AUDIO ACE

PREDEVELOPMENT RESEARCH 2024

DARYA HAINES, DUSTIN HUYNH, JORDAN NGUYEN,
LAYLA SMITH, NIHAR KOPPOLU, SCOTT THORKELSON, SIENNA DAY

CONTENTS

PREDEVELOPMENT RESEARCH

INTRO TO PROJECT

OBJECTIVE

Create an IOS and Android available phone/tablet application for practicing sound and word recognition.

SIGNIFICANCE

Cochlear implants (CIs) do not automatically restore speech recognition for post lingually deafened adults. Average word recognition remains at 60%, and enormous variability exists. Training can improve this, but it can be inaccessible for some.

AUDIENCE

English speaking individuals who have recently received cochlear implants and who need to train their implant for word and sound recognition.

TIMELINE

Two quarter terms, 10 weeks each. The first 10 weeks will be devoted to researching environments, techniques, and implementation while generating a design to follow for the second 10 weeks of implementation.

INTRO TO AURAL REHABILITATION

Aural rehab, auditory therapy, and cochlear implant rehab are all names for counseling, treatment, and therapy after a patient gets cochlear implants in. Aural Rehab includes exercises that help a new CI user:

- Understand the difference between sounds and whole words
- Understand new sounds that have not been heard before
- Read along and follow someone else's speech while they read aloud
- Notice when you or someone you are talking to does not understand what is said.
- Learn when to change your setting to improve your understanding. Learn how to set up the phone to work with your implant
- Enjoy music
- Learn how implants affects the people around you, and help your family and friends learn about your implant
- Make speech clearer. Learn and practice skills that will make it more comfortable when talking

When a patient receives Aural Rehab from a speech language pathologist (SLP) or other audio professional, they will be evaluated to test:

- How the CI user makes speech sounds
- How the CI user understand speech
- The CI user memory
- The CI user's reading and writing skills
- The CI user's listening skills
- How well the CI user can understand someone talking without being able to see their lips

These all impact what treatment is used by the SLP. Since our app cannot reasonably account for the status of these tests with an app user, we believe it is safest to approach from the most basic level - syllabalic and then increase difficulty as the user progresses. Or to allow the user to choose their preferred methods and work at their own pace. Our app should be clear that it does not replace a patient's care team and does not replace receiving aural rehab from an expert. CI users should regularly reach out to their care team if problems arise. Our app also only covers one aspect of comprehensive aura rehabilitation: "perceptual training to improve speech perception and communication". Our app cannot fulfill the sensory management, auditory function, implant mapping, and emotional counseling that working with a care team can.

DATABASES

ACCOUNT TYPE

To connect a user with their associated data, the user must have an associated identifier. There are two main ways we considered completing this, using a local account or using OAuth. If a local account is used, the user will not be required to login to an account to access their data, rather their data would be saved on their personal device. This would mean that data could not be accessed upon clearing the device's data or across multiple platforms. The data would then be processed using SQLite and saved in a file on the user's device that the app will read from and write into. If OAuth is used, the user would link their usage with Auditory Ace to their personal Google, Facebook, or other OAuth connected account. This would connect the Auditory Ace application to 3rd party web services such as Google Cloud, Microsoft Azure, AWS, or Facebook. This path is secure and would allow the user's information to be protected throughout the reading and writing process. It would also allow the user to access their personal data on multiple devices or even after resetting the device itself.

DATABASE ACCESS

Most databases have C#/C++ integration for direct access, though using direct access is highly discouraged for security reasons. Rather than using this direct path, we recommend using a separate server to access the database using API calls. This however will have a cost attached.

DATABASES

There are several options for possible databases. At the free tier, some of the following options are available.

Database	Limitations
Firebase	1 GB of Storage, 100 simultaneous connections, 10 GB/month data transfer
DynamoDB	15GB storage, 25 RUs
MongoDB	5GB storage
Cosmos DB	25 GB Storage, 1000 RUs

EXISTING TRAINING EXERCISES

These training exercises are based on Cochlear's exercise sheets (linked below). Exercises are in order from most basic to most complex. These exercises are specifically designed to focus on speech, conversation, and reading, rather than environmental noise.

SYLLABALIC

CATEGORIZED BY

- Encouraging CI user to count syllables rather than jump straight to the word as a whole
- Differentiation between monosyllabic and polysyllabic words (i.e. Man vs Manic)

EXERCISE EXAMPLES

- Word Length Identification
  - Man vs Magnificent
  - Turkey vs Telephone
- High and Low Frequency Discrimination
  - "Paul brought all the wood home" vs "She drinks really sweet tea"
  - "Its easy to see" vs "My brother liked blue"

PHONEMIC

CATEGORIZED BY

- Comparing different phenomic tones such as
  - Short and long vowels (fawn vs fun, sheep vs ship)
  - Formant Frequencies (bath vs booth)
    - Second Formant
- Consonant Pattern (saw vs whisk, mass vs Sam)

EXERCISE EXAMPLES

- Phonemes - Short versus long vowels, contrasting formant frequencies
    - “Theme” vs “Thumb”
    - “Sharp” vs “Ship”
- Phonemes - Second Formant Discrimination
    - “Tea” vs “Too”
    - “Pit” vs “Put”

STRESS

CATEGORIZED BY

- Differentiation between words that the speaker emphasizes versus those they do not
- Recognize inflection and emotional context

EXERCISE EXAMPLES

- Word Stress
    - “*How* did *you know* the answer?”
    - “*Please go* with *me*”

TEXT FOLLOWING

CATEGORIZED BY

- Following which words the speaker is speaking in a text
- Creating associations between visible words and their audio equivalents

EXERCISE EXAMPLES

- Text following - Australia
    - The listener follows the passage with their finger and points out what word the speaker stops on when they halt

COMPREHENSION, CONTEXT, AND COMMUNICATION

CATEGORIZED BY

- Combining text following with word definitions to form sentences
- Responding to situation specific context
- Interpreting the emotion and sentiment behind phrases

EXERCISE EXAMPLES

- Two-Scripted conversation - shopping role-play
    - Role play a someone shopping and a shop keeper
- Text following - Two jokes, joke 1
    - Follow passage and point to words
    - Interpret meaning behind joke
- Overlearned speech
    - Learn basic and common phrases
    - Interpret emotion and tone
    - Listen to phrases that are commonly squished, combined, or modified in different dialects and settings
- Closed-set - visual identification task
    - Associated words and phrases with visual meanings

GAME EXERCISES

COMMON FEATURES

When analyzing existing auditory rehabilitation apps and software on the market, we encountered a few common features.

