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Language development in deaf children following cochlear implantation

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BCBL. Basque Center on Cognition, Brain and Language

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Important disclaimers

Personal background

- I am not an audiologist or speech-language therapist, nor a psychologist or educator
- So who am I?
  - PhD in linguistics
    - *Speech and sign perception in deaf children with cochlear implants (2011, University of Amsterdam, Netherlands)*
  - Postdoctoral research with deaf and hearing adult bilinguals of spoken and signed languages
    - *Laboratory for Language and Cognitive Neuroscience (San Diego State University, USA, 2011-2015)*
    - *Basque Center on Cognition, Brain and Language (San Sebastian, Spain, 2015-current)*

Giving credit where it's due

- A lot of the information in this lecture was inspired by these 2 recent review articles
  - I can highly recommend them

Contents lists available at ScienceDirect

Hearing Research

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

Review

What can we expect of normally-developing children implanted at a young age with respect to their auditory, linguistic and cognitive skills?

Astrid van Wieringen*, Jan Wouters

KU Leuven – University of Leuven, Dept Neurosciences, Experimental Oto-rhino-laryngology, Herestraat 49, Bus 721, Leuven, Belgium

Neuroscience Discovery
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HOAJ
Herbert Open Access Journals

Commentary Open Access

Some observations about cochlear implants: challenges and future directions

Kathleen F. Faulkner* and David B. Pisoni
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Department of Psychological and Brain Sciences, Indiana University 1101 E. 10th Street, Bloomington, USA.

Some advertising

Pediatric Cochlear Implantation

Learning and the Brain

Editors: **Young**, Nancy, **Iler Kirk**, Karen (Eds.)

- A very promising book – I hope and think - that will be released on June 21st

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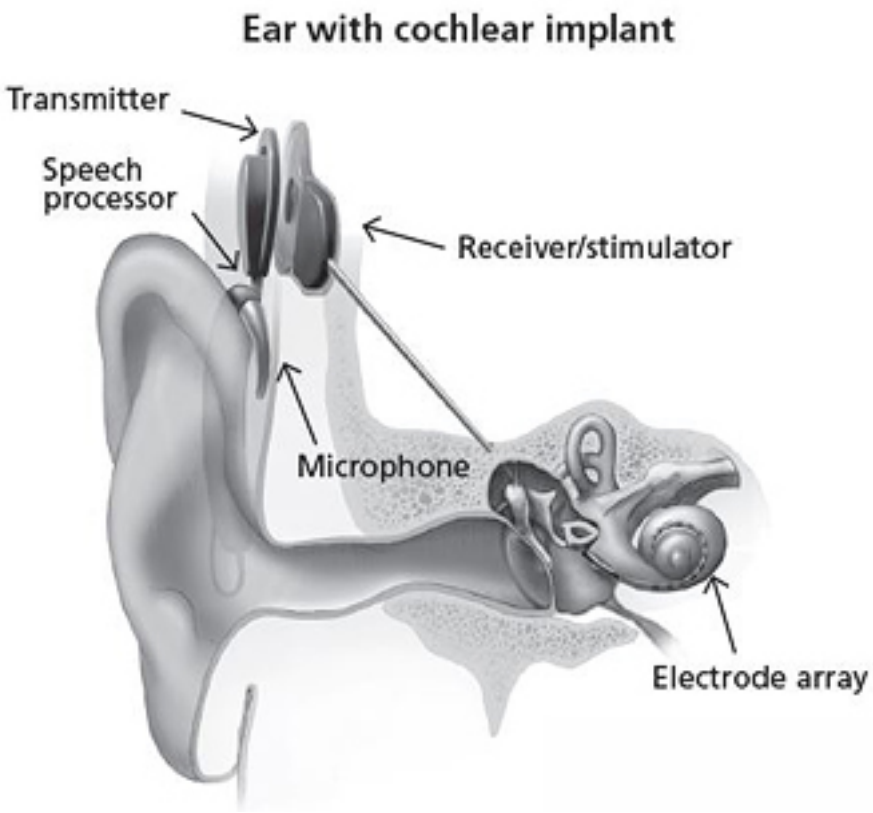
Cochlear implant technology and design

Cochlear implants



Source: NIH/NIDCD

- Partially "restores" hearing by electrical stimulation of the hearing nerve
- > 300.000 users worldwide, including > 80.000 children
- In some European countries, > 90% of congentitally deaf children receive CIs
- Three main CI manufacturers
  - MED-EL
  - Cochlear
  - Advanced Bionics

