Exploring the Feasibility of Remote Cardiac Auscultation Using Earphones

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“Heart diseases are the leading cause of death” -- CDC

“**One in every 4** deaths is caused by heart diseases” – Penn Medicine

https://www.cdc.gov/vitalsigns/million-hearts/index.html

Existing approaches for heart disease pre-screening

Heart Auscultation (PCG)

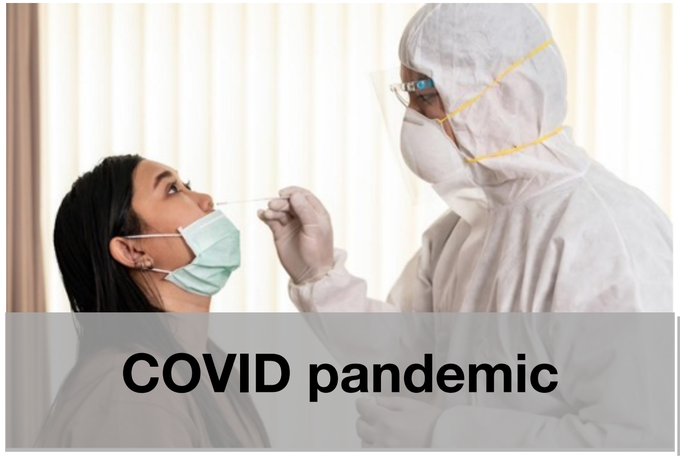
- Easy to access
- Effective to detect most cardiac diseases
- Cheap

Electrocardiography (ECG)

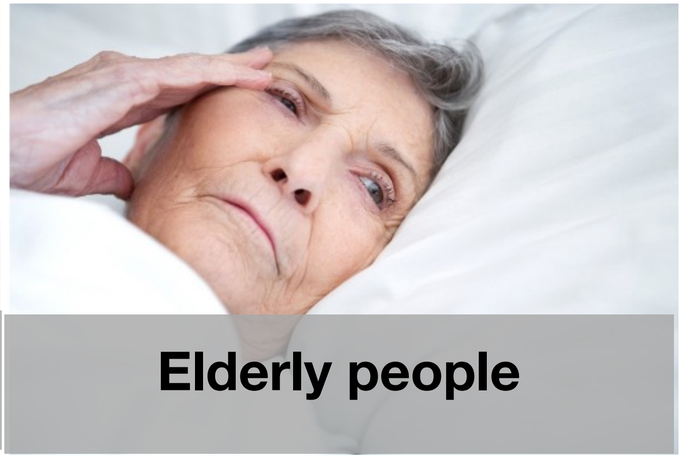
- Can detect more fine-grained heartbeat signals
- Difficult to operate
- Less accessible (only in clinic settings)
- Expensive

Echocardiography (Echo)

The rise of video visit



COVID pandemic



Elderly people

Video visits gains popularity during and after the pandemic:

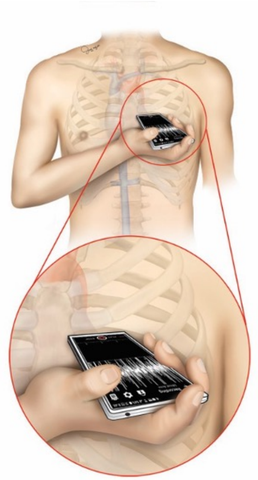
- Less COVID exposures
- Patient can access specialist at home around the clock
- Avoid unnecessary hospitalizations

However, heart auscultation is not feasible in video visit settings!