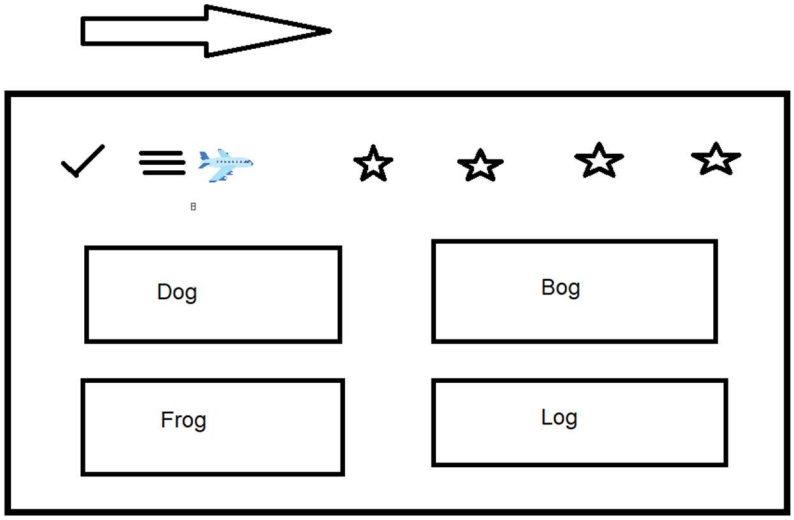
- Fun visuals: Colors, shapes, and layouts were engaging and exciting to interact with
- Entertaining: Exercises were not just about learning, but also about having a fun time
- Replay Audio Button: After answering a question or completing an exercise there was the option to go back and practice individual audios
- Personal High Score: Each exercise had a score associated with it, this high score was shown at the beginning of the exercise
- Pre Exercise Page: A page displayed before the exercise with the following info
    - Background Noise: Options to add background noise for increased difficulty
    - Sound Options: Options to work on specific word lists, phoneme types, and more
    - Instructions: Instructions on how to complete it and what the goals were
- Correct/Incorrect Answer Pop Up: Clear pop up to show user if they got the answer correct
- Measure of Time of Exercise: A measure of how much time was left in exercise
- Word Games: Games that focused on individual words
- Sentence Games: Games that focused on completing sentences

IDEAS

Most apps had multiple exercise options, here are some ideas for what we could develop in the second half of the term.

SIMPLE MULTIPLE CHOICE

Read a word out to the user and have them press which word they believe they heard.



Pros:

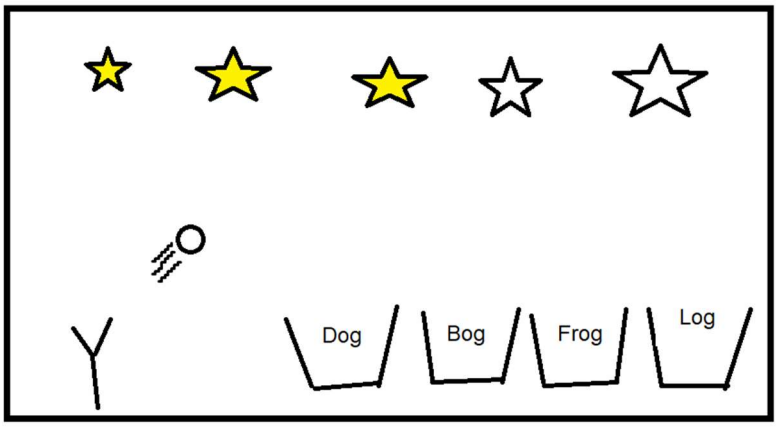
- Nice and self explanatory
- Good for tracking statistics
- Easy to fit a consistent theme throughout the app

Cons:

- Boring
- Easy to find on other apps

ANGRY BIRDS INSPIRED SELECTION GAME

Read a word out to the user and have them shoot a ball into the correct bucket that matches the word they believe they heard.



Pros

- Still fairly easy
- A little more fun
- Slightly more gamified, does not feel like a quiz

Cons

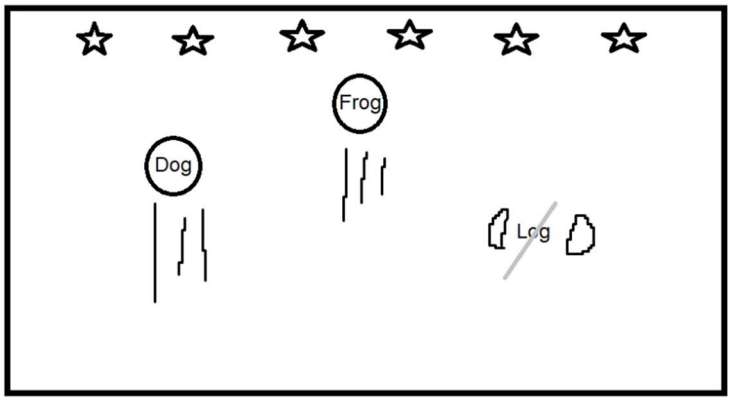
- Less self explanatory
- Room for inaccuracy with player skill

FRUIT NINJA INSPIRED SELECTION GAME

Read a word out to the user and have them slice the fruit that correctly matches.