Technological limitations

- Number and spacing of (inserted) electrodes
- Speech processing technology

Number and spacing of electrodes

- Number of electrodes and the spacing of electrodes affects the signal information
  - No 1-to-1 relationship between number of electrodes (12-22) and functional channels
    - Most patients have less than 10 effective sites of stimulation
  - Better signal with more stimulated electrodes, but closer proximity of electrodes increases risk of channel interaction and signal degradation
  - Steered interaction between electrodes also allows to create “virtual” channels through simultaneous weighted stimulation of adjacent electrodes

Cochlear implant simulations

- 4 channels
- 8 channels
- 12 channels
- 16 channels
- Original recording

- Be careful! This is only an approximation and probably not very close to what any given CI user hears
  - *Cochlear Implant Simulation 2.0*
    (De la Torre Vega, Bastarrica Martí, De la Torre Vega & Sainz Quevedo, University of Granada, 2004)

- In case someone is interested in the BCBL database of LSE signs (LSE-Sign, Guttierrez et al., 2015)
  - http://lse-sign.bcbl.eu/web-busqueda/

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Current pediatric practice

Newborn hearing screening

- Age of diagnosis of hearing loss has decreased substantially in many countries
- Early diagnosis paves the way for early intervention
  - Hearing aids, cochlear implants, …

Early implantation

- Sharp decline in age of implantation over the last 10 years
  - Many children receive a CI within 1st year of life
  - For example, in one implant center in the Netherlands
    - Mean age decreased from 2.4 yrs (2003-2006) to 1.2 yrs (2007-2010) after the introduction of newborn hearing screening
    - Percentage of early-implanted children (< 1 yr) increased from 9% to 37% (even 60% in 2011)
      In 2010, ~80% of children received two implants
      (Lammers et al., 2015)

bcbl

Bilateral implantation

- In many countries, bilateral implantation has become standard
- Bilateral hearing enables access to interaural timing and loudness differences
- Why is this important?

Documented benefits of 2 CIs

- Sound localization
- Speech-in-noise understanding
- *Language development???*

- Simultaneous or sequential bilateral implantation
  - Impact of simultaneous vs. sequential implantation
  - Role of inter-implant interval
    - Bilateral implantation with minimal delay (< 1.5 years) may prevent atypical development of neural auditory pathways (Gordon et al., 2013)

Limitations of bilateral implantation

- Fitting a 2nd CI is no guarantee for success
  - Optimal way to coordinate input from 2 CIs?
  - Managing mismatched alignment of electrodes (different frequency shifts for each ear)
- For some children combining a CI and a hearing aid across the ears may be more beneficial
  - For example, when low frequencies are preserved in the better ear

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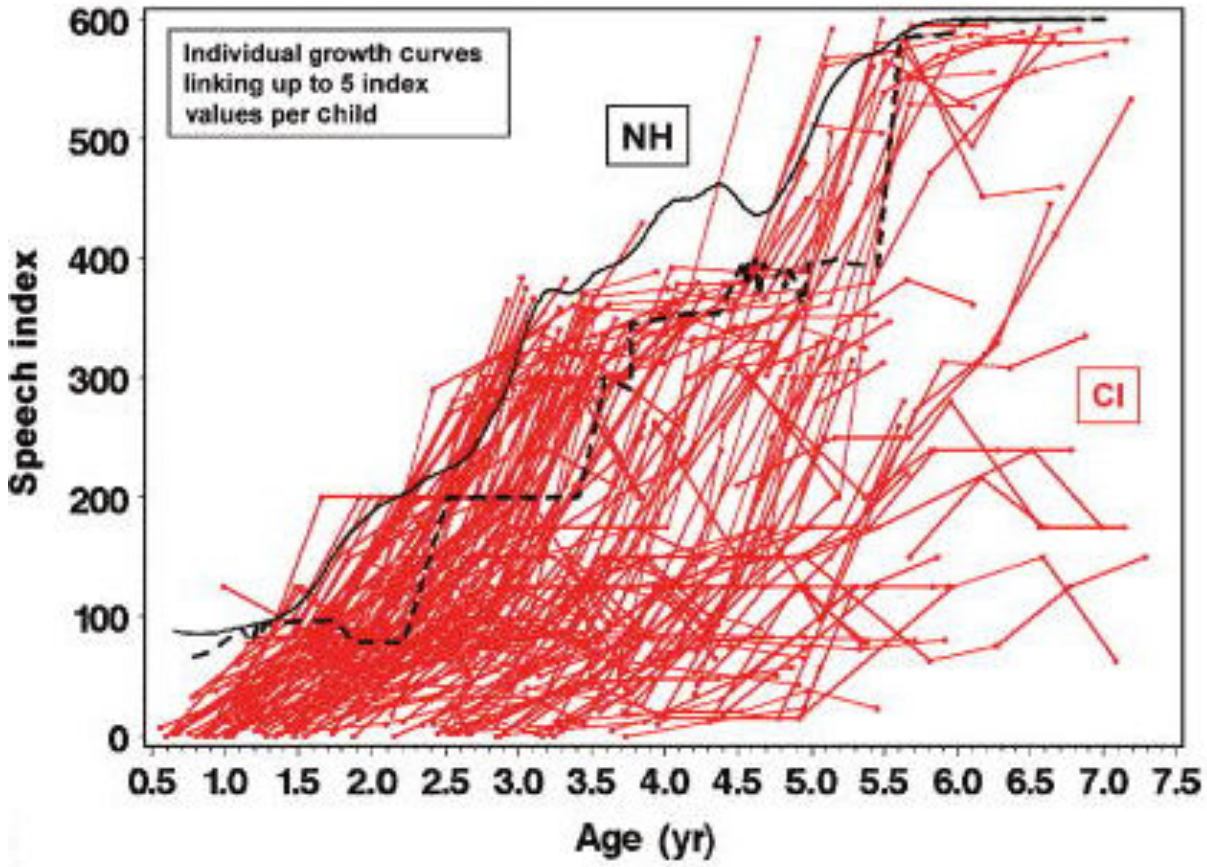
Spoken language outcomes

