Dhruv Jain | University of Washington

Sound & Speech Sensing and Feedback for Deaf and Hard of Hearing (DHH) Users

Our world is filled with a rich diversity of **sounds.**


A microwave beep…

A fire alarm...


A waterfall...

15% of US adults

"some trouble hearing"

"disabling hearing loss"

2% of adults aged 45 to 54

50% of those 75 and older

[National Institute on Deafness and Other Communication Disorders, 2016]

Many DHH people use **alternative ways** to deal with sound information

Sign Language

Flashing Doorbell

Vibratory Alarm Clock

Deaf and Hard-of-hearing Individuals' Preferences for Wearable and Mobile Sound Awareness Technologies

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ABSTRACT

To investigate preferences for mobile and wearable sound awareness systems, we conducted an online survey with 201 DHH participants. The survey explores how demographic factors affect perceptions of sound awareness technologies, gauges interest in specific sounds and sound characteristics, solicits reactions to three design scenarios (smartphone, smartwatch, head-mounted display) and two output modalities (visual, haptic), and probes issues related to social context of use. While most participants were highly interested in being aware of sounds, this interest was modulated by communication preference–that is, for sign or oral communication or both. Almost all participants wanted both visual and haptic feedback and 75% preferred to have that feedback on separate devices (e.g., haptic on smartwatch, visual on head-mounted display). Other findings related to sound type, captions vs. keywords, sound filtering, notification styles, social context provide direct guidance for the design of mobile and wearable sound awareness systems.

KEYWORDS

Deaf, hard of hearing, hearing loss, sound awareness, mobile, wearable, online survey, user study

ACM Reference Format:

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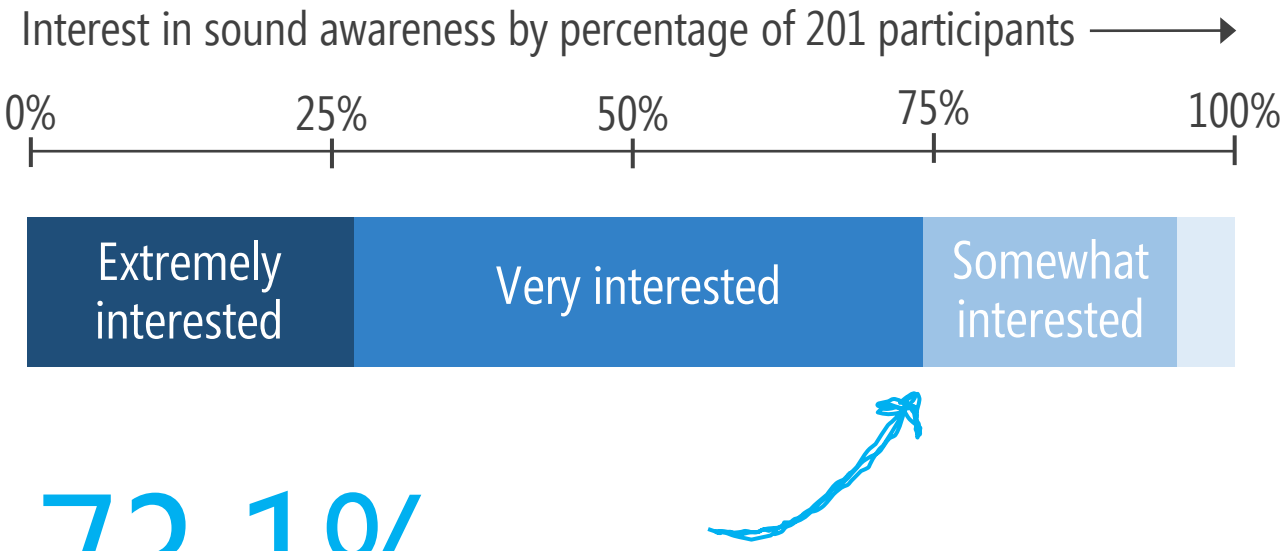
1 INTRODUCTION

Sound awareness has wide-ranging impacts for persons who are deaf or hard of hearing (DHH), from being notified of safety-critical information like a ringing fire alarm to more mundane but still useful sounds like the clothes dryer ending a cycle [27]. While hearing aids and surgically implanted devices can improve sound and speech recognition, they do not eliminate hearing loss; residual issues can include speech intelligibility, ability to interpret sound direction, sensitivity to background noise, or in the case of directional hearing aids, missed noises to the side and back of the wearer [5]. The success of these devices also depends on a number of factors, such as the wearer's level of hearing loss, linguistic abilities, and, in the case of cochlear implants, therapy to learn (or relearn) the sense of hearing [32].

Motivated by these limitations and to complement existing sound awareness strategies, researchers have investigated systems to sense and feed back speech and non-speech sounds to DHH users. Early work by Matthews et al. [27] examined sound awareness needs across a variety of contexts (at home, at work, while mobile), and built and eval-