Pros

- Significantly more fun
- Can do multiple words at a time to increase difficulty
- Does not feel like a quiz, more of a game

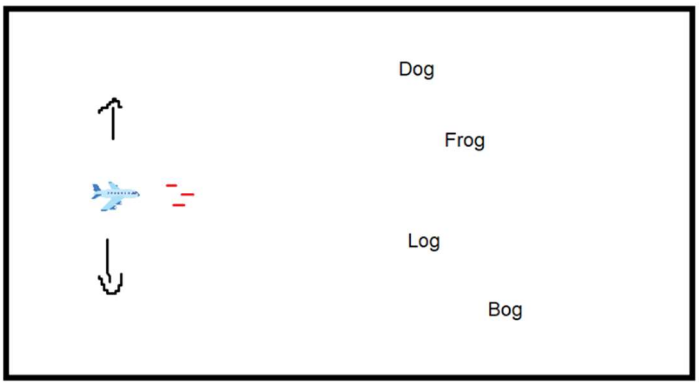


Cons

- Requires some reaction time and skill, more room for inaccuracy
- Less self explanatory

SPACE INVADERS INSPIRED SELECTION GAME

Read a word out to the user and have them shoot the word that correctly matches.



Pros

- Still fairly easy
- A little more fun
- Slightly more gamified, does not feel like a quiz
- Fits the airplane theme

Cons

- Shooters are a little contentious
- Requires some reaction time and skill, more room for inaccuracy

CATCH THE FRUIT

Read a word out to the user and have them grab the fruit with the word that correctly matches.

Pros

- Still fairly easy
- A little more fun
- Slightly more gamified

Cons

- Requires reaction time and skill, more room for inaccuracy

MEMORY MATCHING GAME

User selects a card from the set, the card will either play a sound or show a word. The user must select the correct sound and word pairs from the set of cards.

Pros

- A little more fun

Cons

- Difficult for user
- Hard to measure accuracy
- Slightly weird user interface with cards not having symbols on them

SENTENCE MATCHING GAMES

This type of game is difficult to make entertaining. Most of these interfaces are also less fun. Some possible ideas are listed below.

- Play a sentence with one word incorrect and have the user select which word was wrong
- Play a paragraph or phrase and stop at a certain point. Have the user select the stopping point.
- Play a sentence and then have the user type the sentence back.

GAME ENGINES

Since this application will end up being closer to a game, we will likely be using a game engine throughout our development process. Here are some options.

UNITY FEATURE LIST

- Cross Platform Development
  - Runs on Windows, MacOS, Linux, iOS, Android, Web, Consoles, and more
- Editor Interface
  - User friendly and visually intuitive environment
  - Includes scene composition, asset management, scripting and more
- Scripting
  - Primarily uses C#, but also supports JS
- Asset Store
  - Includes several ready-made assets, tools, plug-ins, and more resources
- Visual Scripting
  - Can use Bolt (drag and drop logic)
- Documentation
  - Active and supportive community
  - Lots of tutorials, forums, and resources to help us learn
  - Helpful because Unity has a high learning curve
- Collaborative Development
  - Unity Collaborate and Unity Teams allow multiple developers to work on one project
- Extensibility
  - Several third party libraries, SDKs, and plugins available

GODOT ENGINE FEATURE LIST

- Open Source and Free
  - Completely open source and accessible
- Cross Platform Development
  - Runs on Windows, MacOS, Linux, Android, iOS, HTML5, and more
- Editor Interface
  - Includes scen and node-based system for organization of projects
- Scripting
  - Primarily uses GDScript (Python-esque), but can also use C# and VisualScript
- Physics Engine
  - Supports both 2D and 3D physics simulations
- Animation Tools
  - Embedded animation system

REACT NATIVE FEATURE LIST

- Cross Platform Development
  - Ios and Android
- Scripting
  - Primarily uses JS
- Hot Reloading
  - Allows developers to instantly see results of code changes without rebuilding
- Component Based Architecture
  - UI elements are broken into reusable components
  - Developers can make their own components or access third party libraries of components

OVERVIEW

Here is an overview of the pros and cons of each engine.

Name	Unity	Godot	React Native
Pros	• Cross platform support • Large asset store • Large amount of documentation	• Open source • User friendly • Cross-platform support	• Cross-platform support • Third party libraries • Hot reloading
Cons	• Hard to learn • Size intensive • Updates can break compatibility	• Has its own language • Small asset store • Lack of advanced features	• Platform specific code • Debugging challenges • Poor performance for CPU heavy tasks

SOUNDFILE SOURCING

To speak words and sentences to the users for them to identify, we must have access to sound files associated with different phonemes and words. Here are some options.

GOOGLE CLOUD SPEECH

Google Cloud Speech has a Python API that allows users to paste text and read it in a specific human sounding voice. This might be useful for an exercise where you read a story and have to identify at what word the user stopped at.

FORVO

This site gives users the ability to search for and download pronunciations of individual words in MP3 format by multiple speakers. To access the various pronunciations of the same word, you must click on the word after searching it and filter out accents you do not want to hear. One possible exercise we could create is one where we play a word and have the user determine which word it is.

COMMON VOICE

There are multiple entries, each entry contains an MP3 file and an associated text file. I have noticed a lot of these sound files have interesting accents associated with them.

TEXT TO SPEECH OPTIONS

TTSMP3

This website converts text to speech online with the option to download the audio as an MP3.

PY-TTSX

This is a free Python text to speech API. There are limitations with the number of voices available and it is not intuitive, but it does work.

GOOGLE TTS API

Very high-quality text to speech API, but it requires a paid subscription.

