	0	0	0	0	0	0	1	5	5	0	0	0				1	5	5
	4.5	0	0	1	0	0	4	0	0	3	0	0	0				0	0	8
	5.5	1	3	4	4	13	12	1	3	1	0	0	0				6	19	17
	6.5	1	8	4	3	23	30	0	0	3	0	0	0				4	31	36
	7.5	0	0	6	9	53	31	1	6	6	0	0	0				10	59	44
	8.5	4	12	8	6	18	26	4	12	13	0	0	1				14	41	48
	9.5	4	11	10	3	9	16	7	20	15	1	3	1				15	43	42
	10.5	1	7	8	3	21	16	2	14	16	0	0	12				6	43	51
	11.5	1	5		4	18		3	14		7	32					15	68	
	mean	1.2	4.6		3.2	15.4		1.9	7.3		0.8	3.5					7.1	30.8	
central	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	0	0	0	0	0	0	0	0	0	0	0	0	1	5	5	1	5	5
	4.5	0	0	2	0	0	0	0	0	1	0	0	0	0	0	3	0	0	6
	5.5	2	6	7	0	0	0	1	3	4	0	0	0	1	3	4	4	13	14
	6.5	2	15	9	0	0	2	1	8	4	0	0	0	1	8	6	4	31	20
	7.5	1	6	14	1	6	2	0	0	6	0	0	1	1	6	7	3	18	31
	8.5	7	21	9	0	0	3	4	12	4	1	3	1	3	9	6	15	44	22
	9.5	0	0	16	1	3	1	0	0	4	0	0	3	1	3	6	2	6	31
	10.5	4	29	19	0	0	1	0	0	2	1	7	2	1	7	3	6	43	27
	11.5	6	27		0	0		1	5		0	0		0	0		7	32	
	mean	2.2	10.4		0.2	0.9		0.7	2.7		0.2	1.0					4.3	20.3	
back	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	8	38	38	11	52	52	0	0	0	0	0	0				19	90	90
	4.5	8	44	39	10	56	46	0	0	0	0	0	1				18	100	86
	5.5	11	34	29	10	31	37	0	0	3	1	3	1				22	69	69
	6.5	1	8	14	3	23	26	1	8	3	0	0	1				5	38	44
	7.5	0	0	6	4	24	17	0	0	3	0	0	0				4	24	26
	8.5	3	9	13	2	6	16	0	0	0	0	0	0				5	15	30
	9.5	11	31	13	7	20	13	0	0	0	0	0	0				18	51	27
	10.5	0	0	10	2	14	11	0	0	0	0	0	0				2	14	22
	11.5	0	0		0	0		0	0		0	0					0	0	
	mean	4.7	22.7		5.1	25.1		0.1	0.8		0.1	0.3					10.0	48.9	
total	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	8	38	38	11	52	52	1	5	5	0	0	0	1	5	5	21	100	100
	4.5	8	44	42	10	56	51	0	0	4	0	0	1	0	0	3	18	100	100
	5.5	14	44	40	14	44	48	2	6	7	1	3	1	1	3	4	32	100	100
	6.5	4	31	27	6	46	57	2	15	9	0	0	1	1	8	6	13	100	100
	7.5	1	6	26	14	82	51	1	6	15	0	0	1	1	6	7	17	100	100
	8.5	14	41	30	8	24	46	8	24	16	1	3	2	3	9	6	34	100	100
	9.5	15	43	40	11	31	30	7	20	19	1	3	4	1	3	6	35	100	100
	10.5	5	36	37	5	36	28	2	14	17	1	7	14	1	7	3	14	100	100
	11.5	7	32		4	18		4	18		7	32		0	0		22	100	
	mean	8.1	37.7		8.5	41.4		2.7	10.8		1.1	4.8					21.4	100	

NH-2		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
front	2.5	0	0		1	3		0	0		0	0					1	3	
	3.5	0	0	1	14	32	19	1	2	2	0	0	0				15	34	23
	4.5	2	4	2	11	22	33	2	4	3	0	0	0				15	31	38
	5.5	1	3	10	17	45	24	1	3	5	0	0	0				19	50	40
	6.5	5	24	40	1	5	16	2	10	4	0	0	0				8	38	60
	7.5	36	92	51	0	0	2	0	0	6	0	0	0				36	92	59
	8.5	8	36	50	0	0	5	2	9	5	0	0	2				10	45	62
	9.5	8	21	19	6	16	5	2	5	6	2	5	2				18	47	32
	10.5	0	0	11	0	0	8	1	4	7	0	0	4				1	4	29
	11.5	3	11		2	7		3	11		2	7					10	37	
	mean	6.3	19.1		5.2	13.0		1.4	4.8		0.4	1.3					13.3	38.2	
central	2.5	0	0		0	0		0	0		0	0		2	6		2	6	
	3.5	2	5	4	1	2	1	1	2	1	0	0	0	0	0	2	4	9	7
	4.5	3	6	4	0	0	1	0	0	1	0	0	0	0	0	0	3	6	5
	5.5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	4
	6.5	0	0	0	0	0	0	0	0	0	0	0	0	1	5	2	1	5	2
	7.5	0	0	14	0	0	0	0	0	0	0	0	0	0	0	3	0	0	17
	8.5	9	41	28	0	0	1	0	0	0	0	0	2	1	5	2	10	45	32
	9.5	16	42	51	1	3	3	0	0	3	2	5	2	0	0	2	19	50	60
	10.5	18	69	49	2	8	3	2	8	5	0	0	4	0	0	1	22	85	63
	11.5	10	37		0	0		2	7		2	7		1	4		15	56	
	mean	5.8	20.0		0.4	1.3		0.5	1.7		0.4	1.3					7.6	26.2	
back	2.5	12	36		16	48		0	0		2	6					30	91	
	3.5	10	23	27	15	34	41	0	0	0	0	0	2				25	57	70
	4.5	11	22	19	20	41	37	0	0	0	0	0	0				31	63	57
	5.5	5	13	23	14	37	34	0	0	0	0	0	0				19	50	57
	6.5	7	33	16	5	24	22	0	0	0	0	0	0				12	57	38
	7.5	1	3	15	2	5	10	0	0	0	0	0	0				3	8	25
	8.5	2	9	5	0	0	2	0	0	0	0	0	0				2	9	6
	9.5	1	3	6	0	0	1	0	0	0	0	0	0				1	3	8
	10.5	2	8	6	1	4	1	0	0	0	0	0	0				3	12	7
	11.5	2	7		0	0		0	0		0	0					2	7	
	mean	5.3	15.7		7.3	19.3		0.0	0.0		0.2	0.6					12.8	35.6	
total	2.5	12	36		17	52		0	0		2	6		2	6		33	100	
	3.5	12	27	32	30	68	61	2	5	3	0	0	2	0	0	2	44	100	100
	4.5	16	33	25	31	63	71	2	4	4	0	0	0	0	0	0	49	100	100
	5.5	6	16	35	31	82	58	1	3	5	0	0	0	0	0	2	38	100	100
	6.5	12	57	56	6	29	38	2	10	4	0	0	0	1	5	2	21	100	100
	7.5	37	95	79	2	5	11	0	0	6	0	0	0	0	0	3	39	100	100
	8.5	19	86	82	0	0	8	2	9	5	0	0	4	1	5	2	22	100	100
	9.5	25	66	76	7	18	10	2	5	9	4	11	4	0	0	2	38	100	100
	10.5	20	77	66	3	12	12	3	12	12	0	0	8	0	0	1	26	100	100
	11.5	15	56		2	7		5	19		4	15		1	4		27	100	
	mean	17.4	54.9		12.9	33.6		1.9	6.5		1.0	3.1					33.7	100	

NH-3		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
front	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	0	0	0	0	0	0	9	43	43	1	5	5				10	48	48
	4.5	2	6	6	29	88	38	0	0	14	0	0	6				31	94	64
	5.5	na	na	3	na	na	44	na	na	4	na	na	0				na	na	51
	6.5	0	0	7	0	0	24	1	8	7	0	0	4				1	8	41
	7.5	2	8	6	12	46	18	3	12	9	0	0	0				17	65	33
	8.5	3	9	8	3	9	22	2	6	8	0	0	0				8	24	38
	9.5	1	6	8	2	12	7	1	6	4	0	0	0				4	24	19
	10.5	2	11	7	0	0	4	0	0	7	0	0	3				2	11	21
	11.5	1	5		0	0		3	15		2	10					6	30	
	mean	1.2	5.7		4.8	18.0		1.9	9.0		0.4	2.7					8.3	35.4	
central	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	0	0	0	0	0	0	0	0	0	0	0	0	1	5	5	1	5	5
	4.5	1	3	1	0	0	0	0	0	4	0	0	0	0	0	2	1	3	7
	5.5	na	na	2	na	na	0	na	na	8	na	na	0	na	na	0	na	na	10
	6.5	0	0	0	0	0	0	2	17	17	0	0	0	0	0	0	2	17	17
	7.5	0	0	8	0	0	0	6	23	17	0	0	0	0	0	1	6	23	26
	8.5	8	24	12	0	0	0	4	12	12	0	0	2	1	3	5	13	39	31
	9.5	2	12	37	0	0	0	0	0	6	1	6	5	2	12	5	5	29	53
	10.5	14	74	45	0	0	0	1	5	7	2	11	7	0	0	4	17	89	63
	11.5	10	50		0	0		3	15		1	5		0	0		14	70	
	mean	3.5	16.3		0.0	0.0		1.7	8.5		0.4	2.1					6.0	28.8	
back	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	3	14	14	7	33	33	0	0	0	0	0	0				10	48	48
	4.5	0	0	13	1	3	16	0	0	0	0	0	0				1	3	29
	5.5	na	na	13	na	na	10	na	na	0	na	na	17				na	na	39
	6.5	3	25	18	2	17	12	0	0	0	4	33	11				9	75	41
	7.5	1	4	19	2	8	11	0	0	0	0	0	11				3	12	41
	8.5	9	27	14	3	9	15	0	0	2	0	0	0				12	36	32
	9.5	2	12	13	5	29	13	1	6	2	0	0	0				8	47	28
	10.5	0	0	4	0	0	10	0	0	2	0	0	0				0	0	16
	11.5	0	0		0	0		0	0		0	0					0	0	
	mean	2.5	17.9		2.1	11.2		0.1	0.6		0.6	6.2					5.3	35.8	
total	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	3	14	14	7	33	33	9	43	43	1	5	5	1	5	5	21	100	100
	4.5	3	9	20	30	91	54	0	0	18	0	0	6	0	0	2	33	100	100
	5.5	na	na	17	na	na	54	na	na	13	na	na	17	na	na	0	na	na	100
	6.5	3	25	25	2	17	36	3	25	24	4	33	15	0	0	0	12	100	100
	7.5	3	12	32	14	54	30	9	35	26	0	0	11	0	0	1	26	100	100
	8.5	20	61	34	6	18	38	6	18	22	0	0	2	1	3	5	33	100	100
	9.5	5	29	58	7	41	20	2	12	12	1	6	5	2	12	5	17	100	100
	10.5	16	84	56	0	0	14	1	5	16	2	11	10	0	0	4	19	100	100
	11.5	11	55		0	0		6	30		3	15		0	0		20	100	
	mean	7.2	39.8		6.9	29.2		3.7	18.0		1.4	11.1					19.6	100	

