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Communication for **C**hildren with **H**earing **I**mpairment to optimise **L**anguage **D**evelopment

Workshop 3

Abstracts of ESR's presentations

Grenoble, May 19th

WORK PACKAGE 1

Biological diversity in plasticity and adaptation

ESR2. Automatic landmark localization in CT images using deep learning

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For cochlear implantation, it is critical for otologists to get insight into the patient specific anatomy through CT imaging of the temporal bone, however, manually segmenting the relevant anatomical structures — especially the micro-anatomy of the cochlea — is difficult and time consuming for both surgeons and radiologists. Hence, we plan to create a 3D automated segmentation pipeline of certain anatomical structures in temporal bone images. We want to go beyond state of the art, which is voxel-wise segmentation (Neves, Tran, Kessler & Blevins, 2021) by providing interactive high detailed 3D models, which the surgeons can (optionally) further adapt and correct. Additionally, these models allow for automated analysis and individual computation of optimal insertion trajectories which will benefit future minimally-invasive and robotic implantation techniques. We trained a deep learning neural network to localize anatomic landmarks. Based on this automatic landmark localization, we can instantiate high detailed 3D models. We implemented our network in Keras (Chollet et al., 2015) as a 2D binary convolutional feed-forward neural network, which can classify if a certain landmark is visible in the center of a given 2D image patch (45x45 pixel). We present the results of the classification accuracy and precision as well as the localization error of the landmarks. The accuracy is reaching 99 % on images of the same and different CT/DVT scanners.

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Neves C. A., Tran E. D., Kessler I. M., &Blevins N. H. (2021). Fully automated preoperative segmentation of temporal bone structures from clinical CT scans. Sci Rep,11(1):116. https://doi.org/10.1038/s41598-020-80619-0

ESR3. Neural mechanisms of cross-modal plasticity in hearing impairment

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In continuation of our previous step in the project and in line with the purpose of investigating cross-modal changes in a higher auditory area and a visual area of congenitally deaf cats and characterizing deafness-induced changes in auditory and visual responsiveness in the 'deaf' auditory cortex of congenitally deaf cats and hearing cats, we analyzed the strength of the responses in the responsive sites which were identified using the thresholding method which chose sites with evoked activity exceeding the threshold of ± 3 STD for at least ten milliseconds above the pre-stimulus baseline. Visualizing the strength of all responses for different penetration sites and also for both normal-hearing and deaf cats was of interest in this step, the results of which will be presented in the upcoming workshop. In addition, sensitivity to the visual stimulus features, namely orientation was also investigated. The visual stimulus used in the dataset consisted of different orientations presented to the animals through phase-reversal gratings. Investigating whether orientation tuning is present in the areas being recorded in this dataset or not was another task accomplished in this stage of the project. Results of all the analyses will be presented in the workshop.

ESR 4. Can vibrotactile speech information enhance intelligibility?

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The presence of a vibrotactile stimulus conveying speech information to the skin has been found to enhance the intelligibility of acoustic speech presented in noise. This has been shown in participants with normal hearing thresholds listening to vocoded speech (Cieśla et al., 2019; Fletcher et al., 2018) as well as in cochlear implant users (Fletcher et al., 2019; Huang et al., 2017). However, only very few studies have investigated this effect so far, and the neural mechanisms underlying the enhancement are unknown.

Therefore, we investigated whether a tactile enhancement effect as reported in Fletcher et al. (2018) [1] could be replicated, and in addition we included an audio-tactile control condition in which a tactile stimulus was presented, but whose information content was unrelated to the speech stimulus. Furthermore, the study aimed to identify neural correlates of a possible audio-tactile enhancement effect using functional near-infrared spectroscopy, however this talk will focus on the initial behavioral results.

Speech intelligibility of noise-vocoded sentences was measured in 23 German native speakers with normal hearing, using the Hochmair-Schulz-Moser (Hochmair-Desoyer et al., 1997) sentence test. In the speech intelligibility task, noise-vocoded sentences were presented in a 2x3 task design with *auditory alone, auditory + tactile envelope*, *auditory + tactile noise* conditions presented in 2 difficulty levels (*easy* and *difficult* SNR). While the *tactile envelope* comprised the sum of four envelope modulated carriers, *tactile noise* was generated by white noise processed with the same pipeline.