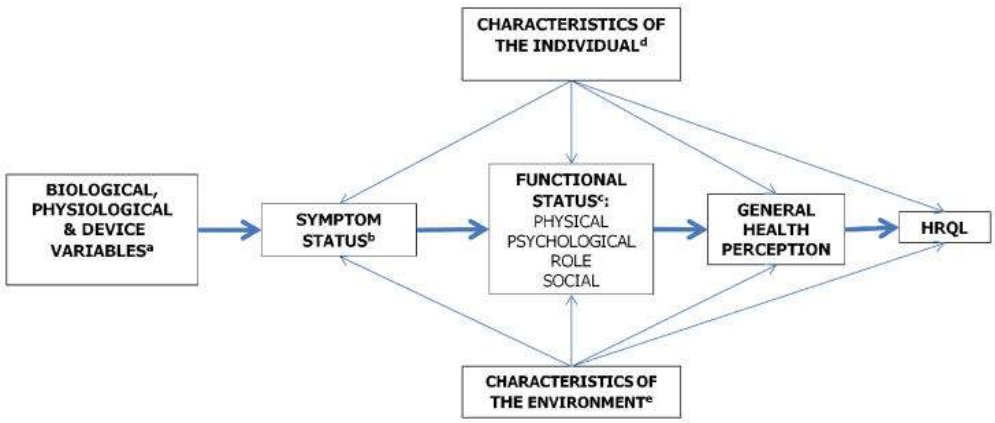
RANDOM SPEECH LIBRARIES

There is also the possibility of using random snippets of conversation in exercises. This would need to be annotated by one of our developers to make sure it is attached to the correct word. Here are some existing libraries.

- Lingua Libre
- Open SLR

USER SPECIFIC METHODOLOGY

When considering which exercises to use for a certain person, age is significantly less important than whether the CI user's hearing loss is prelingual or postlingual. This drastically changes the starting point of the user and their context levels in certain rehabilitation situations. Cochlear implant rehabilitation for postlingually deaf or hard of hearing patients is also dependent on how long they have experienced hearing loss. This section addresses how rehabilitation looks under these different distinctions.



PEDIATRIC

Children who receive cochlear implants before a delay in spoken language is developed - usually between the ages of 12-16 months - have a much higher likelihood of achieving age-specific speaking and hearing measures. If students are born with significant hearing loss or are infected in a way that impacts their hearing, a provider may recommend cochlear implants before 24 months. Even if the implant procedure is performed before any sort of linguistic understanding or training it is highly unlikely that the child will recover on their own and achieve speaking and hearing milestones. Therefore, aural rehabilitation, or more accurately aural habilitation, post cochlear implantation is still viable and relevant to small children and adults alike.

BABIES AND TODDLERS

Habilitation for babies and toddlers focuses more on fun and interactive ways for the child to connect sound to information. This begins first with the concept of sound as a whole and acknowledging that there will always be sound, this can be incredibly overwhelming. Once the child is comfortable with the concept of constant environmental noise, then the counselor or parent can begin to guide the CI user to the separation of sounds. Differentiating between music, speech, animal noises, and more can begin the process of linking sound to environment. Sound generation can then be incorporated into their training, allowing the child to mimic the sounds they here can begin the link between speech, sound, and definition. These methods and intentions are regularly incorporated into lessons along with methods to increase engagement such as movement, interactivity, and games. Since babies and toddlers do not have the ability to communicate how their implant is performing for them, it is important to highlight what is expected and unexpected tech wise. If the child cannot hear, they are taught to inform a trusted adult. A series of sounds called Ling sounds are used to test the functionality of the implant, so the child is taught to inform their trusted adult if they can or cannot hear them.

CHILDREN

This stage of auditory development has a lot more room for longer phrases and more complex language structures. The main change here is the development of auditory memory that allows the child to remember 5-7 word sentences with words they are familiar with. This allows for a more in depth focus on vocabulary and the concept of expanding vocabulary outside of training sessions. Similar to the baby and toddler stage there is a high priority placed on color and physical engagement. Rather than only expanding vocabulary, words are connected to movements, games, and other generally fun things. This stage requires a continued development for prioritizing and announcing needs. The patient is expected to connect their current situation and emotions to requests, i.e. if you are hungry, you should ask your parent for a snack. This focus on emotion carries to the emotions of others as well, children are encouraged to think about the emotion behind a sentence rather than just the words themselves.

ADOLESCENTS

The educational techniques for adolescents are the same or incredibly similar to adult strategies. The main change with adolescents is the focus on community and connection. Resources oriented towards teens include public forums, shared stories, and chat rooms where CI using teens can connect with peers. This stage also includes information specific to teachers and how to express your needs in a classroom setting.

SENIORS

The educational techniques for adolescents are the same or incredibly similar to adult strategies. Rather than focusing on age for specific rehabilitation strategies, length of deafness is a relevant predictor of auditory and quality of life outcomes. From the perspective of an audiologist, the specific characteristics and challenges of aural rehabilitation for seniors focus more on the medical complexities of aging. Since these can vary widely from person to person, it does not seem like it would be beneficial to add senior specific features. If an audiologist was working with a senior to treat hearing loss they would need to address the memory, social status, emotional status, and any other medically degenerating senses. These would also be accounted for in other age brackets, but the expected increase in difficulty makes them a higher priority.

POSTLINGUAL HEARING LOSS

Postlingual hearing loss is hearing loss that occurs after some language has been learned by the patient. This is usually caused by external factors such as infections, illness, trauma, or aging. This is an important consideration from the audiologist's perspective as different etiologies can result in different reasons or further complications for hearing loss. Cochlear implant rehabilitation has a consistently high level of success for postlingual children and adults. Since patients with postlingual hearing loss have experienced sound and speech previously, they have a predetermined expectation of what certain sounds are like to experience. For instance, postlingual cochlear implant users have substantial difficulty in identifying vowels which is likely due to the fact that the first and second formants are altered by the implant compared to what users previously heard.

PRELINGUAL HEARING LOSS

Prelingual hearing loss is hearing loss that occurs before language has been learned by the patient due to congenital deafness. While individuals who are prelingually deaf can still be good candidates for cochlear implants, their average performance plateau with regard to age specific speech and hearing metrics is consistently lower than post lingually deaf patients. This performance plateau is often met after around one year of aural rehabilitation.