The current practice on remote heart auscultation

Digital stethoscope

- Effective to detect most cardiac disease
- High cost (e.g., 500 USD)
- Difficult to operate



Smartphone auscultation

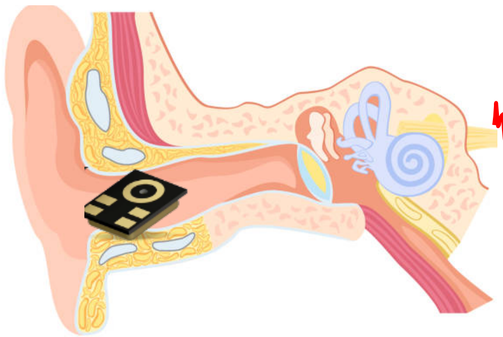
- Pervasive
- Suffer from extra noise
- Difficult to operate (especially with long time holding)

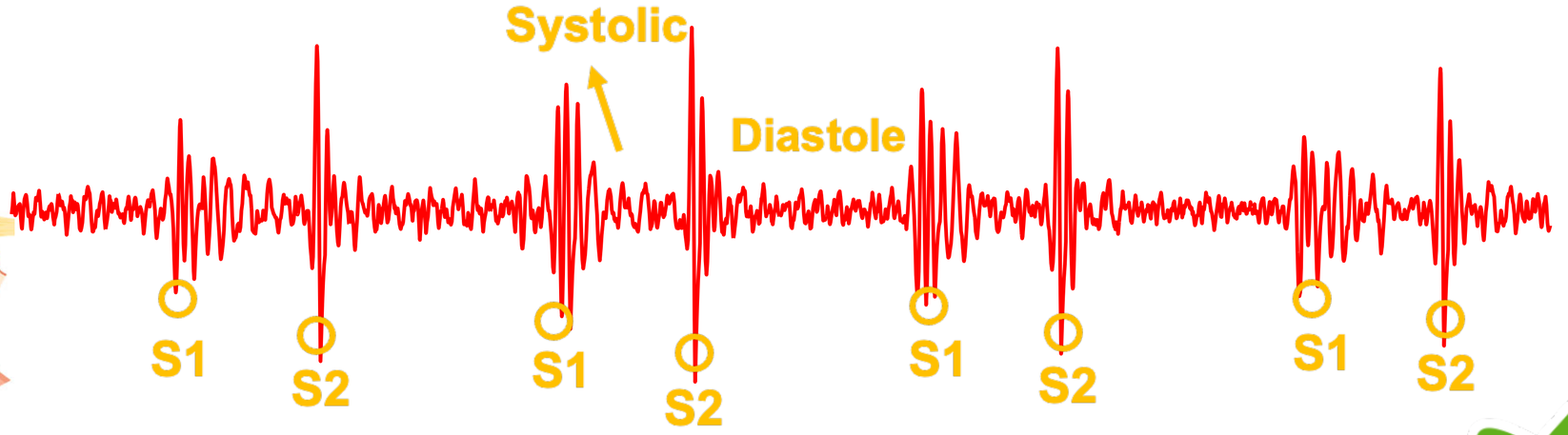
How about using earphone as a stethoscope?

Why earphone for cardiac function?

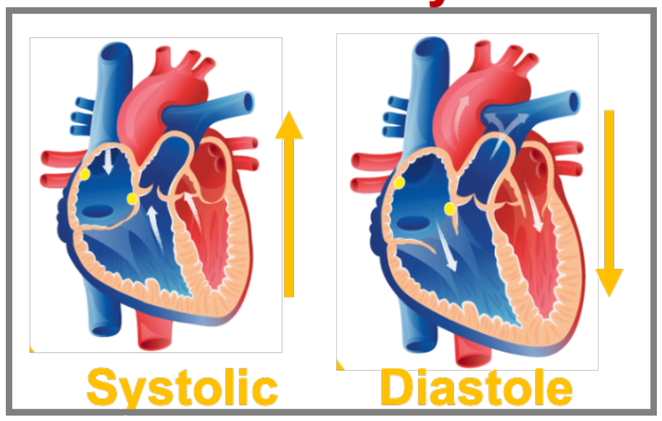
- Cheap and pervasive (One-time disposable in airplane, museums, etc.)
- Comfortable to wear, no extra burden for user to operate
- Ear canal is an excellent channel for capturing cardiac activities