Auditory development

- Most available research with young CI children focuses on speech perception and intelligibility
- For example, tracking progress along a speech recognition hierarchy
  1. Sound detection and auditory awareness
  2. Closed-set speech recognition (word identification)
  3. Open-set speech recognition (word repetition)
  4. Speech-in-noise understanding

Speech recognition growth over 2 years



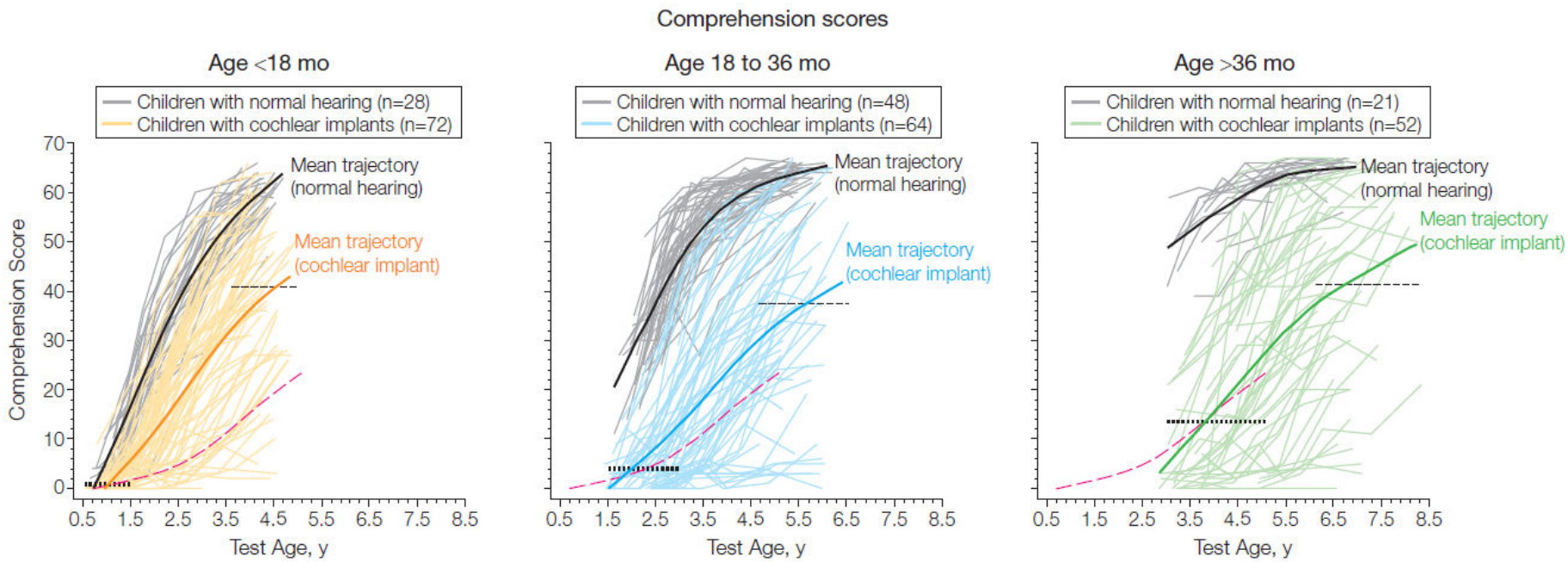
188 US children, 97 NH children

Wang et al. (2008)