INTRO TO ACOUSTIC PHONETICS

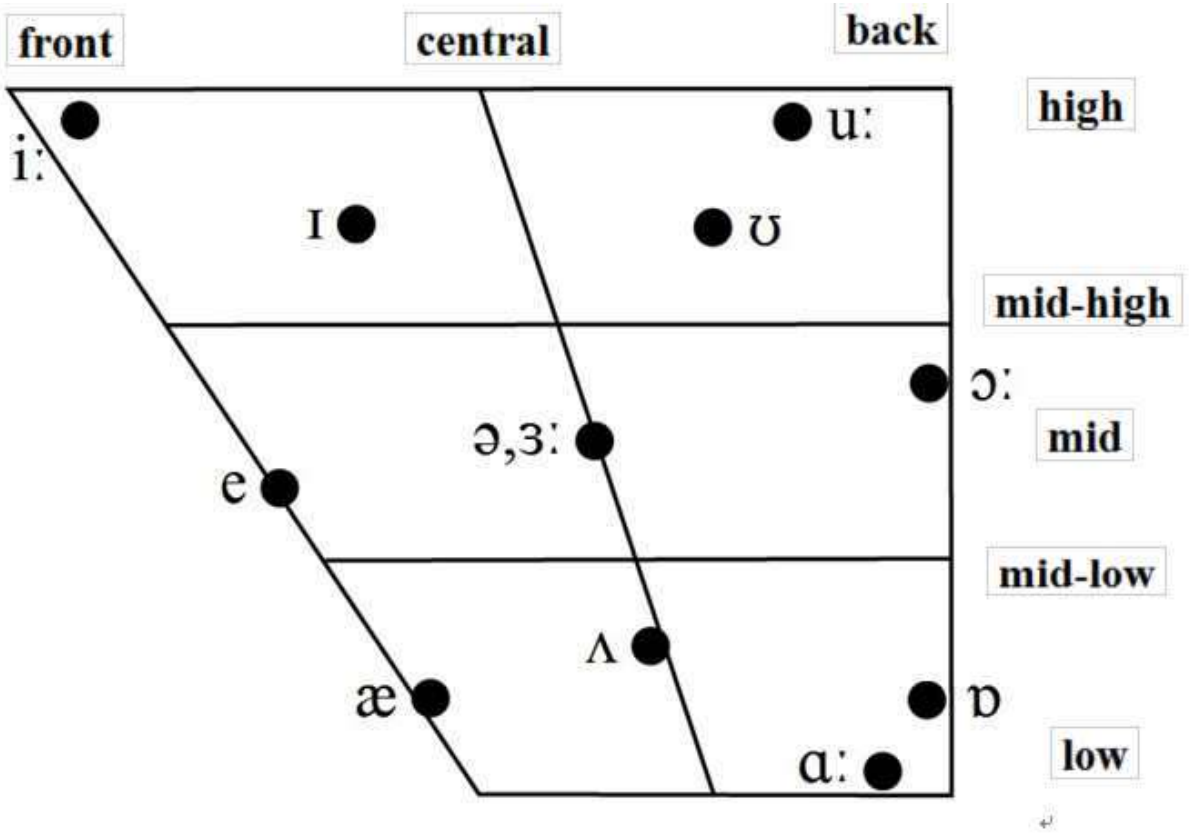
Acoustic phonetics is the study of the physical properties of speech. This study mainly aims to analyze sound wave signals that occur within speech through varying frequencies, amplitudes, and durations. This is relevant to our study of cochlear implants as it will provide a way to distinguish between the variety of different vowel and consonant sounds heard in the English language.

VOWELS

A sound that is pronounced with an opened mouth, no contact between the tongue and the top of the mouth or teeth and no obstruction to the flow of air. There are 20 vowels in total:

- 7 Short Vowels: /ɪ/ /ʊ/ /ə/ /e/ /ɒ/ /ʌ/ /æ/
- 5 long vowels: /iː/ /uː/ /ɑː/ /ɔː/ /ɜː/
- 8 diphthongs: /eɪ/ /aɪ//ɔɪ/ /əʊ/ /aʊ/ /ɪə/ /eə/ /ʊə/

These categories are based on the length of the sound, the position of the tongue, and the shape of the lips. The length of the sound can be either long or short. The position of the tongue can be closed (tongue higher in mouth) or open (tongue lower in mouth) and front or back (where tongue is raised in mouth). The shape of the lips can be rounded, neutral, or spread. This is summarized in the chart below.



You can feel the difference with the following sample words.

Type	Words
Length of Sound	Sheep (lax), ship (tense) Late (lax), let (tense)
Position of Tongue	Front: beet, bit, bait, bet, bat Back: Boot, boat
Shape of Lips	Boot, Book, Boat, Bore

You can see word examples for all the vowel types listed below.

Symbol	Example
/ɪ/	Sit, Pin, Dip
/ʊ/	Book, Crook, Rook
/ə/	Vendor, Monitor
/e/	Pet, ten
/ɒ/	Goggles, fog, dog
/ʌ/	Cut, Butter, Rum
/æ/	Cat, Bat, Rat
/iː/	Theme, fleet, beat
/uː/	Boot, Root, Scoot
/ɑː/	Park, far, DAR
/ɔː/	Score, Roar, Bore
/ɜː/	Bird, worm
/eɪ/	Bagel, day, slay
/aɪ/	Sky, buy, cry
/ɔɪ/	Boy, toy, coy
/əʊ/	Phone, oh, no
/aʊ/	Brown, cow, how
/ɪə/	Beer, pier, hear
/eə/	Bear, pear, hair
/ʊə/	Tour, poor, door

CONSONANTS

Consonants are a basic speech sound in which the breath is at least partly obstructed, and which can be combined with a vowel to form a syllable. They can be divided into plosives, fricatives, approximates, and nasals.