73.1%

were "extremely" or "very" interested in sound awareness

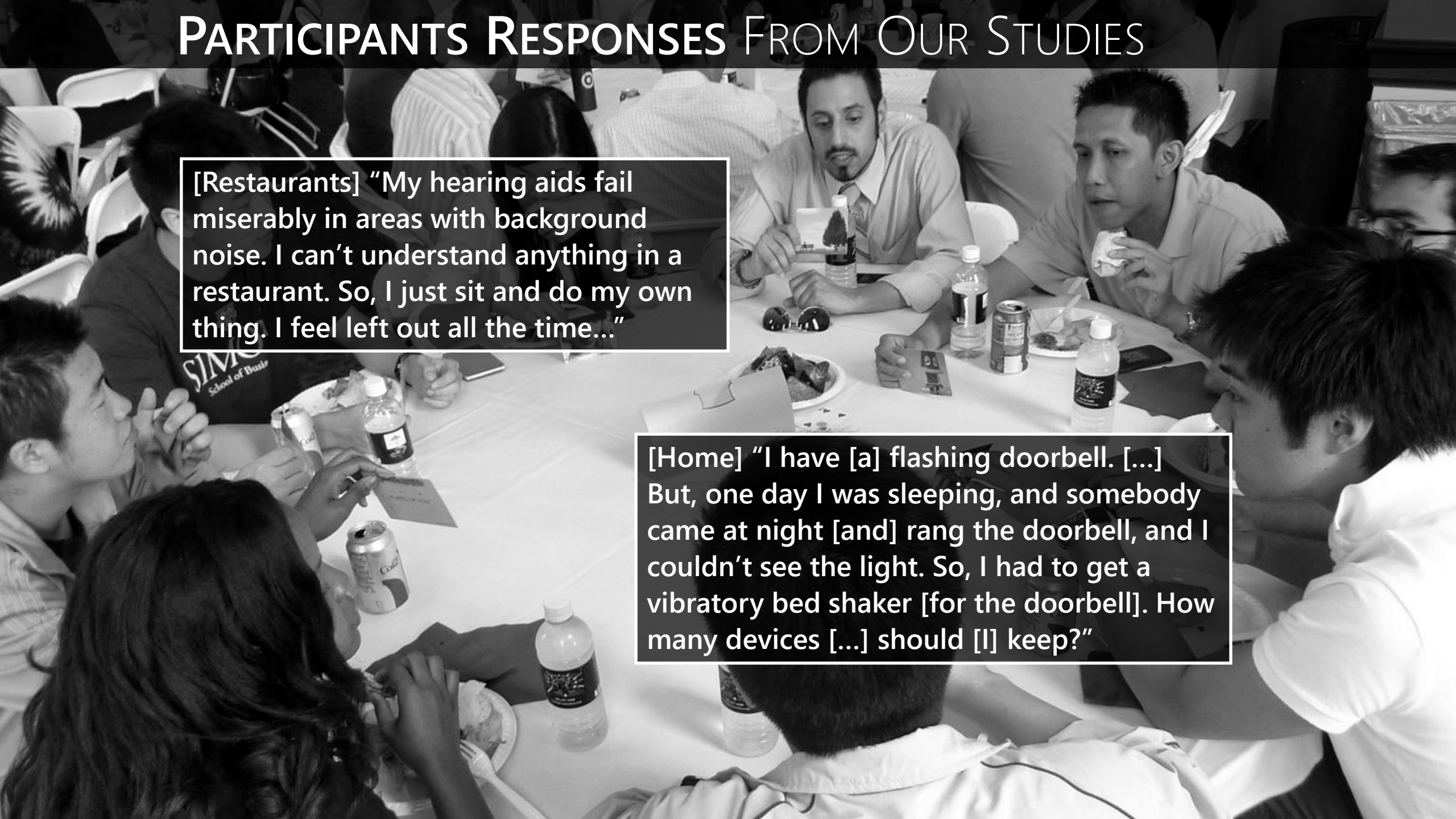
Hearing Aid

Cochlear Implant

Live Transcribe

Participants Responses From Our Studies

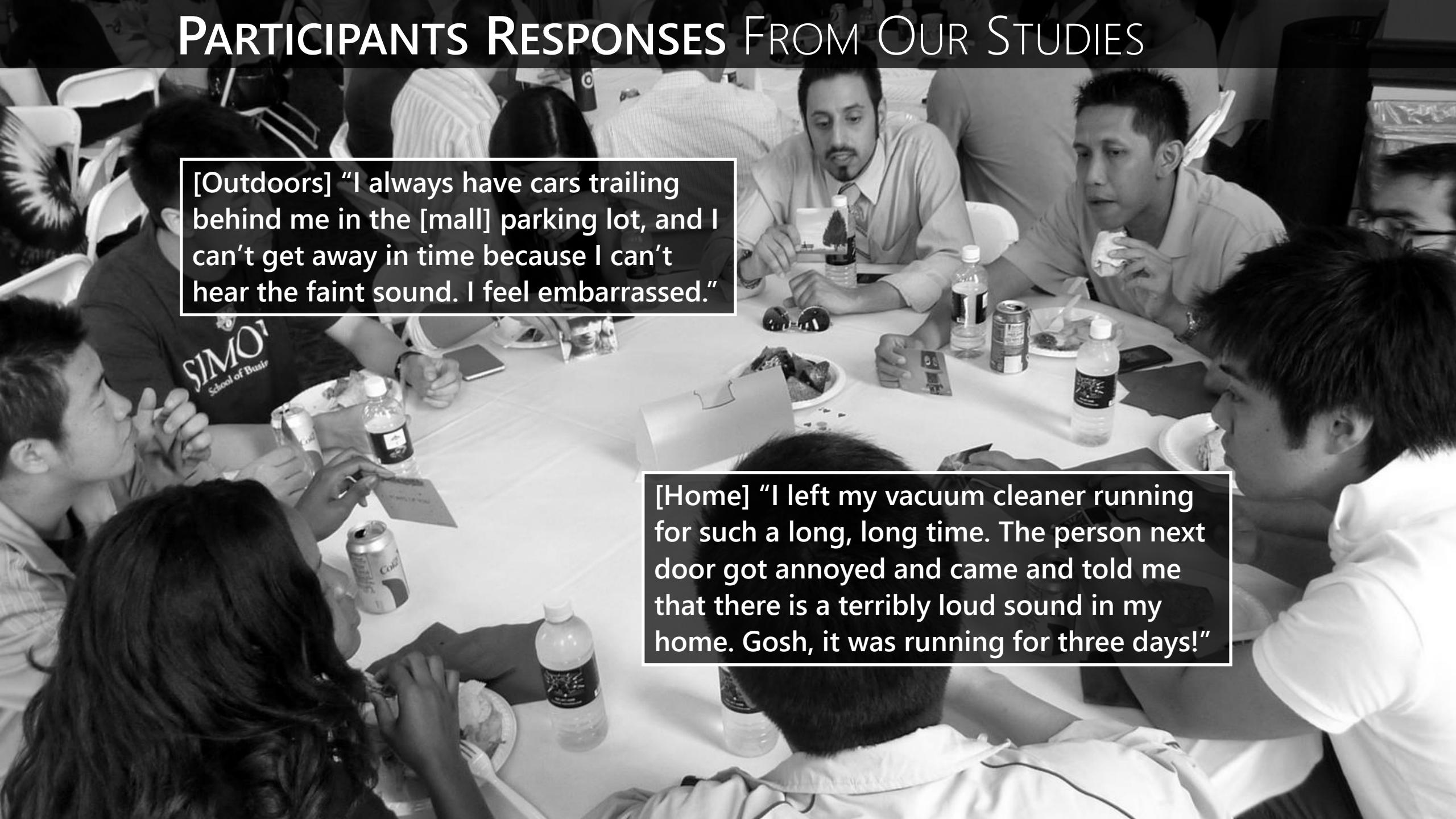
Participants Responses From Our Studies



[Restaurants] "My hearing aids fail miserably in areas with background noise. I can't understand anything in a restaurant. So, I just sit and do my own thing. I feel left out all the time…"

[Home] "I have [a] flashing doorbell. […] But, one day I was sleeping, and somebody came at night [and] rang the doorbell, and I couldn't see the light. So, I had to get a vibratory bed shaker [for the doorbell]. How many devices […] should [I] keep?"

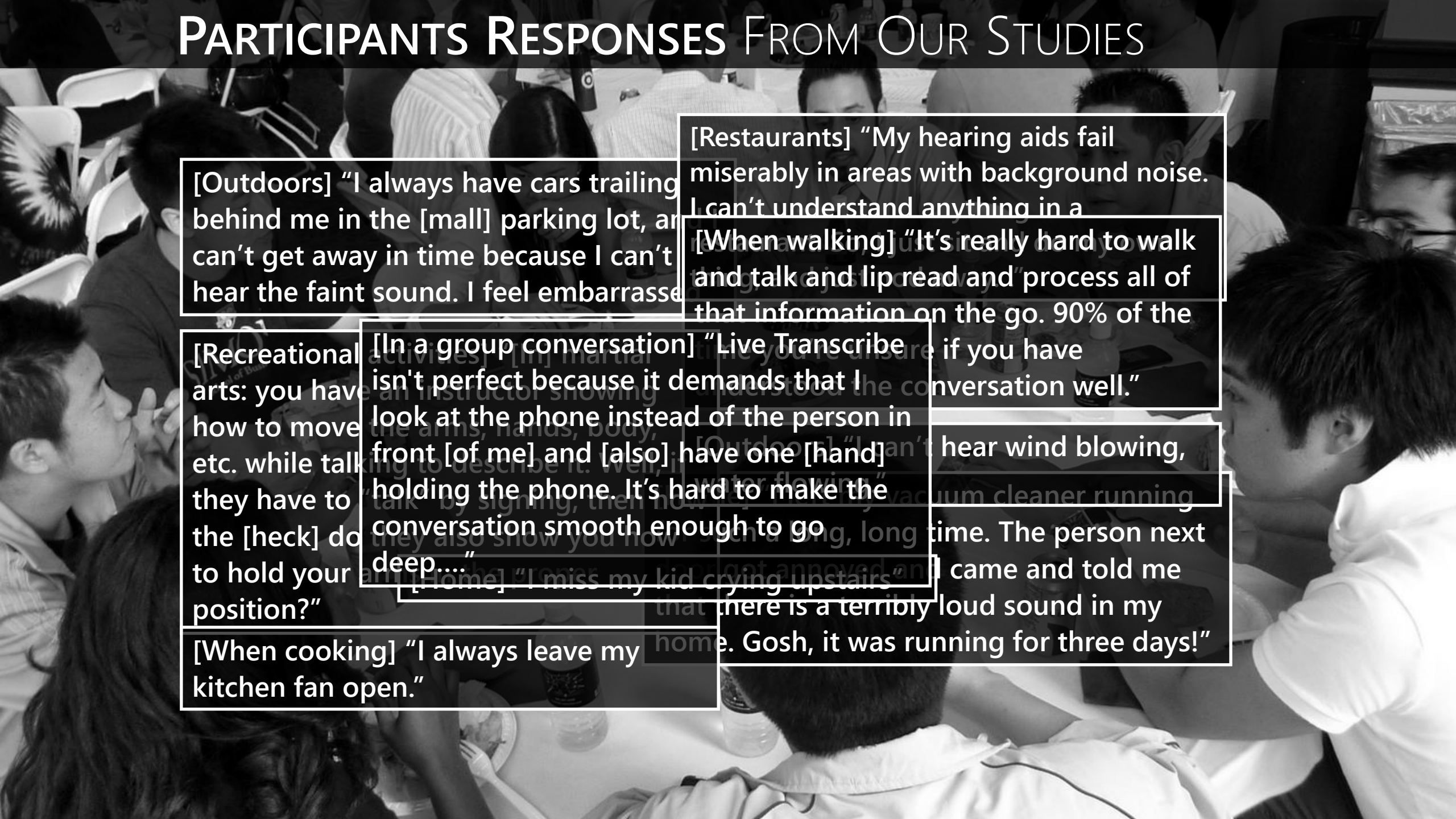
Participants Responses From Our Studies



[Outdoors] "I always have cars trailing behind me in the [mall] parking lot, and I can't get away in time because I can't hear the faint sound. I feel embarrassed."

