



# Prosodic focus acquisition in French early cochlear implanted children

Chadi Farah

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UFR ALSHS  
Pôle Langues, Langage et Cultures  
Département de Sciences du  
Langage

## Prosodic Focus Acquisition in French Early Cochlear Implanted Children



Mémoire de Master II de Recherche  
Sciences du Langage - Théories Linguistiques : Terrain et expérimentation  
(TheLiTex)  
Parcours Linguistique Expérimentale

**Chadi FARAH**

Sous la direction de

Pr Mariapaola D'IMPERIO  
Pr Stéphane ROMAN

Année 2016-2017



*To my Dad, Antoine, my Mom, Fadia, and my brother, Wadih, who were always my support. They are the reason of my success in life...*

*To my lovely wife, Farah, who is always next to me facing all life difficulties. You are the one who makes life easier, you are the one who gives me hope for a great future to our newly built home...*



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## **Abstract**

Speech and hearing are important elements in the action of communication and are interrelated closely. If any of these elements is altered, communication can be affected.

According to the World Health Organization (WHO), hearing impairment and deafness are defined as follows: "Hearing impairment is the inability to hear as well as someone with normal hearing. Hearing impaired people can be hard of hearing or deaf. If a person cannot hear at all, then they have deafness" (WHO, 2017). Their February 2017 updated report, shows that around 32 million children around the world suffer from invalidating hearing impairment (WHO, 2017). The impact of hearing deficiency varies on different levels. On the social and emotional levels, the person affected by hearing impairment risks isolation and exclusion from social life cycle. On the economical level, hearing impairment is estimated by the WHO of having an annual cost of 750 billion international dollars worldwide. It includes health sector costs, educational support costs, loss of productivity, and costs for the society (WHO, 2017).

Cochlear implantation (CI) has been considered as the sole surgery that can replace efficiently a sensorial organ by an electronic device that has been able to progressively restore an almost normal hearing function. This has provided hearing impaired children with a new beginning and almost full communication capabilities (Bruijnzeel, Ziylan, Stegeman, Topsakal, & Grolman, 2016).

Age at implantation is crucial for auditory and speech development in pre-lingually hearing impaired children. Normal function of the central pathways is a requirement for normal development of speech and language skills. Children with hearing loss risk losing these skills. The absence of auditory input hinders normal growth needed to form a functional sensory system. CIs bypass peripheral cochlear damage, stimulating auditory nerve to prevent the detrimental effects of stimulus deprivation (Sharma, Gilley, Dorman, & Baldwin, 2007).

Prosody, the melody of speech, is an important element in communication; in both speech perception and production (D'Imperio, Dittinger, & Besson, 2016; Nygaard, Herold, & Namy, 2009; Speer & Ito, 2009). It is a determinant aspect of speech in order to correctly send a linguistic and paralinguistic message. It is defined as a grammatical component of language including accentuation, phrasing and intonation (Beckman, 1996; D'Imperio et al., 2016).

Among the functions of prosody and accentuation, information structure is responsible for the focus/background separation within an utterance. Rooth in 1985 introduced the idea that each expression comes with two semantic meanings; its regular denotation and a set of alternatives. Prosodic focus or prominence is used to create these alternatives (Rooth, 1985). Where the accent is placed can change according to context and to the message that should be sent to the audience, as well as the real speaker's intentions (Nygaard et al., 2009). Focus can be broad, when focusing on a whole utterance, or narrow when focusing on a word or a segment in an utterance. Narrow focus can be contrastive, when contrasting between different elements, or corrective, when correcting a wrong information. Prosodic focus is acquired progressively with the fine-tuning of communication skills and matures with age.

This is the first study of prosodic focus in early CI French children. Our results show that early CI French speaking children start to produce prosodic focus at the age of 6 years while starting to become adult-like at the age of 7 years. They are better in using prosodic cues to focus in corrective than contrastive narrow focus than broad focus contexts.

## I- State of the art

### Chapter 1: Anatomy and physiology of the inner ear

#### 1.1. Anatomy of the auditory system

The auditory apparatus is divided into two main components the ear and the central nervous system auditory pathways.

The ear is part of the temporal bone and is composed of three compartments; the external, the middle and the inner ear (Fig. 1). Here we will be specifically concerned with the anatomy and functioning of the inner ear, given that it is the locus of the cochlea.

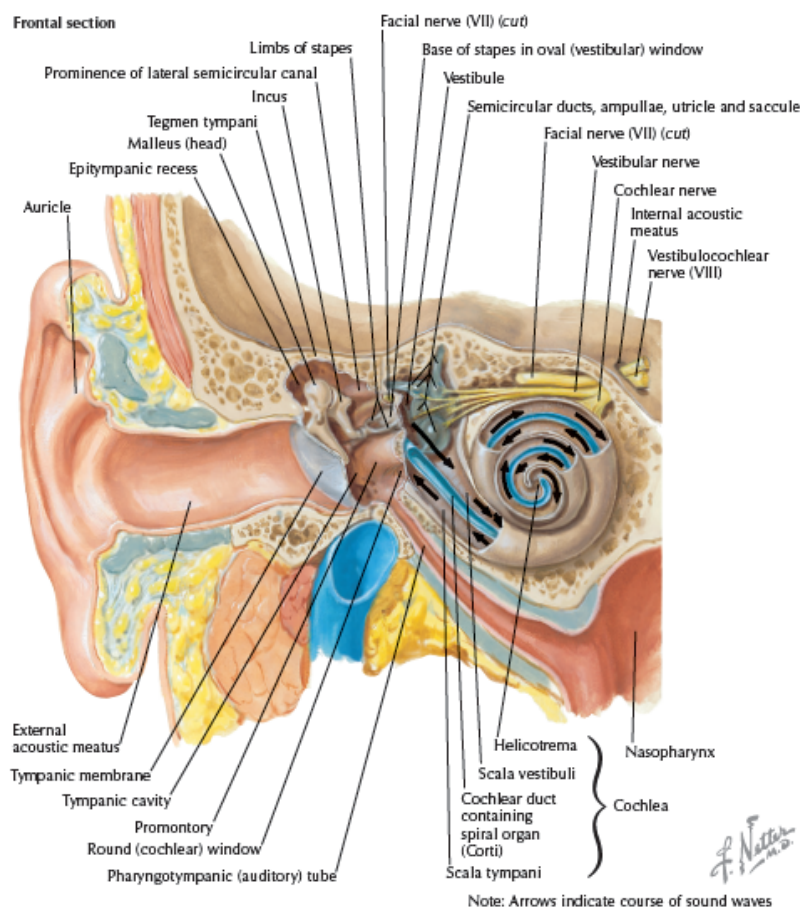


Figure 1: The ear with its three compartments: the external, the middle and the inner ear. (Norton, 2012)

##### 1.1.1. Inner ear (IE)

The IE can be divided into the cochlea; the organ of hearing, and the organs of equilibrium formed by the vestibule, the three semicircular canals (the horizontal, the superior and the posterior semicircular canals) with their associated ducts, the endolymphatic duct and sac, the saccule and the utricle. The oval window opens into the vestibule and the round window membrane opens into the basal turn of the cochlea (in the scala tympani). (Fig. 2-A)

The cochlea lies anterior to the vestibule and consists of two and half turns, with a total average length of 32 mm. Within the bony labyrinth, the cochlea is formed by three fluid-filled

spaces called the scala media (filled with endolymph), the scala tympani and the scala vestibuli (both filled with perilymph) which are connected by the helicotrema at the apex of the cochlea. Scala vestibuli is separated from scala media by the Reissner's (vestibular) membrane and the basilar membrane separates the scala media from the scala tympani (Fig. 2-B). The scala media, where lies the organ of Corti, contains three rows of outer hair cells and one row of inner hair cells. At the apical side of these hair cells, stereocilia are in contact with the tectorial membrane, and the basal sides of these cells are in close contact with afferent nerve fibers of the auditory nerve (Fig. 2-C) (Runge-Samuelson & Friedland, 2015; Staecker & Eshraghi, 2006; Weber & Khariwala, 2014).

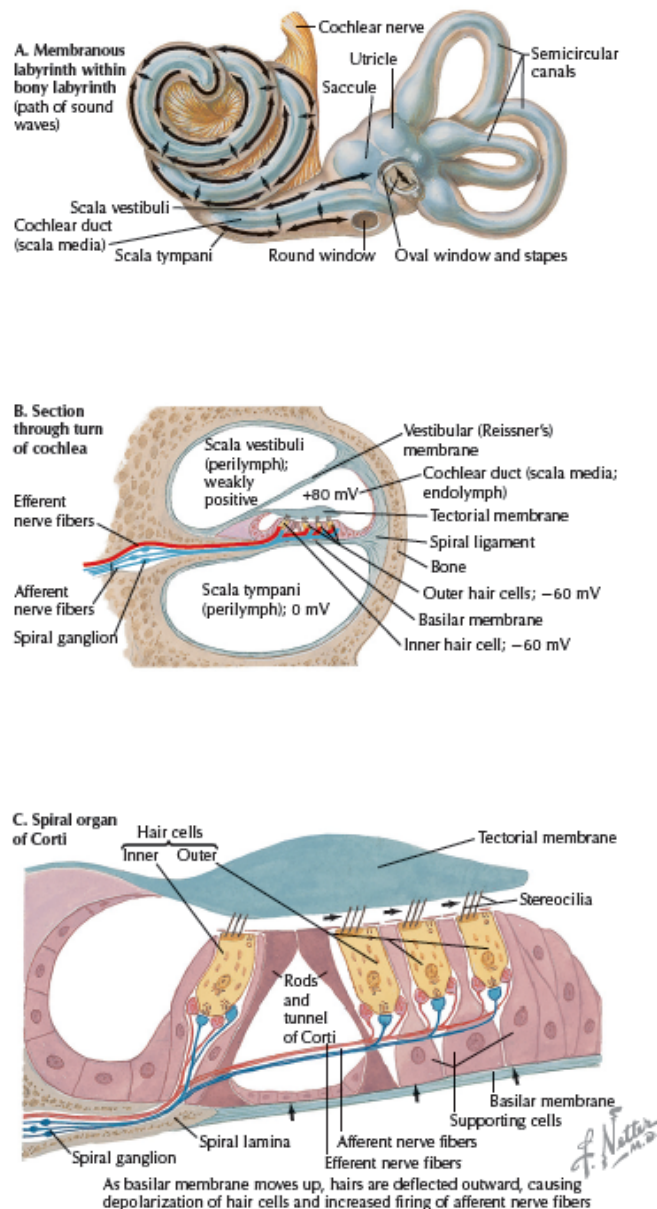


Figure 2: The inner ear: A- The labyrinth; B- Section through turn of cochlea; C- Spiral organ of Corti. (Norton, 2012)

## 1.2. Physiology of the inner ear and central pathways

The external ear funnels the sound into the ear from the external environment and then soundwaves are channeled to the inner ear through the middle ear.

When the sound wave is transmitted through the oval window, a traveling wave is initiated across the scala vestibuli, around the helicotrema, and across the scala tympani toward the round window. The pressure in the scala vestibuli will be higher than the pressure in the scala tympani. This sets up a pressure gradient, which causes the basilar membrane to vibrate (Fig. 3) (Chien & Lee, 2015; Weber & Khariwala, 2014).

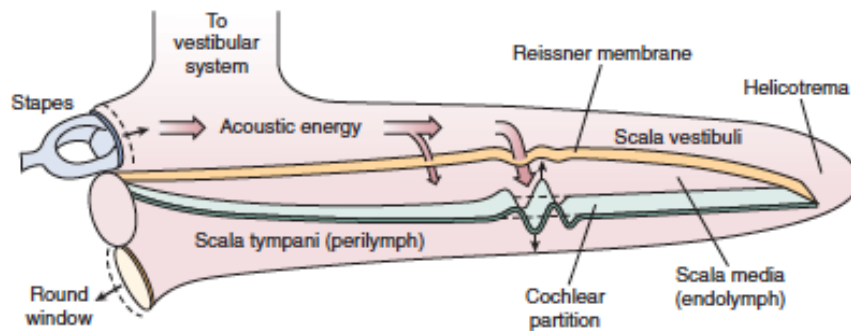


Figure 3: Sound wave propagation in the cochlea. (Chien & Lee, 2015)

Georg von Békésy was the first to describe the physiology of the inner ear and found that the basilar membrane varied in its stiffness along its length, with higher stiffness near the base and lower stiffness near the apex. This property of the basilar membrane allows it to act as a series of frequency filters and to map frequency-specific information, with the higher frequencies at the base and the lower frequencies toward the apex. This is called the tonotopic organization of the basilar membrane. This travelling wave theory permitted von Békésy to win the Nobel Prize in Physiology or Medicine in 1961 (Chien & Lee, 2015).

Basilar membrane vibration causes deflection of the stereocilia on inner hair cells and results in depolarization or hyperpolarization of the hair cells. Thus, hair cells transduce acoustic energy to an electrochemical signal that is propagated along the auditory nerve. Inner hair cells conduct sound information to the cochlear nucleus while outer hair cells act as cochlear modifiers of the signals transmitted to the inner ear.

The signal transferred to the afferent auditory nerve fibers is propagated to the brain where the information is analyzed and processed. Tonotopic organization is maintained along the cochlear partition, the basilar membrane, hair cells, and afferent neurons all having the same characteristic frequency. This organization is preserved in the central auditory pathway (Chien & Lee, 2015; Weber & Khariwala, 2014).

The first relay on the auditory nerve is the cochlear nucleus, located in the pontomedullary junction of the dorsolateral brainstem, receiving auditory information from the spiral ganglion (Weber & Khariwala, 2014).

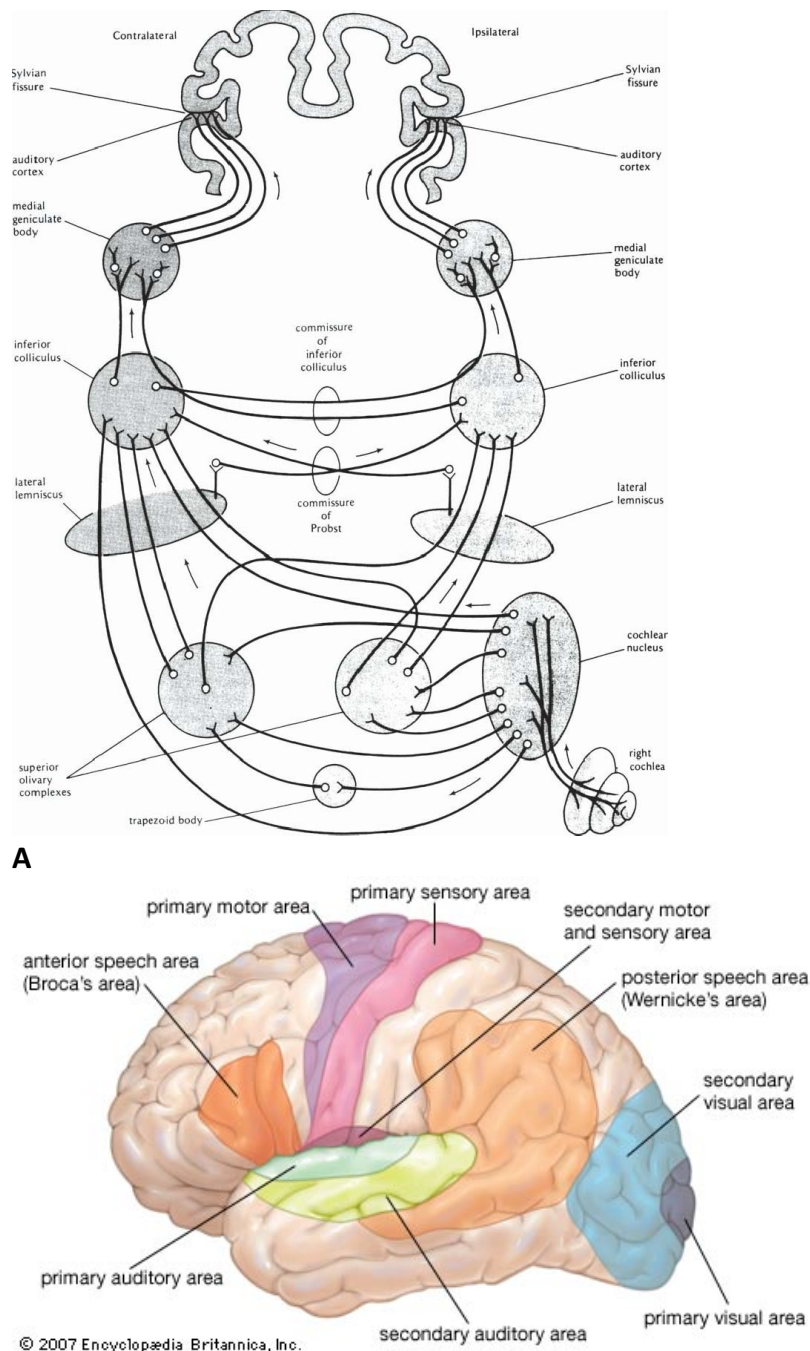
From the cochlear nucleus, most fibers cross the brainstem to the contralateral superior olivary complex (SOC) and a smaller number of fibers run to the ipsilateral SOC. The SOC is considered the first center in the ascending auditory system, where inputs from both ears converge playing an important role in sound localization.