Linguistic development

- Primarily assessed with relatively low-level standardized tests of general language levels
  - Receptive/expressive vocabulary knowledge
  - Comprehension/production of simple sentences
- Studies assessing language development across different domains (semantic, morphological, syntactic, pragmatic, literacy…) are slowly emerging

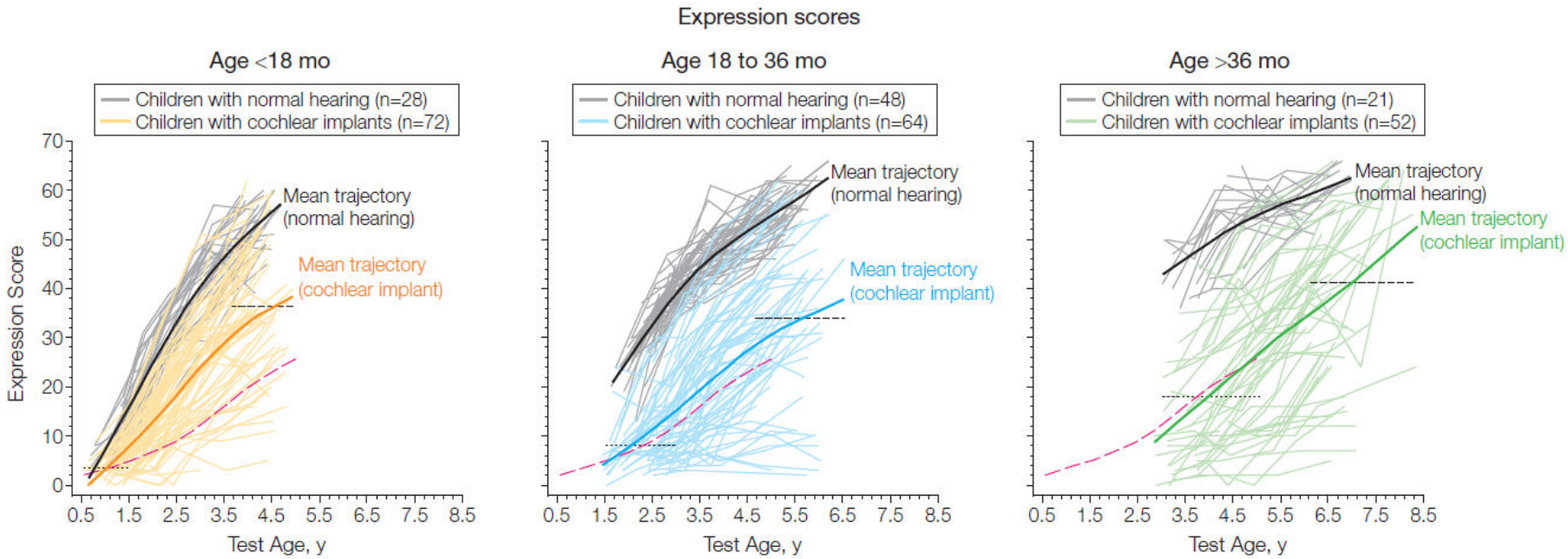
Language comprehension growth over 3 years



188 US children, 97 NH children

Niparko et al. (2010)

Language production growth over 3 years



Children undergoing cochlear implantation

- - - Mean preimplantation scores (all children undergoing cochlear implantation)