[Home] "I left my vacuum cleaner running for such a long, long time. The person next door got annoyed and came and told me that there is a terribly loud sound in my home. Gosh, it was running for three days!"

Participants Responses From Our Studies



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[When walking] "It's really hard to walk and talk and lip read and process all of that information on the go. 90% of the

[Recreational arts: you have how to move etc. while talk they have to the [heck] do to hold your position?"

[In a group conversation] "Live Transcribe isn't perfect because it demands that I look at the phone instead of the person in front [of me] and [also] have one [hand] holding the phone. It's hard to make the conversation smooth enough to go deep…."

[Home] "I miss my kid crying upstairs."

[Outdoors] "I can't hear wind blowing, water flowing."

time. The person next came and told me there is a terribly loud sound in my home. Gosh, it was running for three days!"

[When cooking] "I always leave my kitchen fan open."

Participants Responses From Our Studies

[Outdoors] "I always have cars trailing behind me in the [mall] parking lot, and can't get away in time because I can't hear the faint sound."

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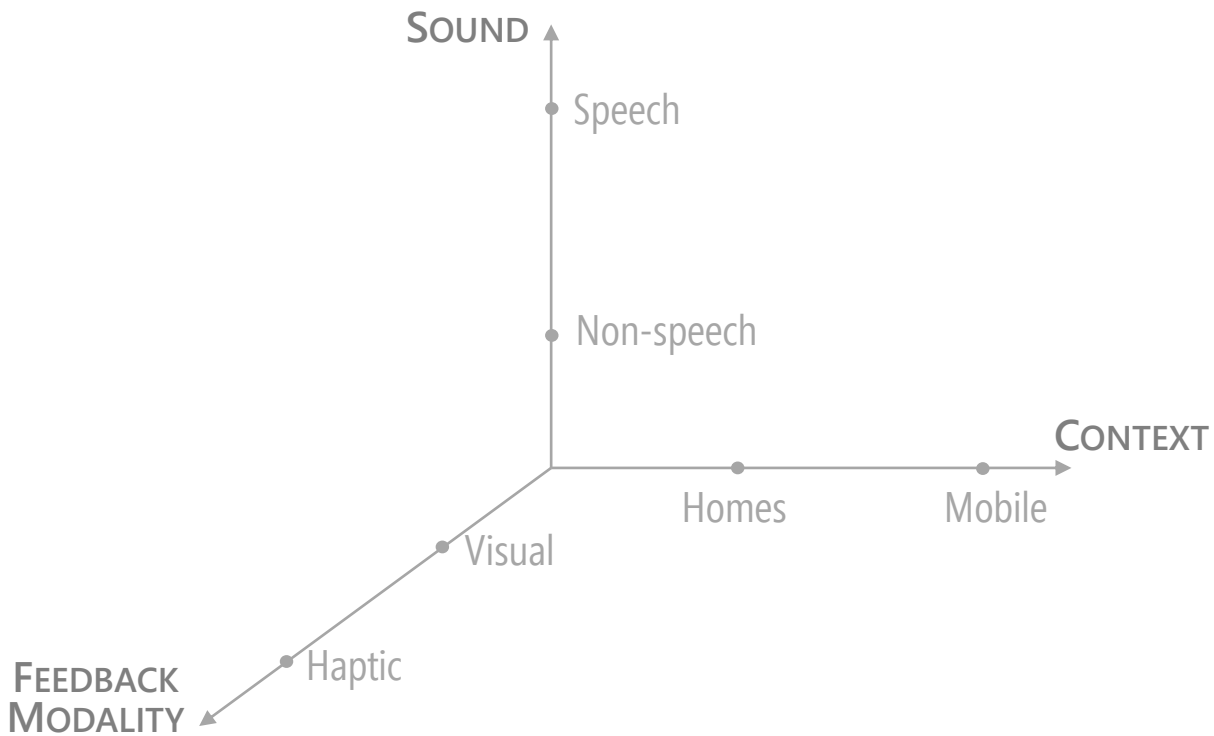
[When walking] "It's really hard to walk and talk and lip read and process all of that information on the go. 90% of the

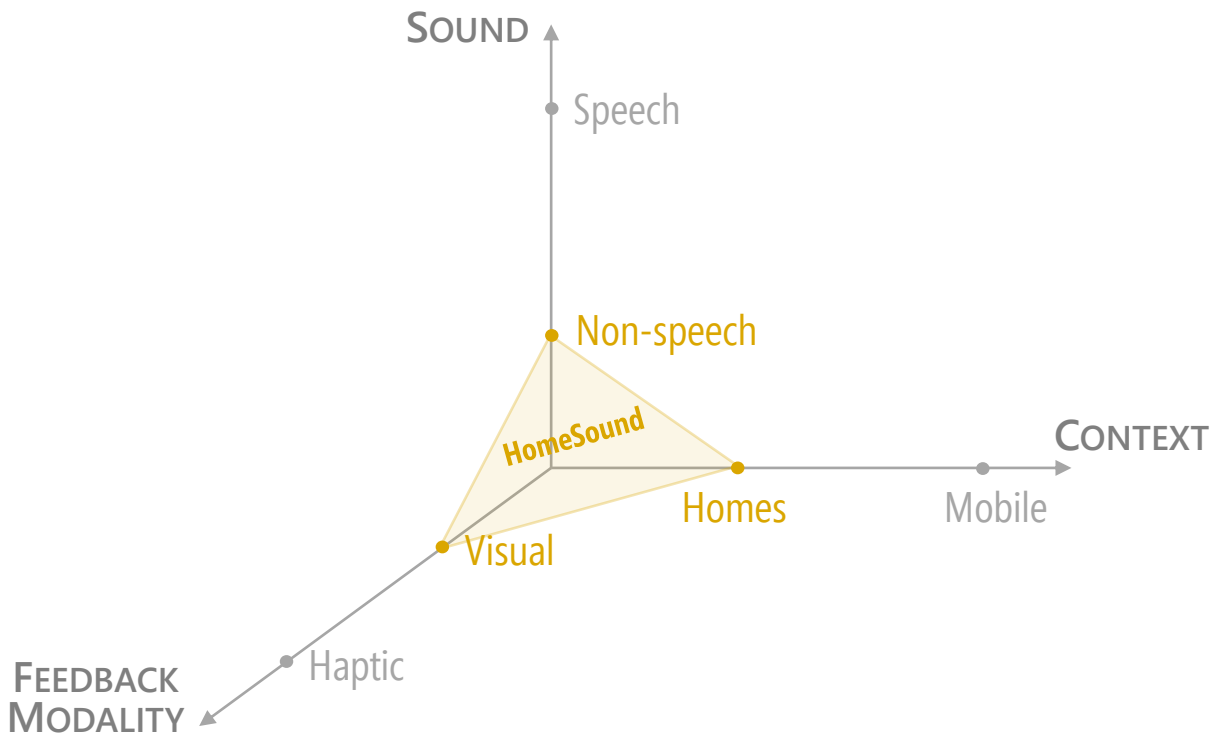
[Recreational activities] "In martial arts, you have an instructor showing how to move the arms, hands, body, etc. while talking to describe it. Then they have to [do it] by signing, then the [heck] do they also show you how to hold your arms in the proper position?"