Ear canal is an excellent channel for capturing cardiac activities





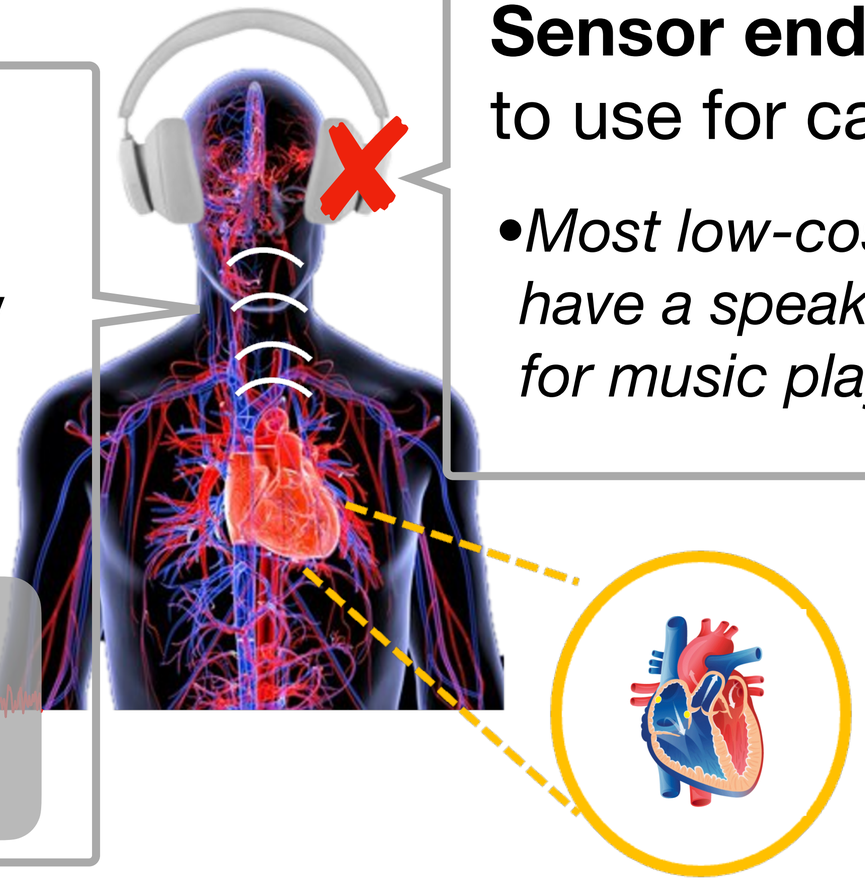
One heart cycle



Technical challenges for enabling cardiac auscultation via earphones

Signal end: Heart sounds suffer significant attenuation and frequency distortion as they travel from chest to ear.