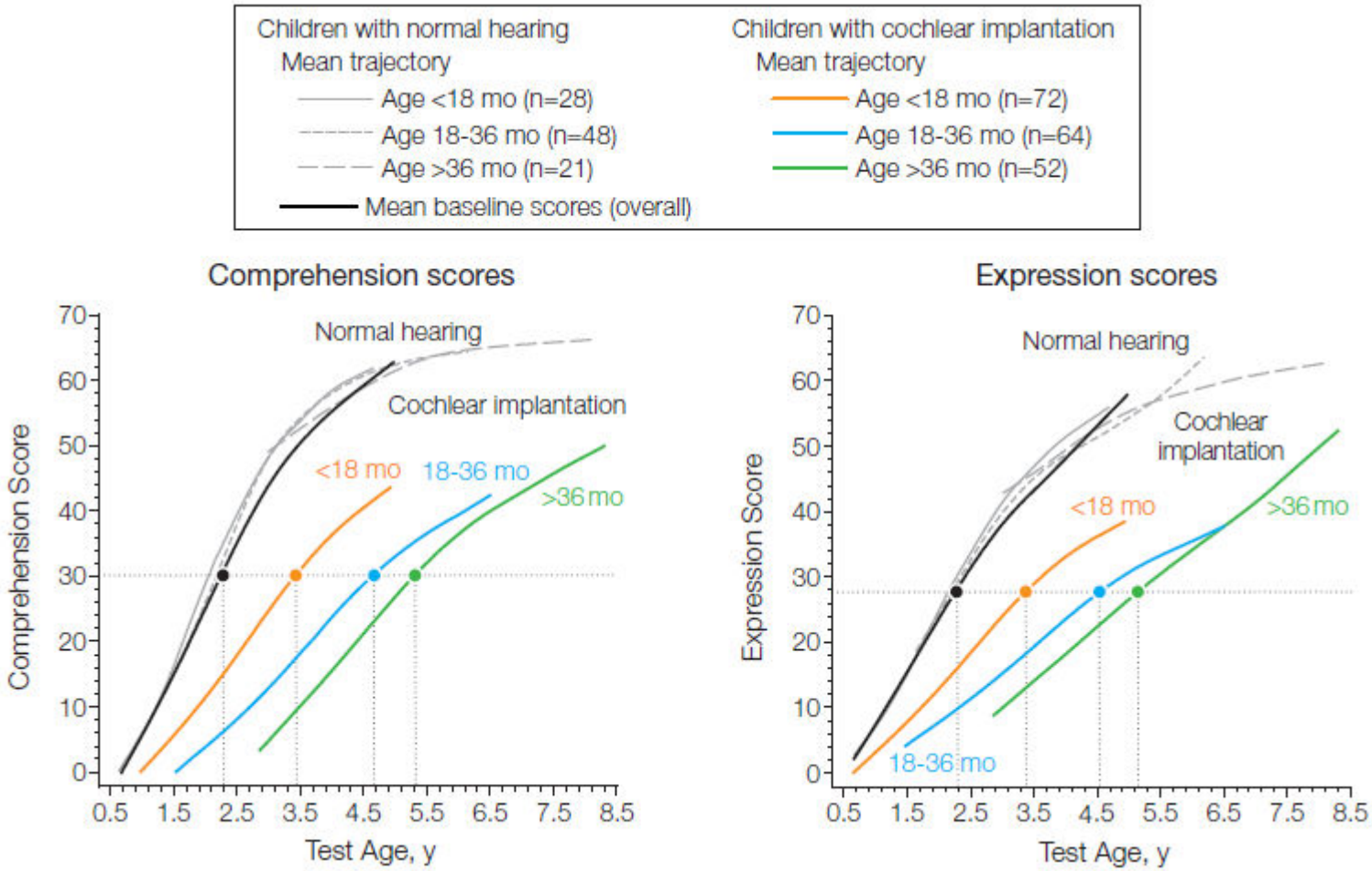
····· Mean score at baseline

------ Mean score at 3-y follow-up

188 US children, 97 NH children

Niparko et al. (2010)

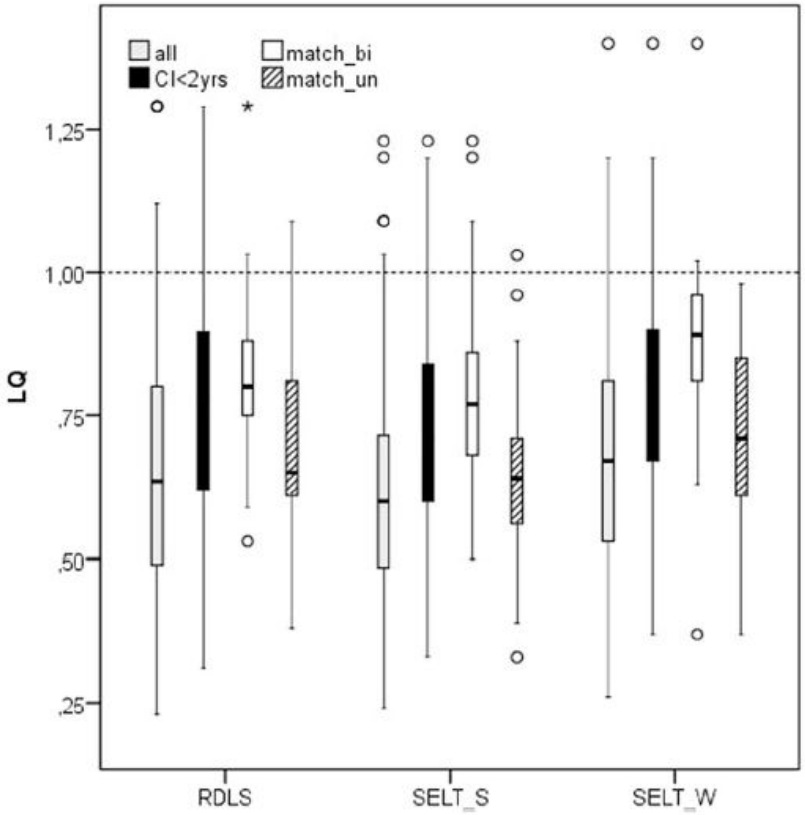
Impact of age at implantation



188 US children, 97 NH children

Niparko et al. (2010)