The next central auditory relay is the inferior colliculus. It is thought to be involved in all forms of auditory behavior, including differential sensitivity for frequency and intensity, loudness, and binaural hearing. Then, the medial geniculate body of the thalamus sends projections to



the primary auditory cortex located on the Heschl gyrus in the Sylvian fissure of the temporal lobe (Fig. 4). The primary auditory cortex is tonotopically organized and processes complex auditory signals to enable speech and language comprehension. The auditory association cortex, located lateral to the primary auditory cortex, is part of the language reception area, the Wernicke area (Chien & Lee, 2015; Weber & Khariwala, 2014).

Descending pathways to the ear (auditory efferents) play an important role in protecting the cochlea from loud sounds, modulating the response of the middle ear (acoustic reflex) and inner ear (medial olivocochlear reflex) (Chien & Lee, 2015; Weber & Khariwala, 2014).



**B** Figure 4: A- The central auditory ascending pathways. (Weber & Khariwala, 2014) B- Auditory cortex located in the temporal lobe (from Encyclopedia Britannica, Inc.)



### 1.3. The link between auditory processing and speech production

Hearing and speech are obviously linked, in that hearing impairment can variously affect the quality of speech.

Human beings use auditory feedback to stabilize their voice's fundamental frequency (F0) by making compensations if there are perturbations that they can hear in their voice pitch feedback. In experimental studies, speakers were shown to compensate for changes in voice pitch feedback; the subjects' F0 lowers when their auditory feedback is shifted upward while it increases when their feedback is shifted downward, with the subjects being unaware of the quick changes being produced. This mechanism is called pitch-shifted voice feedback. (Behroozmand, Korzyukov, Sattler, & Larson, 2012; Korzyukov, Sattler, Behroozmand, & Larson, 2012)

According to the DIVA model (Guenther & Vladusich, 2012), which is a computational model that provides a quantitative framework for understanding the roles of various brain regions involved in speech acquisition and production, auditory feedback is driven by axonal projections that arise when the speaker hears himself/herself while speaking. The target that should be produced is compared to incoming auditory information. If the auditory feedback is not compatible with the target, neurons in the auditory error map become active and corrective commands are sent to motor cortex in order to correct the produced voice. (Guenther & Vladusich, 2012; Sato & Grabski, 2014)

The complete system and pathways are shown in figure 5.

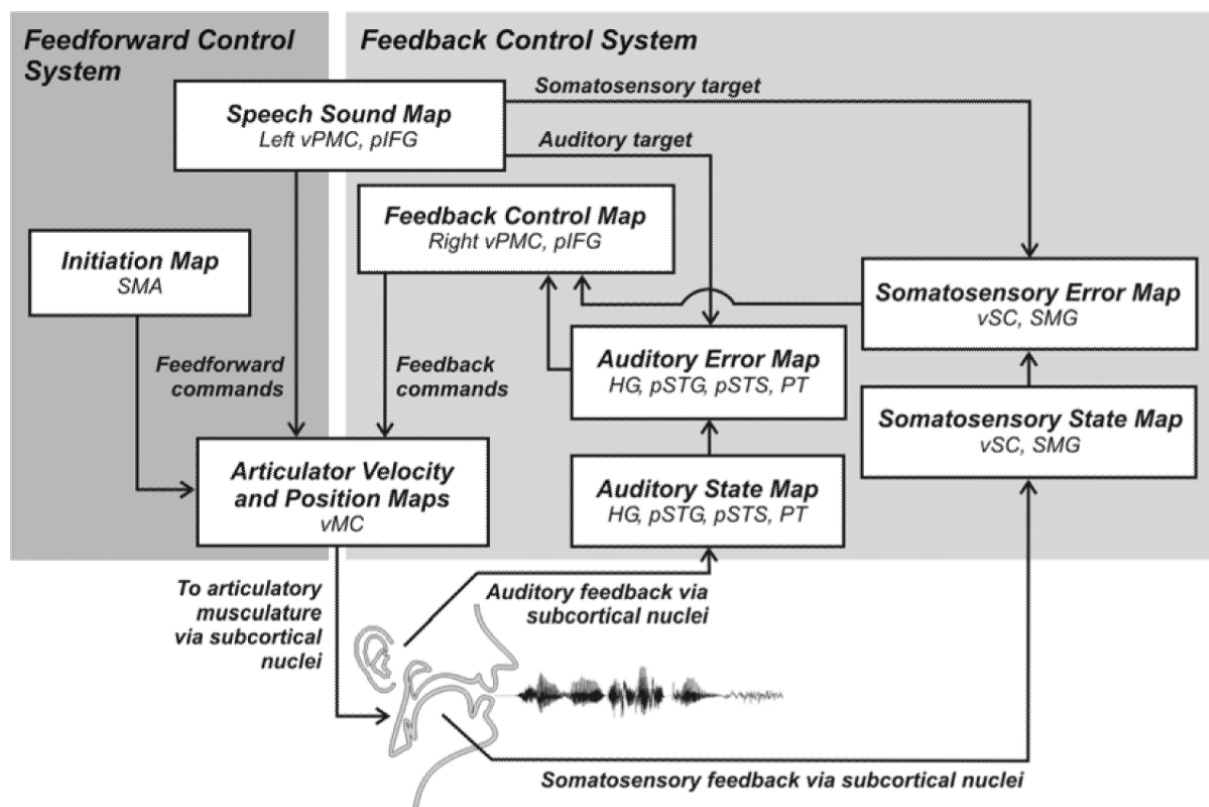


Figure 5: Cortical components of the DIVA model of speech acquisition and production (Guenther & Vladusich, 2012)

SMA: Supplementary Motor Area, vPMC: ventral Premotor Cortex, pIFG: posterior Inferior Frontal Gyrus (Broca's area), vMC: ventral Motor Cortex, HG: Heschl's Gyrus, pSTG: posterior Superior Temporal Gyrus, pSTS: posterior Superior Temporal Sulcus, PT: Planum Temporale, vSC: ventral Somatosensory Cortex, SMG: SupraMarginal Gyrus

## Chapter 2: Normal hearing and hearing impairment

### 2.1. Normal hearing and degrees of hearing loss

In children, normal hearing is defined by a hearing level threshold of 15 dB or better (Fig. 17). Hearing thresholds of 25 dB or poorer are considered of educational significance. Occasionally, thresholds of 20 dB can be considered as normal especially in younger children or children with developmental delays. Degrees of hearing loss are determined by the air conduction hearing levels thresholds, with mild HL between 21 and 40 dB, moderate HL between 41 and 55 dB, moderately severe HL between 56 and 70 dB, severe HL between 71 and 90 dB, and profound HL 91 dB and more (Fig. 6). (Fligor, 2014)

Timing of hearing impairment is important to determine (HAS, 2012):

- Post-lingual HL: HL manifested after the acquisition of language.
- Pre-lingual HL: HL manifested before the acquisition of language (before age of 2 years) or congenital HL. The impact of this HL is deleterious on written and spoken language development with an extension to all the aspects of social and educational development.
- Peri-lingual HL: HL manifested between 2 and 4 years at the time of language acquisition.

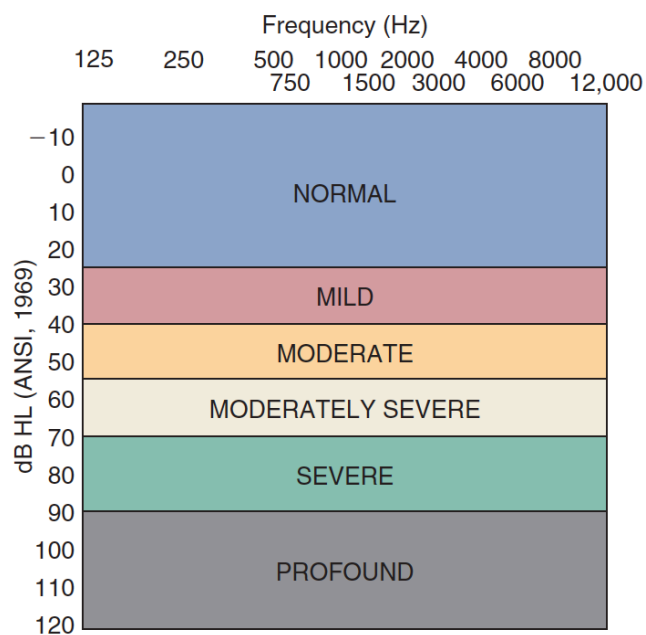


Figure 6: Normal hearing and degrees of hearing loss (Kileny & Zwolan, 2015)

### 2.2. Etiologies of hearing loss

Hearing loss can be divided into two types; sensorineural hearing loss (SNHL) and conductive hearing loss (CHL). SNHL is caused by cochlear pathologies or anomalies affecting the auditory nerve or the central auditory pathways. CHL is usually caused by pathologies affecting the external and middle ear causing a limited transmission of soundwave to the inner ear. Hearing loss can be also caused by a mixed cause and is then called mixed hearing loss. (Fligor, 2012, 2014)

In order to diagnose hearing loss etiologies, a complete family and child history should be recorded, pregnancy and birth events (including newborn hearing screening) should be investigated and psychosocial development should be evaluated. An otoscopic inspection is very crucial in any child with suspected hearing loss and a physical examination ruling out associated malformations should be performed.

The detailed etiologies of congenital hearing loss are out of the aim of this report. The most frequent etiologies of CHL can be congenital, such as ear atresia which is defined by the absence of EAC, malformation of the ossicular chain, such as congenital ossicular dysplasia or congenital stapedial fixation. Other frequent acquired CHL are due to EAC obstruction by cerumen impaction or a foreign body, and the presence of a middle ear effusion as found in acute otitis media or otitis media with effusion. (Mikulec, 2009)

Congenital SNHL can be genetic or environmental. The list of etiologies being extensive, some of the main etiologies are presented in figure 7.

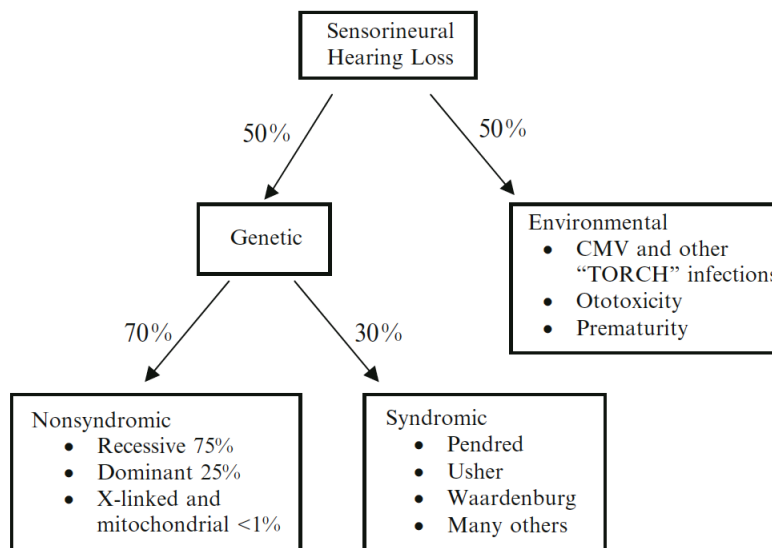


Figure 7: Etiologies of congenital sensorineural hearing loss. (Mikulec, 2009)

## Chapter 3: Cochlear implantation

Many treatments have been suggested for hearing loss, but cochlear implantation (CI) is still the best treatment option for congenital SNHL. It provides the single most effective form of rehabilitation for patients with bilateral severe to profound SNHL, when they can't benefit from hearing amplification anymore.

### 3.1. A brief history of cochlear implantation

In the twentieth century, with the advances in understanding the electrical events in the cochlea, the French team of Djurno and Eyries have placed in 1957 a receiver coil with stainless steel terminals on a small portion of the vestibular nerve in the internal auditory canal during facial nerve grafting in a patient who had a previous petrosectomy for cholesteatoma. During a month, they were stimulating it externally before removing it, and the patient perceived a sound like "a ball going in a roulette wheel". Then Dr William House from House Ear Institute in Los Angeles, got interested after reading news paragraphs regarding the French experience and started experimenting on patients during middle ear surgery under local anesthesia stimulating the promontory and asking the patients what they could hear. By the year 1961, Dr House and Dr Doyle a neurosurgeon had implanted two multichannel devices that had to be removed few months after. But this was a promising beginning of the true CI. (Mudry & Mills, 2013; Ramsden, 2013)

In the same period of time, Michelson in San Francisco and Blair Simmons in Stanford started experimenting on CI but they were faced with unfavorable primary results. But in 1964, Simmons successfully implanted a 6-electrode array through transmastoid approach and through promontory placing it in the modiolus. It was in 1967 that the term "cochlear implant" was used for the first time in the title of Simmons' presentation in a workshop held in Chicago. (Mudry & Mills, 2013)

After that, many objections were facing the Californian experience in the beginning of 1970s. As a response to these objections Dr House stated: *"Don't give me theories why it should not work, give me an explanation why it does work!"* and he added *"Mark my words. We are entering a new era of otology. For the past 30 years, we have been in the conductive hearing loss era. But now we are entering the era of sensory hearing loss. There is a great urgency about this... That is what medicine is about. That is why we are all here. I can't emphasize more that we are entering a new age of otology"*. (Ramsden, 2013)

Various teams around the world started following House, Simmons and Michelson's experience. Of those, Chouard in Paris implanted, in 1978, 6 patients with 7-electrode devices, and Clark in Melbourne who developed in the same year his first multichannel CI and it became the first successful commercialized multichannel CI under the name of Cochlear/Nucleus.

A multichannel single wire electrode was built by Simmons and White and implanted by Michelson in 1974 and Clark in 1978. (Mudry & Mills, 2013)

Then in the 1984, the British Graham Fraser of the UCH Group started implanting a single channel device. But the problem of funding for implantation and research was quickly an important question. In 1990, a 3-year multicenter study on profoundly SNHL in children and

adults was funded by David Mellor and the results published in 1995 were very positive, which made British NHS (National Health Service) to fund CI in adults and children. (Ramsden, 2013) Meanwhile, research was aiming to improve the CI design in parallel with speech processing and many companies started to come to life Cochlear in Australia, 3M company in the USA, Med-El in Austria, MXM in France and many other. The spectacular results of CI in selected patients silenced the opposition and widened CI indications. With the understanding of plasticity in the maturation of auditory pathways, the age of CI was brought down to one year and younger, especially when seeing hearing and speech results in these patients (Mudry & Mills, 2013; Ramsden, 2013).

### 3.2. Definition and functioning of cochlear implants

CI is biomechanical device with electrodes placed in the cochlea in order to stimulate the cochlear nerve (HAS, 2012). It is formed by two parts, one internal and one external (fig. 8), that must work in unified system in order to be functional (Wilson & Dorman, 2009).

The external part is formed by:

- A microphone to sense the sound received,
- A speech processor to transform the sound input into electrical stimuli
- An external transmitter that transmits the electrical signal transcutaneously to the implanted internal part via a magnet.