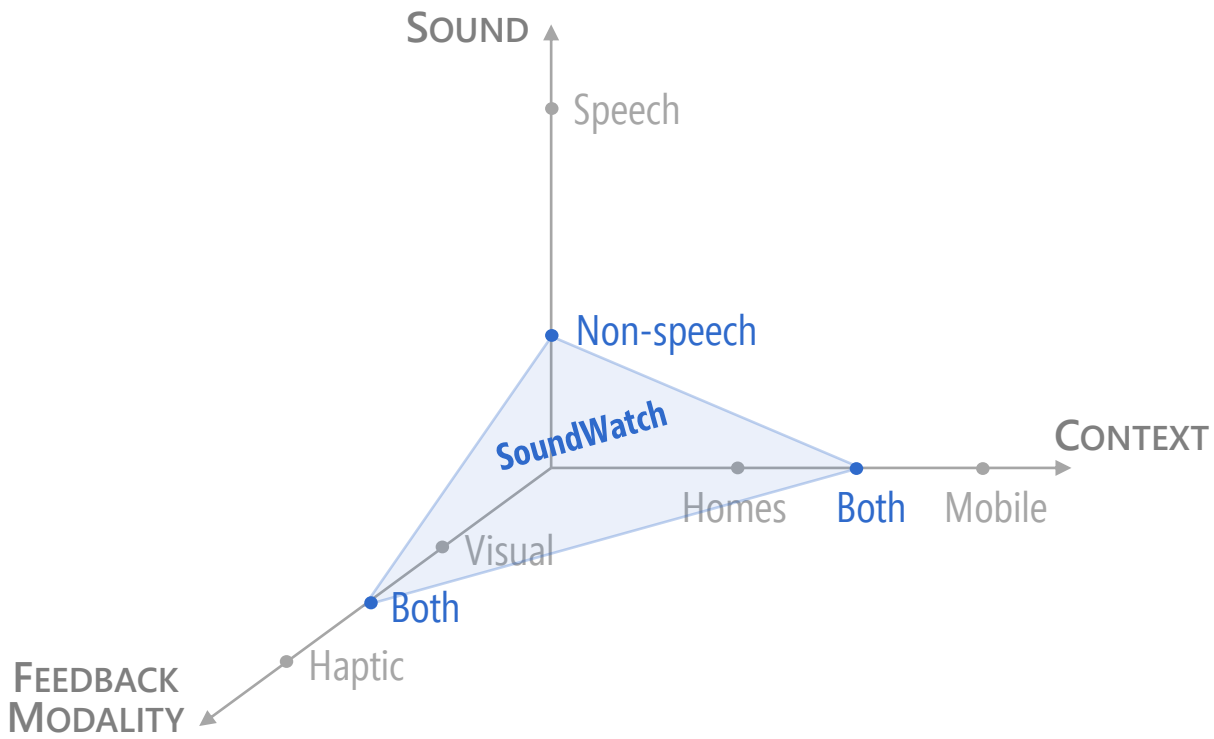
[In a group conversation] "Live Transcribe isn't perfect because it demands that I front [of me] and [also] have one [hand] holding the phone. It's hard to make the conversation smooth enough to go deep…."

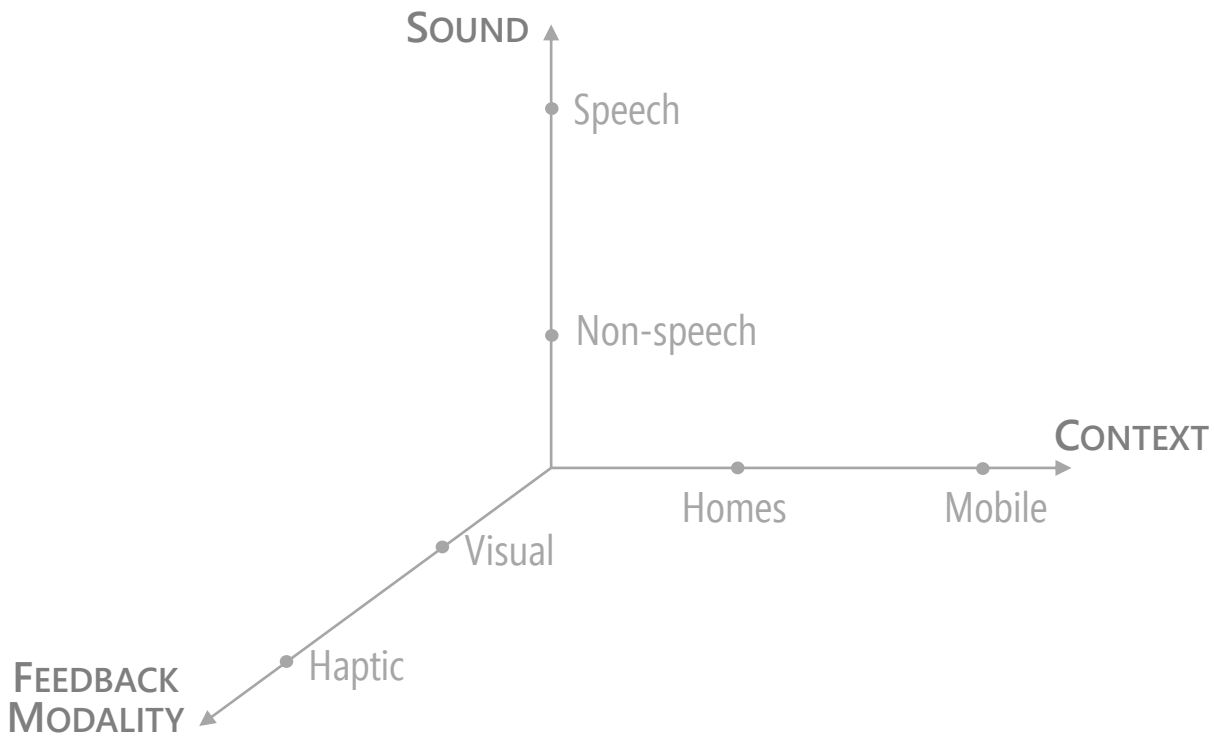
[When cooking] "I always leave my kitchen fan open."

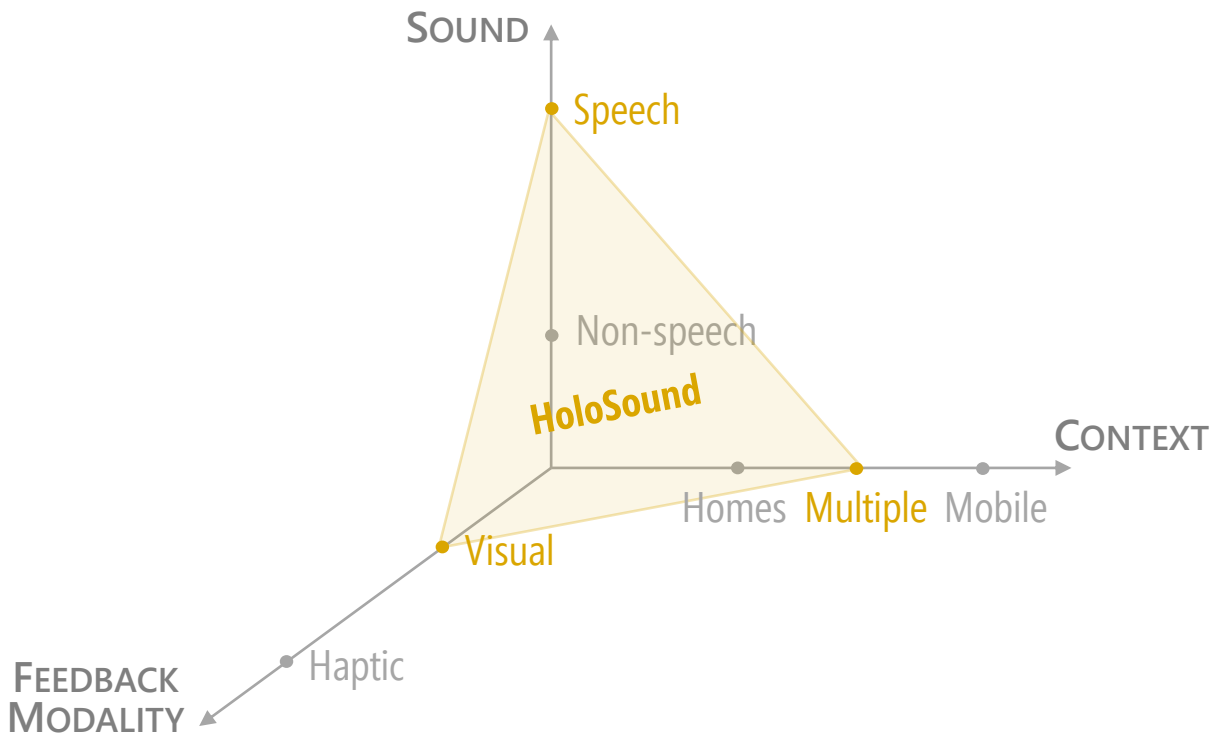
New approaches to enhance **sound awareness** for DHH people…