According to the law of inverse effectiveness for multisensory integration, we anticipated an enhancement effect of speech recognition for sentences presented in the *auditory + tactile envelope* condition in the *difficult* but not in the *easy* SNR condition.

In the difficult task conditions, an enhancement of 6,79 % in speech intelligibility between the *auditory alone* and the *auditory + tactile envelope* condition was found, however not reaching significance when considering all test conditions in an ANOVA. Interestingly, the *auditory + tactile noise* condition led to a small, although non-significant improvement compared to *auditory alone* as well.

All in all, these trends indicate that it is not purely information from the envelope signal leading to the enhancement effect reported by Fletcher et al. (2018), but much simpler features of the stimulus or attentional effects that may contribute to the results.

Cieśla, K., Wolak, T., Lorens, A., Heimler, B., Skarżyński, H., & Amedi, A. (2019). Immediate improvement of speech-in-noise perception through multisensory stimulation via an auditory to tactile sensory substitution. *Restorative Neurology and Neuroscience*, *37*(2), 155–166. https://doi.org/10.3233/RNN-190898

Fletcher, M. D., Hadeedi, A., Goehring, T., & Mills, S. R. (2019). Electro-haptic enhancement of speech-in-noise performance in cochlear implant users. *Scientific Reports*, *9*(1), 11428. https://doi.org/10.1038/s41598-019-47718-z

Fletcher, M. D., Mills, S. R., & Goehring, T. (2018). Vibro-Tactile Enhancement of Speech Intelligibility in Multi-talker Noise for Simulated Cochlear Implant Listening. *Trends in Hearing*. https://doi.org/10.1177/2331216518797838

Hochmair-Desoyer, I., Schulz, E., Moser, L., & Schmidt, M. (1997). The HSM Sentence Test as a tool for evaluating the speech understanding in noise of cochlear implant users. In *American Journal of Otology* (Vol. 18, Issue 6 SUPPL.).

Huang, J., Sheffield, B., Lin, P., & Zeng, F.-G. (2017). Electro-Tactile Stimulation Enhances Cochlear Implant Speech Recognition in Noise. *Scientific Reports*, *7*(1), 2196. https://doi.org/10.1038/s41598-017-02429-1

WORK PACKAGE 2

Multimodality and optimisation of cognitive resources

ESR 5. The effect Cued Speech (CS) perception on audiovisual speech processing with typically hearing adults who are naïve or experts towards CS

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Cued Speech (CS) is a visual communication system designed to facilitate oral speech perception in hearing impaired people (HI). Manual gestures positioned around face code phonemes that would be ambiguously perceived through lipreading only. Visual information delivered by manual gestures combined with lipreading enables speech perception without sound. Nevertheless, audiovisual speech perception is possible when the auditory input is available through a cochlear implant, for example. Furthermore, in the presence of noise, CS provides a visual enhancement on audiovisual speech perception that increases speech intelligibility (1). In this context, it is worth wondering whether CS information interacts with auditory processing in audiovisual (AV) speech perception. In the present study, we used an Event Related Potential (ERP) paradigm to investigate the effect of CS perception on auditory processing in subjects that were either naive or experts in the system. Participants were presented /pa/,/ta/,/ka/ syllables in unimodal audio-only (A), visual-only (Lipreading only or CS-gesture only or both) and in bimodal conditions (Audio-Lipreading; Audio-CS gestures; Audio-Lipreading-CS gestures). We compared the amplitude and latency of the auditory N1 and P2 components in bimodal conditions to the sum of unimodal conditions (e.g. Audio-Lipreading versus Audio + Lipreading) in both groups. We replicated previous finding of cross-modal interaction of lipreading and auditory processing at N1 and P2 time-windows. Similar modulatory effect was found in the Audio-Lipreading-CS gesture condition in both groups. We created an artificial condition 'Audio-Lipreading + CS gesture' to disentangle lipreading and CS gestures effects on N1 and P2 amplitude. Result indicates that the effect at P2 time-window was related to lipreading in the group of naïve subjects and to CS in group of experts. In this sense, CS information would interact with auditory processing within the phonological extraction stage (P2 time-window). Despite being an artificial mode of communication, CS modulate speech perception even in typically hearing subjects exposed to the system in adulthood.

