**Supplementary Table 4.** A table summary of included studies according to the PICOS criteria for cochlear implant group

| Study | Design | Participants | | | Intervention: Music Training | | Outcomes | Findings |
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| | | Uni/ Bilateral Implant | n, Age and Gender | Control Group | Stimuli | Frequency and Duration | | |
| Torrpa et al. (2014) | Randomized control trial | Unilaterally implanted Finnish speaking cochlear implant user | Cochlear implant group N=21 Age; 4-13 y/o | Normal hearing (NH) group N=21 Age= 4-13 y/o | ITPA- test for psycholinguistic abilities<br><br>All acoustic stimuli were presented at a comfortable level (averaging 60 dBA and 70 dBA, as measured at the ear cantus) | Not clearly stated | Auditory discrimination<br><br>Auditory working memory<br><br>Related to exposure to music. | -Sentence stress perception, mean (Pre; 69.64, Post; 75.79)<br>-Discrimination of fundamental frequency (F0) (mean) (Pre;7.54, Post;5.20)<br>-Intensity and duration (mean) (Pre; 9.13, Post; 9.38)<br>-Forward digit span (mean) (Pre; 20.38, Post; 24.38) |
| Torppa et al. (2018) | Randomized control trial | Unilaterally implanted children | Cochlear implant group N=21 (9 boys, 12 girls) Age; 6 years 7 months | Normal hearing (NH) group N = 22 (11 boys, 11 girls) Age: m= 6 y 9 m | Piano, cembalo, cymbal, and violin sounds from the McGill University Master Sample DVD.<br>Tone stimuli; 295 Hz; 200 ms duration with 20 ms offset ramp. Pitch($f_0$) deviant's tones at 312, 351 and 441 Hz.<br>Semitones changes consist of 1, 3, 7 semitones.<br>Increment intensity: 3, 6 and 9 dB.<br><br>Loudspeakers were placed at a 45° angle (to each side) Presented at a comfortable sound level; 60 to the NH group, 70 dB to the cochlear implant group.<br>Each stimuli sequence comprised 4500 stimuli.<br>Each presented 125 times (randomly). | ERP exp: 75 min per session<br><br>Behavioral exp: 45 min (cochlear implants) and 30 min (NH). | Behavioral measurement<br><br>Discrimination of pitch and intensity (speech in noise) | Speech in noise performance; cochlear implant group<br>-pre to post-training ($p<0.01$)<br>-Timbre change ($p=0.003$)<br>-Pitch discrimination ($p<0.01$)<br>-Intensity decrement/ increment ($p<0.01$) |
| Welch et al. (2015) | Pilot study | Uni/ bilateral cochlear implant children | Cochlear implant group N=12 Age:5-7 years | No control group | A singing competence profile, based on one used in the evaluation of the National Singing Programme (NSP) Sing Up; a specially designed chord pitch discrimination test; 6 colors and 8 number options. | Participant involved in weekly music lessons in large group with NH. | Singing competence<br><br>Chord pitch discrimination<br><br>Speech perception in noise | Repeated measures ANOVA:<br>-Comfortable singing range: $p= 0.02$<br>-Singing measure, NSS: $p <0.001$<br>-Natural speech frequency: $p=0.54$<br>-Pitch perception task: $p=0.001$ |

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| Jiam et al., (2019) | Controlled trial study | Uni/bilateral cochlear implant children | Cochlear implant group<br>N=8<br>6 bilateral implant, 2 unilateral HA<br>Age: 12 to 18 months | No cochlear implant (bilateral HA)<br>N=7<br>Age: 5 to 11 months | The BabyBeats$^{TM}$ habilitation program<br><br>The inclusion of a range of timbre, tempo, dynamics, and texture begins to guide the listening skills in how to hear, discriminate and assimilate the sound and develop the ability to listen and understand music | Four stages are:<br>i) Learning through tactile stimulation<br>j) "hearing ' music<br>Listening to the music<br><br>Period of 8 months.