SOUND
Speech
Non-speech
CONTEXT
Homes
Mobile
Visual
Haptic
FEEDBACK
MODALITY


SOUND
Speech
Non-speech
HomeSound
CONTEXT
Homes
Mobile
Visual
Haptic
FEEDBACK
MODALITY


SOUND
Speech
Non-speech
SoundWatch
CONTEXT
Homes
Both
Mobile
Visual
Both
Haptic
FEEDBACK
MODALITY


SOUND
Speech
Non-speech
CONTEXT
Homes
Mobile
Visual
Haptic
FEEDBACK
MODALITY


SOUND
Speech
Non-speech
HoloSound
CONTEXT
Homes
Multiple
Mobile
Visual
FEEDBACK MODALITY
Haptic

transform how DHH

think about,

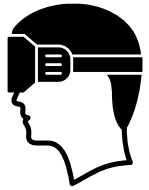
experience,

and engage

with the sound.

HomeSound

SoundWatch



HoloSound

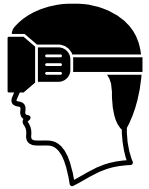
HomeSound

Two formative studies
(CHI'19)

Field studies
(CHI'20)

SoundWatch

Two studies
(ASSETS'20)



HoloSound

Three initial explorations
(DIS'18, ASSETS'18, ASSETS'20)

GlassEar, CHI'15
DHH Survey, CHI'19
Autoethnography, ASSETS '19
Smartwatch Sound Awareness, CHI'20
Navigating Graduate School, ASSETS '20
Vibes, ISWC'20

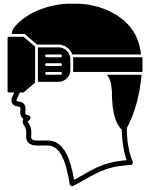
HomeSound

Two formative studies

Field studies

SoundWatch

Two studies



HoloSound

Three initial explorations

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

End-user customization

Field study

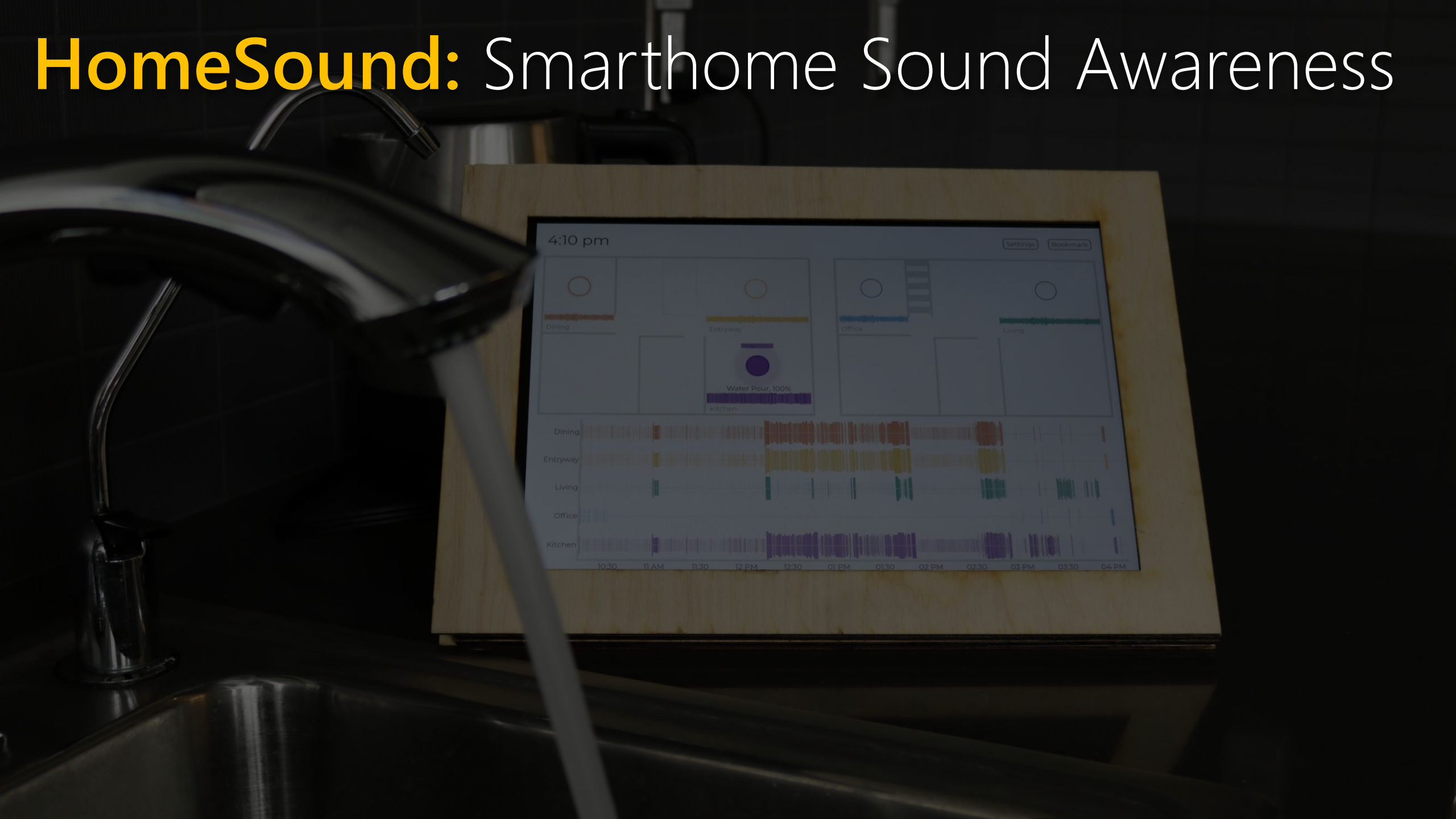
HoloSound

Three initial explorations

Field study

Yellow: proposed work

HomeSound: Smarthome Sound Awareness



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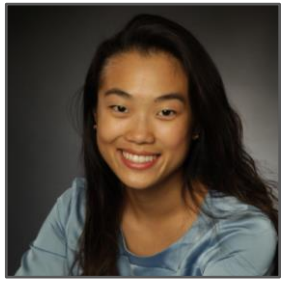

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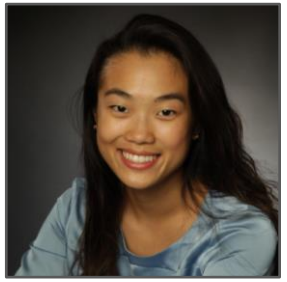

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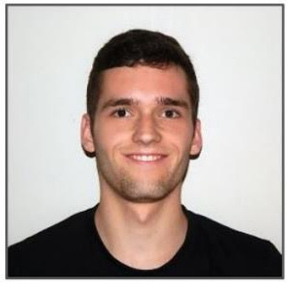

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Sponsors


design principles in developing and modifying
our prototypes
Sounds

Smarthome technology has been a longstanding topic of interest in HCI research.

However, examination of its potential to support accessibility is only recent...