Bayard C, Machart L, Strauß A, Gerber S, Aubanel V, Schwartz JL. Cued Speech Enhances Speech-in-Noise Perception. J Deaf Stud Deaf Educ. 2019 Jul 1;24(3):223-233. doi: 10.1093/deafed/enz003. PMID: 30809665.

ESR 6. Auditory-somatosensory integration in speech perception in individuals with hearing-impairment

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Individuals with impaired hearing ability can have varying levels of speech production and perception ability depending on their profile of hearing impairment, such as onset of deafness, age of implantation and usage/type of hearing device. These differences may also affect the development of auditory-somatosensory integration in speech perception. Recent studies showed that the perception of speech sounds was altered by orofacial somatosensory inputs associated with facial skin deformation, providing sensory information corresponding to the associated articulatory speech movements (Ito et al., 2009; Trudeau-Fisette et al., 2019). Such somatosensory effects on speech perception can also be studied on individuals with hearing-impairment. The present study examined whether and how impaired hearing ability affects the auditory-somatosensory integration in speech perception. The main test involved a vowel identification test with somatosensory stimulation associated with facial skin deformation as done in Trudeau-Fisette et al., (2019). We also carried out two additional tests for the evaluation of the perception and production abilities. The perception ability was assessed to examine threshold of speech sound perception in noise (Digit Triplet Test, Jansen et al., 2010)). The characteristics of speech production were assessed by checking each formant values in the corresponding vowel sounds. We first examined whether the somatosensory effect in vowel perception was related to the characteristics of production of the vowel space in individuals with normal hearing. The results showed that the participants who have a large acoustic distance between target vowels showed large somatosensory effect in speech perception. This suggests that the somatosensory effect in speech perception could be linked to the speech production performance. Then, we tested individuals with hearing impairment. Although we did not yet test a sufficient number of participants, we observed a tendency that variability in auditory-somatosensory interaction could be dependent on their profile of hearing impairment. These preliminary data support the idea that the development of auditory-somatosensory integration could be improved based on the level of hearing ability in individuals with hearing impairment.

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Jansen, S., Luts, H., Wagener, K. C., Frachet, B., & Wouters, J. (2010). The French digit triplet test: A hearing screening tool for speech intelligibility in noise. *International Journal of Audiology*, *49*(5), 378–387. https://doi.org/10.3109/14992020903431272

Trudeau-Fisette, P., Ito, T., & Ménard, L. (2019). Auditory and Somatosensory Interaction in Speech Perception in Children and Adults. *Frontiers in Human Neuroscience*, *13*, 344. https://doi.org/10.3389/fnhum.2019.00344

ESR 7. Speech-in-noise understanding and cognitive factors in children with normal hearing and hearing impairment

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Speech-in-noise comprehension is an everyday task performed by most people, and children are no exception. In our study, we aim to explore the extent to which children with normal hearing and children with hearing impairment fitted with a cochlear implant early in their lives differ from each other in a speech-in-noise comprehension task under cognitively demanding conditions. We will present our methodology and preliminary pilot data from adults. We hope to get feedback on our methods and design.

ESR 8. Novel word detection and dynamic learning in cochlear implant simulated speech: a pilot study in Danish

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The assimilation of new phonological patterns, as in novel words, is dependent on, first, the accurate detection of a categorical phoneme change that will configure a new pattern and, second, on the fairly stable representation of this pattern in multiple exposures. The degradation of acoustic cues in the cochlear implant might disturb both these processes and explain difficulties in novel word acquisition.

In this pilot study we investigate the effect of a cochlear implant simulated speech on the ability to detect and learn novel words when presented in auditory form. Additionally, we validate the Danish material for phonological discrimination, nonword detection in sentences and dynamic novel word learning.