NH-4		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
front	2.5	0	0		0	0		1	5		0	0					1	5	
	3.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	4.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	5.5	1	8	8	3	25	25	1	8	8	0	0	0				5	42	42
	6.5	na	na	6	na	na	36	na	na	10	na	na	0				na	na	52
	7.5	1	4	35	12	46	17	3	12	4	0	0	0				16	62	56
	8.5	0	0	3	2	6	21	0	0	7	0	0	8				2	6	38
	9.5	1	4	3	3	12	8	2	8	14	6	24	8				12	48	32
	10.5	1	5	4	1	5	6	7	33	14	0	0	8				9	43	32
	11.5	1	2		1	2		0	0		0	0					2	5	
	mean	0.6	12.3		2.3	11.6		1.4	6.6		0.6	2.4					4.9	32.9	
central	2.5	0	0		0	0		0	0		0	0		0	0		0	0	
	3.5	na	na	na	na	na	na	na	na	na	na	na	0	na	na	na	na	na	na
	4.5	na	na	na	na	na	na	na	na	na	na	na	0	na	na	na	na	na	na
	5.5	0	0	0	0	0	0	2	17	17	0	0	0	0	0	0	2	17	17
	6.5	na	na	6	na	na	0	na	na	8	na	na	0	na	na	0	na	na	14
	7.5	3	12	24	0	0	0	0	0	1	0	0	0	0	0	2	3	12	27
	8.5	21	62	36	0	0	4	1	3	1	0	0	0	2	6	2	24	71	43
	9.5	9	36	47	3	12	4	0	0	1	0	0	0	0	0	4	12	48	55
	10.5	9	43	57	0	0	4	0	0	0	0	0	1	1	5	2	10	48	64
	11.5	38	93		0	0		0	0		1	2		0	0		39	95	
	mean	8.0	24.5		0.3	1.2		0.3	2.0		0.1	0.2					9.0	29.0	
back	2.5	8	36		12	55		0	0		1	5					21	95	
	3.5	na	na	na	na	na	38	na	na	na	na	na	na				na	na	na
	4.5	na	na	na	na	na	31	na	na	na	na	na	na				na	na	na
	5.5	1	8	8	4	33	33	0	0	0	0	0	0				5	42	42
	6.5	na	na	4	na	na	26	na	na	4	na	na	0				na	na	34
	7.5	0	0	1	5	19	13	2	8	3	0	0	0				7	27	17
	8.5	1	3	1	7	21	15	0	0	3	0	0	0				8	24	18
	9.5	0	0	4	1	4	8	0	0	0	0	0	0				1	4	12
	10.5	2	10	3	0	0	1	0	0	0	0	0	0				2	10	5
	11.5	0	0		0	0		0	0		0	0					0	0	
	mean	1.8	17.7		3.2	19.2		0.2	0.8		0.1	0.5					5.3	38.1	
total	2.5	8	36		12	55		1	5		1	5		0	0		22	100	
	3.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	4.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	5.5	2	17	17	7	58	58	3	25	25	0	0	0	0	0	0	12	100	100
	6.5	na	na	16	na	na	62	na	na	22	na	na	0	na	na	0	na	na	100
	7.5	4	15	60	17	65	31	5	19	7	0	0	0	0	0	2	26	100	100
	8.5	22	65	40	9	26	40	1	3	10	0	0	8	2	6	2	34	100	100
	9.5	10	40	54	7	28	20	2	8	15	6	24	8	0	0	4	25	100	100
	10.5	12	57	64	1	5	12	7	33	14	0	0	9	1	5	2	21	100	100
	11.5	39	95		1	2		0	0		1	2		0	0		41	100	
	mean	10.4	54.5		5.8	32.0		1.9	9.3		0.8	3.1					19.2	100	

NH-5		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	1	7	7	0	0	0	2	13	13	2	13	13				5	33	33
	4.5	na	na	11	na	na	6	na	na	22	na	na	4				na	na	44
	5.5	2	17	14	2	17	7	1	8	42	0	0	2				5	42	65
	6.5	4	13	16	1	3	13	23	74	28	2	6	5				30	97	61
front	7.5	2	18	19	2	18	7	0	0	29	1	9	6				5	45	62
	8.5	9	27	20	0	0	9	4	12	8	1	3	11				14	42	48
	9.5	4	15	17	2	7	2	3	11	9	6	22	8				15	56	37
	10.5	4	10	10	0	0	2	1	3	9	0	0	9				5	13	30
	11.5	1	4		0	0		4	15		1	4					6	22	
	mean	2.8	12.1		0.7	4.5		4.2	18.1		1.3	5.8					9.0	40.5	
	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	0	0	0	0	0	0	0	0	0	0	0	0	1	7	7	1	7	7
	4.5	na	na	0	na	na	0	na	na	4	na	na	4	na	na	3	na	na	12
	5.5	0	0	0	0	0	0	1	8	14	1	8	3	0	0	0	2	17	17
	6.5	0	0	0	0	0	0	0	0	3	0	0	3	0	0	6	0	0	12
central	7.5	0	0	6	0	0	0	0	0	0	0	0	0	2	18	7	2	18	13
	8.5	6	18	11	0	0	0	0	0	0	0	0	5	1	3	7	7	21	23
	9.5	4	15	28	0	0	1	0	0	2	4	15	12	0	0	3	8	30	46
	10.5	21	53	34	1	3	1	2	5	4	9	23	22	2	5	2	35	88	63
	11.5	9	33		0	0		2	7		8	30		0	0		19	70	
	mean	4.0	11.9		0.1	0.3		0.8	5.4		2.2	7.5					7.7	28.4	
	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	6	40	40	0	0	0	1	7	7	2	13	13				9	60	60
	4.5	na	na	28	na	na	13	na	na	3	na	na	7				na	na	51
	5.5	2	17	7	3	25	12	0	0	0	0	0	0				5	42	19
	6.5	1	3	7	0	0	20	0	0	0	0	0	0				1	3	27
back	7.5	0	0	4	4	36	21	0	0	0	0	0	0				4	36	25
	8.5	3	9	4	9	27	25	0	0	0	0	0	0				12	36	29
	9.5	1	4	4	3	11	13	0	0	0	0	0	0				4	15	17
	10.5	0	0	2	0	0	5	0	0	0	0	0	0				0	0	7
	11.5	1	4		1	4		0	0		0	0					2	7	
	mean	1.5	17.6		2.1	11.5		0.1	0.7		0.2	1.3					3.9	31.1	
	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	7	47	47	0	0	0	3	20	20	4	27	27	1	7	7	15	100	100
	4.5	na	na	40	na	na	21	na	na	18	na	na	18	na	na	3	na	na	100
	5.5	4	33	20	5	42	19	2	17	56	1	8	5	0	0	0	12	100	100
	6.5	5	16	23	1	3	33	23	74	30	2	6	8	0	0	6	31	100	100
total	7.5	2	18	30	6	55	28	0	0	29	1	9	6	2	18	7	11	100	100
	8.5	18	55	35	9	27	33	4	12	8	1	3	16	1	3	7	33	100	100
	9.5	9	33	50	5	19	16	3	11	10	10	37	21	0	0	3	27	100	100
	10.5	25	63	46	1	3	8	3	8	14	9	23	31	2	5	2	40	100	100
	11.5	11	41		1	4		6	22		9	33		0	0		27	100	
	mean	8.3	41.7		2.9	16.3		5.1	24.2		3.7	14.6					20.6	100	