Another large multicenter study



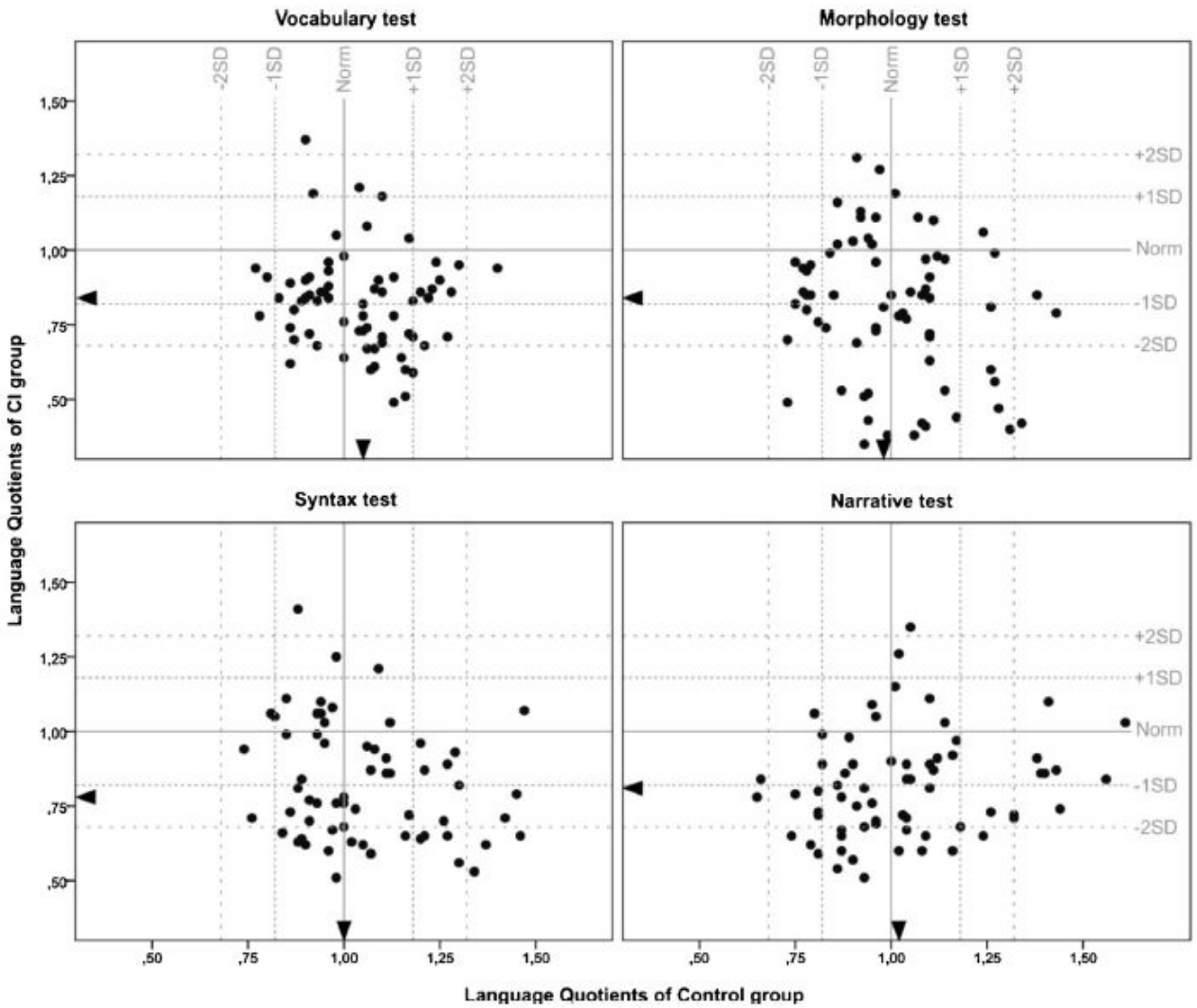
- 288 Dutch-speaking children
  - ~50% implanted < 2 yrs
  - ~20% bilateral CI
- ~50% achieved age-adequate comprehension and expression 3 years after implantation (< 1 SD beneath the norm)
- ~25% developed a language level comparable to half their chronological age or less

Boons et al. (2012)