Normal hearing Danish speaking adults performed a test battery composed by phonological discrimination, word recognition, nonword detection in sentence, and dynamic novel word learning using an 8-channel noise vocoder. Performance in non-vocoded audio tests was used to validate the material for further use in children. Performance data as well as objective data from pupillometry were registered. With exception of the word recognition task, all tests were adapted for the Danish phonology/language, based on already published material and in material developed in other pilot studies.

Cochlear implant simulated speech induced an increase in the false alarms in the discrimination task (perceiving two presentations of the same word as different words) and misses in nonword detection in a sentence (interpreting a nonword in a sentence as a real word). Growth curves in word learning were slower under vocoded speech, with stronger effects when the stimuli are acoustically similar. The higher peak pupil dilations observed when nonwords are detected in a sentence are smoothed under cochlear implant simulated speech.

Using a cochlear implant simulated speech we could validate that the developed material is sensible to speech degradation, and relevant for tracking the nonword detection in pupil dynamics.

ESR 9. Theory of mind, language and cognition in deaf and deafblind children (Usher syndrome) with cochlear implants

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Theory of mind (ToM) is the ability to understand and take into account own and other people's mental states. It is related to language and cognitive skills both in typically developing (TD) children and children with atypical development, such as deaf children with cochlear implants (CIs) who show delay in the ToM development. Deaf and deafblind children (Usher syndrome) with CIs also achieve lower results on some language tasks and have poorer cognitive skills that are central for information processing in most language-related activities. To support the development of ToM, cognition and language in deaf and deafblind children with CIs, early implantation and inclusion in early intervention are necessary.

Deaf children in Norway are entitled to receive bilateral CIs in their first year of life, free of charge. They undergo the same implantation procedure, as there is only one implantation centre in the country. On top of that, Norway is a country with a high-quality health care system and highly standardized education. However, intervention for deaf children is not defined (e.g. in terms of content or frequency).

The aim of this research to compare ToM, cognitive and language skills in deaf and deafblind children (Usher syndrome) with CIs to TD children to determine the relationship between those variables. We further aim to examine what type of intervention can be related to higher ToM, cognitive and language skills - taking into account the Norwegian context and similar ''starting positions'' of early implanted deaf children.

Participants will be early implanted deaf and deafblind children with Usher syndrome (age 6-12) and age-matched TD hearing children. The data collection will consist of two individual assessments (45 minutes each) during which ToM, language and cognitive tests will be administered. Testing of cognitive skills will be computer based and it will assess working memory, phonological skills and lexical access. Standardized test will be used to get the overview of a child's general language ability across receptive and expressive modalities. ToM will be examined to get an insight into its cognitive and emotional aspect.

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ESR10. Multilingual data collection and cued speech generation

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Cued Speech (CS) is a visual communication tool developed by Cornett (1967) to help people with hearing impairment to better understand the spoken language. It encodes speech as a combination of visible hand shapes (for consonants) and hand positions (for vowels) to highlight the uttered phoneme and complement lip-reading (1967). In our present study, we explore different architectures to develop a system that will be capable of generating Cued Speech videos from spoken language sentences provided as text. We propose to achieve this by first breaking down the sentences to corresponding phonemes. Then, we translate the phoneme sequences into cue skeletons using an encoder-decoder architecture with attention mechanism. The cue skeleton is a set of features derived using Mediapipe (2019). The resulting cue skeleton (features) will then be used to condition a generative model that produces realistic cued speech video sequence for the given sentence. For this approach, we require clean data that can be used to train the model. Therefore, we are also in the process of recording new dataset to expand our French Cued Speech dataset and to create a new dataset for American English Cued Speech.

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WORK PACKAGE 3

Environment and enhancement of language skills

ESR 11. The Acquisition of Multiple Spoken Languages in deaf children with Cochlear Implants who grow up in Plurilingual Contexts

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The research focuses on the context for spoken language development in deaf children who wear Cochlear Implants and come from plurilingual and multicultural families. To this day, scientific literature about children who are d/Deaf and hard of hearing has focused on estimating their linguistic development quantitatively, in order to compare them to their hearing, '*typically developed*' peers. This has been done by assessing d/DHH children with tests created for and standardised on a hearing (and often) monolingual population. Few researchers have posed their attention on the role of context and amount of exposure to each language as significant for these children's language development. This study aims to bring attention to these aspects as we believe they are crucial to understanding their language and communication development.