NH-6		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	0	0	0	0	0	0	1	3	3	1	3	3				2	6	6
	4.5	na	na	0	na	na	5	na	na	2	na	na	2				na	na	8
	5.5	0	0	17	1	9	20	0	0	0	0	0	0				1	9	36
	6.5	na	na	3	na	na	25	na	na	18	na	na	0				na	na	45
front	7.5	1	5	18	8	40	44	7	35	16	0	0	0				16	80	79
	8.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd				na	na	nd
	9.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	10.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	11.5	1	8		1	8		3	25		4	33					9	75	
	mean	0.3	1.7		1.3	7.2		1.4	7.9		0.6	4.5					3.5	21.3	
	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	0	0	0	0	0	0	1	3	3	1	3	3	2	6	6	4	12	12
	4.5	na	na	0	na	na	0	na	na	6	na	na	2	na	na	12	na	na	20
	5.5	0	0	0	0	0	0	1	9	11	0	0	0	2	18	14	3	27	26
	6.5	na	na	3	na	na	0	na	na	7	na	na	0	na	na	12	na	na	21
central	7.5	1	5	5	0	0	0	1	5	5	0	0	0	1	5	5	3	15	15
	8.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd
	9.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	10.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	11.5	0	0		0	0		1	8		2	17		0	0		3	25	
	mean	0.1	0.6		0.0	0.0		0.5	3.2		0.4	2.5		0.6	3.7		1.6	9.9	
	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	2	6	6	25	76	76	0	0	0	0	0	0				27	82	82
	4.5	na	na	3	na	na	70	na	na	0	na	na	0				na	na	73
	5.5	0	0	0	7	64	30	0	0	0	0	0	8				7	64	38
	6.5	na	na	0	na	na	23	na	na	0	na	na	0				na	na	23
back	7.5	0	0	0	1	5	5	0	0	0	0	0	0				1	5	5
	8.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd				na	na	nd
	9.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	10.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	11.5	0	0		0	0		0	0		0	0					0	0	
	mean	0.3	0.8		4.1	18.0		0.0	0.0		0.0	0.0					4.4	18.8	
	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	2	6	6	25	76	76	2	6	6	2	6	6	2	6	6	33	100	100
	4.5	na	na	3	na	na	74	na	na	8	na	na	3	na	na	12	na	na	100
	5.5	0	0	17	8	73	49	1	9	11	0	0	8	2	18	14	11	100	100
	6.5	na	na	5	na	na	59	na	na	25	na	na	0	na	na	12	na	na	100
total	7.5	2	10	10	9	45	45	8	40	40	0	0	0	1	5	5	20	100	100
	8.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd
	9.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	10.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	11.5	1	8		1	8		4	33		6	50		0	0		12	100	
	mean	0.6	3.0		5.4	25.2		1.9	11.1		1.0	7.0		0.6	3.7		9.5	100	

HI-1		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
front	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	4.5	0	0	0	0	0	0	1	8	8	0	0	0				1	8	8
	5.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	6.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	7.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	8.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	9.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	10.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	11.5	na	na		na	na		na	na		na	na					na	na	
	mean	0.0	0.0		0.0	0.0		0.1	1.0		0.0	0.0					0.1	1.0	
central	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	4.5	1	8	8	0	0	0	1	8	8	0	0	0	0	0	0	2	15	15
	5.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	6.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	7.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	8.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	9.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	10.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	11.5	na	na		na	na		na	na		na	na		na	na		na	na	
	mean	0.1	1.0		0.0	0.0		0.1	1.0		0.0	0.0		0.0	0.0		0.3	1.9	
back	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	4.5	1	8	8	8	62	62	0	0	0	1	8	8				10	77	77
	5.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	6.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	7.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	8.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	9.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	10.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	11.5	na	na		na	na		na	na		na	na					na	na	
	mean	0.1	1.0		1.0	7.7		0.0	0.0		0.1	1.0		0.0	0.0		1.3	9.6	
total	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	4.5	2	15	15	8	62	62	2	15	15	1	8	8	0	0	0	13	100	100
	5.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	6.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	7.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	8.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	9.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	10.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	11.5	na	na		na	na		na	na		na	na		na	na		na	na	
	mean	0.3	1.9		1.0	7.7		0.3	1.9		0.1	1.0		0.0	0.0		1.6	100	

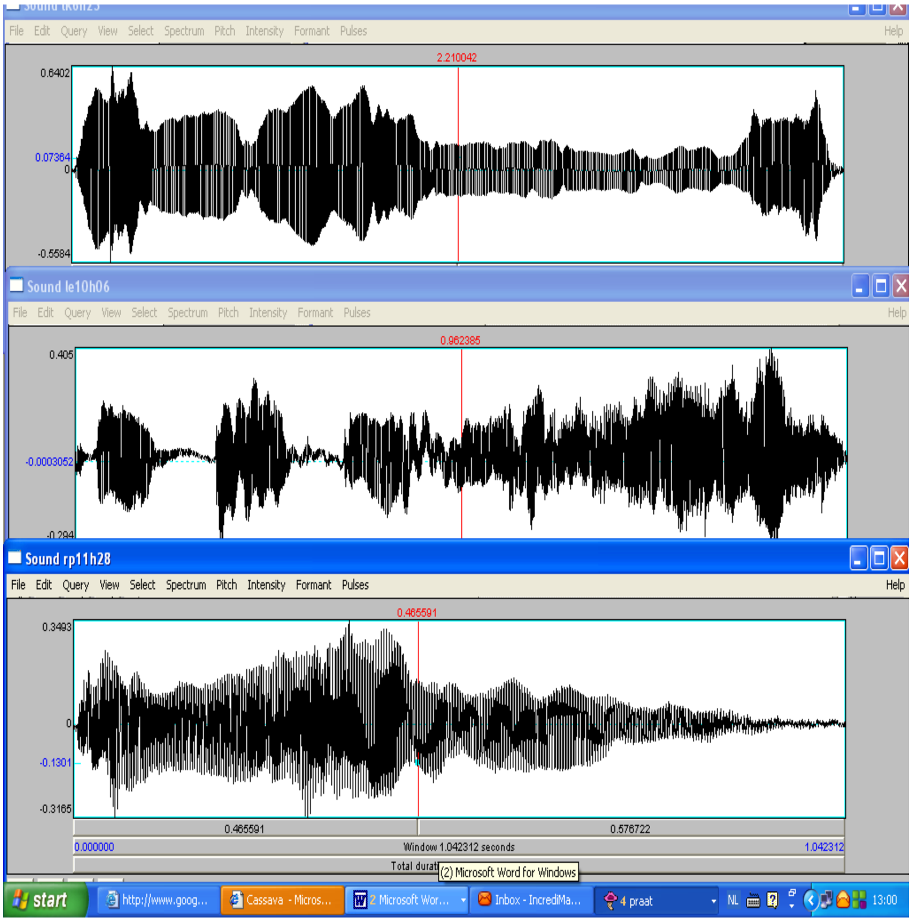
HI-2		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
front	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	5.5	3	16	16	5	26	26	1	5	5	0	0	0				9	47	47
	6.5	2	15	17	0	0	9	0	0	2	0	0	0				2	15	29
	7.5	11	21	13	1	2	1	1	2	1	0	0	0				13	25	15
	8.5	1	4	8	0	0	9	0	0	17	0	0	0				1	4	35
	9.5	na	na	2	na	na	0	na	na	5	na	na	0				na	na	7
	10.5	0	0	0	0	0	0	2	10	10	0	0	0				2	10	10
	11.5	na	na		na	na		na	na		na	na					na	na	
	mean	2.4	8.0		0.9	4.0		0.6	2.5		0.0	0.0					3.9	14.5	
central	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6.5	0	0	11	0	0	0	1	8	4	0	0	1	0	0	6	1	8	21
	7.5	17	33	34	0	0	0	2	4	5	1	2	1	9	17	7	29	56	47
	8.5	18	69	34	0	0	0	1	4	3	0	0	1	1	4	7	20	77	44
	9.5	na	na	45	na	na	0	na	na	17	na	na	0	na	na	4	na	na	66
	10.5	4	20	20	0	0	0	6	30	30	0	0	0	1	5	5	11	55	55
	11.5	na	na		na	na		na	na		na	na		na	na		na	na	
	mean	5.6	17.4		0.0	0.0		1.4	6.5		0.1	0.3		1.6	3.7		8.7	27.9	
back	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	5.5	6	32	32	4	21	21	0	0	0	0	0	0				10	53	53
	6.5	1	8	14	9	69	36	0	0	0	0	0	0				10	77	50
	7.5	1	2	3	9	17	35	0	0	0	0	0	0				10	19	38
	8.5	0	0	9	5	19	12	0	0	0	0	0	0				5	19	21
	9.5	na	na	5	na	na	22	na	na	0	na	na	0				na	na	27
	10.5	2	10	10	5	25	25	0	0	0	0	0	0				7	35	35
	11.5	na	na		na	na		na	na		na	na					na	na	
	mean	1.4	7.3		4.6	21.7		0.0	0.0		0.0	0.0					6.0	29.0	
total	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5.5	9	47	47	9	47	47	1	5	5	0	0	0	0	0	0	19	100	nd
	6.5	3	23	42	9	69	45	1	8	6	0	0	1	0	0	6	13	100	100
	7.5	29	56	51	10	19	36	3	6	6	1	2	1	9	17	7	52	100	100
	8.5	19	73	51	5	19	21	1	4	20	0	0	1	1	4	7	26	100	100
	9.5	na	na	52	na	na	22	na	na	22	na	na	0	na	na	4	na	na	100
	10.5	6	30	30	5	25	25	8	40	40	0	0	0	1	5	5	20	100	100
	11.5	na	na		na	na		na	na		na	na		na	na		na	na	
	mean	9.4	32.8		5.4	25.7		2.0	8.9		0.1	0.3		1.6	3.7		18.6	100	