The implanted internal part is formed by

- The implanted receiver/stimulator that receives signal and sends stimuli to the electrodes
  - A reference electrode found in some models
  - A cable connecting the receiver/stimulator to the electrodes array
  - The electrodes array that is implanted in the scala tympani in order to stimulate the nerve.
- (Wilson & Dorman, 2009)

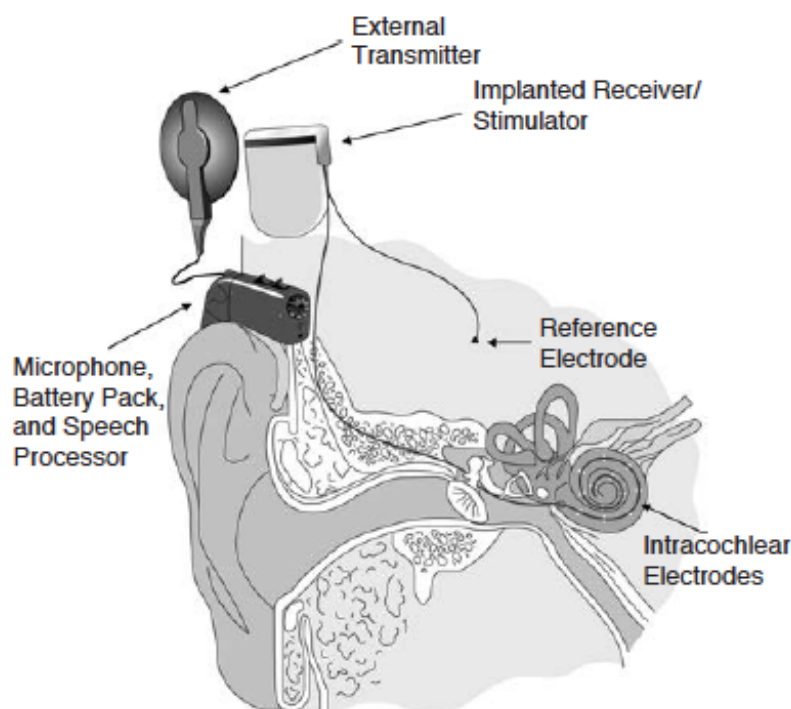


Figure 8: Cochlear implant system. (Wilson & Dorman, 2009)

### 3.3. Indications of cochlear implantation in children

According to HAS recommendations for CI that was updated in 2011, CI is indicated in children with bilateral severe to profound SNHL (HAS, 2012). CI can be unilateral or bilateral.

#### 3.3.1. Age at implantation

The “earlier the better” trend in CI was the result of many studies showing better performance in hearing and speech in early CI children (Bruijnzeel et al., 2016). A recent systematic review of the literature, showed that CI before the age of 12 months produced better results in speech production (Bruijnzeel et al., 2016).

According to the French recommendations of HAS in 2012, in pre-lingual SNHL, CI should be performed as early as possible usually before the age of 12-18 months. Passing the age of 5, profound non-progressive SNHL with no previous development of oral communication, CI is not indicated. However, in case of post-lingual profound SNHL, children can be implanted at any age (HAS, 2012).

Studies showed that CI in pre-lingually hearing impaired children has two critical age limits, 2 and 7 years. Sharma et al confirmed by means of cortical evoked auditory responses that passing the age of 7 years, brain plasticity is critically reduced leading to an altered response to cortical stimulation by sound (Sharma, Dorman, & Spahr, 2002). These alterations are mainly due to abnormalities in synaptic connectivity, deficiencies in higher order cortical maturation and development leading to an abnormal functioning of auditory cortex. As a result, late CI children present great difficulties in oral speech and language skills development even after many years of implant usage (Kral & Sharma, 2012). The optimal time for CI is before 2 to 4 years of age because this period represents the peak of synaptic density in the temporal cortex in normal hearing humans. During this period, hearing experience must be provided to a child in order to establish a refinement of synaptic networks and a maturation of the auditory cortex (Kral & Sharma, 2012).

#### 3.3.2. Audiometric indications

In profound SNHL, CI is indicated if hearing aids (HA) is of no benefit for language development. In severe SNHL, it is indicated if discrimination is inferior or equal to 50% on speech audiometry at 60 dB in sound field while using adequate HA. In case of fluctuating HL, CI is indicated if the abovementioned criteria are met many times per month and/or when language development is affected. (HAS, 2012)

#### 3.3.3. Indications for bilateral CI in children

In the last update of HAS recommendations, bilateral CI is now indicated in children with bilateral profound SNHL (using the same indications as above), and for Usher syndrome (hereditary disease causing ocular and hearing deficiencies). Moreover, in cases of pathologies with high risk of cochlear ossification, such as, but not limited to, bacterial meningitis and bilateral temporal bone fracture, bilateral CI should be performed without delay. (HAS, 2012)

### 3.4. Cochlear implantation evaluation and follow-up

Pre-implantation evaluation of children is very important in confirming the benefits of the CI. A multidisciplinary team approach is needed. HAS recommended in 2007 (HAS, 2007), in order to form an efficient CI program, each center must have a team formed by:

- A medical otolaryngologist experimented in hearing and ear diseases

- An experienced ear surgeon
- An audiologist
- A speech therapist
- A psychologist/psychiatrist
- A technician experienced in electrophysiologic testing

As in many centers in the world (table 1), the center of CI at La Timone Children's Hospital, Marseille-France, has its own multidisciplinary team. Children candidates for CI benefit from pre-implantation audiometric tests, HA evaluation with the trial of high potency HA for a period of 3 months or less if no benefit or if an emergent CI is needed, phoniatic evaluation, psychologic evaluation of the child and his parents, speech therapist evaluation, vestibular testing, computed tomodensitometry scan (CT scan) of temporal bones to evaluate the anatomical structures, and magnetic resonance imaging (MRI) of the brain and temporal bones to evaluate the integrity of the brain and the VIII<sup>th</sup> nerve.

Table 1: Components of cochlear implantation evaluation (Heman-ackah, Roland, Haynes, & Waltzman, 2012)

Evaluation	Components
Medical	History Prenatal exposures (TORCH infections, teratogens) Perinatal concerns (prematurity, low birth weight, neonatal intensive care unit low Apgar score, hyperbilirubinemia, sepsis, intubation) Postnatal concerns (ototoxins, meningitis, mumps) Family history Physical examination Syndromes Otitis media Pneumococcal vaccination
Imaging	High-resolution computed tomography of temporal bones Magnetic resonance imaging of the internal auditory canal
Audiologic	Pure tone audiometry Speech discrimination Hearing aid evaluation Speech perception assessment
Speech and language	Assess language development Screen for articulation disorders
Physiologic	Auditory brainstem response test Electrically evoked auditory brainstem response test
Cognitive and development	Assess for cognitive and developmental delays
Patient and family counseling	Establish patient and family expectation Assess family commitment to aural rehabilitation protocol Selection of cochlear implant device Informed consent

Follow-up is an important step after CI. Three weeks after surgery the CI device is activated and the external part is positioned. Tune-up sessions follow for the next few weeks then once per month for the first year and at lesser frequency the following years. A regular audiometric follow-up is proposed in order to evaluate hearing status. A psychologic follow-up is proposed on an as-needed basis and speech therapy is performed at 3 months, 6 months and 12 months from the date of CI, then once a year.

## Chapter 4: Prosody

### 4.1. Prosody and prosodic focus

#### 4.1.1. Definition of prosody

Prosody is a determinant aspect of spoken language which can transfer a linguistic and paralinguistic message (D'Imperio et al., 2016; Shattuck-Hufnagel & Turk, 1996). It is considered as the first aspect of language acquired even in the prenatal stage, offering the child the access to linguistic structures (D'Imperio et al., 2016).

According to Beckman, prosody is "a complex grammatical structure that must be parsed in its own right"; it is "the organizational structure of speech" and cannot be considered only as another term for "suprasegmentals" (pitch, temporal structure, loudness...) (Beckman, 1996).

Phonetically, prosody represents rhythmic and melodic variations of speech in order to give the pragmatic meaning of a message. These variations should be taken into consideration to understand the message underlying, without being limited to lexical, semantic and syntactic components of an utterance (D'Imperio et al., 2016).

A sentence can be interpreted with only its literal meaning if it is said with an assertive tone, for example; "the weather is good today", or it can be the opposite if said with an ironic prosody (as in the example it can mean that the weather is *bad*). Moreover, prosody can have a role in syntactic disambiguation by placing of spoken boundaries, as in this example:

(old) (men and women) vs. (old men) (and women)

In the first sentence of the example, men and women are considered old, but in the second, men are only considered old (D'Imperio et al., 2016; Shattuck-Hufnagel & Turk, 1996).

In other words, prosody can reflect the intentions, the emotional state and the attitude of the speaker. (Wagner & Watson, 2010)

#### 4.1.2. Phonetic and phonologic components of prosody

Prosody has three components: intonation (melodic modulations), phrasing (structuration by prosodic constituents which boundaries are marked by rhythmic and/or intonative rupture) and prominence (accentuation on a word or a sentence) (D'Imperio et al., 2016; Shattuck-Hufnagel & Turk, 1996).

Intonation is one of the mostly studied components by researchers. According to Ladd, intonation is the melodic modulations of an utterance which translate the pragmatic meaning of the message (Ladd, 2008). The central idea is that intonational elements have meanings that are very general, but *they are part of a system with a rich interpretative pragmatics*. In other words, it can have rich nuances according to specific contexts (Ladd, 1996). Many points of view in the linguistic world were given on the phonological categories of intonation, but all linguists agree on the idea that these categories participate at certain degree in transmitting the meaning of an utterance (Ladd, 1996). However, linguists have not come to an agreement in the analysis of intonation. This disagreement doesn't mean that the linguistic theory of intonation is wrong, but it rather means that a careful analysis of intonation should be done without separating it from its paralinguistic context (Ladd, 1996). Ladd suggested that



intonation has a categorical linguistic structure, consisting of a linear sequence of phonological events that occur at well-defined points in an utterance.

According to Ladd, intonation has three defining characteristics. *Intonation refers to the use of suprasegmental phonetic features to convey “post-lexical” or sentence-level pragmatic meanings in a linguistically structured way* (Ladd, 2008).

- Suprasegmental features: Fundamental frequency (F0), intensity and duration.
- Sentence-level or post-lexical: Intonation gives meanings to the whole phrase or utterance, such as the type of the sentence, speech act, or focus and information structure. It is not involved in distinguishing between two words using lexical features such as stress, accent and tone, but of course, these features can interact with intonational features.
- Linguistically structured: Paralinguistic features (eg. Tempo, loudness...) are excluded from intonational features but are in close interaction with intonation. Intonational features are organized in categorically distinct entities (low tone or boundary rise) and relations (stronger than or weaker than). According to Ladd, it is extremely difficult to distinguish between paralinguistic and intonational features, which is a subject of controversy (Ladd, 2008).

Intonation can be used to determine the pragmatic value of an utterance. For example, it can differentiate between an affirmative and an interrogative sentence; “John came” vs “John came?”, where the final rise in the interrogative form can be used for confirmation or an information request. It can signal an informational focus or a contrast in the discourse; “Marie WILL COME tomorrow, she is not going then”, where the accent is put on the segment that should be contrasted in order to clarify an information (D’Imperio et al., 2016).

The interpretation of prosody is complex, because objective measures such as pitch, duration or intensity in an utterance can only give a partial image of what the prosody of the utterance is. That’s why, prosody should be described as a system both phonologic and phonetic. As Beckman suggested that prosody should be analyzed as a grammatical structure while using phonetic components in order to translate the phonologic representation into acoustic properties of speech signal (Beckman, 1996; D’Imperio et al., 2016).

Two sentences with the same syntactic structure can have different prosodic structure because the speaker can place the focal accent on a segment of an utterance or change the rising tone according to the message he wants to send to the audience (D’Imperio et al., 2016). A well-known phonological model of intonation, the “Autosegmental-Metrical” theory (AM), has been used to determine pitch contours in an utterance. Pitch contour can be considered as a series of rises and falls in F0 (High [H] or Low [L]) that can be associated metrically strong syllables (D’Imperio et al., 2016). The phonological elements and the local features of pitch contour (rises and falls of F0) in the AM theory define pitch accents. Pitch accents have a double function: they are building blocks of intonation contours while simultaneously being important cues to the prominence of the syllables with which they are associated, they are noted as H\* and L\* (D’Imperio et al., 2016; Ladd, 2008). Pitch accents were first introduced by Bolinger in 1958 and then developed by Pierrehumbert in 1980 (Ladd, 2008). They are now one of the basics of prosody and along with AM model they gave birth to the prosodic transcription system ToBI (Tones and Break Indices) used in many languages in the world and recently used in French language (D’Imperio et al., 2016).

The distribution of tonal boundaries (H% and L%) define intonational phrases. These phrases can differ by the boundary tone marking types as in figure 9.

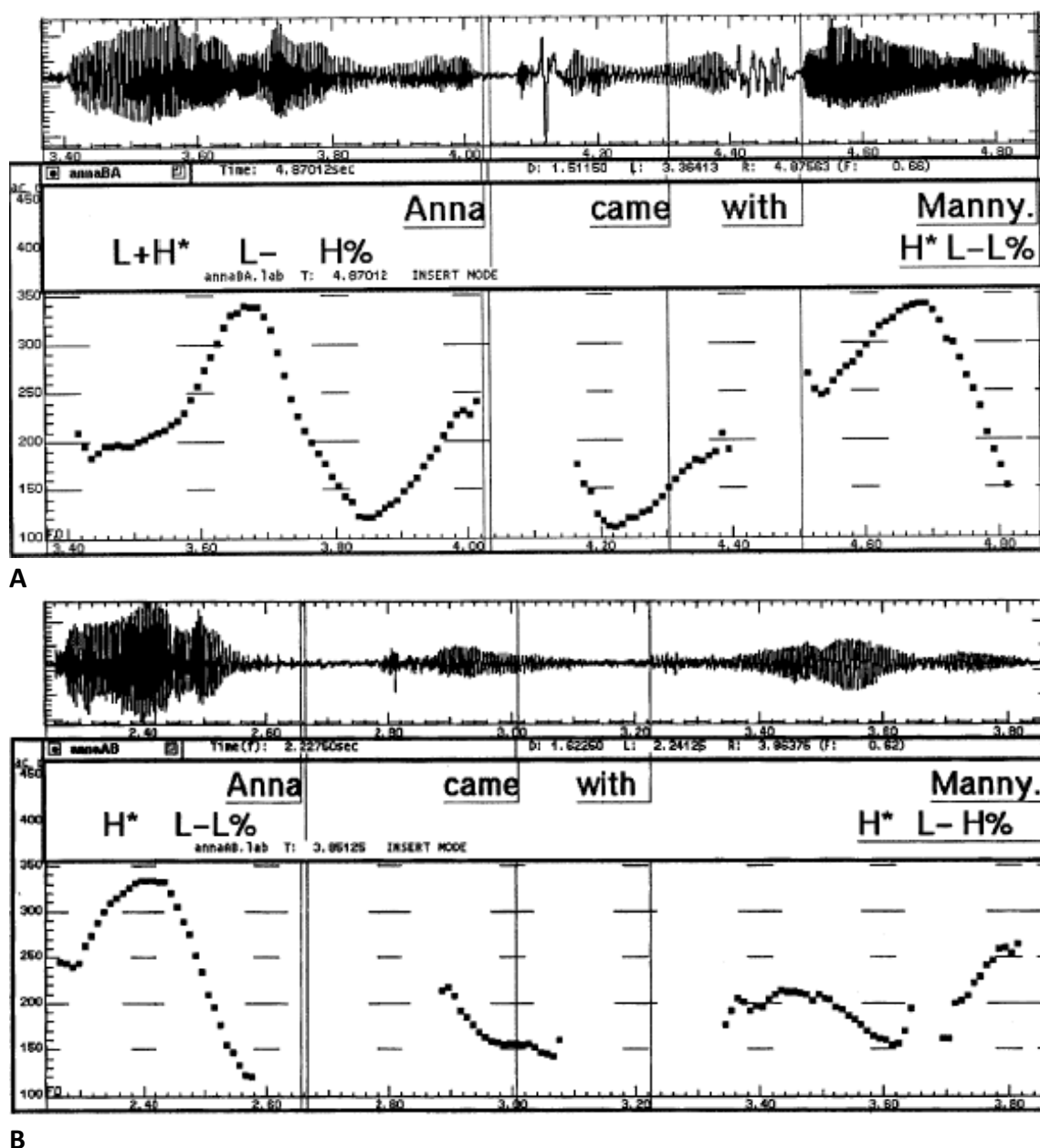


Figure 9: *Fundamental frequency contours for utterances of the sentence Anna came with Manny, each produced as two intonational phrases, and illustrating L% versus H% boundary tones at the utterance–medial and utterance–final phrase boundaries. The rendition in A puts the greater “answer” focus on Manny and backgrounds Anna, whereas the rendition in B puts greater focus on Anna and backgrounds Manny. (Beckman, 1996)*

In order to evaluate prosody in an utterance and to analyze it, we need phonetic and phonologic elements that can be measured. The main acoustic correlates of prosody are duration, F0 with its perceptual correlate pitch, and intensity with its perceptual correlate loudness.