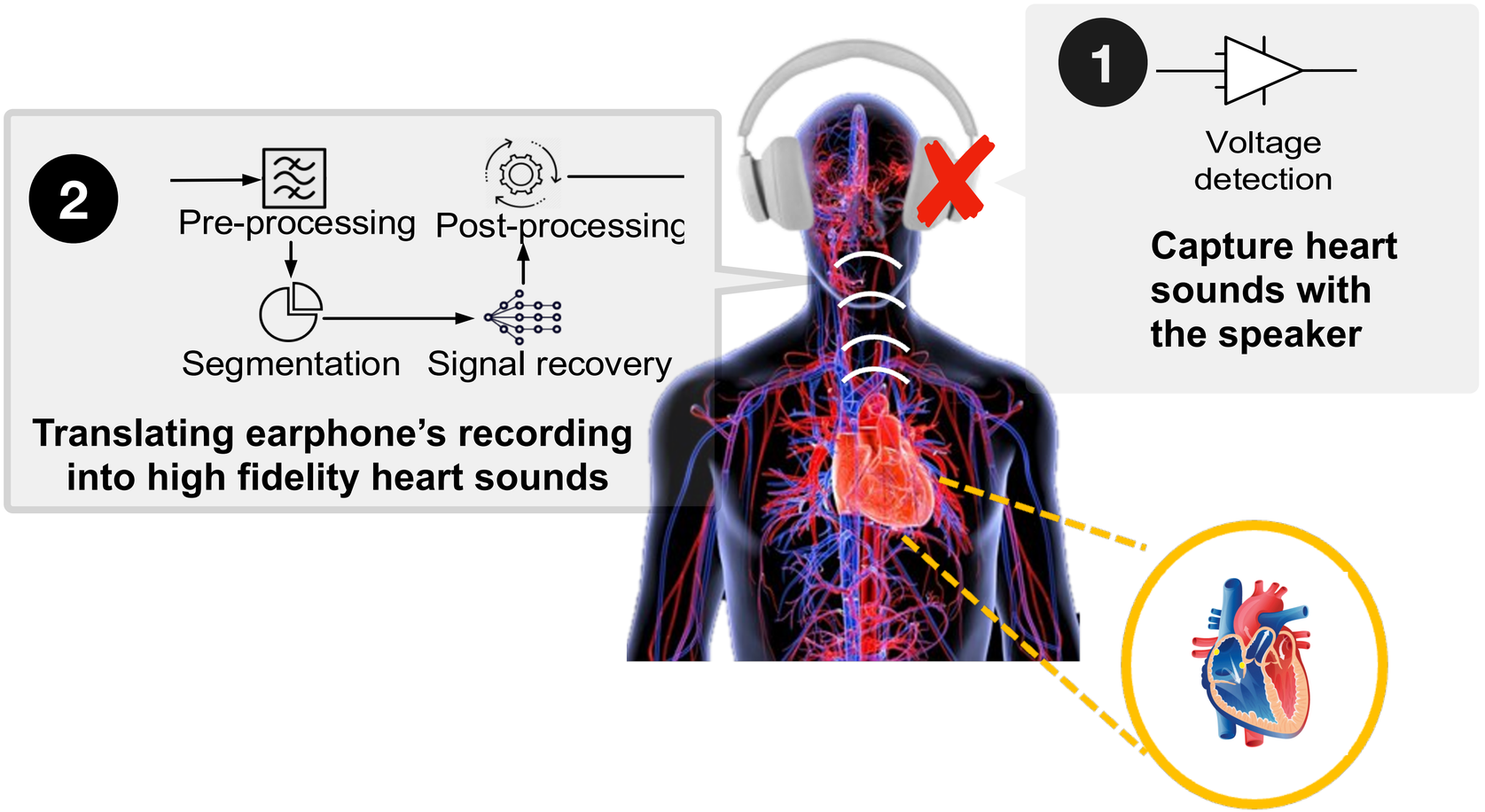
Not real heart sounds for auscultation



Sensor end: Which sensor to use for capturing?

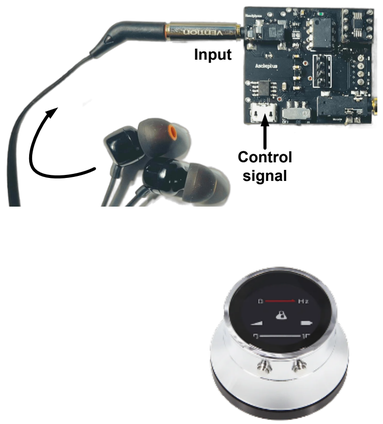
- *Most low-cost earphones only have a speaker sensor, meant for music playback.*

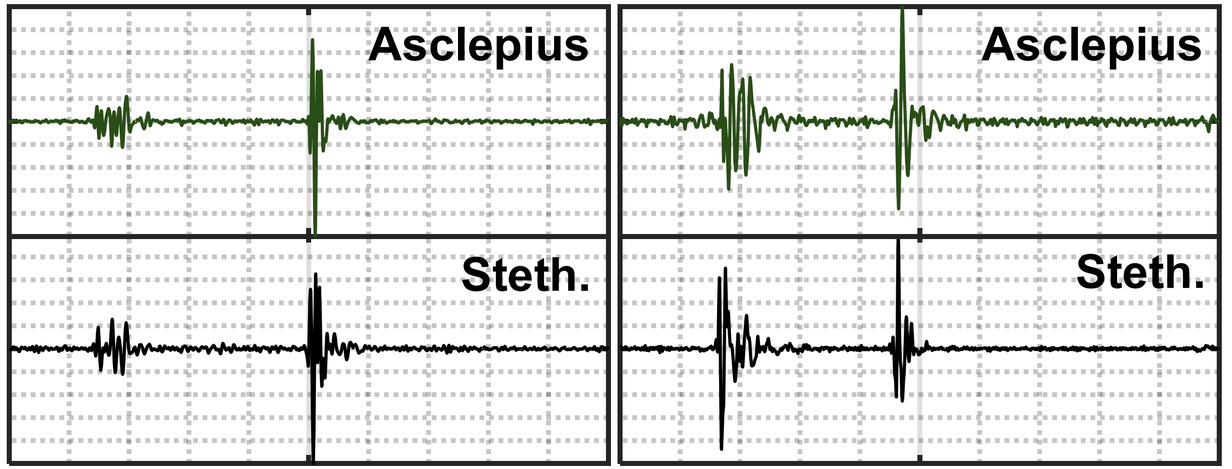
Design architecture: a hardware-software solution