This study will focus on young deaf children who have been fitted with cochlear implants and grow up in plurilingual and multicultural families. A specifically created questionnaire will be used to gather data about the family linguistic background and habits, and will be paired with parental semi-structured interviews. SOLOM will be used to gain a general understanding of the child's linguistic skills in both English and in the other language(s) used in the child's environment. LENA technology will also be used to record the exposure the child has to each language during two typical days, to see if and how these data relate to the child's linguistic abilities reported by both professionals and parents.

ESR 12. Multimodal Communication in the Presence of Sensory and Communication Asymmetries

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In a social-constructivist approach, we investigate how individuals with different experiences and resources of language and communication draw on multimodal communication strategies in order to accommodate sensory and communicative needs. We focus on episodes of joint attention in early parent-child interactions in the time prior to cochlear implantation when access to auditory input and/or sign language is often not (yet) available to children with severe to profound hearing loss. Moving away from predominantly language-driven approaches of the past, the current project picks up on the multimodal nature of communication and, in a more holistic approach, goes beyond the bimodal distinction of spoken and/or sign language(s) when looking at early interactions. The aim of the project is (1) to reveal the potential of multimodal communication strategies in making communication accessible to children who are deaf or hard of hearing while facilitating interactions with their hearing family members and peers; and (2) to understand how multimodal communication strategies are influenced by individual affordances, context and the interactional situation. Video-recorded data of unstructured play sessions between parents and children (9-24 months of age) with severe to profound hearing loss will be collected in collaboration with the Yorkshire Auditory Implant Service (YAIS) at Bradford Teaching Hospitals, NHS Foundation Trust (UK). Detailed multimodal analysis with ELAN, an annotation tool for audio and video recordings, will be used to identify and understand multimodal communication strategies involved in initiating and sustaining episodes of joint attention while offering a more systematic approach to multimodal analysis of early interactions. The application of findings, emphasizing individual resources rather than deficits, will be relevant to early intervention with families and will provide parents with informed guidance on how to make communication more accessible to their child, especially within the critical period of the first year/s of life that form the building blocks for later (language) development.

ESR 13. Using a written picture naming task to assess lexical orthography in deaf or hard of hearing children in French

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Assessing orthographic knowledge and spelling abilities is often done with dictation tasks. In speech therapy for example, the standardized tools are **oral dictation**, allowing lipreading or not. The spelling score collected with dictation might not fully reveal deaf children's own spelling performances given their variability in the success using the prosthesis or the cochlear implant. Some authors adapted original tests to a written picture naming task (e.g. Simon et al., 2019 adapted *Ortho-3 of the BELEC test*, Mousty et al., 1994). In that case, the original words were turned into pictures. In the present study, we will use this task to assess orthographic abilities of deaf and hard of hearing children.

To do so, the children will be exposed to several items. Usually, the items selected vary in frequency, length, and phoneme-to-grapheme predictability. They are also commonly divided into categories according to their orthographic particularities: consistent words, words with contextual inconsistencies or words with silent final letters that can be derivate from a morphological link. Then, spelling accuracy and error analysis enable one to infer on the orthographic processes used by children. Here, our first aim is to devise a spelling test, following the method used in the *BOQS spelling test* of Chetail et al. (2019). From a wide set of words (n=150) carefully pre-tested in typical hearing children in Grade 5th (pilot study), the words that are the most efficient to distinguish between good and poor spellers will be selected (n=25-30 words) for the written picture naming task. The items for the pilot study were selected from several databases: words with double consonants, final silent letters derivate or not from morphology (*Silex,* Gingras & Sénéchal, 2017), consonantal clusters or nasal vowels and were detailed in frequency, length, phoneme-to-grapheme predictability (*Manulex,* Lété & al., 2004) and accuracy scores of typical hearing children in Grade 5 (*EOLE*, Pothier & Pothier, 2004). From this list, we selected words that were on the one hand picturable and on that include common sources of errors in French-speaking deaf children on the other hand (Leybaert & Lechat, 2001, Grandon, 2016, Simon & al., 2019). Our final set included 150 words to pre-test, with some consistent words to ensure that children know how to use conversion rules. Other items require morphological knowledge or statistical regularities to be learnt. We will discuss these steps in more detail during the workshop.