## **Duration**

The duration of a segment in an utterance is related closely to boundary strength, with lengthening, pauses and domain-initial strengthening being the main durational cues affecting it. (Wagner & Watson, 2010)

Pre-boundary lengthening correlates closely with the strength of the following boundary. The more the following boundary is complex and important, the more is the pre-boundary lengthening. (Wagner & Watson, 2010)

The presence of pauses and their length before the stressed segment correlate with the next stressed segment importance and complexity. The more complex the upcoming part of speech the longer is the pause at boundary. (Wagner & Watson, 2010)

Domain-initial strengthening is when the phonetic realization of segments depends on the strength of a preceding boundary. Thus, initial strengthening increases cumulatively with the strength of the preceding prosodic boundary. Even languages that are not stress-based such as French, Korean, and Taiwanese, show very similar patterns of domain-initial strengthening to English. It is a general reflex of prosodic organization. At the beginning of prosodic domains where the segment is lengthened, sometimes new segments can be inserted in order to strengthen the beginning of a domain. (Wagner & Watson, 2010)

## **F0**

F0 plays an important role in cueing prosodic boundaries. Changes in the pitch curve are the major determinants of prosodic cues. Pitch excursions at prosodic boundaries and pitch accents represent these changes. Pitch events that occur at the edges of boundaries are boundary tones at the end or beginning of a prosodic domain. They can be related to semantic or pragmatic meaning of the segment. Pitch accents depend on the structure of the utterance and on prosodic phrasing and they are relative to the preceding accents on the preceding words. As an example, Ladd in 1988 and Féry and Truckenbrodt in 2004 looked at the following type of coordination structure in English and German respectively, where A, B, and C stand in for sentences (Féry & Truckenbrodt, 2005; Ladd, 1988). There were two types of structures:

(1a) A but (B and C)

(1b) (A and B) but C

In structures of type (1a), conjunct C has a lower F0 than B, and B in turn has a lower F0 than A. The pitch level goes down from accent to accent. In structures of type (1b), on the other hand, C and B are at about the same level, but both are set to a lower pitch compared to A. (Féry & Truckenbrodt, 2005; Ladd, 1988; Wagner & Watson, 2010)

## **Intensity**

This prosodic cue has been less studied than the two others as a signal of prosodic boundary. Some authors such as Kim et al have found that some speakers lower the intensity of the segment preceding the stronger prosodic boundary. This was not consistent across speakers. (Kim, Yoon, Cole, & Hasegawa-Johnson, 2006; Wagner & Watson, 2010)

### **4.1.3. Prosodic focus**

It has been discussed by Bolinger in 1972, that prominence is related to predictability in that only words that carry more information or are less expected in the context are accented (Bolinger, 1972). Expressions that are salient should be more easily retrieved and hence do not need to be accented in order to transmit the correct message. But this idea is not the only determinant of prominence. Prominence shift can depend on contextual variations.

Rooth in 1985 introduced the idea that each expression comes with two semantic meanings; its regular denotation and a set of alternatives. Prosodic focus or prominence is used to create these alternatives (Rooth, 1985). Where the accent is placed can change according to context and to the message that should be sent to the audience. Syntactically an “F” is noted next to the word or segment subject to focus. Here’s an example of what can be alternatives for an expression with the change of focused segment:

A: Who read Moby Dick?

a. B: **John**<sub>F</sub> read Moby Dick

Alternative set: {John read Moby Dick, Jane read Moby Dick, ...}

b. # B: John read **Moby Dick**<sub>F</sub>

Alternative set: {John read Moby Dick, John read Walden, ...}

In this example, alternatives have changed according to the focused segment. But the question “A” has set the context and in that, the most suitable focused form of response would be the “a” response. (Vander Klok, Goad, & Wagner, 2017)

Focus can be also differentiated by its width. It can be a wide focus, broad focus or narrow focus. In the previous example (VP; Verbal Phrase, NP; Noun Phrase):

a. VP-Wide focus: [**John read Moby Dick**]<sub>F</sub>

b. VP-Broad focus: John [**read Moby Dick**]<sub>F</sub>

c. NP-Narrow focus: John read [**Moby Dick**]<sub>F</sub>

The “a” expression of wide focus can be a response of “What is everyone doing?”, the “b” expression requires alternatives in the action “John” is doing, and the expression “c” represent a narrow focus on the object and requires alternatives in the choice of object. (Vander Klok et al., 2017)

Narrow focus can also be divided into two types; a contrastive narrow focus and a corrective narrow focus. The focus is contrastive when it is narrowed on a constituent in order to show contrast with the possible alternatives (“John read [**Moby Dick**]<sub>F</sub>” contrasted from “John read Walden”). It is corrective when its constituent is a direct rejection of an alternative either spoken by the speaker or by the listener (A: “Did John read Walden?”, B: “No, John read [**Moby Dick**]<sub>F</sub>!”) (Gussenhoven, 2007).

Other forms of focus can exist such as syntactic parallelism, where the antecedent is found in the same utterance as the focused constituent, and clefting, which is bi-clausal and is a strategy to single out a constituent by putting it in a separate clause. (Vander Klok et al., 2017)

Prosodic prominence is revealed by duration, F0 and intensity cues. The importance of each one is still controversial. The use of each one of these cues and its importance differ from a language to another. (Wagner & Watson, 2010)

Duration can signal prominence by signaling word stress and phrasal prominence. It is the acoustic correlate of focus lengthening. A lengthening of the duration of the focused segment is performed to mark prominence and usually it is associated with durational lengthening of the end part that is achieved by slowing down gestures. F0 can encode prominence by various ways. These can be, a higher pitch excursion on the stressed word, an increase in pitch range, and a reduced post focused segment pitch range. Relative pitch scaling, however it is done, is a main cue in English prominence encoding. Questions were whether pitch is a reliable cue outside experimental studies, but Kochanski et al found that pitch cues vary across utterances

(Kochanski, Grabe, Coleman, & Rosner, 2005). They demonstrated that pitch was not a good predictor of prominence in an English corpus, but loudness could be considered as the best acoustic correlate. It was considered that in English, duration and intensity can be considered as a reliable correlate of prominence. (Wagner & Watson, 2010)

#### 4.1.4. Prosodic focus in French

Studies showed cross-linguistic differences in prosodic focus uses. It was shown that accent placement or prominence shift differs between languages. Two main types of languages Germanic and Romance languages. English is a representative of Germanic languages and French of Romance ones. (Vander Klok et al., 2017)

It has long been considered that in Romance languages, prominence shift occurs only in specific contexts where corrective focus is needed (Cruttenden, 2006; Ladd, 2008). Lambrecht in 1994 found that in French prominence shift is produced in the end of the sentence (Lambrecht, 1994).

In French prosodic phonology, word-level focus is generally word-final and depends on the position of the word in the phrase in such, stress correlates are determined by the position of the word in the sentence (German & D'Imperio, 2016). The basic units of phrasing in French prosody are traditionally accentual phrases (AP) (also referred to as rhythm unit, prosodic word or accentual group) which have a tonal structure of LHiLH\* sequence and where there are two tonal events. The primary accent is a phrase final accent (LH\*) which is marked by an obvious F0 movement and a preboundary lengthening and is related to the last full syllable of the AP, it is considered as obligatory in an AP. The secondary accent, which is optional, is defined as the initial rise (LHi) (fig. 10). It is an additional F0 rise occurring in the left edge of the focused constituent (D'Imperio, German, & Michelas, 2012; German & D'Imperio, 2016). Phonologically, only the final accent corresponds to a unique stress location and phonetically rhythm lengthening only appears within the final accent domain (D'Imperio et al., 2012). The role and the consistency of initial rise in focus has been discussed in many studies.

According to Féry, initial rise depends on the size of the focus domain. Narrow focus is more likely to be marked by initial rise, while broad focus is often only marked by a final falling tone (Féry, 2001).

Wh-interrogatives in French, usually start with an initial high F0 on the wh-word that is followed by a series of final rises marking the AP boundaries, but that are lower than the initial rise (fig. 11) (German & D'Imperio, 2016). The interpretation of focus in this type of utterances depend on the context and congruence.

In the study by German and D'Imperio evaluating the role of initial rise as a focus marker, authors found a strong association between contrastive focus and initial rise in French. The initial rise was more likely to occur in longer APs than shorter ones (German & D'Imperio, 2016).

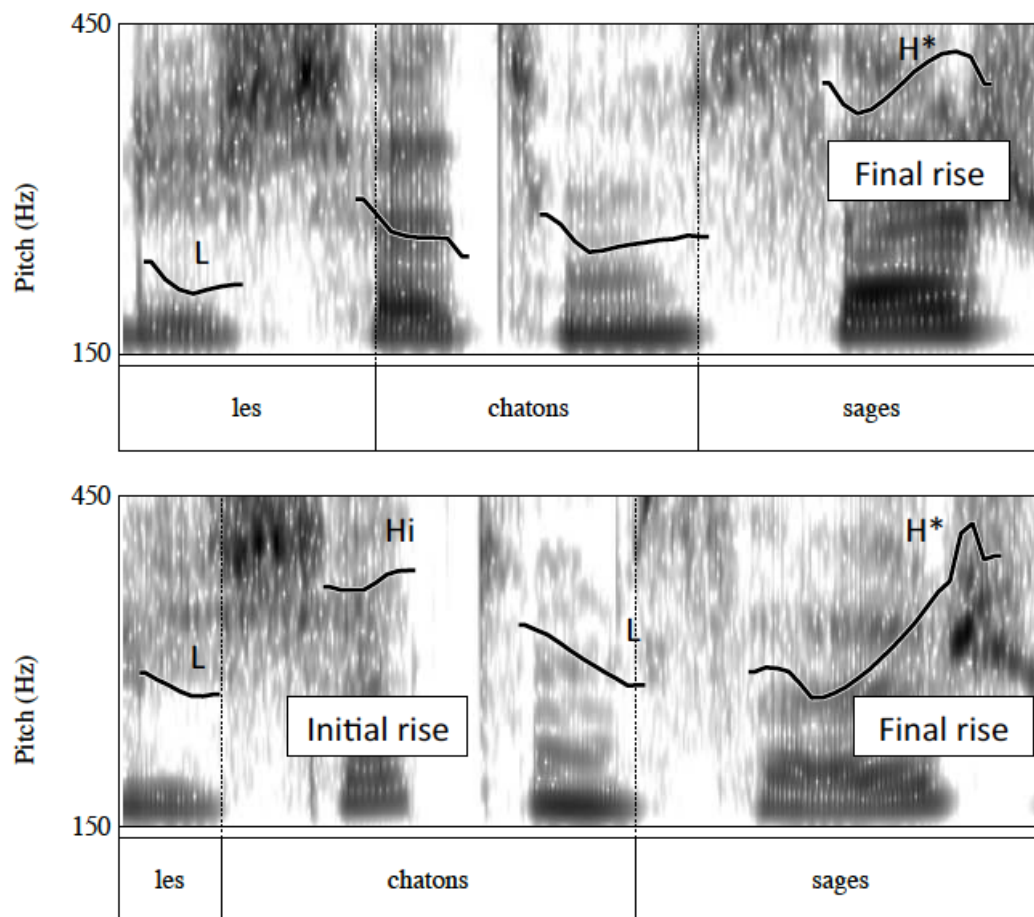


Figure 10: Example of two types of Accentual Phrase for the sequence *les chatons sages* ‘the good kittens’ realized with either only a final rise (upper figure) or with an additional/optional early rise (lower figure). (Excerpt taken from the utterance *Les chatons sages buvaient leur lait* ‘The good kittens were drinking their milk’ read by a native speaker of French) (D’Imperio et al., 2012)

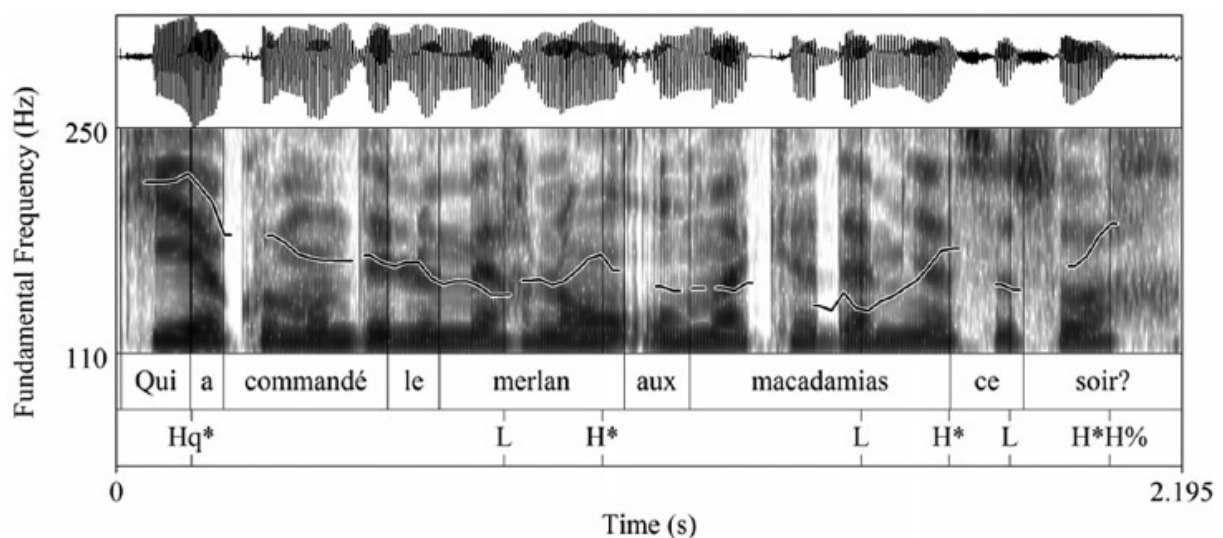


Figure 11: F0 tracing of a French wh-question showing an initial rise on “qui” the wh-word (Hq\*) followed by final rises (H\*). (“Who ordered the whiting with macadamias this evening?”) (German & D’Imperio, 2016)

The context is an important element in determining focus effect in French. In corrective context, the focused element is realized with a contour higher and earlier aligned than typical final rise in broad focus context, with a deaccentuation or a dephrasing of the element following the focused one. This is marked by the reduction of F0 variations and range. In contrastive contexts, the focused element attracts the nuclear accent to its rightmost edge, which is the last major prominence in an utterance, followed by a deaccentuation up to the end of the utterance. (German & D'Imperio, 2016)

#### 4.1.5. Development of prosody in children

It has been discussed in the literature that full understanding and mastering of prosodic intonation is not acquired before 12 – 13 years of age. However, in children in middle childhood (5-13 years), prosodic development is much less studied. At 4 years of age, some progression in the acquisition of prosodic skills have been noted especially in contrastive stress, while acquiring independent production of prosody at the age of 11 years. The prosody acquisition is a progressive process that continues to develop even if language skills are mastered. Children start by acquiring simple prosodic cues until the age where they start relying on more complex adult form of prosodic cues especially phrasal stress. Prosody plays a supporting role to other linguistic processes and is critical for acquiring language through there neurocognitive development. (Whalley & Hansen, 2006)

### 4.2. Prosody and prosodic focus in cochlear implanted children: Where are we now?

#### 4.2.1. Prosodic focus in speech perception

Many studies have tried to evaluate prosody perception in CI children. The major problem is that currently used devices have limited capacities in coding some aspects of speech, such as the variation in F0, limiting the perception of the spectral changes compared to normal hearing (NH) children. The ability to discriminate F0-based differences and the acquisition of linguistic contrasts based on pitch and intonation is hampered in CI children (Torppa, Faulkner, Järvikivi, & Vainio, 2010) as they are limited to the gross rhythmic and melodic information provided by prosody (Torppa et al., 2014).