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

HoloSound

Three initial explorations

HomeSound

Two formative studies

Field studies

SoundWatch

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SoundWatch

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HoloSound

Three initial explorations

Taylor & Francis

iour & Information Technology, Vol. 25, No. 4, July–August 2006, 333–351

Evaluating non-speech sound visualizations for the deaf

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…MANKOFF‡
†Compute… …Berkeley, USA
‡Huma… …USA
§M…

Sounds su…
awareness…
ambient …
people w…
ambient …
sounds…
for a …
based…
desig…
imp…
ab…
su…

1. Introduction

Sounds occur…
surrounding…
tous events …
in a publi…
problemat…
indicator…
critical …
relevan…
this aw…
some …
event…
there…
sou…
vis…
to…
v…

A Personalizable Mobile Sound Detector App Design for Deaf and Hard-of-Hearing Users

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ABSTRACT

Sounds provide informative signals about the world around us. In situations where non-auditory cues are inaccessible, it can be useful for deaf and hard-of-hearing people to be notified about sounds. Through a survey, we explored which sounds are of interest to deaf and hard-of-hearing people, and which means of notification are appropriate. Motivated by these findings, we designed a mobile phone app that alerts deaf and hard-of-hearing people to sounds they care about. The app uses training examples of personally relevant sounds recorded by the user to learn a model of those sounds. It then screens the incoming audio stream from the phone's microphone for those sounds. When it detects a sound, it alerts the user by vibrating and providing a pop-up notification. To evaluate the interface design independent of sound detection errors, we ran a Wizard-of-Oz user study, and found that the app design successfully facilitated deaf and hard-of-hearing users recording training examples. We also explored the viability of a basic machine learning algorithm for sound detection.

CCS Concepts

•**Human-centered computing** → **Sound-based input / output; Accessibility systems and tools;**

Keywords

Sound detection, accessibility, deaf, hard-of-hearing

I. INTRODUCTION

Knowing which sounds are happening in one's … …ings can be useful. Auditory … …events … …

and emergencies; loud speakers broadcast airport announcements; microwaves beep to tell us our food is cooked; and people ring doorbells and knock on doors to announce their arrival. These societal conventions make important information inaccessible to many deaf and hard-of-hearing people.

Non-technical sound awareness methods like visual inspection can be distracting and inconvenient, and technical solutions are often specific to individual sounds. For example, alarm clocks that ring loudly, flash bright lights, and vibrate are commercially available. Many deaf people also connect their doorbell to the home lights, so that the lights flash when the doorbell is rung. However, these solutions address individual sounds, and it can be expensive and inconvenient to purchase a different device for every sound. Even with many devices, some sounds cannot be covered because each person's life, and the sounds therein, is unique.

In this paper, we present the design of a personalizable mobile phone app to detect sounds that deaf and hard-of-hearing users find important. Guided by visual feedback, users train the app to identify the sounds they want to know about by providing recorded examples of those sounds. The user categorizes recordings into groups representing different sounds. Because the app learns models of sounds from training examples, it is flexible and gives the user control. Instead of buying a separate sound detector for each important sound, the user can download and train a single app. Furthermore, because it is a mobile app, the detector is portable. It accompanies the user throughout the day, detecting sounds in any location – at work, home, or in transit.

Our mobile app design provides sound detec… …and hard-of-hearing peo…

While prior work has examined sound awareness needs of DHH users, **only a few studies** that explored needs in multiple contexts **have included questions about the home.**

Two Formative Studies

Study 1 A **semi-structured interview** on sound awareness needs in the home with 12DHH participants

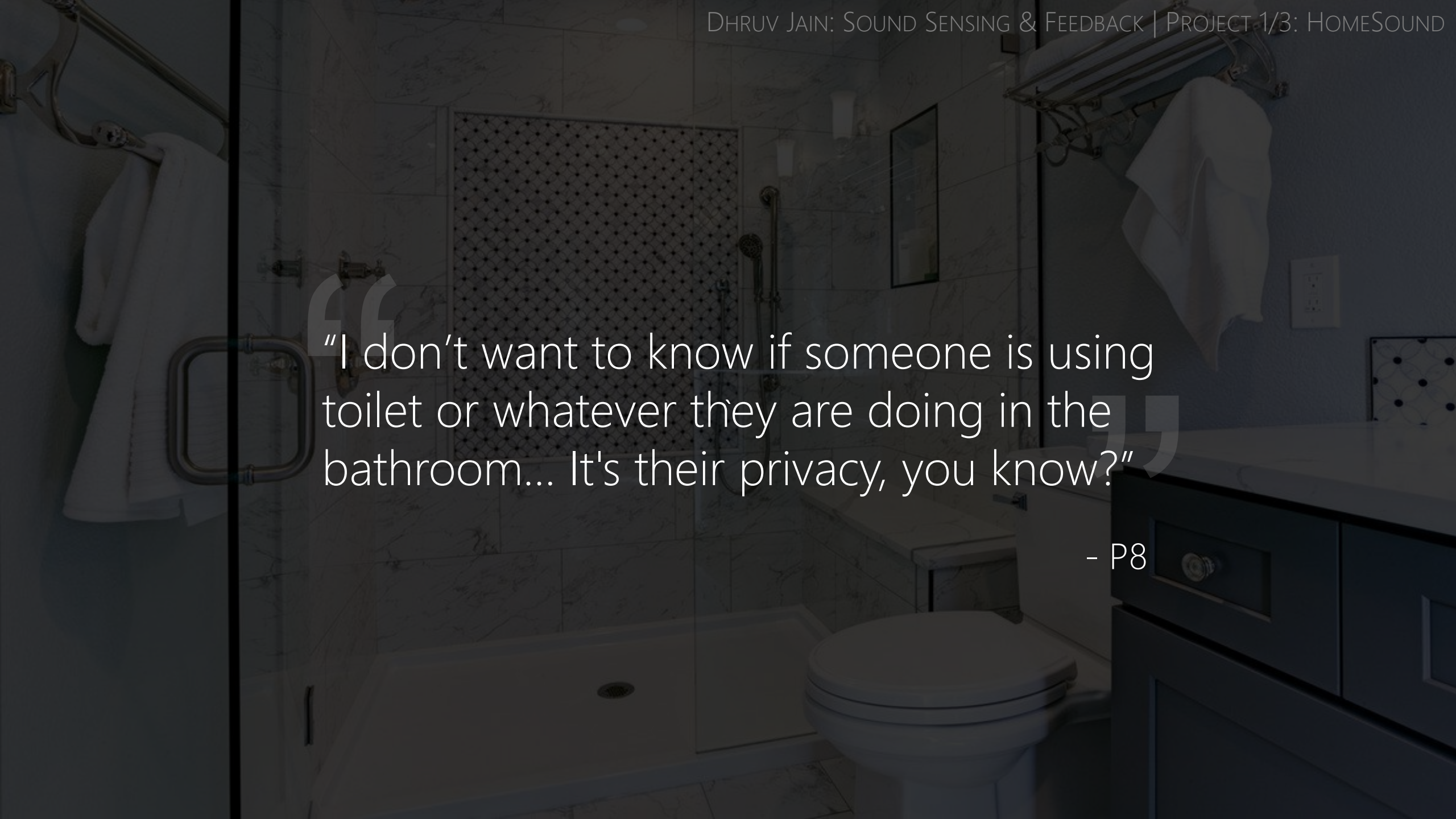
Study 2 A **scenario-based evaluation** of three initial sound awareness prototypes with 10 DHH participants

Two Formative Studies

Study 1 A **semi-structured interview** on sound awareness needs in the home with 12DHH participants