HI-3		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	5.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd				na	na	nd
	6.5	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
front	7.5	0	0	0	0	0	0	2	12	4	2	12	4				4	24	8
	8.5	0	0	0	0	0	0	0	0	4	0	0	4				0	0	8
	9.5	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
	10.5	0	0	0	0	0	6	0	0	0	0	0	0				0	0	6
	11.5	0	0		3	19		0	0		0	0					3	19	
	mean	0.0	0.0		0.4	2.7		0.3	1.7		0.3	1.7					1.0	6.0	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd
	6.5	0	0	0	0	0	0	1	6	6	1	6	6	0	0	0	2	11	11
central	7.5	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	4
	8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10.5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	11.5	1	6		0	0		0	0		0	0		0	0		1	6	
	mean	0.1	0.9		0.0	0.0		0.1	0.8		0.1	0.8		0.0	0.0		0.4	2.5	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	5.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd				na	na	nd
	6.5	1	6	6	15	83	83	0	0	0	0	0	0				16	89	89
back	7.5	1	6	4	10	59	81	2	12	4	0	0	0				13	76	88
	8.5	0	0	2	24	100	86	0	0	4	0	0	0				24	100	92
	9.5	0	0	0	30	100	100	0	0	0	0	0	0				30	100	100
	10.5	0	0	0	17	100	92	0	0	0	0	0	0				17	100	92
	11.5	0	0		12	75		0	0		0	0					12	75	
	mean	0.3	1.6		15.4	73.9		0.3	1.7		0.0	0.0					16.0	77.2	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd
	6.5	1	6	6	15	83	83	1	6	6	1	6	6	0	0	0	18	100	100
total	7.5	1	6	4	10	59	81	4	24	10	2	12	6	0	0	0	17	100	100
	8.5	0	0	2	24	100	86	0	0	8	0	0	4	0	0	0	24	100	100
	9.5	0	0	0	30	100	100	0	0	0	0	0	0	0	0	0	30	100	100
	10.5	0	0	2	17	100	98	0	0	0	0	0	0	0	0	0	17	100	100
	11.5	1	6		15	94		0	0		0	0		0	0		16	100	
	mean	0.4	2.5		15.9	76.6		0.7	4.2		0.4	2.5		0.0	0.0		17.4	100	

HI-4		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
	4.5	0	0	2	1	9	2	0	0	2	0	0	2				1	9	12
	5.5	1	5	5	3	16	16	0	0	0	1	5	5				5	26	26
	6.5	na	na	3	na	na	11	na	na	3	na	na	3				na	na	20
front	7.5	0	0	0	1	7	7	1	7	7	0	0	0				2	13	13
	8.5	0	0	0	12	52	52	0	0	0	0	0	0				12	52	52
	9.5	na	na	0	na	na	31	na	na	14	na	na	0				na	na	45
	10.5	0	0	0	2	10	10	6	29	29	0	0	0				8	38	38
	11.5	0	0		1	8		1	8		0	0					2	15	
	mean	0.1	0.5		2.7	22.0		1.0	6.5		0.1	0.5					3.9	29.6	
	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	1	6	6	0	0	0	0	0	0	0	0	0	1	6	6	2	11	11
	4.5	0	0	2	0	0	2	0	0	2	0	0	2	1	9	2	1	9	12
	5.5	1	5	5	0	0	0	0	0	0	1	5	5	1	5	5	3	16	16
	6.5	na	na	6	na	na	0	na	na	3	na	na	3	na	na	6	na	na	18
central	7.5	1	7	7	0	0	0	1	7	7	0	0	0	1	7	7	3	20	20
	8.5	1	4	0	0	0	0	2	9	0	0	0	0	0	0	0	3	13	13
	9.5	na	na	5	na	na	0	na	na	4	na	na	0	na	na	0	na	na	9
	10.5	1	5	5	0	0	0	0	0	0	0	0	0	0	0	0	1	5	5
	11.5	2	15		0	0		1	8		0	0		1	8		4	31	
	mean	0.9	6.4		0.0	0.0		0.4	2.3		0.1	0.5		0.1	0.3		2.1	15.5	
	2.5	na	na		na	na		na	na		na	na					na	na	
	3.5	7	39	39	7	39	39	0	0	0	2	11	11				16	89	89
	4.5	4	36	2	5	45	2	0	0	2	0	0	2				9	82	76
	5.5	1	5	5	10	53	53	0	0	0	0	0	0				11	58	58
	6.5	na	na	16	na	na	46	na	na	0	na	na	0				na	na	62
back	7.5	4	27	27	6	40	40	0	0	0	0	0	0				10	67	67
	8.5	2	9	9	6	26	26	0	0	0	0	0	0				8	35	35
	9.5	na	na	7	na	na	37	na	na	0	na	na	2				na	na	46
	10.5	1	5	5	10	48	48	0	0	0	1	5	5				12	57	57
	11.5	2	15		4	31		0	0		1	8					7	54	
	mean	2.3	16.9		5.1	34.0		0.0	0.0		0.5	4.0					7.9	54.9	
	2.5	na	na		na	na		na	na		na	na		na	na		na	na	
	3.5	8	44	44	7	39	39	0	0	0	2	11	11	1	6	6	18	100	100
	4.5	4	36	2	6	55	2	0	0	2	0	0	2	1	9	2	11	100	100
	5.5	3	16	16	13	68	68	0	0	0	2	11	11	1	5	5	19	100	100
	6.5	na	na	25	na	na	58	na	na	7	na	na	5	na	na	6	na	na	100
total	7.5	5	33	33	7	47	47	2	13	13	0	0	0	1	7	7	15	100	100
	8.5	3	13	0	18	78	0	2	9	0	0	0	0	0	0	0	23	100	100
	9.5	na	na	11	na	na	68	na	na	19	na	na	2	na	na	0	na	na	100
	10.5	2	10	10	12	57	57	6	29	29	1	5	5	0	0	0	21	100	100
	11.5	4	31		5	38		2	15		1	8		1	8		13	100	
	mean	3.3	23.9		7.8	56.0		1.4	8.8		0.7	5.1					13.9	100	

HI-5		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd				na	na	nd
	4.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	5.5	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
	6.5	0	0	1	0	0	0	2	9	5	0	0	0				2	9	6
front	7.5	1	3	1	0	0	0	2	5	5	0	0	0				3	8	6
	8.5	0	0	1	0	0	0	0	0	2	0	0	0				0	0	3
	9.5	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
	10.5	0	0	1	0	0	30	0	0	1	0	0	0				0	0	31
	11.5	1	2		40	89		1	2		0	0					42	93	
	mean	0.2	0.5		4.4	9.9		0.6	1.8		0.0	0.0					5.2	12.2	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd
	4.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	5.5	0	0	0	0	0	0	0	0	0	1	4	4	2	8	8	3	12	12
	6.5	0	0	0	0	0	0	1	5	2	1	5	3	3	14	7	5	23	12
central	7.5	0	0	0	0	0	0	0	0	2	0	0	2	0	0	5	0	0	8
	8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.5	0	0		0	0		0	0		0	0		0	0		0	0	
	mean	0.0	0.0		0.0	0.0		0.1	0.5		0.2	0.9		0.6	2.4		0.9	3.9	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd				na	na	nd
	4.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	5.5	1	4	4	19	76	76	0	0	0	2	8	8				22	88	88
	6.5	2	9	5	13	59	74	0	0	0	0	0	4				15	68	83
back	7.5	1	3	4	34	87	82	0	0	0	1	3	1				36	92	87
	8.5	0	0	1	32	100	96	0	0	0	0	0	1				32	100	97
	9.5	0	0	1	39	100	99	0	0	0	0	0	0				39	100	100
	10.5	1	2	2	42	98	67	0	0	0	0	0	0				43	100	69
	11.5	1	2		2	4		0	0		0	0					3	7	
	mean	0.7	2.2		20.1	58.3		0.0	0.0		0.3	1.2					21.1	61.7	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd	na	na	nd
	4.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	5.5	1	4	4	19	76	76	0	0	0	3	12	12	2	8	8	25	100	100
	6.5	2	9	6	13	59	74	3	14	6	1	5	6	3	14	7	22	100	100
total	7.5	2	5	5	34	87	82	2	5	6	1	3	2	0	0	5	39	100	100
	8.5	0	0	2	32	100	96	0	0	2	0	0	1	0	0	0	32	100	100
	9.5	0	0	1	39	100	99	0	0	0	0	0	0	0	0	0	39	100	100
	10.5	1	2	2	42	98	97	0	0	1	0	0	0	0	0	0	43	100	100
	11.5	2	4		42	93		1	2		0	0		0	0		45	100	
	mean	0.9	2.8		24.6	68.1		0.7	2.3		0.6	2.1		0.6	2.4		27.2	100	

HI-6		Manner																	
		Stops			Fric/trill			Glides			Nasals			Laterals			Total		
Place	Age (m)	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run	Abs.	%	Run
	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	5.5	0	0	0	0	0	0	1	6	6	0	0	0				1	6	6
	6.5	1	2	2	22	47	17	1	2	3	0	0	0				24	51	22
front	7.5	1	5	5	1	5	5	0	0	0	0	0	0				2	10	10
	8.5	na	na	3	na	na	3	na	na	14	na	na	6				na	na	24
	9.5	0	0	0	0	0	0	5	28	28	2	11	11				7	39	39
	10.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	11.5	na	na		na	na		na	na		na	na					na	na	
	mean	0.3	1.0		3.3	7.4		1.0	5.1		0.3	1.6					4.9	15.1	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5.5	3	17	17	0	0	0	0	0	0	4	22	22	1	6	6	8	44	44
	6.5	6	13	11	0	0	0	0	0	3	3	6	21	0	0	4	9	19	40
central	7.5	1	5	5	0	0	0	2	10	10	7	35	35	1	5	5	11	55	55
	8.5	na	na	22	na	na	0	na	na	11	na	na	20	na	na	5	na	na	58
	9.5	7	39	39	0	0	0	2	11	11	1	6	6	1	6	6	11	61	61
	10.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	11.5	na	na		na	na		na	na		na	na		na	na		na	na	
	mean	2.4	10.5		0.0	0.0		0.6	3.0		2.1	9.9		0.4	2.3		5.6	25.7	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd					nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd				nd	nd	nd
	5.5	4	22	22	4	22	22	1	6	6	0	0	0				9	50	50
	6.5	2	4	9	11	23	27	0	0	2	1	2	1				14	30	38
back	7.5	0	0	0	7	35	35	0	0	0	0	0	0				7	35	35
	8.5	na	na	0	na	na	18	na	na	0	na	na	0				na	na	18
	9.5	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
	10.5	na	na	na	na	na	na	na	na	na	na	na	na				na	na	na
	11.5	na	na		na	na		na	na		na	na					na	na	
	mean	0.9	3.8		3.1	11.5		0.1	0.8		0.1	0.3					4.3	16.4	
	2.5	nd	nd		nd	nd		nd	nd		nd	nd		nd	nd		nd	nd	
	3.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	4.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5.5	7	39	39	4	22	22	2	11	11	4	22	22	1	6	6	18	100	100
	6.5	9	19	23	33	70	44	1	2	8	4	9	22	0	0	4	47	100	100
total	7.5	2	10	10	8	40	40	2	10	10	7	35	35	1	5	5	20	100	100
	8.5	na	na	24	na	na	20	na	na	24	na	na	26	na	na	5	na	na	100
	9.5	7	39	39	0	0	0	7	39	39	3	17	17	1	6	6	18	100	100
	10.5	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
	11.5	na	na		na	na		na	na		na	na		na	na		na	na	
	mean	3.6	15.3		6.4	18.9		1.7	8.9		2.6	11.8		0.4	2.3		14.7	100	