<br>3 times/week at home<br>One session/week in clinical setting. | Observation in terms of infants' babbling (pre-post)<br><br>Responses to tactile/ sensory inputs from the activities, movements, and instruments. | Pre-implant group:<br>-50% noted on the questionnaire that they had seen improvement in attention, movement, playing, singing, and anticipation.<br>-Improvement in eye contact and vocalization.<br><br>Post-implant group:<br>-Improvement in early listening and communication skills.<br>-Improvement in interest in sounds, attention, reaction and copying (outside of training time).<br><br>Both groups:<br>-Increased level of joined and sustained attention during long periods of training time (up to 45 minutes). |
| Fu Q et al. (2015) | Randomized trial | Unilateral cochlear implant user with congenital HL<br><br>Native Mandarin speakers | Cochlear implant group<br>N= 14 (7 boys, 7 girls)<br>Age: m=7.8 years old (5.5-9.7 years old) | No control | 9 set of melodic contours; rising, rising-flat-rising-falling, flat-rising, flat, flat-falling, falling-rising, falling-flat, falling. 5 tones, 3 tones, 5 piano stimuli (different root notes used for training). 3 to 5 notes of equal duration (250ms, 50ms silent in between).<br><br>Musical instrument: 5 tone complex or piano sample. All stimuli presented at 70 dB. | Home-trained<br>30 minutes/day<br>Every day for 10 weeks. | MCI performance improvement<br><br>Tone recognition and speech perception | Performance mean improved all outcome measures.<br>-5 TONES (mean improvement = 57.3 points; SE=11.1)<br>-3 TONES (mean improvement = 45.8 points, SE= 10.9)<br>-5 PIANO (mean improvement = 45.8 points, SE=8.2) |
| Innes-Brown (2013) | Non-randomized control study | Unilateral cochlear implant / bimodal school-age children | Children with hearing device.<br>N=11<br>(4 girls, 7 boys)<br>(Cochlear implant = 6, HA=5) | Normal hearing group<br>N=9 (5 girls, 4 boys) | The "music club" with musical activities based on round play.<br><br>Session divided into vocal play, physical music, and singing games.<br><br>All games targeted rhythm, tempo, pitch, and timbre. | Conducted every week, 45 minutes/session. | Auditory perception (tonal, rhythmic, and timbre perceptions) | Rhythmic test:<br>-Pre and post training:<br>$p<0.01$<br><br>Tonal test:<br>-Pre and post training: $p=0.04$<br><br>Timbre test:<br>-pre and post training: $p=0.01$ |
| Cheng et al. (2018) | Non-Randomized control trial | Unilateral/ bilateral cochlear implant children<br><br>Mandarin-speaking<br><br>Prelingually deaf & diagnosed | Cochlear implant group<br>N=16<br>(girls =5, boys =11)<br>Age: 1.7 to 6.1 years old, M= 6.3 years old<br>Cochlear implant experience: 0.8 to 6.0 | Normal group<br>N=22<br>(girls - 11, boys = 11)<br>Age: 4.5 to 9.3 years old, M=6.2 years old. | MCI stimuli: 9 melodic contours consist of: rising, rising-flat, rising-falling, flat-rising, flat, flat-falling, falling-rising, falling-flat, falling)<br>5 notes of equal duration (250ms, 50ms of silence between notes)<br><br>Lexical tone stimuli: 64 stimuli (4 tone times 4 monosyllable times 4 talkers) | Training session: 5 days per week for 8 weeks, 15min per session<br><br>3 sessions per training day for 2 months | - Music skill measured using MCI and accuracy of tone recognition<br>- Speech perception measured by sentence recognition. | Significant effect noted for<br>-MCI (melodic contour identification) mean improvement: 22.0 (range 5.7 to 47.2)<br>-Tone recognition score: 14.5 (range 4.7-32.8)<br>-Sentence's recognition score: 14.5 (1.5 to 34.3) |

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| | | before 1 year old. | years old, M=2.8 years old | | | | | |