Plosives - Produced by stopping the airflow using the lips, teeth, or palate, followed by a sudden release of air.	**/p/**	**Voiceless, bilabial**	**Popular, Paper**
	/b/	Voiced, bilabial	Bad, Bagel
	/t/	Voiceless, alveolar	Toy, Touch
	/d/	Voiced, alveolar	Day, Dog
	/k/	Voiceless, velar	Kick, Cat
	/g/	Voiced, velar	Goat, Goofy
Fricatives - Made by the friction of breath in a narrow opening, producing a turbulent air flow.	/f/	Nonsibilant, Voiceless	Fat, Fork
	/v/	Nonsibilant, voiced	Van, vase
	/θ/	Nonsibilant, voiceless	Think, thick
	/ð/	Nonsibilant, voiced	This, those
	/s/	Sibilant, voiceless	Sick, Sun
	/z/	Sibilant, voiced	Zip, Zoom
	/ʃ/	Sibilant, voiceless	Ship, Shut
	/ʒ/	Sibilant, voiced	Genre, Jaque
	/h/	Non sibilant	Ham, heat

Approximants - formed by the passage of air between two articulators which are closing but not touching	/w/	Labial-velar	War, wam
	/r/	Alveolar	Rot, roar
	/l/	Alveolar lateral	Lot, fly
	/j/	Palatal	Yacht
Nasals - pronounced by the voice resonating in the nose.	/m/	Bilabial	Arm, Make
	/n/	Alveolar	Anchor, Uncle
	/ŋ/	Velar	Bank, Anger

DIFFICULT TO DISTINGUISH SOUNDS

Hearing with a cochlear implant is not the exact same as hearing clearly without one. Differences in tone along with adjusting to hearing in general create difficulties for interpreting the signals that the implant transmits. Post lingual users have defined the sound as robotic and distorted, especially at first, but over time the brain starts to recognize and humanize speech patterns. Music is particularly difficult to distinguish as the implant cannot reasonably process all the complex pitches, so for CI users, songs are often interpreted as one single set of tones rather than the entire array. Cell phones are also difficult for some CI users, and it is not guaranteed that a CI user can effectively use a cell phone. Some cochlear implants can connect directly to the phone via Bluetooth which can be helpful.

VOWELS

TABLE III. Vowel confusion matrix, better listeners.

	æ	ɑ	ɛ	eɪ	ɚ	ɪ	i	oʊ	ʊ	ʌ	u
æ	358	4	26	2	0	0	0	0	0	0	0
ɑ	25	357	1	0	1	0	0	1	0	4	1
ɛ	8	1	310	1	0	55	1	0	3	11	0
eɪ	0	0	1	374	3	2	10	0	0	0	0
ɚ	0	0	3	0	342	3	1	3	22	3	13
ɪ	0	0	48	4	2	332	3	0	1	0	0
i	0	0	3	14	0	0	371	2	0	0	0
oʊ	0	0	0	0	0	1	1	328	1	3	56
ʊ	1	1	6	1	9	1	1	7	320	9	34
ʌ	0	2	10	0	2	0	0	1	52	322	1
u	0	0	0	1	22	0	0	60	8	4	295

Difficult to distinguish between:

- **B**ird and **B**a**d**
- **B**a**t** and **B**a**r**d
- **B**ird and **S**i**t**
- **B**o**o**k and **V**e**n**dor
- **S**i**t** and b**a**gel
- Br**o**wn and B**oo**k
- **Boo**k and **Boo**t
- C**u**t and C**oo**k

CONSONANTS

Observed (O)															
p															
d															
t		**14**													
g			*4*												
k		**33**		**20**											
v	30														
f		14													
z					24		**10**								
s								**40**							
ð							**24**	14	**10**						
ʃ															
m									*0*						
n															
l							0		*0*		*0*		**17**	**34**	
i														*0*	
	b	p	d	t	q	k	v	f	z	s	ð	ʃ	m	n	l

Difficult to distinguish between:

- **T**op and **P**op
- **K**ick and **P**ick
- **T**ick and **K**ick
- **V**einy and **Z**any
- **S**anta and **F**anta
- **Th**ow and **V**ow
- **Th**ought and **Z**ot
- **L**amb and **M**aam
- **L**ook and **N**ook

GLOSSARY

Voiceless: Made with just air, no sound from vocal cords, weaker formants

Voiced: Made with air and sound from vocal cords, stronger formants

Bilabial: Formed by a closure or near closure of the lips

Alveolar: produced with the tongue close to or touching the ridge behind the teeth on the roof of the mouth.

Velar: pronounced with the back of the tongue near the soft palate.

Nonsibilant: produce their characteristic sound directly with the tongue or lips etc. and the place of contact in the mouth, without secondary involvement of the teeth.

Sibilant: Sounding with a hissing effect, usually louder than nonsibilants.

Labial-velar: Consonants doubly articulated at the velum and the lips.

Alveolar lateral: When the blade of the tongue touches the alveolar ridge and air is released around the tongue

Palatal: a consonant sound produced by raising the blade, or front, of the tongue toward or against the hard palate just behind the alveolar ridge

Frequency: Frequency relates to the individual pulsations produced by vocal cord vibrations for a unit of time. The rate of vibration depends on the length, thickness, and tension of the vocal cords, and thus is different for child, adult male and female speech. A speech sound contains two types of frequencies: fundamental frequency (F0) which relates to vocal cord function and reflects the rate of vocal cord vibration during phonation (pitch) and formant frequency which relates to vocal tract configuration.

Time: Time as a property of speech sounds reflects the duration of a given sound.

Amplitude: The amplitude is marked by darkness of the bands: the greater the intensity of the sound energy presents in a given time and frequency; the darker will be the mark at the corresponding point on the screen.

Formant: A formant is the concentration of acoustic energy around a particular frequency in the speech wave. There are several formants, each at a different frequency, roughly one in each 1000Hz band. To put it differently, formants occur at roughly 1000Hz intervals. Each formant corresponds to a resonance in the vocal tract.

SOURCES

[1] C. M. Reed and L. A. Delhorne, “Reception of environmental sounds through cochlear implants,” *Ear and Hearing*, vol. 26, no. 1, pp. 48–61, Feb. 2005. doi:10.1097/00003446-200502000-00005 (accessed Nov. 2023).