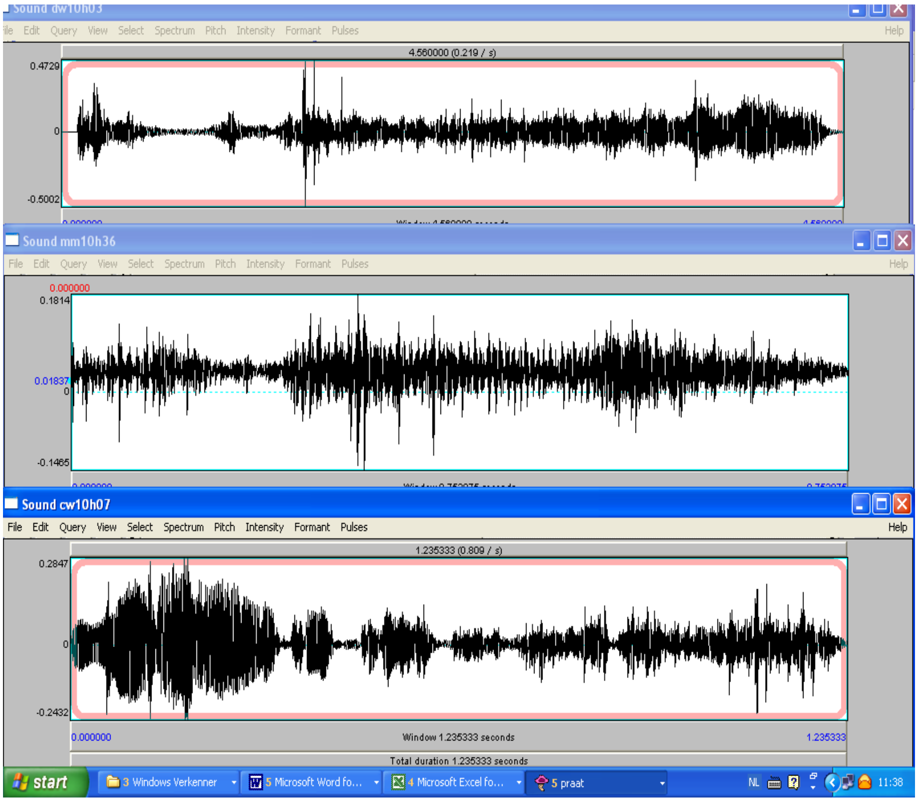


Utterance with front stop of NH-1 at 6.5 months of age

Utterance with dental stop of NH-3 at 10.5 months of age

Utterance with front nasal of NH-2 at 11.5 months of age

Appendix Figure A8.2 Examples of place and manner of articulation utterances of three NH infants



Utterance with back fricative of HI-3 at 10.5 months of age

Utterance with back fricative of HI-4 at 10.5 months of age

Utterance with back fricative of HI-5 at 10.5 months of age

Appendix Figure A8.3 Examples of utterances with back fricative of three different HI subjects at 10.5 months of age.

Appendix Table A9.1. Overview of individual data of the six NH infants from Chapters 5, 6, 7 and 8. Nr. criteria is the number of criteria that are met for the most produced pattern. Stage=most often produced pattern for a specific subject in a specific month. I=Initial stage, C=cooing stage, VArt=Variegated Articulation, VPho=Variegated Phonation, B1=Babbling 1, B2=Babbling 2. The grey cells are the correct criteria for that stage.

2.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	34	41	68	122	38	62
Utt. duration	479	695	525	736	470	655
Mean F0	240	332	297	318	253	319
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	8	33	7	22	1	3
Nr. categories	2	4	2	2	0	1
%Back	na	91	na	95	na	na
%Centr	na	6	na	0	na	na
%Front	na	3	na	5	na	na
Nr. of Babbles	0	0	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr Criteria	5	3	5	4	5	5
Stage	I	C	I	C	I	I

3.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	96	49	83	56	61	116
Utt. duration	1060	1401	1602	1457	1708	1417
Mean F0	320	301	411	320	249	363
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	21	44	21	5	15	33
Nr. categories	2	4	3	2	4	3
%Back	90	57	48	na	60	82
%Centr	5	9	5	na	7	12
%Front	5	34	48	na	33	6
Nr. of Babbles	0	0	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	5	2	3/2	2	4	5
Stage	C	VArt	C/VArt	I/VPho	VArt	C

4.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	176	81	151	123	50	62
Utt. duration	1217	941	917	821	997	841
Mean F0	286	289	431	601	320	373
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	18	49	33	5	9	4
Nr. categories	2	6	2	1	2	0
%Back	100	63	3	na	na	na
%Centr	0	6	3	na	na	na
%Front	0	31	94	na	na	na
Nr. of Babbles	0	0	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	5	4	3	4	2	3
Stage	C	VArt	VArt	VPho	VPho	VPho

5.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	89	52	51	92	95	73
Utt. duration	965	983	972	674	776	857
Mean F0	380	313	491	581	235	369
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	32	38	8	12	12	11
Nr. categories	4	3	2	3	4	2
%Back	69	50	na	42	42	64
%Centr	13	0	na	17	17	27
%Front	19	50	na	42	42	9
Nr. of Babbles	1	0	2	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	3	2	1	3	4	2/2
Stage	VArt	VArt	B1	VArt	VArt	Vart/VPho

6.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	132	64	60	40	109	135
Utt. duration	557	907	904	596	1582	511
Mean F0	321	406	406	483	278	291
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	13	21	12	1	31	2
Nr. categories	3	4	4	0	3	0
%Back	38	57	75	na	3	na
%Centr	31	5	17	na	0	na
%Front	31	38	8	na	97	na
Nr. of Babbles	3	0	1	0	3	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	1	3/2	2	3	1	3
Stage	B1	VArt/Vpho	VArt	VPho	B1	VPho

7.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	135	77	152	94	50	70
Utt. duration	640	1182	1019	716	803	1127
Mean F0	386	386	477	378	370	355
Nr.Var&Com	9	6	8	4	13	9
Nr. artic. utt.	17	39	26	26	11	20
Nr. categories	2	2	5	5	4	2
%Back	24	8	12	27	36	5
%Centr	18	0	23	12	18	15
%Front	59	92	65	62	45	80
Nr. of Babbles	1	13	0	2	0	6
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	3	1	4	1	3/2	1
Stage	VArt	B1	VArt	B1	VArt/VPho	B1

8.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	82	80	121	62	58	28
Utt. duration	752	548	1225	1301	583	1509
Mean F0	405	334	358	405	338	364
Nr.Var&Com	3	3	8	8	2	18
Nr. artic. utt.	34	22	33	34	33	7
Nr. categories	8	4	7	4	5	2
%Back	15	9	36	24	36	na
%Centr	44	45	39	71	21	na
%Front	41	45	24	6	42	na
Nr. of Babbles	8	5	6	17	2	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	1	1	1	1	1	3
Stage	B1	B1	B1	B1	B1	VPho

9.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	208	62	41	94	70	na
Utt. duration	702	695	1439	920	1041	na
Mean F0	324	361	447	340	379	na
Nr.Var&Com	2	4	12	4	9	na
Nr. artic. utt.	35	38	17	25	27	na
Nr. categories	5	6	5	5	7	na
%Back	51	3	47	4	15	na
%Centr	6	50	29	48	30	na
%Front	43	47	24	48	56	na
Nr. of Babbles	0	11	2	5	4	na
Nas.Babbles	0	3	0	2	3	na
Nr. Criteria	4	1	1	1	1	
Stage	VArt	B2	B1	B2	B2	na

10.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	89	78	85	29	129	na
Utt. duration	899	694	610	679	814	na
Mean F0	345	436	395	347	336	na
Nr.Var&Com	17	7	9	2	4	na
Nr. artic. utt.	14	26	19	21	40	na
Nr. categories	4	4	3	3	5	na
%Back	14	12	0	10	0	na
%Centr	43	85	89	48	88	na
%Front	43	4	11	43	13	na
Nr. of Babbles	0	1	2	6	8	na
Nas.Babbles	0	0	0	0	3	na
Nr. Criteria	3	3	1	1	1	
Stage	VArt	VArt	B1	B1	B2	na

11.5 months	NH-1	NH-2	NH-3	NH-4	NH-5	NH-6
Nr. utterances	84	66	120	61	55	28
Utt. duration	975	625	429	840	928	1287
Mean F0	288	334	449	354	330	422
Nr.Var&Com	5	1	6	3	8	8
Nr. artic. utt.	22	27	20	41	27	12
Nr. categories	4	8	4	1	4	3
%Back	0	7	0	0	7	0
%Centr	32	56	70	95	70	25
%Front	68	37	30	5	22	75
Nr. of Babbles	5	5	2	10	9	11.3[1]
Nas.Babbles	3	1	1	1	7	8.1[1]
Nr. Criteria	1	1	1	1	1	1
Stage	B2	B1/(B2)	B1/(B2)	B1/(B2)	B2	B2

[1] Corrected data, since the number of utterances in this recording was only 31 instead of 50

Appendix Table A9.2. Overview of individual data of the six HI infants from Chapters 5, 6, 7 and 8.
Nr. criteria is the number of criteria that are met for the most produced pattern.
Stage=most often produced pattern for a specific subject in a specific month.
I=Initial stage, C=cooing stage, VArt=Variegated Articulation, VPho=Variegated Phonation, B1=Babbling 1, B2=Babbling 2. The grey cells are the correct criteria for that stage.