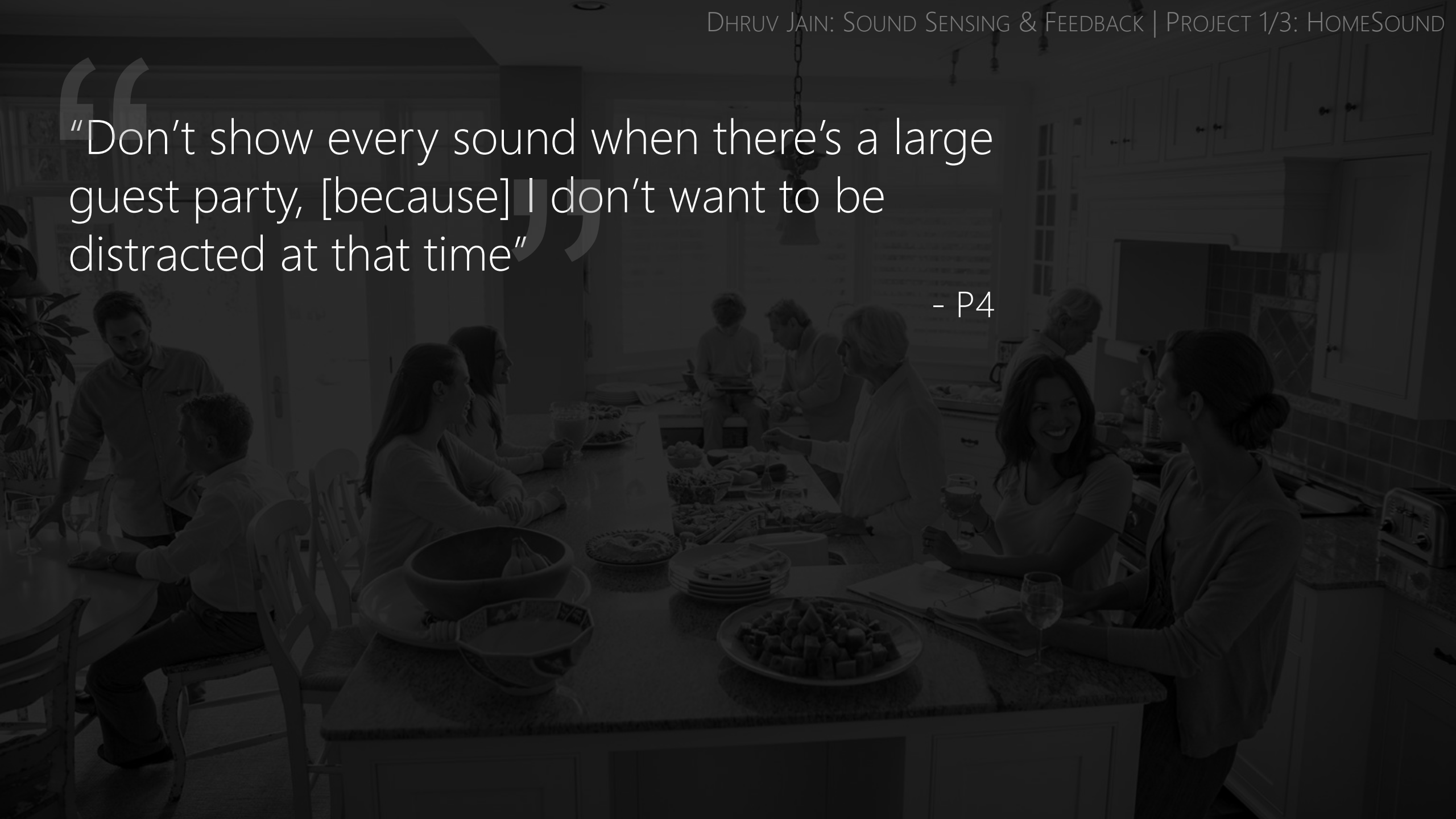
Study 2 A **scenario-based evaluation** of three initial sound awareness prototypes with 10 DHH participants


Participant
Actor
Coffee Pour
Wizard



“I don’t want to know if someone is using toilet or whatever they are doing in the bathroom... It's their privacy, you know?”

- P8



"Don't show every sound when there's a large guest party, [because] I don't want to be distracted at that time"

- P4

HomeSound

Two formative studies

Field studies

Prototype 1: Simple but accurate sound feedback (e.g., loudness, pitch)

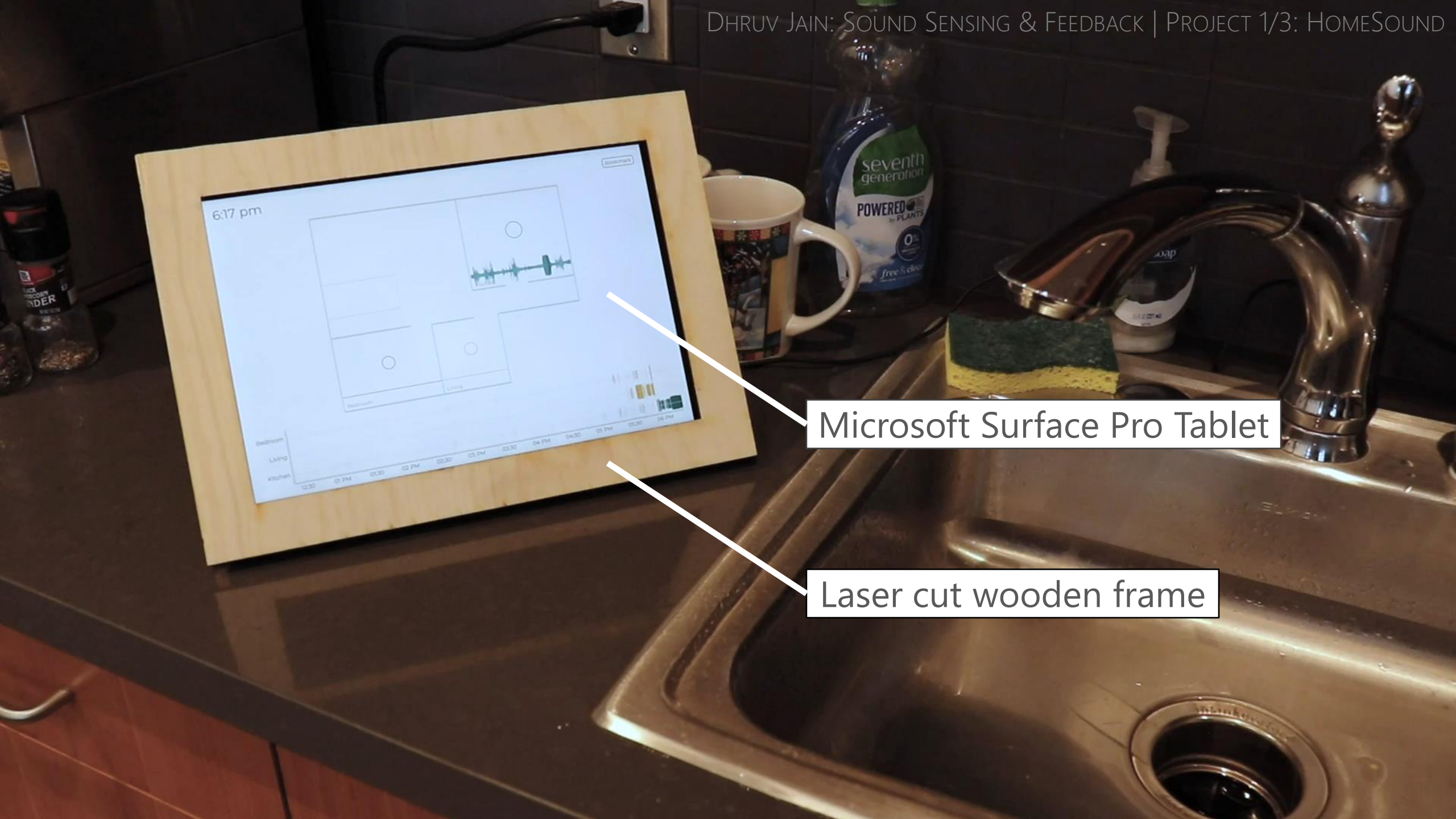
Prototype 2: More complex sound features (e.g., sound identity)