| Yucel (2009) | Randomized controlled trial | Unilaterally HiRes cochlear implant children. | Cochlear implant group; music group<br>N=9<br>Age: non available<br>Age at implantation: 39-96 month<br>sex: N/A | -Normal hearing children<br>-N=9<br>-Age: not available | Instrument: electronic keyboard (YAMAHA PSR-295)<br>Task: listen to two pairs of notes; based on note discrimination | -Music training conducted from 24 months (2 years)<br>-10 minutes /day every day for 2 years.<br>-Evaluation after 1, 3-, 6-, 12-, and 24-months' time | Home training | MAIS/ IT MAIS questionnaire: (pre; p= 0.351, post; p=0.455)<br><br>MUSS questionnaire: (pre; p=0.825, post; p=0.345)<br><br>Open set speech perception scores (CI vs NH group; p=0.141)<br><br>Closed set (CI vs NH group; p= 0.698) |
| Good et al. (2017) | Randomized control trail | Unilateral and bilateral cochlear implant users | Cochlear implant group<br>N= 9 (2 girls, 7 boys)<br>Age; 6 to 15 years old, M= 10.22 | Art group<br>N= 9 (4 girls, 5 boys) | Music lesson; training with piano.<br><br>Divided into two segments: music theory rudiments and technical exercises.<br>Stimuli adapted from Faber and Faber vocal song.<br><br>All test stimuli presented on a laptop computer through external speakers at listening level (60 to 65 dBA) | One private half-hour lesson/week<br><br>Total 24 lesson<br><br>All music students had access to a keyboard and were expected to practice two times per week for 30 minutes. | Pre-, mid-, and post training results measured.<br>Interval, rhythm, and memory<br>Emotional prosody perception | Musical abilities: Montreal Battery for Evaluation of Amusia (MBEA) showed improvement/<br>-main effect (p = 0.037)<br>-contour effect (p=0.037)<br>-rhythm (p=0.03)<br>-memory (p=0.04)<br>-emotional prosody (pre-mid training; p=0.04)<br>-Overall (mid- post training; p=0.14) |
| Polonenko et al. (2017) | Control trial | Uni/ Bilateral cochlear implant user | Cochlear implant group<br>N=34<br>Bilateral= 26<br>Unilateral= 8<br>Age; 6 to 18 years | Normal group<br>N= 16<br>Age; 11.8 (+/- 3.0) | Montreal Battery of Evaluation of Amusia (MBEA)<br><br>Consisted of five subtests of 2 practices, 20 items each subtest: Contour, rhythm, memory.<br><br>Played using Windows Media Player through loudspeaker at 0° Azimuth and 1m from the participant at an average fixed level of 60-65 dB SPL. | Received formal music training for 6 months | Accuracy of music detection.<br><br>Reaction times<br>MBEA (contour, rhythm & memory) | Improvement in accuracy of music detection (p=0.003)<br><br>Faster reaction times (p=0.007)<br><br>MBEA<br>-Contour (p=0.03)<br>-Rhythm (p=0.001)<br>-Memory (p<0.001) |

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| Yang et al. (2019) | Control trial | Unilateral cochlear implant user | Cochlear implant group. N=10 (7 girls, 3 boys) Age; 7.4 and 12.3 years | Control group; NH N=8 (7 girsl, 1 boy) Age= 6-10 y/o | Musical stimuli: Children's songs -Twinkle Twinkle Little Star, Frère Jacques -Choir song (such as Little Carp Jumping the Dragon Gate, I Can So You Can, etc.) | All trained for 2 weeks. 2hours/day | Evaluation of pitch accuracy, tempo accuracy, percentage of correct F0 contour direction<br><br>Absolute differences and music scores were calculated. | Contour direction; p=0.076<br><br>Mean note deviation (semitone); p=0.199<br><br>Mean interval deviation; p=0.082<br><br>Mean duration ratio deviation; p=0.357<br><br>Mean absolute duration deviation; p=0.001 |