[2] V. Shafiro, N. Luzum, A. C. Moberly, and M. S. Harris, “Perception of environmental sounds in Cochlear Implant Users: A systematic review,” *Frontiers in Neuroscience*, vol. 15, Jan. 2022. doi:10.3389/fnins.2021.788899 (accessed Nov. 2023).

[3] B. M. Sheffield and F.-G. Zeng, “The relative phonetic contributions of a cochlear implant and residual acoustic hearing to bimodal speech perception,” *The Journal of the Acoustical Society of America*, vol. 131, no. 1, pp. 518–530, Jan. 2012. doi:10.1121/1.3662074 (accessed Nov. 2023).

[4] V. Shafiro, S. Sheft, S. Kuvadia, and B. Gygi, “Environmental sound training in cochlear implant users,” *Journal of Speech, Language, and Hearing Research*, vol. 58, no. 2, pp. 509–519, Apr. 2015. doi:10.1044/2015_jslhr-h-14-0312 (accessed Nov. 2023).

[5] C. M. Reed and L. A. Delhorne, “Reception of environmental sounds through cochlear implants,” *Ear and Hearing*, vol. 26, no. 1, pp. 48–61, Feb. 2005. doi:10.1097/00003446-200502000-00005 (accessed Nov. 2023).

[6] J. H. Clark *et al.*, “Cochlear implant rehabilitation in older adults: Literature review and proposal of a conceptual framework,” *Journal of the American Geriatrics Society*, vol. 60, no. 10, pp. 1936–1945, Sep. 2012. doi:10.1111/j.1532-5415.2012.04150.x (accessed Nov. 2023).

[7] “Auditory training for teens and adults: 113: Aural rehabilitation,” AudiologyOnline, https://www.audiologyonline.com/audiology-ceus/course/auditory-training-for-teens-and-113 (accessed Nov. 2023).

[8] S. M, A. S, D. S, and K. MH, “Outcomes of cochlear implantation in post-lingually deaf patients,” *The International Tinnitus Journal*, vol. 25, no. 1, 2021. doi:10.5935/0946-5448.2020005 (accessed Nov. 2023).

[9] “Types of hearing loss,” Centers for Disease Control and Prevention, https://www.cdc.gov/ncbddd/hearingloss/types.html#:~:text=Pre%2Dlingual%20or%20Post%2Dlingual,talk%20(post%2Dlingual) (accessed Nov. 2023).

[10] A. S. Jaiswal *et al.*, “Cochlear implantation in adults with post-lingual hearing loss: Clinico-Demographical Study and Outcomes in the current times,” *Indian Journal of Otolaryngology and Head & Neck Surgery*, vol. 75, no. S1, pp. 548–551, Mar. 2023. doi:10.1007/s12070-022-03467-6 (accessed Nov. 2023).

[11] S. Wooi Teoh, D. B. Pisoni, and R. T. Miyamoto, “Cochlear implantation in adults with prelingual deafness. part I. clinical results,” *The Laryngoscope*, vol. 114, no. 9, pp. 1536–1540, Sep. 2004. doi:10.1097/00005537-200409000-00006 (accessed Nov. 2023).

[12] A. K. Rødvik, J. von Koss Torkildsen, O. B. Wie, M. A. Storaker, and J. T. Silvola, “Consonant and vowel identification in cochlear implant users measured by nonsense words: A systematic review and meta-

analysis," *Journal of Speech, Language, and Hearing Research*, vol. 61, no. 4, pp. 1023–1050, Apr. 2018. doi:10.1044/2018_jslhr-h-16-0463 (accessed Nov. 2023).

[13] B. Munson, G. S. Donaldson, S. L. Allen, E. A. Collison, and D. A. Nelson, "Patterns of phoneme perception errors by listeners with cochlear implants as a function of overall speech perception ability," *The Journal of the Acoustical Society of America*, vol. 113, no. 2, pp. 925–935, Jan. 2003. doi:10.1121/1.1536630 (accessed Nov. 2023).

[14] A. C. Moberly, "Variability in word recognition by adults with cochlear implants: The roles of perceptual attention versus auditory sensitivity," *Journal of the Acoustical Society of America*, vol. 137, no. 4_Supplement, pp. 2411–2411, Apr. 2015. doi:10.1121/1.4920786 (accessed Nov. 2023).

[15] M. A. Svirsky, E. Sagi, T. A. Meyer, A. R. Kaiser, and S. W. Teoh, "A mathematical model of medial consonant identification by cochlear implant users," *The Journal of the Acoustical Society of America*, vol. 129, no. 4, pp. 2191–2200, Apr. 2011. doi:10.1121/1.3531806 (accessed Nov. 2023).

[16] B. Munson, G. S. Donaldson, S. L. Allen, E. A. Collison, and D. A. Nelson, "Patterns of phoneme perception errors by listeners with cochlear implants as a function of overall speech perception ability," *The Journal of the Acoustical Society of America*, vol. 113, no. 2, pp. 925–935, Jan. 2003. doi:10.1121/1.1536630 (accessed Nov. 2023).

[17] T. C. says: et al., "What does a cochlear implant sound like?," Auditory Implant Service, https://ais.southampton.ac.uk/cochlear-implant/cochlear-implant-sound-like/ (accessed Nov. 2023).

[18] "Making music enjoyable for cochlear implant users," National Institutes of Health, https://nihrecord.nih.gov/2022/07/08/making-music-enjoyable-cochlear-implant-users (accessed Nov. 2023).

[19] I. Anderson *et al.*, "Telephone use: What benefit do cochlear implant users receive?," *International Journal of Audiology*, vol. 45, no. 8, pp. 446–453, Jan. 2006. doi:10.1080/14992020600690969 (accessed Nov. 2023).

[20] L. Friesen, "What does the world sound like through a cochlear implant?," Cochlear Implant Brain and Behavior Lab, https://cochlearimplant.lab.uconn.edu/cochlear-implant-information/sounds/#:~:text=Sounds%20heard%20through%20a%20cochlear,of%20an%20off-tuned%20radio (accessed Nov. 2023).