Live demo

Evaluation: Healthy and pathological heart sounds





RMSE = 1% *RMSE = 2%*

Healthy: Overall RMSE (Root Mean Squared Error) < 3%

30 users test and cardiologists feedback can be found at: https://asclepius-system.github.io/

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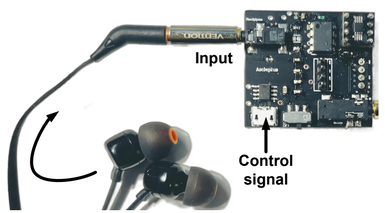

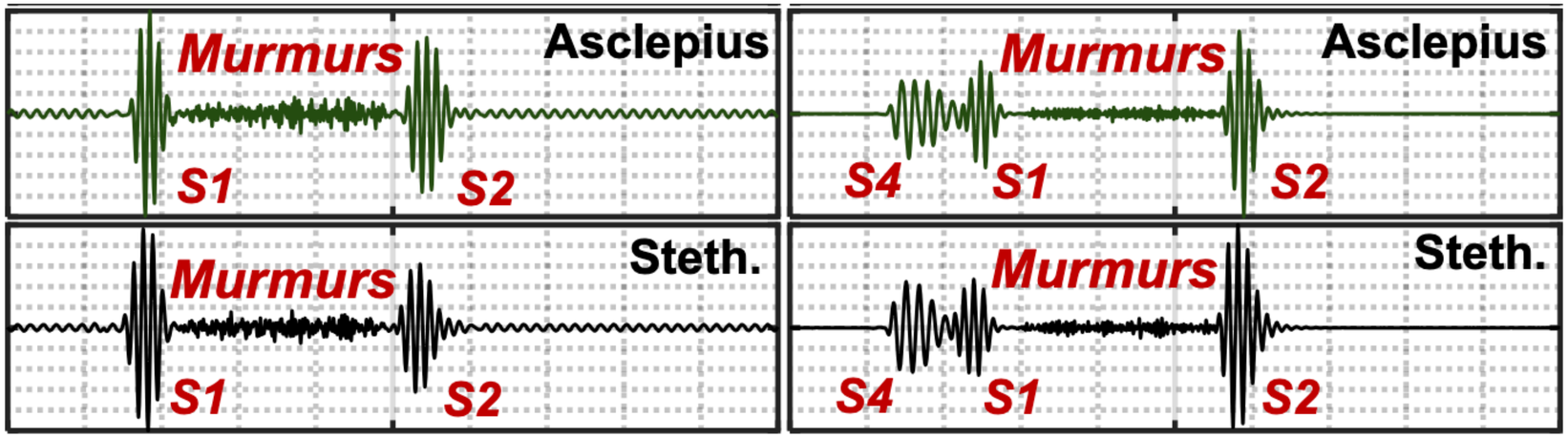

G2 example G4 example

Pathological: Overall RMSE < 5%

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Cardiologists feedback and blind listening test

Table 1. Dialog with cardiologist A.