| Kim et al. (2016) | Pilot study | Unilateral cochlear implant user | Cochlear implant group N=6 (2 girls, 4 boys) Age=4.4 years old | Control group N=5 Age= 5.0 years old. | Consists of 5 levels of training that includes:<br>i) -Rhythm discrimination<br>j) -Melodic contour discrimination<br>k) -Pitch discrimination<br>l) -Timbre discrimination<br>m) -Singing<br><br>Stimuli used were the recording of an instrument (gayageum, daegeum, janggu) Consist of Single pitches<br>i) 5 note-melodic patterns; C4 to C5 | 6 months' training (24 weeks)<br><br>30 to 40 minutes/ weeks<br><br>Pretest- 1st week<br>Post-test- 24th week | Performance measurement (pre-post):<br><br>i) Rhythm, pitch, and timbre discrimination<br>j)<br>k) Identificati on task performance | Identification of task performance after training:<br>-rhythm (p=0.041)<br>-pitch (p=0.066)<br>-timbre (p=0.066)<br>-song/singing skills (p=0.414)<br><br>Discrimination test:<br>-rhythm (p=0.039)<br>-pitch (p=0.109)<br>-timbre (p=0.141) |
| Patrio de Lima. (2018) | Experimen tal study (Repeated measue) | Unilaterall y implanted cochlear implant user | Cochlear implant group N=21 (12 girls, 9 boys) Age= 4 to 13 y/o | NH N=22 Age mean= 6 y 9 months | Piano, harpsichord (cembalo), violin, and cymbals sounds (selected from McGill University Sample DVD)<br>Piano tones: 295 Hz, duration 200 ms including 20 ms fall time.<br>Deviant tones different from the standards at three different levels of fundamental frequency (pitch), all harmonics changed from 295 Hz.<br>standard to 312, 351, and 441 Hz corresponding to 1, 3, and 7 semitones, respectively, timbre (change from standard piano tone to cembalo, violin, and cymbal tones) | Singing and musical activities were done weekly at home for one year before the study began.<br><br>All stimuli were presented in an acoustically insulated and dampened room (2 loudspeaker; placed at 45°) | ERP responses for amplitude and latencies | Pre-post training<br>; -Timbre MMN changes (mean)<br>(pre; 2.82, post; 2.50)<br>-Pitch MMN changes<br>(pre; 1.55, post; 2.58)<br>-Gap<br>(pre; 2.43, post;2.95)<br>-Duration<br>(pre; 1.90, post; 1.39) |
| Bedoin et al. (2018) | Clinical trial | Uni/Bilater al implanted cochlear implant children | Cochlear implant group N= 5 (5 boys) Age= 75 to 125 months | Control group; NH N=5 (2 boys, 3 girls) Age= 72-101 months | Morphosyntactic training<br>A set of items; regular primes, and environmental sound scenes without rhythmic structure. | 16 sessions of training<br><br>Assessed 3 times (For baseline, T1, T2; post training) | Morphosyntactic tests, non-word repetition, visual selective attention, sustained attention test and memory test. | Morphosyntactic processing:<br>-Grammatical judgments (p=0.0065)<br>-Syntax comprehension (p=0.0002)<br>-Zazzo test (p<0.0018)<br>-d2 test (p=0.02) |

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| Kosaner (2012) | Experimental study (Repeated measure) | Unilaterally implanted cochlear implant users | N=25<br>Divided into 3 groups:<br>Group A: N=12 (3 girls, 9 boys, mean age=26 months)<br>Group B: N= 6<br>(3 girls, 3 boys, mean= 72 months) | N= 7<br>(5 girls, 2 boys, mean Age= 43 month | Live or recorded music: set of 6 songs and 6 rhymes for each group.<br><br>Tonal music with range timbre, pitch, with different intensity, and frequency.<br><br>Animal's sound, actions sound effect, and stories related to music were created. | Both A & B group: participated with parents in one group session (total 45/min per individual. 20-30 min/ session weekly for 18 months.<br><br>Group C: one group and one individual session/ week for 3 months | Improvement in performance of the musical component including rhythm, pitch, timbre and singing skills. | Recognizing song, tunes, and timbre, responding to music and rhythm, and singing skills<br><br>Overall improvement<br>-Group A: p<0.001<br>-Group B: p<0.001<br>-Control: 0.02:7 |