Measuring what matters

- Assessing development in different linguistic domains is crucial to establish profiles of strengths and weaknesses
- Performance on low-level language measures may not be representative for performance in more complex language domains
  - Especially when children enter school age and language demands increase

Language outcomes across domains



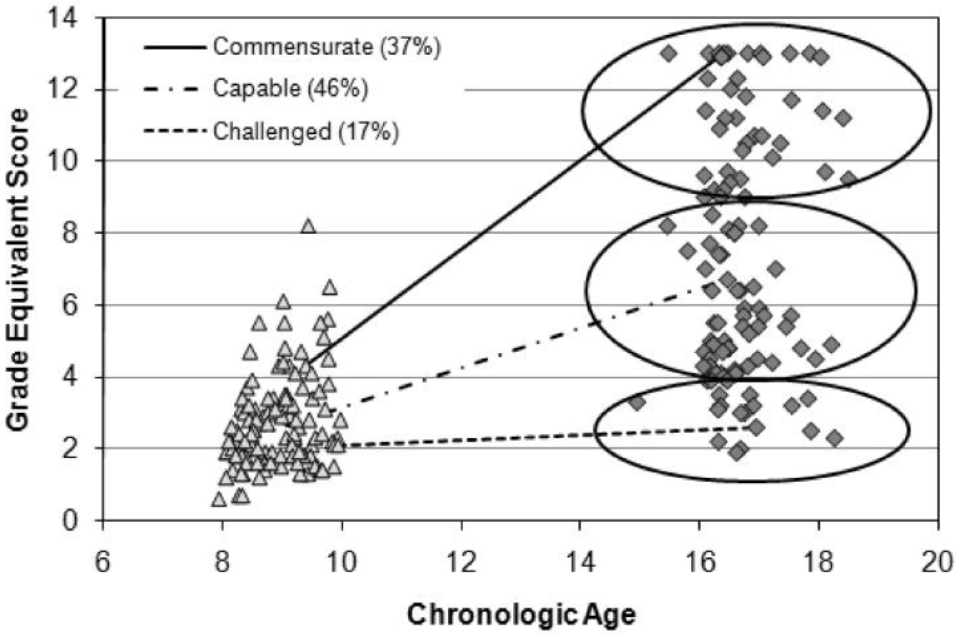
70 closely matched CI and NH children
Boons et al. (2013)

Language outcomes across domains

- General lack of knowledge of morphological and syntactic rules and relatively poor narrative skills (content and efficiency) among CI children
  - 47%-57% of the CI children achieved age-adequate language scores (< 1 SD beneath the norm)
  - 19%-26% showed severe delay (> 2 SD beneath the norm)
  - Performance in different domains did not correlate with each other

Boons et al. (2013)

Reading comprehension



112 US students
Geers et al. (2011)

- Development of reading comprehension between elementary grades and high school
  - 40% scored age-adequate (< 1 SD beneath the norm) at both measurement moments, ~20% dropped from age-adequate to below age-adequate

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Predicting outcomes

Predicting outcomes is near-impossible

- Large amounts of variance remain unexplained
  - In the multicenter study by Boons et al. (2012), 11 demographic, auditory and environmental factors were considered
  - 6 factors predicted interindividual variation
    - Age at implantation
    - Bilateral stimulation
    - Monolingualism
    - Parent involvement
    - Oral communication
    - Presence of additional disabilities
  - Yet, these only accounted for 50% of the variance in the sample

Identifying risk factors

- Early research has focused on the “stars” as proof of principle
- More recently, specific research endeavours targeted towards better understanding of children who do not meet expectations
  - For example, children who after 5 years of CI use do not achieve open-set word recognition (Barnard et al., 2015; 30 out of 185 children)

Types of risk factors/predictors

- Child-related factors
  - Age at implantation, degree and duration of hearing loss, pre-implant hearing aid use, cognitive ability, …
- Environment-related factors
  - Access to early intervention, social-economic status, family involvement, communication mode, …
- Device-related factors
  - Implant functioning, implant generation, active channels, …

Cognitive development

- Many deaf children have “additional” disabilities
  - Often reported to be as many as 30-40%
    - Cognitive or learning difficulties, global developmental delay, ASD, ADHD, …
  - Important risk factor
    - More children with additional disabilities receive CI
    - They generally make slower progress and may be more prone to develop behavioral problems
      (e.g., Cruz et al., 2012)

Cognitive development

- More generally, interindividual variation in cognitive processes contributes to speech-language outcomes
  - Working memory capacity
  - Verbal processing speed
  - Attention/inhibition
- Most of the work on this topic done by David Pisoni and colleagues
  - Different patterns of development of short-term and working memory capacity are related to the growth of language skills (Kronenberger et al., 2012)
  - CI children have a 2 to 5 times higher risk for clinically significant impairments in various domains of executive functioning than NH children (Kronenberger et al., 2014)