▹ **P1: Introducing Asclepius to the clinician:**
Q1: *In your clinical experience, what do you consider to be the most crucial aspects of heart sounds when making a diagnosis?* **Answer:** When evaluating heart conditions, it's crucial to carefully assess the primary S1 and S2 heart sounds, as well as any murmurs. While you might also hear S3 and S4 sounds during auscultation, distinguishing between normal and abnormal variants can be challenging. Therefore, the primary focus should always be on the clarity and consistency of the S1 and S2 heart sounds and any identified murmurs.
▹ **P2: Playing PCG signals that Asclepius captured from a healthy individual, and informing the cardiologist that the audio clips are a product of our technology:**
Q2: *Based on the heart sounds you've just heard, which specific cardiac features can you pinpoint?* **Answer:** I can clearly tell the S1 and S2 components.
Q3: *How would you compare the heart sounds produced by Asclepius to those you'd typically hear using a stethoscope? Are there any inconsistencies that stood out?* **Answer:** In my experience, I have not observed any discernible differences between the heart sounds produced by your technology and those usually obtained using a stethoscope. The signal quality is exceptional.
▹ **P3: Playing the same PCG signals captured by Asclepius again, then playing the stethoscope recording immediately afterward so the clinician can compare:**
Q4: *After listening to both, can you tell any differences between the recordings from Asclepius and those from the stethoscope?* **Answer:** Yes, I can tell some differences between these two recordings. Asclepius's recordings are somewhat less crisp compared to those from the stethoscope, and there seem to be some S3 sounds in the background. The stethoscope recordings, on the other hand, have more distinct sounds and no S3 sounds.
▹ **P4: Playing pathological PCG sounds captured by Asclepius. The cardiologist is informed that these clips were produced by our technology and sourced from a patient. After the cardiologist responds to Q5, recordings from the stethoscope are played for comparative analysis:**
Q5: *Based on these pathological heart sounds you just heard from our system, what cardiac features caught your attention?* **Answer:** I picked up on the S1 and S2 components and also some evident murmurs. **Q6:** *After listening to both, can you pinpoint any differences between Asclepius's recording and the one from the stethoscope?* **Answer:** Honestly, I didn't find any significant differences between the heart sounds from Asclepius and those from the stethoscope.
▹ **P5: Engaging in a conversation with the cardiologist to discuss the advantages and disadvantages of our technology:**
Q7: *From your expert viewpoint, can you share the benefits you see in using Asclepius?* **Answer:** Certainly. One potential benefit of your technology is that the earphone recording method naturally produces less noise interference compared to a stethoscope. We often face challenges with noise interference when using a stethoscope, which can be caused by factors such as sweat on the skin, environmental noises, and improperly fitted chest contacts. In contrast, earphones are less likely to pick up interference from the ear canal. Additionally, the visual representation of heart sounds in your technology is a significant advantage. We are pleased to have the ability to observe the PCG signal, which will aid in identifying pathological features during auscultation. Furthermore, your system could serve as a valuable tool for remote visits, fostering trust between patients and clinicians by enabling auscultation.
Q8: *Any thoughts on the limitations and challenges of Asclepius?* **Answer:** A potential challenge I see is tied to the practice of auscultation. Typically, we move the stethoscope to different spots on the chest to obtain better signal quality from specific areas of the heart, such as the right ventricle, pulmonary valve, or tricuspid valve. This allows for an optimized signal quality and comprehensive assessment. With earphones, such precise maneuvering isn't feasible, which might restrict their capacity to capture certain pathological heart activities in these specific areas.

"I can clearly tell the S1 and S2 components "

"In my experience, I have not observed any discernible differences btw the heart sounds produced by your technology and those usually obtained using a stethoscope"

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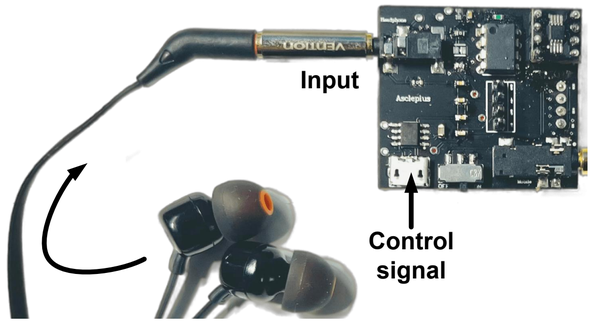
Bring mobile health technologies to under-developed world



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Design → *Evaluation* → *Deployment (early 2025)*

Thanks for listening!

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