Peng et al. showed that pre-lingually hearing impaired children with CI have difficulties identifying speech intonation contrasts in questions vs statement, while NH children started acquiring this capacity at the age of 6 years. They found that CI children performance was correlated positively with chronologic age and hearing experience (hearing age) but not with age at implantation. (Peng, Tomblin, Spencer, & Hurtig, 2007; Peng, Tomblin, & Turner, 2008) Some authors reported that English-speaking CI children, might acquire the ability to identify prosodic focus as late as 10 years of age. But this was found to be in contrast with the early development of auditory discriminative ability for different rhythmic and prosodic patterns and their production (Juszyk, Houston, & Newsome, 1999; Torppa et al., 2010; Vogel & Raimy, 2002). However, Carter et al found that CI children have the capacity to encode non-words prosodic patterns. (Carter, Dillon, & Pisoni, 2002)

Whatever are the results found in studies, CI children have a development of prosody perception that has the similar trajectory as NH children (Vogel & Raimy, 2002). But even in CI adolescents, Holt et al reported a less efficient processing of prosodic cues than NH peers

that was demonstrated in slower reaction times in predicting the location of an accented word while using the cues present in the preceding prosodic contour. (Holt, Demuth, & Yuen, 2016)

#### 4.2.2. Prosodic focus in speech production

In the literature, there have been few studies investigating some aspects of prosody production in CI children, none, to our knowledge, in the French speaking population.

The major problems in speech production in CI children were found mainly in rate, loudness and laryngeal quality (Lenden & Flipsen, 2007) and as they had difficulties in detecting F0 changes, they had the difficulties in using phrase-final F0 rises to signal requests (Holt, Yuen, & Demuth, 2017). In their study on conversational speech, Lenden and Flipsen (2007) found abnormalities in word and sentence stress in six CI children aged 3 to 6 years. Evaluation of stress production was performed in order to see if stress was “excessive, equal, or misplaced”. Phrasing, voice quality, and pitch were relatively unaffected. All CI children included in this study received implant before the age of 3 years. (Lenden & Flipsen, 2007)

A recent study on phonetic production of prosody in disyllabic babble and first words in English CI and NH infants (between 6 months to 2 years of age), showed that CI infants had weaker acoustic prosodic cues use. They analyzed pitch distance, intensity, and duration ratios. They found that there were mainly difficulties in pitch in line with the limiting perception by the CI device. Duration differences between the 2 groups were due to greater articulatory difficulties in words for the CI infants. NH infants were able to prolong end phrase words and syllables while CI infants have difficulties in that. (Pettinato, Clerck, Verhoeven, & Gillis, 2017)

Lower scores in prosody were reported in CI children when compared to NH children at the level of word and phrase production (Lyxell et al., 2009). Intonation was studied in CI children, and authors found that performance was lower in this group compared to NH children especially in using accurate utterance type and appropriate contour, but performance increased with the increased use of CI (Peng et al., 2007, 2008). In Peng et al 2008, evaluation of children’s performance was based on subjective criteria and an evaluation score by a panel of adults, no objective measures for prosodic cues were done. Chin et al also reported a poorer performance in interrogative intonation due mainly to restrictions on rising intonation (Chin, Bergeson, & Phan, 2012).

A recent study, investigating discourse strategies and prosody production in pre-lingually deafened CI adolescents, found that CI adolescents were preferentially repeating directives rather than seeking information to understand their interlocutor’s point of view by using information requests as their NH peers did. They were less interactive, less talkative and were more in silence than their NH peers (Holt et al., 2017).

The results of the studies on prosody production in CI children seem appealing, but data analysis was not differentiating early implanted children (before 18 months of age) from late implanted ones.



## **II- Experimental Study**

### **1. Aim of the study**

To evaluate prosodic cues to focus in speech production in early CI, pre-lingually hearing-impaired French-speaking children

### **2. Research questions**

In our study, we tried to answer two main questions: How do early CI French-speaking children use prosody to structure information in the discourse? At what age do they acquire prosodic cues to focus and what are the difficulties in doing so?

In order to answer these questions a group of 4- to 7-year-old French early CI children will be tested and compared to their adult caregivers in different focus conditions (broad and narrow focus) while producing a noun phrase (NP) composed of a noun and an adjective.

Our hypothesis would be: Prosodic cues to focus (tonal marking, lengthening) would be stronger for corrective than contrastive narrow focus, and for contrastive narrow focus than for broad focus. Focus marking would start to be acquired at age of 7 years especially for corrective narrow focus, but would not be fully acquired by then.

In this study, we predict a lengthening of the duration of the target focused word by means of lengthening of the accentual phrase when focus is produced. We also predict in the same way the lengthening of the target word pitch range depending of focus conditions. The problem that we could face in our word-based analysis, is that in French language adjective is always an intonational end phrase and it is supposed to have a lengthened duration and pitch range whatever was the focus condition. One possible solution is to compare between conditions taking as a reference the broad focus and look for an additional lengthening of the adjective in narrow focus conditions on the adjective.

### **3. Methods**

#### **Participants**

This is a cross-sectional study of pre-lingually hearing-impaired French-speaking children, who received CI before the age of 18 months between 2009 and 2012 at La Timone Children's Hospital in Marseille, France.

Inclusion criteria:

- Pre-lingually hearing impaired children.
- Pre-adolescent children to avoid changes in voice in male participants: Age 4 to 7 years at testing.
- French should be the main language used in every day's life.
- CI should be performed before or at the age of 18 months at La Timone Children's Hospital in Marseille, France.

Exclusion criteria:

- Children with associated anomalies or malformations, especially those affecting central nervous system.
- Hearing impairment being part of a syndrome.

Eighteen CI children were eligible for the study, but only 10 were tested and included in the analysis. CI children's caregivers have signed, before the surgery, an informed consent permitting the medical team to use any data related to CI for research while keeping it anonymous, and accepted willingly to participate in this study.

## Procedure

A speech production task was performed by each CI child. This task was appropriate to elicit spontaneous, while still controlled, prosodic focus production. It was provided by an ongoing research work on NH children (Esteve-Gibert, Løevenbruck, Dohen, & D'Imperio, 2017). It consisted of playing a computer-based semi-structured game, where children interacted with the caregiver in the presence of the experimenter. We elicited, using visual elements, sentences containing words that were contrasted in the discourse. For example, in the sentence "prends le **bonnet**<sub>F</sub> orange" (take the orange **hat**<sub>F</sub>) the word in bold and followed by an "F" letter indicate the element under focus. Focused elements could be either a disyllabic object noun (N), familiar to the children, or a disyllabic adjective (A), which is "violet" or "orange", within a noun phrase (NP) (Fig.12). (See the list of NPs in annexes)

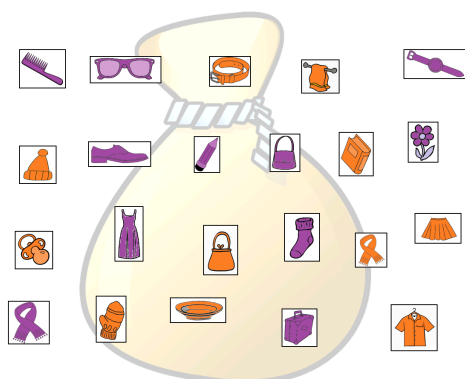


Figure 12: Different items used in the production task.

These elements could be in a broad-focus condition (BF) or in a narrow-focus condition on one of the two elements. Narrow focus conditions were either contrastive (F), eliciting focus while contrasting between two items having in common one element, or corrective (CF), eliciting focus while correcting one wrong element of the NP. Figures 13 to 15 illustrate examples of each condition.

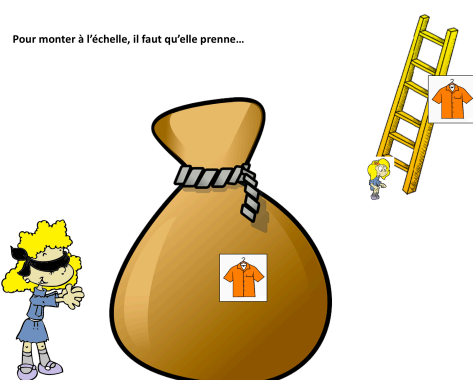
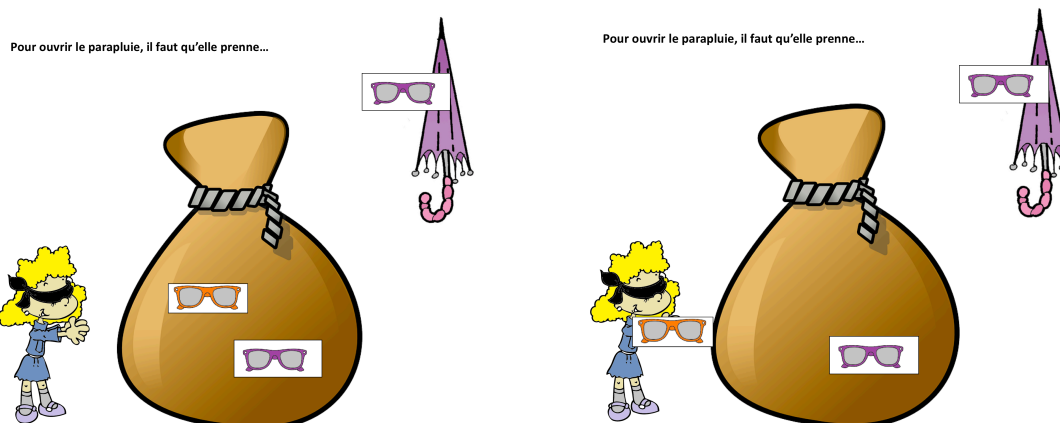


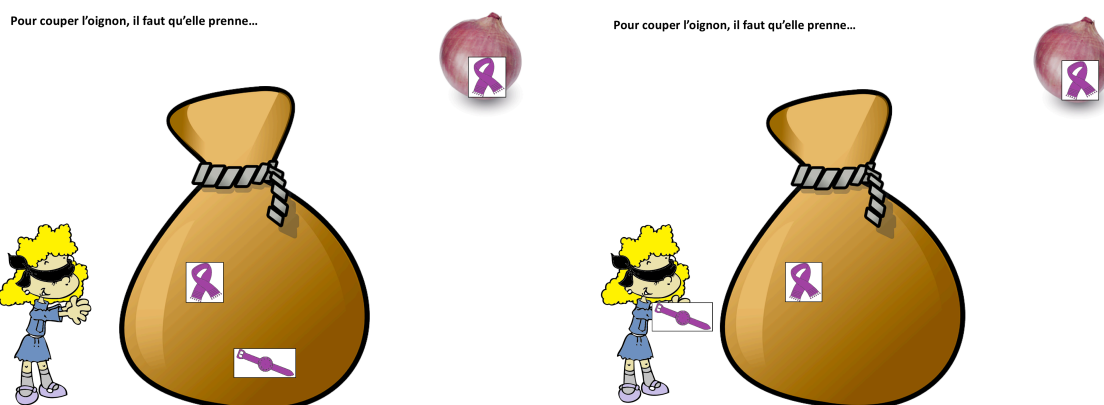
Figure 13: Broad focus condition: The examiner or the caregiver says: "Pour monter à l'échelle, il faut qu'elle prenne la chemise orange" ("To climb the ladder, she needs to take the orange shirt"). The child should say: "Claire prends la **chemise orange**<sub>F</sub>" ("Claire take the **orange shirt**<sub>F</sub>").



A

B

Figure 14: A- Contrastive narrow focus on adjective: The examiner or the caregiver says: “Pour ouvrir le parapluie, il faut qu’elle prenne les lunettes violettes” (“To open the umbrella, she needs to take the violet glasses”). The child should say: “Claire prends les lunettes **violettes<sub>F</sub>**” (“Claire take the **violet<sub>F</sub>** glasses”). B- Corrective narrow focus on adjective: The child should say: “Non Claire! Prends les lunettes **violettes<sub>F</sub>**” (“No Claire! Take the **violet<sub>F</sub>** glasses”)



A

B

Figure 15: A- Contrastive narrow focus on noun: The examiner or the caregiver says: “Pour couper l’oignon, il faut qu’elle prenne l’écharpe violette” (“To cut the onion, she needs to take the violet scarf”). The child should say: “Claire prends l’**écharpe<sub>F</sub>** violette” (“Claire take the violet **scarf<sub>F</sub>**”). B- Corrective narrow focus on noun: The child should say: “Non Claire! Prends l’**écharpe<sub>F</sub>** violette” (“No Claire! Take the violet **scarf<sub>F</sub>**”)

Recordings were performed as part of the yearly speech therapy follow-up at La Timone Children’s Hospital and prosodic focus production was evaluated among regular speech evaluation tests. They were performed in a calm room while using high definition microphone and recording machine (ZOOM H4n). We started with a training phase in order to familiarize the children with the task, and to make sure that they understood it, as well as to make them more comfortable during the whole recording. After the training phase, 12 trials per condition were performed in a random order. Caregivers had to interact with the children in order to produce the same words in the same conditions following the children’s production in order not to influence their performance. CI children results were compared to the control group composed of the CI children’s NH caregivers.

Only CI children aged 5 to 7 years were included in the statistical analysis (7 participants) because CI children aged 4 years couldn't produce interpretable sentences (3 participants). In the adults' group only 6 of the 7 caregivers were recorded because one of the CI children refused his caregiver to participate in the game.

There were 408 produced sentences included in the analysis and 19 rejected in the 7 participants of the CI group. On another hand, 356 sentences were included in the analysis and 10 were excluded in the 6 participants of the adults' group.

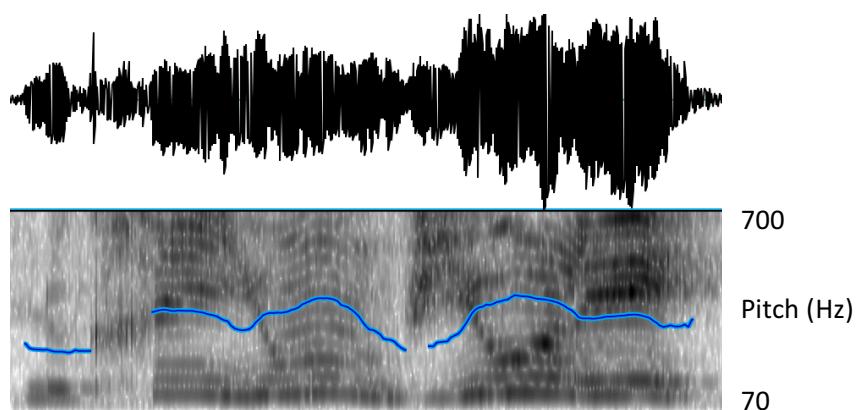
Excluded sentences were:

- When the adjective was said before the noun (eg, "prends le violet crayon"),
- When another noun was used instead of the targeted word (eg, "sucette" instead of "tétine")
- If only one element was said without the other (eg, "non! prends le violet")
- If the caregiver/child spoke at the same time of the tested subject

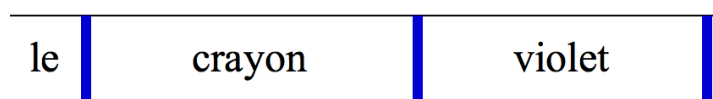
### **Analysis**

Recordings were annotated in SPPAS® software (Bigi, 2015) and manually corrected by the main investigator, then analysed using Praat® software (Boersma, P ; Weenink, 2016) (fig. 16).

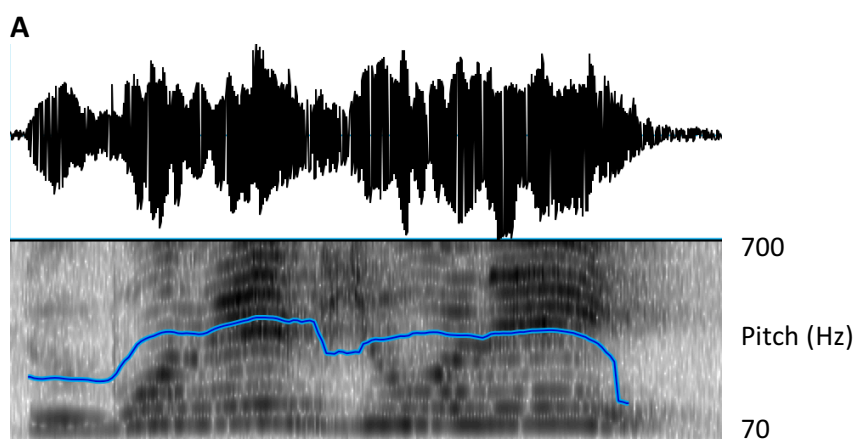
Prosodic characteristics of the target utterances were labelled. F0 range of each word in the NP (calculated by subtracting F0min from F0max of each word), as well as the duration of each one, were compared in the different focus conditions and levels, and between the children and adults' groups. The analysis was performed according to chronological age of CI children and then to hearing age. Hearing age corresponds to the hearing experience of the CI child. It is calculated as the time elapsed between the first CI external device fitting (usually three weeks after the surgery) and the date of the recording. Statistical analysis was conducted on R Studio® software (RStudio Team, 2016) using mixed effects logistic regression.



le crayon violet



Corrective narrow focus on noun



le bonnet violet



Corrective narrow focus on adjective

**B**

Figure 16: A- Example of a corrective narrow focus on noun produced by a 7-year-old CI child.  
B- Example of a corrective narrow focus on adjective produced by the same 7-year-old CI child

#### 4. Results

From the 18 eligible children, we managed to include 10. Children not included in the study were either abroad or have changed their address and are now followed-up by another team. Mean age at testing was 6.06 years, with 3 children in the 4-year-old group, 2 in the 5-year-old group, 2 in the 6-year-old group and 3 in the 7-year-old group. There were 6 girls and 4 boys. All of the children, except three, have received a bilateral CI either simultaneously (CI1) or one to two years after the first CI. The mean age at the first CI intervention was 15.88 months. The detailed CI children characteristics are found in table 2.