[21] C. G. Author, "The importance of aural rehabilitation," Cochlear ProNews, https://pronews.cochlear.com/aural-rehabilitation-cochlear-implantation/ (accessed Nov. 2023).

[22] A. C. Moberly *et al.*, "Comprehensive auditory rehabilitation in adults receiving cochlear implants: A pilot study," *Laryngoscope Investigative Otolaryngology*, vol. 5, no. 5, pp. 911–918, Sep. 2020. doi:10.1002/lio2.442 (accessed Nov. 2023).

[23] A. E. Geers and H. Hayes, "Reading, writing, and phonological processing skills of adolescents with 10 or more years of Cochlear Implant experience," *Ear & Hearing*, vol. 32, no. 1, Feb. 2011. doi:10.1097/aud.0b013e3181fa41fa (accessed Nov. 2023).

[24] A. E. Geers, “Predictors of reading skill development in children with early cochlear implantation,” *Ear and Hearing*, vol. 24, no. Supplement, Feb. 2003. doi:10.1097/01.aud.0000051690.43989.5d (accessed Nov. 2023).

[25] W. J. Parkes, Ed., “Cochlear implants (for parents) - nemours kidshealth,” KidsHealth, https://kidshealth.org/en/parents/cochlear.html#:~:text=Children%20with%20cochlear%20implants%20begin,develop%20and%20understand%20spoken%20language (accessed Nov. 2023).

[26] A. Boothroyd, “Adult aural rehabilitation: What is it and does it work?,” *Trends in Amplification*, vol. 11, no. 2, pp. 63–71, Jun. 2007. doi:10.1177/1084713807301073

[27] “Resources for adults,” Cochlear, https://www.cochlear.com/us/en/home/ongoing-care-and-support/rehabilitation-resources/resources-for-adults (accessed Nov. 2023).

[28] M. Moradi *et al.*, “Family and rehabilitation of children with Cochlear Implant: A qualitative study,” *Florence Nightingale Journal of Nursing*, vol. 30, no. 1, pp. 18–24, Mar. 2022. doi:10.5152/fnjn.2022.21043 (accessed Nov. 2023).

[29] Z. Jeddi, Z. Jafari, M. Motasaddi Zarandy, and A. Kassani, “Aural rehabilitation in children with cochlear implants: A study of cognition, Social Communication, and Motor Skill Development,” *Cochlear Implants International*, vol. 15, no. 2, pp. 93–100, Jan. 2014. doi:10.1179/1754762813y.0000000060 (accessed Nov. 2023).

[30] C. A. Perfetti, “Reading optimally builds on spoken language: Implications for deaf readers,” *Journal of Deaf Studies and Deaf Education*, vol. 5, no. 1, pp. 32–50, Jan. 2000. doi:10.1093/deafed/5.1.32 (accessed Nov. 2023).

[31] A. E. Geers and H. Hayes, “Reading, writing, and phonological processing skills of adolescents with 10 or more years of Cochlear Implant experience,” *Ear & Hearing*, vol. 32, no. 1, Feb. 2011. doi:10.1097/aud.0b013e3181fa41fa (accessed Nov. 2023).

[32] A. Frosolini *et al.*, “Application of patient reported outcome measures in cochlear implant patients: Implications for the design of specific rehabilitation programs,” *Sensors*, vol. 22, no. 22, p. 8770, Nov. 2022. doi:10.3390/s22228770 (accessed Nov. 2023).

[33] C. Wu, L. Lee, W. Chao, Y. Tsou, and Y. Chen, “Paragraph-reading comprehension ability in mandarin-speaking children with cochlear implants,” *The Laryngoscope*, vol. 125, no. 6, pp. 1449–1455, Dec. 2014. doi:10.1002/lary.25081 (accessed Nov. 2023).

[34] A. Frosolini *et al.*, “Application of patient reported outcome measures in cochlear implant patients: Implications for the design of specific rehabilitation programs,” *Sensors*, vol. 22, no. 22, p. 8770, Nov. 2022. doi:10.3390/s22228770 (accessed Nov. 2023).

[35] J. H. Clark *et al.*, “Cochlear implant rehabilitation in older adults: Literature review and proposal of a conceptual framework,” *Journal of the American Geriatrics Society*, vol. 60, no. 10, pp. 1936–1945, Sep. 2012. doi:10.1111/j.1532-5415.2012.04150.x (accessed Nov. 2023).

[36] M. S. Harris *et al.*, "Postoperative rehabilitation strategies used by adults with cochlear implants: A pilot study," *Laryngoscope Investigative Otolaryngology*, vol. 1, no. 3, pp. 42–48, Jun. 2016. doi:10.1002/lio2.20 (accessed Nov. 2023).

[37] "The listening room," The Listening Room, https://thelisteningroom.com/ (accessed Nov. 2023).

[38] "Angel sound - interactive listening rehabilitation and functional hearing Test Program," Angel Sound - Interactive Listening Rehabilitation and Functional Hearing Test Program, https://angelsound.tigerspeech.com/ (accessed Nov. 2023).

[39] "Bring back the beat," Cochlear, https://www.cochlear.com/us/en/campaign/bring-back-the-beat (accessed Nov. 2023).

[40] "Sound Foundation for Babies," Cochlear, https://www.cochlear.com/us/en/home/ongoing-care-and-support/rehabilitation-resources/resources-for-babies-and-toddlers/sound-foundation-for-babies (accessed Nov. 2023).

[41] "Leaping on with language," Cochlear, https://www.cochlear.com/us/en/home/ongoing-care-and-support/rehabilitation-resources/resources-for-school-age-children/leaping-on-with-language (accessed Nov. 2023).

[42] "Sound Foundation for Children," Cochlear, https://www.cochlear.com/us/en/home/ongoing-care-and-support/rehabilitation-resources/resources-for-school-age-children/sound-foundation-for-children (accessed Nov. 2023).

[43] "Auditory training exercises," Cochlear, https://www.cochlear.com/us/en/home/ongoing-care-and-support/rehabilitation-resources/resources-for-adults/auditory-training-exercises (accessed Nov. 2023).