2.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	65	na	na	82	na	na
Utt. duration	584	na	na	606	na	na
Mean F0	309	na	na	256	na	na
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	1	na	na	6	na	na
Nr. categories	0	na	na	2	na	na
%Back	na	na	na	na	na	na
%Centr	na	na	na	na	na	na
%Front	na	na	na	na	na	na
Nr. of Babbles	0	na	na	na	na	na
Nas.Babbles	0	na	na	na	na	na
Nr. Criteria	5			4		
Stage	I	na	na	I	na	na

3.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	170	na	na	103	63	na
Utt. duration	868	na	na	885	772	na
Mean F0	332	na	na	306	389	na
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	4	na	na	18	8	na
Nr. categories	1	na	na	3	2	na
%Back	na	na	na	89	na	na
%Centr	na	na	na	11	na	na
%Front	na	na	na	0	na	na
Nr. of Babbles	0	na	na	0	0	na
Nas.Babbles	0	na	na	0	0	na
Nr. Criteria	4/3			5	4/3	
Stage	I/VPho	na	na	C	I/VPho	na

4.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	78	na	na	89	163	na
Utt. duration	1231	na	na	1047	769	na
Mean F0	303	na	na	398	462	na
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	13	na	na	11	3	na
Nr. categories	1	na	na	2	1	na
%Back	77	na	na	82	na	na
%Centr	15	na	na	9	na	na
%Front	8	na	na	9	na	na
Nr. of Babbles	0	na	na	0	0	na
Nas.Babbles	0	na	na	0	0	na
Nr. Criteria	4			5	4	
Stage	C	na	na	C	VPho	na

5.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI
Nr. utterances	134	169	106	24	162	214
Utt. duration	1247	1044	1786	850	910	824
Mean F0	358	334	401	306	396	390
Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	5	19	7	19	25	18
Nr. categories	1	4	3	2	3	4
%Back	na	53	na	58	88	50
%Centr	na	0	na	16	12	44
%Front	na	47	na	26	0	6
Nr. of Babbles	1	0	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	4	2	2	2/2	5	3
Stage	VPho	VArt	VPho	C/V	C	VArt

6.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	72	231	149	115	118	262
Utt. duration	1942	1075	617	722	806	877
Mean F0	393	449	398	454	341	375
Nr. Nr.Var&Com	na	na	na	na	na	na
Nr. artic. utt.	2	13	18	9	22	47
Nr. categories	0	2	1	3	4	5
%Back	na	77	89	na	68	35
%Centr	na	8	11	na	23	55
%Front	na	15	0	na	9	10
Nr. of Babbles	0	0	0	0	0	0
Nas.Babbles						
Nr. Criteria	3	5	5	3	4	4
Stage	VPho	C	C	VPho	VArt	VArt

7.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	98	106	86	78	151	110
Utt. duration	1387	1303	1111	915	1090	650
Mean F0	296	374	445	284	412	427
Nr.Var&Com	22	5	9	12	4	1
Nr. artic. utt.	2	52	17	15	39	20
Nr. categories	0	5	4	2	2	3
%Back	na	19	76	67	92	35
%Centr	na	56	0	20	0	55
%Front	na	25	24	13	8	10
Nr. of Babbles	0	20	1	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	4	1	3	2/2	5	3
Stage	VPho	B1	VArt	VArt/VPho	C	VArt

8.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	169	146	218	72	151	133
Utt. duration	1032	1210	970	842	843	599
Mean F0	334	476	391	284	469	416
Nr.Var&Com	28	7	15	8	8	4
Nr. artic. utt.	1	26	24	23	32	7
Nr. categories	0	2	1	4	1	2
%Back	na	19	100	35	100	na
%Centr	na	77	0	13	0	na
%Front	na	4	0	52	0	na
Nr. of Babbles	0	14	0	0	0	1
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	4		5/4	3	5	3
Stage	VPho	B1	C/VPho	VArt	C	VPho

9.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	81	205	205	52	120	225
Utt. duration	1232	556	823	726	837	324
Mean F0	335	739	354	270	381	426
Nr.Var&Com	19	35	18	13	1	2
Nr. artic. utt.	0	4	30	4	39	18
Nr. categories	0	1	1	1	1	4
%Back	na	na	100	na	100	0
%Centr	na	na	0	na	0	61
%Front	na	na	0	na	0	39
Nr. of Babbles	0	1	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	4	5	5/3	3	5	5
Stage	VPho	VPho	C/VPho	VPho	C	VArt

10.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	78	222	90	94	164	126
Utt. duration	1244	1260	1062	958	498	711
Mean F0	322	663	358	396	383	409
Nr.Var&Com	14	23	19	14	1	15
Nr. artic. utt.	0	20	17	21	43	4
Nr. categories	0	5	1	3	1	1
%Back	na	35	100	57	100	na
%Centr	na	55	0	5	0	na
%Front	na	10	0	38	0	na
Nr. of Babbles	0	5	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	3	1	5/3	4/3	5	5
Stage	VPho	B1	C/VPho	VArt/VPho	C	VPho

11.5 months	HI-1	HI-2	HI-3	HI-4	HI-5	HI-6
Nr. utterances	79	244	163	53	152	65
Utt. duration	1053	989	874	892	628	896
Mean F0	301	527	413	320	326	512
Nr.Var&Com	17	31	23	24	0	18
Nr. artic. utt.	1	7	16	13	45	8
Nr. categories	0	1	2	3	2	3
%Back	na	na	75	54	7	na
%Centr	na	na	6	31	0	na
%Front	na	na	19	15	93	na
Nr. of Babbles	0	0	0	0	0	0
Nas.Babbles	0	0	0	0	0	0
Nr. Criteria	3	5	5/3	4	3	3
Stage	VPho	VPho	C/VPho	VArt	VArt	VPho

Summary

This thesis is an attempt to answer the question of whether hearing has influence on the vocalization development in infants and, if that is the case, from what age onwards. In other words: how and from what age onwards do vocalizations (all speech-like sounds before the first word productions) of deaf and normally hearing infants differ? In order to be able to answer this question, we studied the vocalization development of two groups of infants longitudinally within the first year of life: six deaf infants (with a hearing loss over 90 dB PTA) and six normally hearing infants. The normally hearing infants were all studied from the age of 2.5 months onwards, while the deaf infants were studied from different ages onwards (mainly dependent of the age of diagnosis); two infants from 2.5 months onwards, one from 3.5 months onwards and three from 5.5 months onwards. All infants were studied until the age of 11.5 months.

In Chapter 1 we give a short introduction of this study. We conclude that several studies have indicated a clear relationship between the vocalization development (before the first word productions) and the later speech and language development (from the first word productions), which underlines the importance of studies on the vocalization development of infants.

In Chapter 2 we gave a description of different types of hearing loss related to different causes of hearing impairment and their prevalence. The goal of early detection of hearing loss and early intervention is also discussed. Several methods for early detection of hearing impairment and audiometry were described, as well as intervention methods for infants with severe hearing loss, as used by the seven early intervention teams in the Netherlands.

We described the stages in vocalization development in normally hearing infants in Chapter 3, based on previous studies. Normally about five stages are described, of which ‘gooing’ and ‘babbling’ are the most well known stages. It is not exactly known, however, how and why these stages in the vocalization development emerge and what the influence of hearing is on these stages. For that reason, we first describe the development of several other aspects within the first year of life, in order to possibly explain these stages. Examples of these aspects are anatomical, physiological, neurological development of the speech organs, the parent-infant interaction and language input, the cognitive development, the development of auditory speech and language processing and the development of internal feedback. On the other hand, it can be expected that several of these factors are affected by a hearing loss directly or indirectly. This implies the expectation that hearing, via these aspects, influences the vocalization development of infants.

Next we described previous studies on vocalizations of deaf infants. There is some, but unfortunately not very systematic and consistent information available regarding vocalizations of deaf infants, which justifies a new, systematic performed study.

Based on the expected relationship between hearing and vocalization development, in interaction with other factors that might influence vocalization development in infants, we propose a model for vocalization development. This model can be tested by studying the vocalization development in deaf infants, on the basis of the research questions of this study, which are pointed out at the end of Chapter 3.

In Chapter 4 we give a description of the methodology for our study, including audiometric characteristics of the deaf infants. Also an overview was shown of all parameters studied, such as numbers of utterances, utterance duration, fundamental frequency, types of articulation and phonation, number of syllables, utterance structure and place and manner of articulation.

The main question addressed in Chapter 5 was: do deaf infants differ from normally hearing infants with respect to their number of utterances? Our results indicated significant differences in number of sound productions between the two groups, namely more utterances are produced by deaf infants compared to normally hearing infants. This difference was found even within the first half year of life, and started around the period turn-taking normally starts in normally hearing infants. These findings suggest a relationship between the high amount of vocalizations in deaf infants and an abnormal turn-taking process with their mothers. This finding is confirmed by another finding, the number of spoken utterances produced by the mothers seemed to be influenced by a hearing loss of their children. The mothers of the deaf infants produced on average fewer utterances than the mothers of the normally hearing infants. This might be explained by an attempt in mothers of deaf infants to pertain a normal turn-taking process with their infants, although other explanations might also be possible.