In the adult group, 6 participants were included and they were all women in the early thirties. In the CI group, the 3 children aged 4 were not included in the analysis because no sentence has been produced. If we analyze these children in more details, the CI2 child had problems in concentration and didn't even finish the training phase and couldn't produce any word. This child has a hearing age of 2.8 years and had severe mastoiditis after the CI surgery (infection of the mastoid bone) which delayed the external processor fitting and didn't even start using her CI immediately after the fitting because of many ear infection episodes. The CI3 child (hearing age of 3 years) couldn't proceed with the test because he had difficulties in concentration and didn't want to perform the tasks. Finally, the CI7 child (hearing age of 3.34 years) had difficulties in producing comprehensible words and this was judged by the speech therapist as being the result of bilingual input at home (French and Arabic) causing a confusion on what language he should learn.

Table 2: Characteristics of cochlear implanted children

Child	Age in months	Age in years	Age group	Age at CI in months	Hearing age in years	Side of CI (first interv)	Bilateralisation	Cause	Spoken language
CI 1	83.33	6.84	6 years	12.00	5.88	B	Sim BCI	M	French
CI 2	53.07	4.36	4 years	18.00	2.81	R	Yes	C	French and SL
CI 3	56.87	4.67	4 years	18.00	3.01	R	Yes	C	French and SL
CI 4	75.53	6.20	6 years	12.80	5.17	L	Yes	C	French mainly and Spanish
CI 5	69.03	5.67	5 years	18.00	3.98	R	No	C	French
CI 6	90.53	7.44	7 years	15.33	6.20	R	No	C	French
CI 7	56.83	4.67	4 years	16.00	3.34	R	Yes	C	French and Arabic (50%)
CI 8	92.33	7.58	7 years	18.00	6.12	R	No	C	French
CI 9	68.13	5.60	5 years	12.67	4.56	L	Yes	C	French
CI 10	92.20	7.57	7 years	18.00	5.98	R	Yes	C	French

CI: cochlear implantation/cochlear implant; interv: intervention; B: bilateral; R: right; L: left; Sim BCI: simultaneous bilateral CI; M: meningitis; C: congenital; SL: sign language.

#### 4.1. Prosodic focus in cochlear implanted children

##### **Duration and F0 range of words in all the CI children group according to focus condition and focused item (N or A)**

Figures 17 and 18 show the distribution of the duration (in ms) and F0 range (in Hz) of NP elements respectively, according to focus conditions for the entire CI group (excluding 4-year-old children). In these plots, we found that the duration of A was longer than N in all focus conditions and levels (Fig.17). These findings were also noticed for the pitch range (Fig. 18).

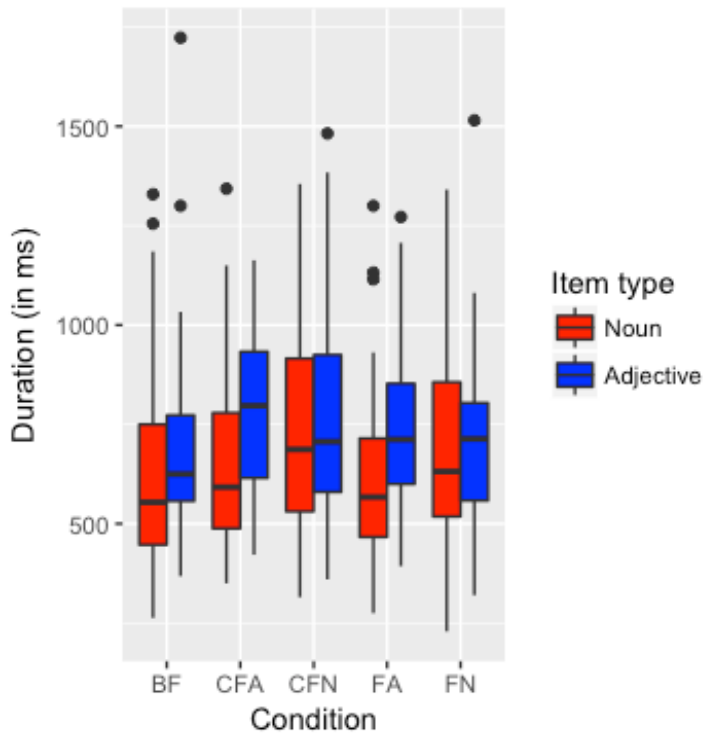


Figure 17: Duration of Noun and Adjective according to focus condition in cochlear implanted children (BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun)

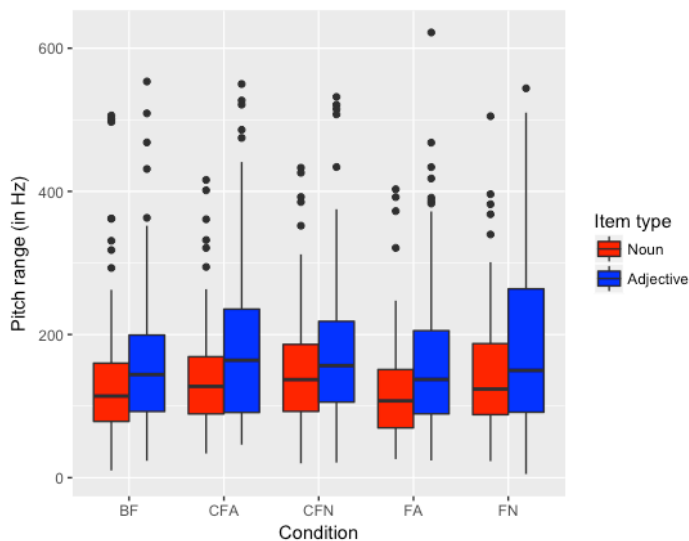


Figure 18: Pitch range of Noun and Adjective according to focus condition in cochlear implanted children. (BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun)

In order to evaluate the statistical significance of our results, we have investigated the effect of specific focus conditions on the duration of the NP elements, then their pitch range, without taking into consideration the age factor.

We have used a linear mixed effect model, with our random effect factors being the participants (1|Participant) and the sentences (1|Sentence), to study the effect of condition and type of the word, as well as their interaction, on the duration and the pitch range of the words. Our dependent variable was the duration ("Duration" in ms) or the pitch range ("F0\_range" in Hz) of the whole word which can be either N or A. We had 2 categorical independent variables, focus conditions' levels ("Condition" with 5 levels: BF, FN, FA, CFN and CFA) and type of the word in the NP ("Position" with 2 positions: "1N" for noun and "2A" for adjective). We chose BF as our baseline condition and N as the reference word position ("1N"). Interaction was noted using the sign "\*" between "Condition" and "Position".

The model can be written in R studio as follows:

- In order to study effect on the duration of the word:  
*Duration ~ Condition\*Position + (1 | Participant) + (1 | Sentence)*
- In order to study effect on the pitch range of the word:  
*F0\_range ~ Condition\*Position + (1 | Participant) + (1 | Sentence)*

We found that the duration of N was significantly longer in FN than BF ( $\beta=72.82$ ,  $t=2.744$ ,  $p<.01$ ), and in CFN than BF ( $\beta=116.48$ ,  $t=4.320$ ,  $p<.001$ ), but in CFN it was longer than FN with a tendency towards significance ( $\beta=43.7$ ,  $t=1.809$ ,  $p=0.07$ ). As for the pitch range of N, we found that it was higher in FN than BF, in CFN than BF, and CFN than FN, but the difference was not statistically significant (Table 3).

Table 3: Noun pitch range in each focus condition on noun

Focus conditions	Estimate ( $\beta$ )	Standard error	T value	P value
FN vs BF	10.323	15.591	0.662	0.508
CFN vs BF	18.040	15.729	1.147	0.252
CFN vs FN	7.717	15.279	0.505	0.614

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun

Regarding A duration, we found that it was significantly longer in FA than BF ( $\beta=56.44$ ,  $t=2.081$ ,  $p<.05$ ), in CFA than BF ( $\beta=113.14$ ,  $t=4.194$ ,  $p<.001$ ), and in CFA than in FA ( $\beta=56.7$ ,  $t=2.366$ ,  $p<.05$ ). As for the pitch range of A, we found that it was higher in FA than BF, and in CFA than FA, but the difference was not statistically significant. In CFA compared to BF, A pitch range was significantly longer (Table 4).

Table 4: Adjective pitch range in each focus condition on adjective

Focus conditions	Estimate ( $\beta$ )	Standard error	T value	P value
FA vs BF	9.657	15.761	0.613	0.540
CFA vs BF	32.227	15.568	2.070	0.039 *
CFA vs FA	22.5706	15.1611	1.489	0.137

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; \*:  $p<.05$



We evaluated the effect of interaction between the focus condition and the type of the NP element on the duration of the word. The duration of the produced A was significantly longer than N in BF ( $\beta=61.98$ ,  $t=2.584$ ,  $p<.01$ ). The number 61.98 represent the difference between the duration of A and N in BF which is significant. There was an interaction effect on duration between the condition and the type of the word. It was statistically significant in FA ( $\beta=68.14$ ,  $t=2.003$ ,  $p<.05$ ) and in CFA ( $\beta=68.69$ ,  $t=2.050$ ,  $p<.05$ ). The duration of A was almost 130 ms (difference between A and N in BF [62] + interaction in FA [68] or CFA [69]) longer than N in FA and CFA. The difference between the duration of A and N in FN was almost 2 ms with a marginally significant interaction ( $\beta=-60.23$ ,  $t=-1.781$ ,  $p=0.07527$ ). In CFN ( $\beta=-30.48$ ,  $t=-0.896$ ,  $p=0.37070$ ), the interaction was not statistically significant but the A duration was 31.5 ms longer than N duration.

Pitch range of A was found to be higher than that of N in all the focus conditions, but the interaction was not statistically significant (Table 5)

Table 5: Effect of the type of noun-phrase element and condition on the pitch range in CI children (effect of the interaction between “Condition” and “Position”)

Type of item/focus condition	Estimate ( $\beta$ )	Standard error	T value	P value
A vs N/BF	22.281	15.243	1.462	0.144
A vs N/FN	23.026	21.490	1.071	0.284
A vs N/CFN	2.182	21.623	0.101	0.920
A vs N/FA	24.350	21.623	1.126	0.260
A vs N/CFA	25.223	21.301	1.184	0.237

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; A: Adjective; N: Noun

#### **Duration and F0 range of words in CI children by age group according to focus condition and focused item (N or A)**

Figures 19 and 20 show the distribution of the duration (in ms) and F0 range (in Hz) of NP elements respectively, according to focus conditions for each CI age group.

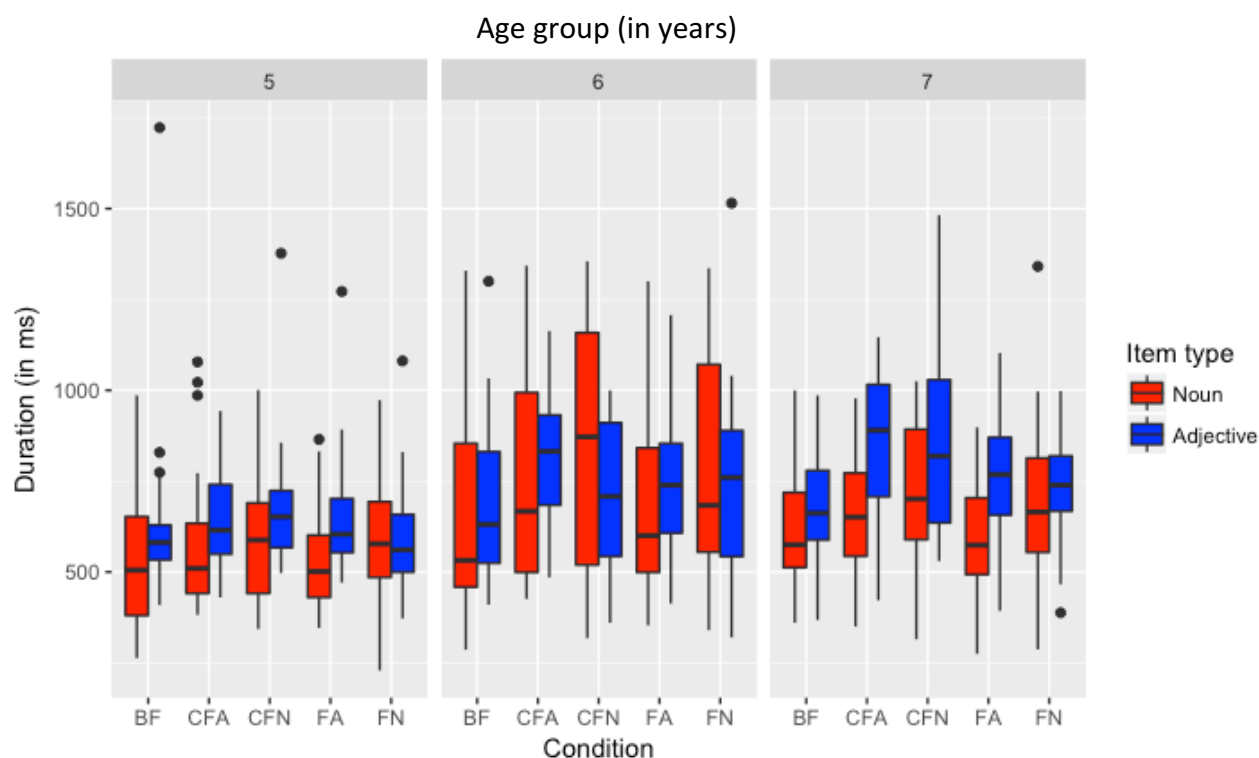


Figure 19: Duration of Noun and Adjective according to focus condition in each age group of cochlear implanted children. (BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun).

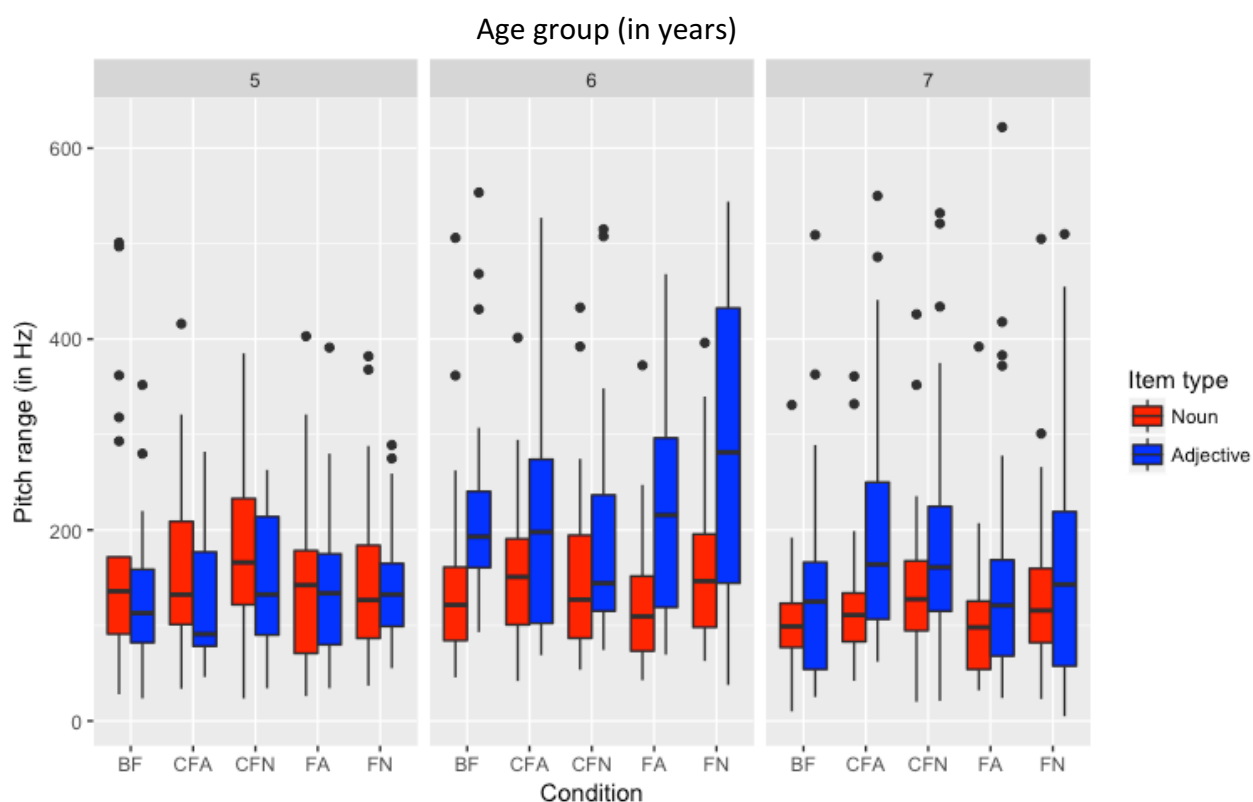


Figure 20: Pitch range of Noun and Adjective according to focus condition in each age group of cochlear implanted children. (BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun).