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ESR 14. Speech perception in children with cochlear implants: A study of Auditory Verbal Therapy and French Cued Speech

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Although cochlear implants improve speech perception, the auditory information transmitted by the cochlear implant (CI) remains degraded (Colin et al., 2017; Leybaert & LaSasso, 2010). Among the available early intervention programs in France adapted to children with CI, Auditory Verbal Therapy (AVT) and French Cued Speech (Cued French, CF) focus on the development of spoken language.

AVT is an early intervention program that relies mostly on the auditory channel to enhance hearing skills in deaf children with CI. However, scientific evidence for the contribution of an AVT program to speech and language development is limited and still debated (Yanbay et al., 2014; Percy-Smith et al., 2018).

CF is a multimodal tool that disambiguates lip reading by adding a manual gesture. The combination of a manual gesture with lip reading associates each phoneme with a single visual cue. Studies have shown that Cued Speech improves auditory speech perception (Kos et al., 2009) as well as speech production (Machart et al., 2020).

AVT and CF differ in that AVT is unimodal whereas CF is multimodal. This study investigates the contribution of these two tools on speech perception in children with CI. A lexicality judgment task from the EULALIES battery (Meloni et al. 2017) was used.

Ninety-four children aged 5 to 11 years were included in the study: 74 normal-hearing children (NH), 9 deaf children with CI who had participated in an AVT program (AVT), 3 deaf children with CI with high CF reading skills (CF+), and 8 deaf children with CI with low CF reading skills (CF-).

Results show that the performance of the AVT children and the CF+ children in the lexicality judgement task is similar to that of their hearing peers. On the other hand, CF- children show significantly lower performance. These preliminary results provide evidence for the effectiveness of both of these communication support methods for spoken language development, even in children with CI: the unimodal method (AVT) which focuses on auditory representations or the multimodal method (CF) which develops phonological representations. However, interpretations should be made with caution given the small sample of deaf children. Recruitment of a larger cohort of children is currently underway.

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ESR 15. The phonological Body: Body Movements to Accompany Speech Perception and Production of Foreign Speech Sounds in a noisy environment.

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A number of studies have shown that adding manual gestures can help learning new lexical items. Much less is known about the impact of using manual gestures when learning new phonological contrasts, although beat gestures have been shown to influence learning of suprasegmental phonological features. To address this gap, this study aims to explore the role of body movements in perceiving foreign speech sounds at the segmental phonological level and compares the use of congruent vs. incongruent body movements. Indeed, research has shown that multi-modal inputs presented simultaneously are processed together to form a single representation, with congruent modalities leading to improved speech perception and incongruent modalities leading to worse speech perception. In our study, French-speaking adults were trained to perceive Arabic syllables in the context of congruent body movements, incongruent body movements, and no body movement. Before and after training, participants were asked to perform an ABX discrimination task to assess speech perception. We hypothesized that (i) the use of body movements would improve learning of new phonological contrasts; (ii) congruence between the articulatory qualities of speech sounds and the characteristics of body movements would improve foreign phoneme perception: congruent body movements will improve speech perception of Arabic speech sounds more than incongruent body movements. Despite a short previous test to ensure the difficulty of the task, our results show a ceiling effect in the ABX discrimination task for all groups during the pre-training which made it impossible to exploit the data. With the aim of counteracting the ceiling effect, we will be conducting a second experiment using the same methodology but this time, adding noise during the presentation of the speech stimuli. Furthermore, we are recruiting a new set of participants for this second experiment. The results will be discussed during the third comm4CHILD conference with respect to the literature on embodied cognition, the impact of an embodied approach on the audiovisual integration in noisy environments and finally, the possible implications for children and adults speakers of different languages with hearing difficulties.