In Chapter 6 some supra-segmental acoustical measurements of the vocalizations of deaf and normally hearing infants are described. The parameters studied were the utterance duration, mean fundamental frequency, minimal and maximal fundamental frequency, variability of fundamental frequency in terms of range and standard deviation, and number of voiceless utterances. The results indicate significant differences in sound productions between deaf and normally hearing infants, especially with respect to utterance duration even as early as 3.5 months of age. All normally hearing infants produced a duration peak around 3.5 months, that was absent in the three deaf infants studied in that month. Moreover, the normally hearing infants produced shorter utterances at 4.5 months compared to 3.5 months, which was not the case for the deaf infants, while we found longer utterances produced by the deaf infants than the normally hearing infants at 5.5 months. These results showed a clear effect of hearing on utterance duration already within the first months of life. It might be the case that the shorter utterances in normally hearing infants at 4.5 months compared to 3.5 months are influenced by the start of the turn-taking process, that might be absent or delayed in deaf infants.

In Chapter 7 we studied the phonation types (such as variegated) and articulation types (with consonant-like productions) found in the vocalizations of deaf and normally hearing infants. Towards the end of the first year several significant differences were found between the two groups with respect to phonation. In the group with deaf infants we found e.g. a significant higher number of utterances with variegated phonation, such as variation in the intonation patterns or extreme high or low pitch, as well as, a significant higher number of voiceless utterances.

In the types structure of the articulated utterances, differences were also found between deaf and normally hearing infants, as well as in the number of syllables. A clear difference is that all normally hearing infants started to babble between 5.5 months and 7.5 months of age, while this was not the case in the deaf infants studied. Only one deaf infant started babbling at 7.5 months of age. Strikingly, also most other deaf infants produced separated syllables during their utterances, but this group used more often glottal obstructions for syllabification, that is, with the vocal cords. One explanation for this phenomenon can be that deaf infants have problems in the coordination of both articulation and phonation of their vocalizations.

In Chapter 8 we focus on the utterances with one or more articulation movements. The two groups of infants clearly differed in number of different place- manner combinations from 6.5-8.5 months onwards. The deaf infants studied produced clearly less variation in their articulated sound productions compared to the normally hearing infants. The deaf infants produced mainly back fricatives (e.g. [x]) and trills' e.g. [Я]) during the whole period studied, from the first months of life until the end of the first year.

In the vocalizations of the normally hearing infants we find, after the start with back fricatives and back trills within the first months of life, two clear developmental changes during the first year of life. First, around six months new consonant categories emerge with front articulations such as front stops (e.g. [b]) and front glides (e.g. [w]). Secondly, at the end of the first year of life, we find a high percentage of central articulations (e.g. [n]). When comparing our data of the normally hearing infants with that of Dutch adults, similarities appear at the end of the first year of life. From these findings it becomes clear that the environmental language influences the consonant productions of normally hearing infants in that period (and thus before the first word productions). We do not see a similar effect in the vocalizations of the deaf infants. Therefore we conclude that (a lack of) auditory feedback influences place and manner of articulation already around six months, while the effect of the environmental language and early phonology (probably mainly on place of articulation) emerges a few months later.

We discussed in Chapter 9 the combined findings for both groups of Chapters 5, 6, 7 and 8, related to the model proposed in Chapter 3.

Firstly we concluded that the data for the normally hearing infants show a development in several stages within the first year of life similarly to the results of previous studies on this topic. The description of the stages are somewhat adjusted to our own findings and are called the 'initial stage', the 'cooing stage', the variegated vocalization stage', the 'babbling stage 1' and 'babbling stage 2' (babbling with nasals, as in [mama]. The variegated vocalization stage has two different patterns: 'variegated articulation' and 'variegated phonation'.

Next, we related the data of the deaf infants to the stages of normally hearing infants. This data showed that the deaf infants produced some of these stages, but not necessarily in the same order. It is also possible that some stages are absent or delayed compared to normally hearing infants during the first year of life. For instance, it seems that in some deaf infants the 'variegated phonation' starts before the cooing stage, thus in reversed order compared to the normally hearing infants studied. An explanation can be that the cooing stage needs a more complex coordination of the articulation and that this is more influenced by a hearing loss compared to the stage with variegated phonation.

Moreover, the deaf infants produced some types of vocalizations that are affected by the hearing loss, but possibly not exactly related to the vocalization stages. These types of utterances can be seen as special phenomena typically produced by deaf infants. Examples are the higher number of utterances, the higher number of voiceless utterances and the higher number with variegated phonation. These special phenomena can be explained, in several ways, by the influence of a hearing loss.

Explanations for individual differences, for instance the influence of a possible residual hearing on the vocalization development, are discussed. Next, our proposed model in Chapter 3 on the basis of previous literature, is adjusted to our own findings and presented at the end of Chapter 9.

Next possible practical implications of our findings are discussed. One may think of the development of a diagnostic and/or prognostic tool to investigate the vocalization development of deaf infants (with or without cochlear implants). Suggestions for practical implications of the results of the present study for intervention programs on the communication development and the early speech and language development are also proposed. Next, some suggestions for further research were discussed.

Main conclusion of this dissertation:
Our findings suggest that, already within the first half year of life, the vocalization development of deaf and normally hearing infants differs substantially. Sound production in infants is not solely determined by motor development and other maturational factors, but also by the strong influence of hearing.

Samenvatting

Ontwikkeling van vocalizaties van dove en normaal horende zuigelingen

Deze dissertatie heeft als doel de vraag te beantwoorden of gehoor invloed heeft op de vocalizatieontwikkeling van zuigelingen en in dat geval, vanaf welke leeftijd. Met andere woorden: in hoeverre en vanaf welke leeftijd verschillen de vocalizaties (alle spraak-achtige geluiden vóór de eerste woordproducties) van dove en normaal horende zuigelingen? Om deze vraag te beantwoorden bestudeerden wij de vocalizatieontwikkeling van twee groepen zuigelingen longitidunaal binnen het eerste levensjaar: zes dove baby's (met een gehoorverlies van 90 dB PTA of hoger) en zes normaal horende baby's. De normaal horende zuigelingen werden allen bestudeerd vanaf een leeftijd van 2.5 maand en de dove zuigelingen vanaf maximaal 5.5 maand; twee dove kinderen vanaf 2.5 maand, één vanaf 3.5 maand en drie kinderen vanaf 5.5 maand. De vocalizaties van alle kinderen zijn bestudeerd tot de leeftijd van 11.5 maand.

In hoofdstuk 1 wordt er een korte introductie op dit onderwerp gegeven. We concluderen dat verschillende onderzoeken een duidelijke relatie tussen de vocalizatieontwikkeling (voor de eerste woordproductie) en de latere spraak-taalontwikkeling (vanaf de eerste woordproductie) indiceren, daarmee het belang van onderzoek naar de vocalizatieontwikkeling van zuigelingen benadrukkend.

In hoofdstuk 2 wordt er een beschrijving van verschillende typen gehoorverliezen gegeven, gerelateerd aan verschillende oorzaken en de prevalentie. Ook wordt het doel van vroege detectie van gehoorstoornissen en vroege interventie besproken. Verschillende screenings- en audiometrische methoden voor vroege detectie van gehoorstoornissen worden beschreven, evenals gebruikelijke interventiemethoden voor zuigelingen met ernstige gehoorstoornissen, zoals toegepast bij de zeven vroegbegeleidingsdiensten in Nederland.

Hoofdstuk 3 begint met een beschrijving van de stadia in de vocalizatieontwikkeling van normaal horende zuigelingen, gebaseerd op eerdere onderzoeken. Er worden meestal zo'n vijf stadia beschreven, waarvan 'gooing' en 'brabbelen', de bekendste zijn. Het is echter niet geheel bekend hoe en waarom deze stadia in de vocalizatieontwikkeling ontstaan en wat de invloed van gehoor is op deze stadia. Om deze reden wordt allereerst de ontwikkeling van een aantal andere aspecten beschreven binnen het eerste levensjaar, om daarmee mogelijk het ontstaan van de stadia te kunnen verklaren. Voorbeelden van deze aspecten zijn de anatomische, fysiologische en neurologische ontwikkeling van de spraakorganen, de ouder-kind interactie en taalaanbod, de cognitieve ontwikkeling, de ontwikkeling van de auditieve spraak- en taalverwerking en ontwikkeling van de interne feedback. Aan de andere kant, is het te verwachten dat verschillende van deze aspecten direct of indirect beïnvloed worden door een ernstig gehoorverlies. Daarmee verwachten we dat het gehoor, via deze aspecten, van invloed is op de vocalizatieontwikkeling van zuigelingen.

Vervolgens beschrijven we de resultaten van eerdere onderzoeken naar vocalizaties van dove zuigelingen. Er zijn enkele, maar helaas weinig systematische, gegevens bekend over de vocalizatieontwikkeling van dove baby's binnen het eerste levensjaar, waardoor een nieuw, systematisch uitgevoerd onderzoek gerechtvaardigd is.

Gebaseerd op de verwachte relatie tussen gehoor en vocalizatieontwikkeling, in interactie met andere aspecten welke mogelijk invloed hebben op de vocalizatieontwikkeling van zuigelingen, doen we een voorstel voor een model voor vocalizatieontwikkeling. Dit model kan geëvalueerd worden door de vocalizatieontwikkeling van dove zuigelingen te bestuderen, aan de hand van de 13 onderzoeksvragen welke aan het einde van hoofdstuk 3 aangegeven zijn.

In hoofdstuk 4 geven we een beschrijving van de methodologie van ons onderzoek, inclusief audiometrische gegevens van de dove zuigelingen. Ook wordt er een overzicht gegeven van alle bestudeerde parameters, uitgewerkt in de hoofdstukken 5, 6, 7 en 8; zoals aantal uitingen, uitingsduur, F0, typen articulatie en fonatie (stemgeving), aantal syllaben (lettergrepen), structuur van de uitingen en plaats en manier van articulatie.