When analyzing the graphical distribution of the obtained results, we found that 5-year-old CI children lengthen the duration of the adjective, which is in the end of the phrase, more than the noun in all the focus conditions except in FN. This pattern is found more evident in the 7-year-old group for all the study conditions. However, in the 6-year-old group this pattern is not found in all the conditions. In this group, the median of the duration of A was higher than N in all the focus conditions except in CFN where the duration of N was longer than A.

We found that in the 6- and 7-year-old groups, the duration of N was longer in CFN more than in FN, and in FN more than in BF, and that of A was longer in CFA more than in FA, and in FA more than in BF. These findings were noticed at a lesser degree in 5-year-old group. (Fig. 19)

Regarding the pitch range, there was an important variability in the results in the 5-year-old group, but it was lengthened for the A more than N in all the focus conditions on all the levels in the 6-and 7-year-old CI children. When comparing between focus conditions and the levels of focus, we only found that in the 7-year-old-group there was a consistent pattern of lengthening the pitch range of N in CFN more than FN, and in FN more than BF. The pitch range for A was longer in CFA than in FA, and in CFA than in BF. (Fig. 20)

We can only consider these results as trends, because we couldn't evaluate them for statistical significance as each group was composed of 2 to 3 participants.

#### **Other strategies used by CI children to mark focus**

Observing the results of the CI children tested, we found that some children used other strategies to mark focus. For example, some used pointing, others made pauses before the word that should be focused especially if it was the adjective, and others increased the intensity of their voice in order to mark focus, especially in corrective narrow focus. These observations were not consistent in all the groups which is why a statistical analysis was difficult to perform.

#### **4.2. Prosodic focus in adults**

Figure 21 and 22 show the distribution of the duration (in ms) and pitch range (in Hz) of NP elements respectively, according to focus conditions in the adult caregivers' group. In these plots, we found that the duration of A was longer than N in all focus conditions and levels (Fig.22). These findings were noticed for pitch range in FN, FA and CFA, but pitch range of A was shorter than N in BF and CFN (Fig. 22).

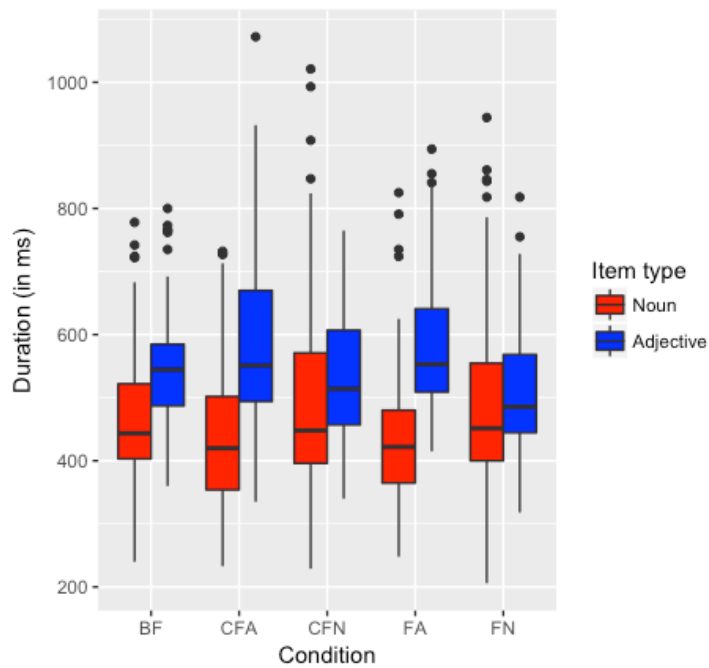


Figure 21: Duration of Noun and Adjective according to focus condition in caregivers (BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun).

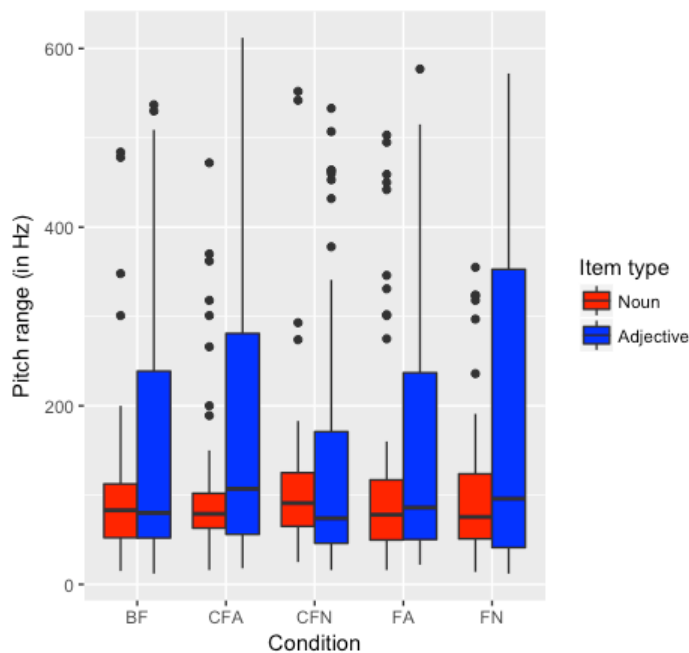


Figure 22: Pitch range of Noun and Adjective according to focus condition in caregivers (BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun).

In order to test the statistical significance of these results, we performed the same statistical analyses in adults as in children, using only adults' data<sup>1</sup>. We found that the produced N duration, was longer in CFN than in FN but the difference was not statistically significant. N

<sup>1</sup> The linear mixed model fit for duration was:  $\text{Duration} \sim \text{Condition} * \text{Position} + (1 | \text{Participant}) + (1 | \text{Sentence})$   
The linear mixed model fit for pitch range was:  $\text{F0\_range} \sim \text{Condition} * \text{Position} + (1 | \text{Participant}) + (1 | \text{Sentence})$

duration in FN was marginally longer than in BF. As for the duration of N in CFN, it was significantly longer than in BF ( $\beta=37.79$ ,  $t=2.377$ ,  $p<.05$ ).

Adults lengthen produced A duration significantly in CFA more than in BF ( $\beta=49.71$ ,  $t=3.116$ ,  $p<.01$ ). They lengthen it also in CFA more than in FA, but the difference was not statistically significant, and in FA more than in BF but there was only a marginally significant result. (Table 6)

Table 6: Duration of noun and adjective in each related focus condition in adults

Item type	Focus conditions	Estimate ( $\beta$ )	Standard error	T value	P value
N	FN vs BF	27.08	15.55	1.741	0.082
	CFN vs BF	37.79	15.90	2.377	0.018 *
	CFN vs FN	10.711	12.810	0.836	0.403
A	FA vs BF	29.70	16.06	1.850	0.065
	CFA vs BF	49.71	15.95	3.116	0.002 **
	CFA vs FA	20.007	12.482	1.603	0.109

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; A: Adjective; N: Noun; \*:  $p<.05$ ; \*\*:  $p<.01$

When studying the interaction between the focus condition and the type of the word, we found that the duration of the produced A was significantly longer than N in BF ( $\beta=77.37$ ,  $t=6.114$ ,  $p<.001$ ). The effect of interaction was present in all the condition and was statistically significant. The A duration was 146 ms longer in FA than N duration with a significant interaction ( $\beta=68.63$ ,  $t=3.835$ ,  $p<.001$ ) and 155.6 ms longer in CFA, with a significant interaction ( $\beta=78.23$ ,  $t=4.474$ ,  $p<.001$ ). The A duration was longer than N in FN and CFN. The difference between A and N in FN was almost 14 ms and in CFN was almost 19 ms. The interaction between condition and type of the word was statistically significant in FN ( $\beta=-63.50$ ,  $t=-3.548$ ,  $p<.001$ ) and in CFN ( $\beta=-58.62$ ,  $t=-3.264$ ,  $p<.01$ ).

As for N pitch range in adults, it was shorter in FN than BF, longer in CFN than BF, and in CFN than FN, but there was no statistically significant difference. For A pitch range, it was shorter in FA compared to BF, longer in CFA compared to BF and in CFA compared to FA, but the difference was not statistically significant. (Table 7)

Table 7: Pitch range of Noun and adjective in each related focus condition in adults

Item type	Focus conditions	Estimate ( $\beta$ )	Standard error	T value	P value
N	FN vs BF	-1.693	22.875	-0.074	0.941
	CFN vs BF	12.966	23.059	0.562	0.574
	CFN vs FN	14.658	22.116	0.663	0.508
A	FA vs BF	-2.413	23.074	-0.105	0.917
	CFA vs BF	20.485	22.626	0.905	0.366
	CFA vs FA	22.899	21.547	1.063	0.288

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; A: Adjective; N: Noun

The pitch range of the produced A was significantly higher than N in BF ( $\beta=66.957$ ,  $t=3.049$ ,  $p<.01$ ). The difference between the pitch range of A and N in FN was 90 Hz, 27 Hz in CFN, 44 Hz in FA and 81 Hz in CFA, but the interaction was not statistically significant. Detailed results can be found in table 12.

Table 12: Effect of the type of noun-phrase element and condition on the pitch range in adult caregivers (effect of the interaction between “Condition” and “Position”)

Type of item/focus condition	Estimate ( $\beta$ )	Standard error	T value	P value
A vs N/BF	66.957	21.962	3.049	0.002 **
A vs N/FN	22.871	31.059	0.736	0.462
A vs N/CFN	-39.885	31.171	-1.280	0.201
A vs N/FA	-22.586	31.059	-0.727	0.467
A vs N/CFA	14.212	30.345	0.468	0.640

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; A: Adjective; N: Noun; \*\*:  $p<.01$

#### 4.3. Prosodic focus in CI children compared to adults

In order to compare between the performances of CI children and adults, we compared the pattern of prosodic focus in each CI children age group to the adults’ production. We only used graphical data from CI children age groups in order to compare them to the results in adults.

Adult patterns of speech production were adopted by 6- and 7-year-old CI children when comparing duration of the word across conditions, where they lengthened N duration in CFN vs BF, and A in CFA vs BF. As for the duration of A vs N, 5-year-old CI children lengthened the duration of A more than N in all conditions except in FN, 6-year-olds lengthened A duration more than N in all conditions except in CFN, and 7-year-olds adopted the same adult pattern in all focus conditions and levels in lengthening A duration more than N.

As for the pitch range lengthening, the adult pattern was mainly adopted by the 6- and 7-year-old CI groups in BF, FN, FA and CFA, and in CFN by the 7-year-old children. Keeping in mind that adult results were not statistically significant except when comparing A to N in BF (table 12).

No statistical comparison can be done between each age group and the adults due to the small number of participants in each CI age group, and their results can only be considered as trends.

## 5. Discussion

This the first study to evaluate prosodic focus production in early CI French speaking children. In order to evaluate prosodic focus, we have recorded NP produced by the CI children and their caregivers. NP were composed of a noun (N) and an adjective (A), and the adjective was always at the end of the phrase which in French risks to have a duration lengthening in every focus condition (Lambrecht, 1994).

In our study, in order to evaluate prosodic focus, we decided to use 2 acoustic correlates of focus, the duration of the focused word and the pitch range of that word.

We compared the duration and the pitch range of the adjective in the conditions where focus should be performed on the adjective to broad focus where it should be the least focused. The same comparison was performed for the duration and pitch range of the noun. These two comparisons were done for the whole group of CI children, in each CI children's age group and for adult caregivers. We then compared the prosodic focus produced between CI children in each age group and to the adults.

First, we found that CI children lengthen significantly the duration of the noun in CFN more than FN, and in FN more than BF. They also lengthen significantly the duration of the adjective in CFA more than FA, and in FA more than BF. However, when studying pitch range of the noun and the adjective, a lengthening was noticed when comparing corrective to contrastive narrow focus and contrastive narrow focus to broad focus. These results were not statistically significant and even though we have a trend towards a significant result when comparing pitch range on adjective in CFA vs BF ( $p=0.057$ ), no conclusion can be retained from this analysis.

Second, when analyzing each CI age group speech production, we have found that 5-year-old children try to lengthen the duration of the target focused word across focus conditions, but they don't control correctly pitch range. In the 6-year-old group of CI children, lengthening of the duration of the adjective was more important than the noun in all conditions except in CFN where the duration of the noun was longer than the adjective. Pitch range was lengthened for the adjective more than the noun in this group in all the conditions. In the 7-year-old group, at the level of the noun they were able to lengthen the duration when comparing corrective narrow focus to broad focus, and at the level of the adjective, they were able to lengthen the duration in corrective narrow focus more than contrastive narrow focus and broad focus, and in contrastive narrow focus more than in broad focus. They were also lengthening the adjective duration more than the noun in all the conditions. Pitch range of the adjective was longer for the adjective than the noun in all the conditions. These results were considered as trends because statistical significance couldn't be tested knowing that each age group was composed of 2 to 3 participants only.

In adults, lengthening of the duration of the noun was not statistically significant when comparing different focus conditions on noun, except in CFN compared to BF where N was significantly longer. Speculated explication of this result can be the fact that the initial rise demonstrated in French speaker by German et al (German & D'Imperio, 2016), could lead to a prolonged entire focused word in corrective focus conditions.

Lengthening of the duration of the adjective was significantly higher in corrective narrow focus versus broad focus and marginally in contrastive narrow focus versus broad focus, but was not significant between CFA and FA. Lengthening of pitch range for the noun or the adjective was not significantly different across the different focus conditions. The duration of the adjective was longer than the noun in all focus conditions, as it is an intonational phrase end word (see table II in annexes).

As it was shown in the literature that French adults lengthen the final word of an intonational phrase whatever was the focus condition (Lambrecht, 1994), which is in our case always the adjective. Our results regarding the group of adults is considered as similar to the data

published in the literature. An ongoing work, by Esteve-Gibert et al, on prosodic focus production in French 4- and 5-year-old NH children and adults, doing a similar task to ours, showed in their preliminary results, that adults always lengthen the final syllable of the adjective. The adjective was always the final word of the intonational phrase, so the duration of the whole adjective word in all focus conditions was lengthened more than the noun (Esteve-Gibert et al., 2017). Other data in the literature showed, that French adults were found to produce focus using an initial pitch rise especially in contrastive focus associated to a final pitch rise. In corrective focus context, the focused element is realized with a pitch contour higher and earlier aligned than typical final rise in broad focus context, with a deaccentuation or a dephrasing of the element following the focused part. (German & D'Imperio, 2016)

In order to determine if French CI children in our study follow the correct adult pattern of prosodic focus, we compared them first to their caregivers.

In our series, we found that 5-year-old CI children start to have a same pattern as adults in lengthening the duration of the whole adjective more than the noun in all the conditions except in contrastive narrow focus on noun, and 6-year-old CI children start doing that in all conditions except in corrective narrow focus on noun where the duration of the noun was longer than the adjective. The 7-year-old CI children were found to adopt better the adult pattern. They lengthened the duration of the end-phrase adjective more than the noun in all focus conditions and levels as adults did. They have also performed focus by means of duration lengthening of the target focused whole word (Noun or Adjective) between different focus conditions. Lengthening was more important in corrective narrow focus than in contrastive narrow focus which was more important than in broad focus but this pattern was found to lesser degree in adults. These children in the 7-year-old group had a hearing age of no more than 6 years and 2 months.