| Joshua Chen et al. 2010 | Experimental study (Repeated measure) | Uni/ Bilateral implanted cochlear implant user | Cochlear implant group N=27 (9 girls, 18 boys)<br>Age; 5- 14 (m=6.7 y/o) | No control group | Main instrument was piano; The first note was any of the following: C, D (294 Hz), E (330 Hz), F (349 Hz), G (392 Hz), A (440 Hz), or B.<br><br>The interval of 2 notes was thus between prime degree (2 same notes, eg, C–C) and major-seventh degree (11 semitones, eg, C–B), either ascending or descending in direction<br><br>70+-6 dB SPL ~1m from the piano | 13 student attended music classes at YAMAHA music school for 2 to 36 months (mean training session: 13.2) | Improvement of pitch perception | Overall correct rate for pitch perception (p=0.0450<br><br>Mean correct for overall task performance (p=0.237)<br><br>Correct rate for ascending pitch (p=0.038)<br><br>Pitch perception (ascending pitch-interval perception); p= 0.006<br><br>Ascending pitch-interval perception (p=0.011) |
| Di Nardo (2015) | Experimental study (Repeated measure) | Unilateral Nucleus cochlear implant user children. | Cochlear implant group N= 10 (6 boys, 4 girls)<br>Age: 5 to 12 years old<br>Hearing age with cochlear implant = +/- 26 months | No control group | Auditory musical training program (the Home-Learning Program)<br><br>Frequency bands: 262Hz-523Hz, 523Hz-1046Hz and 1046Hz- 1976Hz (used for most of song, 36 notes). | 6-month training period at least 2 hours weekly | Improvement in music perception:<br>-frequency discrimination<br>-pitch recognition<br>- appraisal | - Musical Pitch Discrimination (MPD): significantly improved (p=0.001)<br>- Music test result (pre- and post-training, p-0.0151), (melodic version, p=0.0071) |
| Chari et al (2019) | Clinical trial | Uni/bilateral implanted cochlear implant user | Cochlear implant group; G1 N=-5<br>Age; 6.5 to 12.5 y/o<br><br>Cochlear implant group; G2 N=9 | No control group | G1: Orff<br>Method of teaching music to young children; music therapy adapted for mentally retarded and autistic children in U.S.<br><br>G2: Se-Tar (age more than 8 y/o) Se-tar; stringed traditional musical instrument with 3 strings | Training ranged from 3 to 12 months.<br><br>At least one session per week | Improvement in terms of playing skills<br><br>Understanding rhythm<br><br>Understanding frequency<br><br>Effects of other capabilities | Measurement of number of melodies played correctly.<br><br>Number of mistakes made while playing certain familiar melodies.<br><br>Repeating and differentiating rhythmic patterns.<br><br>Frequency change detection<br>Discrimination of wrong note. |

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| | | | Age; 3-6 y/o | | | | | Measured using questionnaire and evaluation from tester and parents. |
| Cason et al (2015) | Controlled trail | Cochlear implant user | Age (7 yr, 1.5 month) | Control: Non musician Aged 7 years 0.5 month | 16 sessions<br>musically regular primes<br>(8 sessions, referred to as M) or environmental sound scenes<br>(8 sessions) without rhythmic structure (baseline/control condition,<br>referred to as B). | 2 trainings (of 8 sessions<br>each) across patients. Each child was assessed 3 times (before the<br>first training T0, between the second training T2) | -receptive syntax processing with<br>-morphosyntactic tests (grammaticality judgments and syntax comprehension).<br>-non-word repetition.<br>-visuospatial attention.<br>- memory. | -Significant improvement in MCI after musical training (p=0.001).<br>- Music test result (pre- and post-training, p-0.0151), (pre and post training of melodic version, p=0.0071) |