Family involvement

- Parent involvement has consistently shown to be an important predictor of outcomes
  - Often associated with higher social-economic status and higher parental education
  - Parental sensitivity, cognitive stimulation and linguistic stimulation
    - Positive regard, joint interaction
    - Engaging in instruction, learning activities
    - Quantity and quality of linguistic input, for example, number of word types and use of facilitative language techniques (e.g., expansions)

  (Cruz et al., 2013; Quittner et al., 2013; Frush Holt et al., 2013; Szagun & Schramm, 2015)

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Cochlear implantation, sign language and bilingualism

Where does the evidence lead us?

- Continuing debate about the advantages or disadvantages of sign language for CI children
  - No conclusive evidence that adding sign language interferes with spoken language development
  - Need for properly controlled cohort studies with early-implanted children
    - In some of the early studies, effects of communication mode were limited to late-identified children

(Fitzpatrick et al., 2015)

Chicken or egg?

- Many studies have found associations between (oral) communication mode and (positive) spoken language outcomes
  - Sometimes this finding may have been confounded by other variables (e.g., age of implantation)
  - This does not imply a causal relationship
    - Does oral communication lead to good spoken language skills or does good spoken language development lead to a preference for oral communication?
  - But we also cannot ignore these findings

(Walker & Tomblin, 2014, Spencer et al., 2011)

Sign support is not the same as bilingualism

- Large variation in non-oral communication modes
  - Total communication, simultaneous communication, Signing Exact English, cued-speech, sign language, …
- In other words, in the majority of the studies we are not talking about bilingual input
  - Only 3 studies reviewed by Fitzpatrick et al. (2015) included samples with children who were raised bilingually
  - For example, in the multicenter study by Boons et al. (2012) 58% of the parents used signs to support spoken language, but only 7% raised their child bilingually in spoken and signed language

Benefits of bilingual-bicultural environments?

- On the other hand, there is no reliable evidence that adding sign language facilitates spoken language acquisition
  - This includes a lack of evidence for benefits of bilingual education programs (Knoors et al., 2014)
- If not for spoken language development, what are other possible benefits of bimodal bilingualism for CI children?
  - For example, social-emotional and social-cultural benefits?
- Challenges of establishing qualitatively good bilingual programs and home environments

Widening the view

- Simultaneous communication/sign-supported speech may also benefit CI children (Knoors & Marschark, 2012; Mayer & Leigh, 2010)
  - In a similar way that audiovisual speech information can provide redundant information to support speech processing in CI children (e.g. Bergeson et al., 2005)
  - For example, when learning new vocabulary or understanding speech in challenging listening conditions
- Many CI children go through a communication journey
  - Their communication preferences may change over time
  - Early decisions about communication mode are not fixed

  (Watson et al., 2006, 2008)

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Discussion and concluding remarks:

Being realistic, honest and careful

We have to be realistic

- ***CI children are not like hearing children***
  - Results are not immediate
    - Hearing with a cochlear implant takes time to (re-)learn
  - Auditory training and speech therapy are needed for several years
  - Many children do not achieve age-adequate spoken language levels
  - Most children experience difficulties in challenging listening conditions

We have to be honest

- ***Deaf children with a CI are not like deaf children without a CI***
  - Many deaf children now have access to sound and speech input at a very early age
  - Many early-implanted CI children achieve relatively good spoken language and reading levels
    - Widespread benefits of implantation < 2 yrs
  - Most CI children grow up in spoken-language dominant home and school environments

We have to be careful

- ***Bilingual children with a CI might not be like monolingual children with a CI***
  - Is it fair to compare the language development of bilingual CI children to that of monolingual hearing children?
  - Can we apply insights from studies with hearing children acquiring two language in a minority language context to CI children?
    - Speech input is not fully accessible to CI children
    - Signed input may be fully accessible but is limited in quantity and quality (at least for children with hearing parents)

Facing the challenges

- Auditory rehabilitation
  - Improving electrode-neuron interactions
  - Developing auditory and linguistic training methods
- Evidence-based sign language support
  - Efficacy of bilingual-bicultural programs
  - Potential benefits of simultaneous communication/sign-supported speech
- Providing parents with realistic expectations and complete information about rehabilitation
  - Including sign language and bilingual education

And let's not forget

Although this may sound paradoxical…

In addition to optimal sign language exposure, a good spoken language development is a prerequisite for CI children to become successful bimodal bilinguals

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Thank You!

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