Next, we wanted to see if early CI French children perform as their age match NH peers. We compared their performance by age group to the results of 4- and 5-year-old NH French children doing the same production task in the work of Esteve-Gibert et al. In their paper, authors found that 4- and 5-year-old French NH children were unable to produce correctly prosodic focus but they lengthened the adjective as it was the end phrasing word, they were able to produce accentual phrases. They used gesture in order to mark focus. The oldest child in the series was 5 years and 9 months old (Esteve-Gibert et al., 2017). Compared to these NH children, only 7-year-old CI children in our series were able to correctly lengthen the duration of the adjective more than the noun in all focus conditions and levels. If we take into consideration the hearing age, these children are considered as being in the beginning of 6-year-old range. Which shows that the pattern of lengthening correctly the end phrase word was mastered a bit later than NH children.

As for the younger CI children groups, especially in the 6-year-old group, where only two participants were included, the hearing age was 5.17 years for the youngest (CI 4) and 5.88 years for the oldest (CI 1) (Table 2). Their results were different than their age-matched NH peers in Esteve-Gibert et al's work. When looking at the results of each of the two participants, we can see that the oldest one had a pattern similar to the 7-year-old CI children while the youngest one had results completely different. She was lengthening the noun more than the adjective in the majority of CFN and FN utterances. This difference can be supposed to be due to pausing between N and A in the majority of the concerned utterances. We can maybe



consider that her difficulties were mainly at the level of phrasing. Instead of taking the whole sentence as one intonational phrase, she was segmenting it into two intonational phrases. As a result, the noun was considered as an end-phrase word in the first intonational phrase and it was more easily lengthened in narrow focus conditions on the noun (see table I in annexes). As we only had 2 participants in this age group, the completely different behavior of one child could change drastically the results of the whole group. Looking into the details of the development of this child, no speech difficulties were noticed in terms of pronunciation or learning capacities according to speech therapy follow-up.

The 5-year-old CI children group was composed of 2 participants. Their hearing ages were 3.98 years and 4.56 years. Comparing them to their age-matched NH peers in Esteve-Gibert et al.'s work, they were able to control duration lengthening of the adjective as NH children except in FN condition. Similar to NH children they were unable to produce focus in all conditions. In this group, one participant (CI 9) had difficulties in pronunciation, was slow in producing the words and segmenting frequently the utterances not having correct phrasing capacities (see table I in annexes). The results of this child can be responsible of a significant variation in the behavior of the entire group and thus altering the results compared to NH children and adults.

The results of the 4-year-old CI children were not included in our analysis, because as mentioned before they were not interpretable. In this group, three participants were included. The oldest child (CI 7) had less than 3.34 years of hearing experience. He had no comprehensible words produced which was judged by speech therapists as a possible result of the bilingual simultaneous stimulation at home causing a conflict with speech therapy interventions, and thus delaying proper language development. The delayed activation of the external processor of the CI, due to severe ear infections as in CI 2 child, which consequently led to a shorter hearing experience (hearing age of 2.8 years), can be responsible of the delay of acquisition of language. In all the participants of this age group, difficulties in concentration and easy fatigability were consistent factors preventing them from performing the production task of our study.

In the literature, to our knowledge, no study has evaluated the use of prosodic cues to mark focus in French early CI children suffering from pre-lingual hearing loss. Only few studies evaluated prosody production in non-French CI children and especially intonation variations. In studies regarding English speaking CI children, authors found that they had mainly difficulties in rate and loudness. They were less interactive, less talkative and were more in silence than their NH peers. Intonation performance was poorer in CI children than their NH peers in terms using appropriate contour especially in using phrase-final pitch rise to signal requests. (Chin et al., 2012; Holt et al., 2017; Lenden & Flipsen, 2007; Lyxell et al., 2009; Peng et al., 2007, 2008).

Two main published studies compared the use of prosodic cues to mark focus and to produce stressed words and sentences.

In their study on conversational speech, Lenden and Flipsen found abnormalities in word and sentence stress in six CI children aged 3 to 6 years. Phrasing, voice quality, and pitch were relatively unaffected. All CI children included in this study received implant before the age of 3 years and no analysis was performed according to age. (Lenden & Flipsen, 2007)

A recent study on phonetic production of prosody in disyllabic babble and first words in English CI and NH infants (between 6 months to 2 years of age), showed that CI infants had weaker

acoustic prosodic cues use. They analyzed pitch distance, intensity, and duration ratios. They found that there were mainly difficulties in pitch in line with the limiting perception by the CI device. Duration differences between the 2 groups were due to greater articulatory difficulties in words for the CI infants. NH infants were able to prolong end phrase words and syllables while CI infants have difficulties in that. (Pettinato et al., 2017)

When comparing our results to these two studies, our CI children had difficulties in pitch control and duration control especially in the youngest participants as it was shown by Pettinato et al. In contrast with Lenden and filpsen work, the youngest participants in our study had difficulties in phrasing and in pitch control. An age group comparison cannot be performed because in the first study no analysis was performed according to different age groups, and in the second, CI participants were all aged between 8 months and 2 years at the beginning of the study and between almost 2 to 3 years at the end of the study. No hearing age based analysis was performed.

In an unpublished work on prosody skills and intonation in storytelling of early CI Italian children (before the age of 2 years), no difference was found between CI and NH children aged between 42 and 83 months. Narrative competence was comparable between the 2 groups with only a difference in lexical variety in favour of NH children. As for intonation, CI children used “the same pitch accents boundary tones, utterance-internal breaks and speech rate” as their NH peers when telling stories. (Zanchi, Zampini, Berici, & D’Imperio, 2017)

Evidence from the literature showed that the acquisition of word focus is prone to be more effortful for CI children. However, it is not impossible. The difficulties are mainly due to the fact that it depends on acoustic discrepancies which are harder to perceive when using a CI. They were also found to be more tenuous to noise perturbation. The spectral and temporal resolution of the implant devices does not permit adequate F0 perception or changes in intensity, but durational characteristics of syllables seem to be available to CI users. (Pettinato et al., 2017)

In order to facilitate the acquisition of prosodic cues to focus, age at CI is an important factor to take into consideration due to the neuroplastic and neurolingistic dynamics in the development of the child. It is optimally beneficial to offer CI during the critical period of cortex neuroplasticity in which speech and language are developed and mastered (De Melo, Lara, TM, & JD, 2012; Sharma et al., 2002, 2007). CI performed before the age of 2 years and optimally before 12 to 18 months has shown better results in terms of hearing and language development (Bruijnzeel et al., 2016).

Another important criterion to take into consideration when analyzing speech in CI pre-lingually hearing impaired children, is hearing experience. Studies showed that the longer the hearing experience with CI, the better were the results in terms of speech production. When comparing CI children to NH peers a fairer criterion to use should be hearing age and not chronological age (Chin et al., 2012; Peng et al., 2008).

In our study, even though we only included early CI children before 18 months, CI children still had difficulties in acquiring adult patterns, especially in the youngest groups. Only 7-year-old CI children acquired adults’ pattern in duration use. When considering hearing age, children

in this group, who had chronological ages distributed between 7 years and 5 months and 7 years and 7 months, were actually not older than 6 years and 2 months.

Bilateral CI as a factor responsible of a better speech production was not considered in our study as almost all our participants received a bilateral CI either simultaneously or sequentially in a 1.5 to 2-year period between the two interventions, except in 3 children who didn't benefit from bilateralisation. Due to the small number of participants, no statistical analysis has been performed. Gordon et al, showed that the ideal delay between the first CI and the second one should be less than 2 years and better if less than 1.5 years. This smaller delay between the two interventions permitted to CI users to develop better both auditory cortex in order to better localize sound and to better develop speech perception capacities. Passing this delay, and even with longer use of bilateral CI, results in speech were poorer. (Gordon, Wong, & Papsin, 2013)

Other strategies of prosodic focus were noted in CI children. Of that we can name pointing and gesture use, pauses before focused word, and rising word intensity when focusing especially in corrective narrow focus. These findings were not consistent in all the participants and statistical analysis could not be considered. Gesture use to mark focus was considered as the main prosodic focus capacity in NH 4- and 5-year-old French children in the study by Esteve-Gibert et al. (Esteve-Gibert et al., 2017)

In our series, difficulties in the acquisition of prosodic focus adult patterns in speech production were mainly due to some factors. The analysis of the recordings in each child showed that CI children had slower rates than adults and difficulties in fluency of the speech. Moreover, the use of pauses inside of the intonational phrase (the noun phrase) has led, in some children, to segmentation of the intonational phrase into 2 phrases which translated a difficulty in phrasing acquisition in some children especially young ones. Other difficulties were detailed earlier in the text according to each age group.

It is important to mention certain limitations to our study.

First, the small sample sizes can limit the extrapolation of the results to a larger population. The number of participants in each CI age group was limited to 2 or 3 subjects. This limitation caused a higher variability in the results as the production in one participant can affect greatly the results of all the group. Moreover, statistical analysis is difficult to perform on such small groups because the interpretation of the results can be misleading.

Second, the absence of a pediatric NH group performing the same tasks can limit our conclusions as we lack an age-matched NH control group.

Third, the use of the whole-word-based analysis of prosodic cues to focus can be especially misleading, as French speakers can lengthen systematically the end phrase word which would always be in our situation, the adjective. But the comparison between the different focus condition on each word, noun and adjective, have shown that even if we consider the adjective would be systematically lengthened, a significant difference was found between corrective narrow focus, contrastive narrow focus and broad focus, in certain tested groups.

### **III- Conclusion**

This is the first study testing the acquisition of prosodic cues in marking focus in pre-lingually hearing impaired early CI French speaking children. We found that CI children aged 5 and 6 years started to use prosody to emphasise discourse elements in certain conditions, while not having a complete control of phrasing with many variabilities among the same age group. They started acquiring adult pattern of prosodic focus at the chronological age of 7 years (hearing age no more than 6 years and 2 months), without having it completely mastered. We found that when they produce focus, they use duration lengthening of the focused word in corrective narrow focus to a higher degree than in contrastive narrow focus which in turn was stronger than in broad focus condition. The same result was found in a lesser degree in our adult group.

This study can be considered as a step towards understanding the rehabilitation needs of these CI children for a better speech and language development. Results found in French CI children have raised some speculated difficulties. This specific population might have problems in articulation, rhythm and rate control in speech production causing difficulties in managing duration of phrases. The comprehension of tasks might be limited in this group. A possible issue in managing the organization of the phrase constituents can be responsible of the difficulties in producing correct accentual phrases as younger French NH children manage to do. These speculated issues should be evaluated in future projects in order to measure the extent of their effect.

Whatever were the difficulties in CI children, a constant language stimulation in their environment is crucial in order to offer them a better social integration. The role of caregivers in the rehabilitation was not studied in this work, but will still be very fundamental in helping CI children gain a normal interactive life.

Future projects are in process in order to better understand the use of prosodic cues to focus in speech production in this population. An age-matched NH French speaking control group will be soon added to our analysis. An analysis based on the syllable vs the whole word will be undertaken while including more participants in each study group in order to better understand how CI children use prosodic cues to focus.

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## V- Annexes

**List of noun phrases used in the production task (words were all disyllabic, verified on *lexique.org* database)**

“bonnet violet”  
“chemise orange”  
“chaussette orange”  
“lunettes violettes”  
“tétine orange”  
“écharpe violette”  
“chaussure violette”  
“bonnet orange”  
“chemise violette”  
“chaussure orange”  
“ceinture orange”  
“tétine violette”  
“valise violette”  
“écharpe orange”  
“lunettes orange”  
“serviette violette”  
“crayon orange”  
“assiette violette”  
“serviette orange”  
“crayon violet”  
“valise orange”  
“assiette orange”  
“chaussette violette”  
“ceinture violette”

**Table I: Average results for duration and pitch range in each condition in CI children**

Child	Age at test (years)	Age at CI (months)	Hearing age (years)	Condition	N pitch range (Hz)	A pitch range (Hz)	N duration (ms)	A duration (ms)
CI 1	6.84	12	5.88	BF	100.06	196.56	450.58	528.33
				FN	142.13	191.43	530.58	530.08
				CFN	89.71	146.69	531.73	520
				FA	106.81	210.44	517.58	637.50
				CFA	138.16	193.23	516.62	705.62
CI 2	4.36	18	2.81	BF/FA/CFA/FN/CFN	N/A	N/A	N/A	N/A
CI 3	4.67	18	3.01	BF/FA/CFA/FN/CFN	N/A	N/A	N/A	N/A
CI 4	6.20	12.8	5.17	BF	196.62	260.76	938.67	877.08
				FN	181.72	379.275	1042.33	918.33
				CFN	223.24	238.25	1154.83	877.08
				FA	138.43	227.93	843.42	835.58
				CFA	177.1	255.72	955.23	889.69
CI 5	5.67	18	3.98	BF	91.83	88.52	408.92	547.83
				FN	109.73	116.23	472.92	506.08
				CFN	137.94	118.63	487.75	653.83
				FA	106.22	112.02	444	606.08
				CFA	110.07	84.42	494.15	636.38
CI 6	7.44	15.33	6.20	BF	106.58	146.71	511	564.42
				FN	132.78	145.53	577.92	628.92
				CFN	133.93	143.43	625.25	617.17
				FA	103.93	129.05	514	650
				CFA	127.06	121.48	573	669.69
CI 7	4.67	16	3.34	BF/FA/CFA/FN/CFN	N/A	N/A	N/A	N/A
CI 8	7.58	18	6.12	BF	111.25	206.33	796.75	849.50
				FN	132.50	247.25	832.33	848.83
				CFN	171.83	211.83	915.92	1009.08
				FA	102.33	239.04	716.67	884.92
				CFA	143.08	296.53	777.61	1017.69
CI 9	5.60	12.67	4.56	BF	274.80	186.70	711.40	760.40
				FN	212.60	164.50	739	700.50
				CFN	220.33	191	743.89	698.44
				FA	199.10	179.50	658.60	716.50
				CFA	240.12	196	731.87	689.12
CI 10	7.57	18	5.98	BF	103.50	47.17	534.17	646.42
				FN	142.92	111.75	640.75	708.58
				CFN	123.25	210.92	637.50	918.92
				FA	78.08	84.83	521.08	773.67
				CFA	94.92	186.85	593.15	841.77

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; A: Adjective; N: Noun; CI: Cochlear implant/implantation; N/A: Not available.

**Table II: Average results for duration and pitch range in each condition in adults**

Participants	Condition	N pitch range (Hz)	A pitch range (Hz)	N duration (ms)	A duration (ms)
Ad 1	BF	64.42	199.83	371.08	444.17
	FN	68.08	275.08	361.83	415.08
	CFN	106.17	201.42	377.75	412.75
	FA	253.60	303.50	340.50	506.10
	CFA	85.31	179.31	316.54	464.15
Ad 2	BF	93.50	197.58	618.92	698.92
	FN	105.08	207.42	748.83	689.50
	CFN	127.50	57.92	798	662.17
	FA	98.58	211.08	590.17	739.17
	CFA	118.92	226.38	608.54	823.31
Ad 3	BF	103.92	138.25	463.42	562.08
	FN	102.27	74.82	462.64	503.91
	CFN	119.64	189.91	437.18	558.27
	FA	104.25	132.58	419.25	565.50
	CFA	128.83	156	418.58	558.92
Ad 4	BF	127.17	244.08	469.83	533.75
	FN	111.17	211.33	527.17	505.58
	CFN	77.42	134.50	547	512.17
	FA	66.33	118	444.67	553.25
	CFA	63.54	227.46	466.62	591.38
Ad 5	BF	100.33	127.33	449.33	512.42
	FN	64.42	148.83	442.58	448.92
	CFN	101.83	127.58	458.75	490.33
	FA	100.58	93.17	421.17	510.75
	CFA	124.31	110.77	441.77	538.23
Ad 6	BF	118.80	86.20	438.30	525.40
	FN	132.45	192.73	426.64	496.91
	CFN	138.70	118	405.50	526.60
	FA	109.50	141.67	396.83	617.08
	CFA	99.23	203.08	377.38	585.85

BF: Broad focus; CFA: Corrective narrow focus on adjective; CFN: Corrective narrow focus on noun; FA: Contrastive narrow focus on adjective; FN: Contrastive narrow focus on noun; A: Adjective; N: Noun; Ad: Adult.