| Fuller (2018) | Randomized control trial | -Dutch speaking adults CI users,<br>-CI experiences more than 1 year.<br>-Includes bimodal participant. | i) Pitch/timbre group (n=6)<br>age: 56-73y/o<br>CI exp: 5 -11 years<br><br>ii) Music group (n=6)<br>Age: 59=71 y/o<br>CI exp: 3-10 years | -Control (non-musical training)<br>- n=4<br>- Age: 66-80 y/o<br>-CI exp: 4-6 y/o | i) Pitch & timbre:<br>-MCI (5train)<br>-MCI 1 test<br>-instrument ID/daily sound ID<br>-MCI (5 train)<br>- MCI (1 test)<br><br>ii) Music therapy<br>-Listening to music & emotional speech<br>-Listening to musical speech<br>-Singing<br>-Playing instrument<br>-Improvising music<br>-Session questionnaire | -2 hours/session (15minutes break)<br>-Weekly session for 6 weeks<br><br>1.5 months | Rehabilitation center | i)Word identification<br>ii)Sentences identification (both consist of speech perception) |
| Hutter (2015) | Experimental study (repeated measure) | -Adults > 18 years old<br>-Post-lingual deafened,<br>-Unilaterally implanted CI users | -N=12<br>(6 female, 6 male)<br>-Age: M=54 y/o | No control group | -5 Module of music therapy:<br>i) Variability of voice and speech<br>ii) Diverse components of music<br>iii) Playfully used components of speech<br>iv) Speech in diverse hearing surroundings<br>v) Complex hearing | -10 individualized sessions.<br>-50 minutes/ session | Hearing performance in musical parameter<br>i) Pitch discrimination<br>ii) Melody recognition<br>iii) Timbre identification | i)Pitch discrimination:<br>p=0.0270 (no significant diff)<br>ii)Melody recognition:<br>p<0.018 (significant)<br>iii)Timbre identification: p= o.oo4 (significant but only in unilateral condition) |
| Driscoll (2012) | Randomized control trial | -Post-lingual deaf adults age 18 < -read/understand written English<br>-have access to a computer with internet and sound capabilities | -N=71 (21 males, 50 females)<br>-Age: 26 to 88 (mean: 62.59)<br>-21: bilateral<br>-50: unilateral<br><br>-Divided into 3 groups. | -N=24<br>Feedback on correct musical cue. | -Recording of solo performance of 8 musical instruments.<br>i) Represent a range of low, middle, and high frequencies<br>ii) 5 melodies from each instrument | -15 sessions<br>-10 minutes/ session<br>-3 times/ week over 5 weeks<br><br>1.2 months | -Improved recognition of musical instruments.<br>-No significant improvement in timbre recognition. | i)Musical background questionnaire<br>Recognition test:<br>Week 3: significant difference observed ($p < 0.001$)<br>ii) The significant improvement observed from week 3 to week 5 (p-=0.0114)<br>iii) Individuals with bilateral CI scored significantly higher compared to the unilateral implant (p=0.02) |

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| | | -Using cochlear implant or hearing aids or both. | | | | | | |
| Firestone et al (2020) | Controlled trail | Cochlear implant adults, N = 11 or 8 weeks | N = 11 Active music listening | N=10 Not active in music | | Active music listening 40 mins/day for 4 or 8 weeks | Speech perception (words, sentences in quiet and noise) Hearing questionnaire EEG (acoustic change response) | Speech perception (words, sentences in quiet and noise) ($p<0.01$, mean = 67 (21) Hearing questionnaire EEG (acoustic change response) ($p= 0.002$, mean = 78 (12). |
| Lo et al (2015) | Randomized control trial | Adults with cochlear implant, N = 8 | N=8 Age = 33.4 | N=8 Age= 30.12 | MCI interval training MCI duration training (No non-music control) | 2 music trainings 1–2 hours/week for 6 weeks | MCI Speech perception in noise Consonant discrimination in quiet and in noise Prosody (question/statement) | MCI ($p<0.001$) Speech perception in noise ($p = 0.03$) Consonant discrimination in quiet and in noise ($p= 0.02$) Prosody (question/statement) ($p<0.001$) |