De hoofdvraag in hoofdstuk 5 is: verschillen dove zuigelingen van normaal horende zuigelingen wat betreft hun aantal geproduceerde uitingen? Onze resultaten indiceren een significant verschil in aantal geluidsproducties tussen de twee groepen, er worden namelijk *meer* uitingen geproduceerd door dove zuigelingen dan door normaal horende zuigelingen. Het verschil wordt significant omstreeks 4.5 maand; omstreeks de periode dat beurtgedrag bij normaal horende zuigelingen begint. Deze bevindingen suggereren een relatie tussen het hoge aantal vocalizaties van dove kinderen en een afwijkend beurtgedrag met hun moeders. Dit wordt bevestigd door een andere bevinding; het aantal gesproken uitingen van de moeders lijkt beïnvloed te worden door een gehoorverlies van hun kinderen. De moeders van de dove kinderen produceren gemiddeld minder uitingen dan de moeders van de normaal horende kinderen. Dit kan worden verklaard door een poging van de moeders van dove kinderen om een normaal beurtgedrag in stand te houden ondanks het hoge aantal uitingen van hun kinderen, hoewel ook andere verklaringen mogelijk zijn.

In hoofdstuk 6 worden de resultaten van verschillende akoestische metingen aan suprasegmentele aspecten van de uitingen van de dove en normaal horende proefpersonen beschreven. De bestudeerde parameters zijn: uitingsduur, gemiddelde F0 (toonhoogte), minimale en maximale F0, F0 variatie binnen de uitingen a.h.v. de range en standaard deviatie, en aantal stemloze uitingen. De resultaten geven aan dat er significante verschillen zijn in verschillende akoestisch gemeten geluidsproducties tussen dove en horende zuigelingen, zelfs al op een leeftijd van

3.5 maand. Alle zes normaal horende zuigelingen produceerden een duurpiek omstreeks 3.5 maand, welke niet aanwezig was bij de drie dove zuigelingen bestudeerd in deze periode. Tevens produceerden de normaal horende zuigelingen vervolgens een kortere uitingsduur op een leeftijd van 4.5 maand in vergelijking met 3.5 maand, wat eveneens niet het geval was bij de dove zuigelingen, terwijl deze laatste groep juist langere uitingen produceerden op een leeftijd van 5.5 maand. Deze resultaten geven een duidelijke invloed van gehoor op uitingsduur weer, al binnen de eerste levensmaanden. Het zou het geval kunnen zijn dat de kortere uitingen van de normaal horende zuigelingen van 4.5 maand in vergelijking met 3.5 maand beïnvloed worden door het startende beurtgedrag, dat afwezig of vertraagd zou kunnen zijn bij dove zuigelingen.

In hoofdstuk 7 beschrijven we de vocalizaties in vijf verschillende fonatie-typen en drie verschillende articulatie-typen (met medeklinkerproducties). Aan het einde van het eerste levensjaar worden verscheidene verschillen gevonden tussen de twee groepen betreffende het type fonatie. Er wordt in de groep met dove zuigelingen o.a. een significant hoger aantal uitingen met gevarieerde fonatie gevonden, zoals variatie in de intonatiepatronen of extreem hoge of lage toonhoogte, evenals een significant hoger aantal stemloze uitingen.

Tevens worden er verschillen gevonden in de articulatie-typen en de structuur van de gearticuleerde uitingen, als ook in het aantal syllaben. Een duidelijk verschil is dat alle normaal horende zuigelingen begonnen te brabbelen (bijv. [bababa]) tussen 5.5 en 7.5 maanden, terwijl dit niet het geval was bij de onderzochte dove baby's. Slechts één dove baby begon met brabbelen op een leeftijd van 7.5 maand. Opvallend is bovendien dat de meerderheid van de bestudeerde dove zuigelingen gescheiden syllaben produceren, maar daarvoor met name glottale afsluitingen gebruiken d.m.v de stembanden. Een verklaring hiervoor zou kunnen zijn dat dove zuigelingen problemen hebben met de coördinatie van articulatie en fonatie tijdens hun vocalizaties.

In hoofdstuk 8 beschrijven we de uitingen met één of meer medeklinkerproducties gespecificeerd. De twee groepen zuigelingen verschillen duidelijk in het aantal verschillende medeklinkerproducties vanaf 6.5-8.5 maanden. Dove zuigelingen produceren namelijk duidelijk minder variatie in hun medeklinkers in vergelijking met de normaal horende zuigelingen. De dove zuigelingen produceren vooral achter-fricatieven (bijv. [x] zoals in 'ugge') en achter-trills (bijv. huig-r) gedurende de hele onderzochte periode, vanaf de eerste levensmaanden tot aan het einde van het eerste levensjaar.

In de vocalizaties van de horende zuigelingen zien we, na de start met achter-fricatieven en achter-trills in de eerste levensmaanden, twee duidelijke ontwikkelingen tijdens het eerste levensjaar. Ten eerste ontstaan omstreeks zes maanden nieuwe medeklinkercategorieën met vooral voor-articulaties, zoals voor-stops (bijv. [b]) en voor-glides (bijv. [w]). Daarna zien we aan het einde van het eerste levensjaar een hoog percentage centrale articulaties, zoals met [n]. Bij het vergelijken van de medeklinkerdata van de door ons onderzochte normaal horende zuigelingen met die van Nederlandse volwassenen, zien we overeenkomsten ontstaan aan het einde van het eerste levensjaar. Hieruit blijkt dat de medeklinkerproducties van normaal horende zuigelingen in deze periode (en dus al vóór de eerste woorden) waarschijnlijk worden beïnvloed door de omgevingstaal. We zien een dergelijk effect in het geheel niet in de vocalizaties van de dove zuigelingen. We kunnen dus concluderen dat (een gebrek aan) auditieve feedback al omstreeks zes maanden van invloed is op de plaats en manier van articulatie, terwijl het effect van de taalomgeving en vroege fonologie (waarschijnlijk vooral op plaats van articulatie) vervolgens een paar maanden later ontstaat.

In hoofdstuk 9 worden de bevindingen van beide groepen uit de hoofdstukken 5, 6, 7 en 8 gecombineerd en vervolgens gerelateerd aan het model zoals voorgesteld in hoofdstuk 3.

We concluderen eerst dat de vocalizaties van de normaal horende zuigelingen een ontwikkeling vertonen in een vast en opeenvolgend patroon van vijf verschillende stadia binnen het eerste levensjaar, zoals ook gevonden in eerdere onderzoeken. De stadia zoals door ons gevonden voor de normaal horende zuigelingen worden qua beschrijving iets aangepast aan onze eigen bevindingen en worden de 'initial stage', de 'cooing stage', de 'variegated vocalization stage', de 'babbling stage 1' en de 'babbling stage 2' (brabbelen met nasalen, zoals [mama]) genoemd. De 'variegated vocalization stage' heeft twee verschillende patronen: één met meer variatie op het gebied van de articulatie ('variegated articulation') en één met meer variatie op het gebied van de fonatie ('variegated phonation').

Vervolgens relateren we de data van de dove zuigelingen aan deze stadia. De data toont aan dat de dove zuigelingen vaak ook enkele van deze stadia produceren, maar niet noodzakelijkerwijs in dezelfde volgorde. De stadia kunnen bovendien afwezig zijn of vertraagd ontwikkelen. Het blijkt bijvoorbeeld dat bij een aantal dove baby's het stadium met gevariëerde fonatie begint voordat het 'cooing' stadium begint, dus in omgekeerde volgorde in vergelijking met de onderzochte normaal horende kinderen. Een verklaring hiervoor kan zijn dat het 'cooing' een meer complexe coördinatie van de articulatie vraagt en het gehoor hierop een grotere invloed heeft dan op het stadium met gevarieerde fonatie.

Hiernaast produceren de dove zuigelingen enkele speciale typen vocalizaties die beïnvloed worden door het gehoorverlies, maar niet precies gerelateerd aan de vocalizatiestadia. Deze typen vocalizaties kunnen dus als speciale fenomenen beschouwd worden en typisch geproduceerd worden door dove zuigelingen. Voorbeelden hiervan zijn het hogere aantal uitingen, het hogere aantal stemloze uitingen en het hogere aantal uitingen met gevarieerde fonatie. Deze speciale fenomenen kunnen op verschillende manieren verklaard worden door de invloed van het gehoorverlies.

Enkele verklaringen voor individuele verschillen, zoals de invloed van een mogelijke hoorrest op de vocalizatieontwikkeling, worden vervolgens besproken. Vervolgens is het door ons voorgestelde model uit hoofdstuk 3 op basis van de eerdere literatuur, aan het einde van hoofdstuk 9 aangepast aan de resulaten van ons eigen onderzoek.

Vervolgens worden verschillende mogelijke praktische implicaties van onze bevindingen besproken. Hierbij is te denken aan de ontwikkeling van een diagnostisch en/of prognostisch instrument voor het volgen van de vocalizatieontwikkeling van dove zuigelingen (al dan niet met cochleaire implantaties). Ook worden er suggesties gegeven voor de praktische implicaties van de huidige onderzoeksresulatаten voor interventieprogramma's op het gebied van communicatie- en vroege spraak-taalontwikkeling, zoals uitgevoerd door vroegbegeleidingsdiensten. Eveneens worden er voorstellen voor verder onderzoek gedaan.

Hoofdconclusie van dit proefschrift:
Onze bevindingen suggereren dat de vocalizatieontwikkeling van dove zuigelingen, al binnen het eerste halve levensjaar, sterk verschilt van die van normaal horende zuigelingen. Geluidsproducties van zuigelingen worden niet slechts bepaald door motorische en andere rijpingsfactoren, maar ook door de sterke invloed van het gehoor.

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