SoundWatch

Two studies

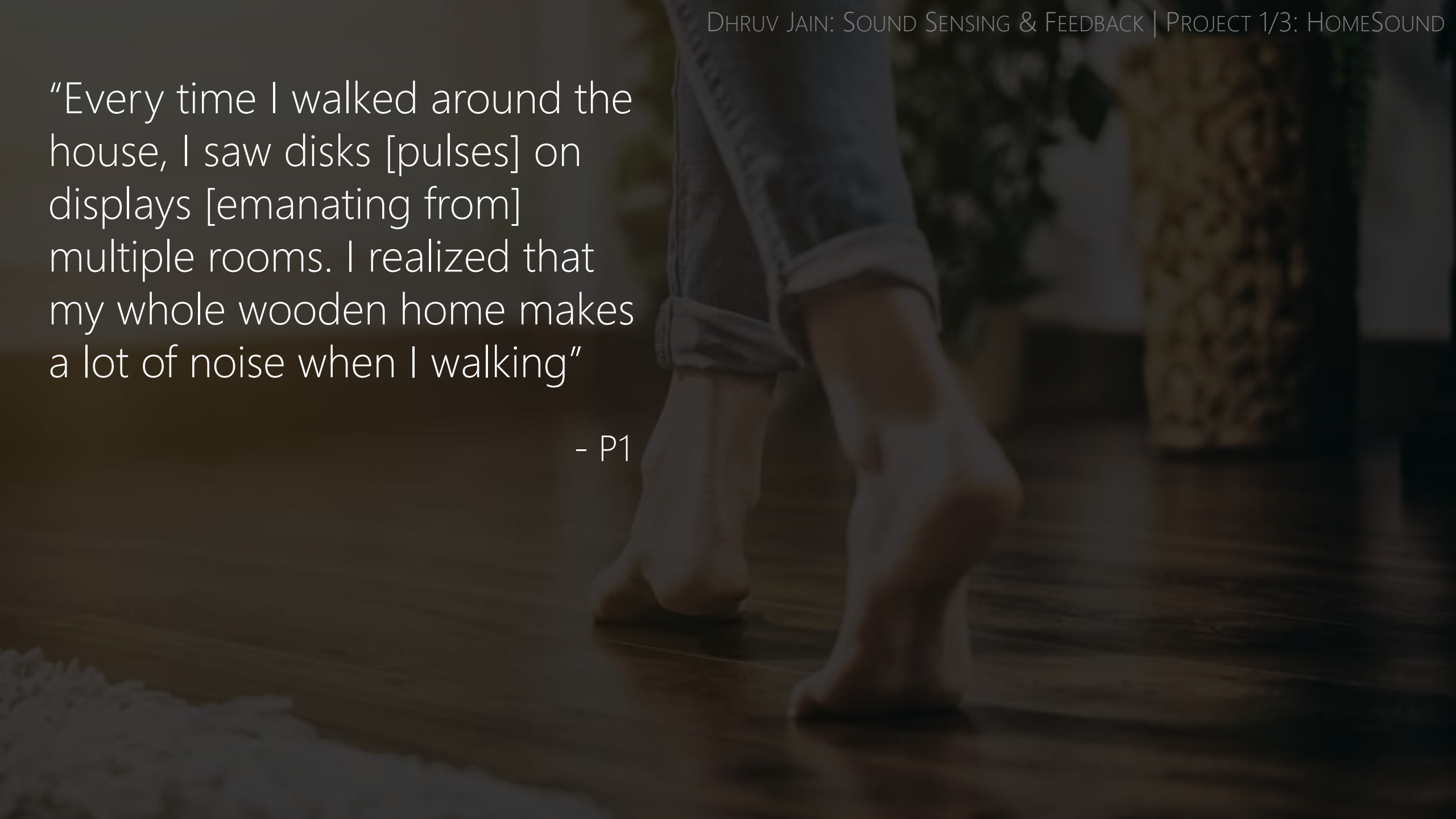
HoloSound

Three initial explorations


6:17 pm
Microsoft Surface Pro Tablet
Laser cut wooden frame

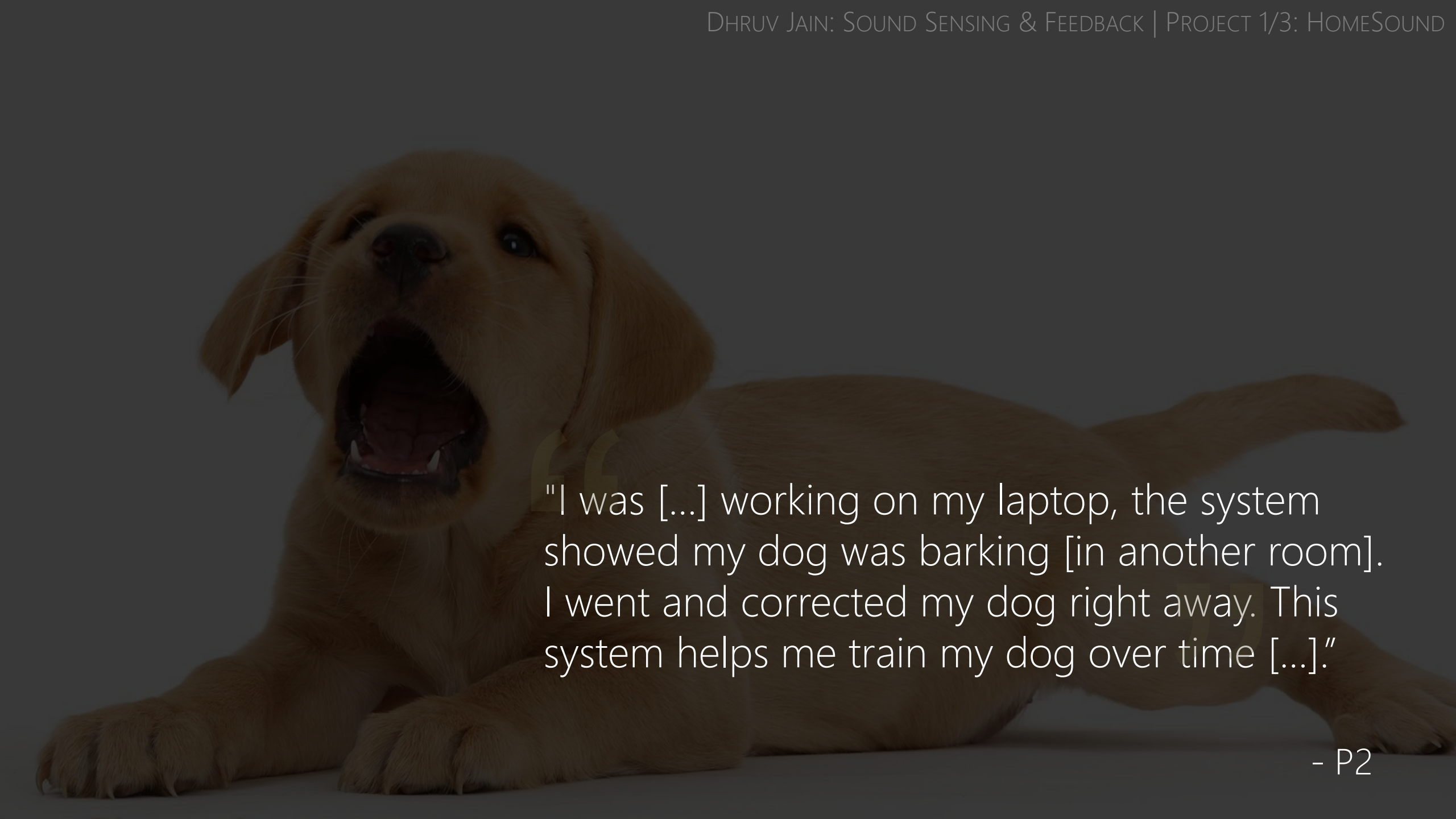

echo show 8
10:10
21°
12:38


Each home contained
3-5 displays.
Kitchen display



"Every time I walked around the house, I saw disks [pulses] on displays [emanating from] multiple rooms. I realized that my whole wooden home makes a lot of noise when I walking"

- P1



"I was [...] working on my laptop, the system showed my dog was barking [in another room]. I went and corrected my dog right away. This system helps me train my dog over time [...]."

- P2

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

HoloSound

Three initial explorations

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SoundWatch

Two studies

HoloSound

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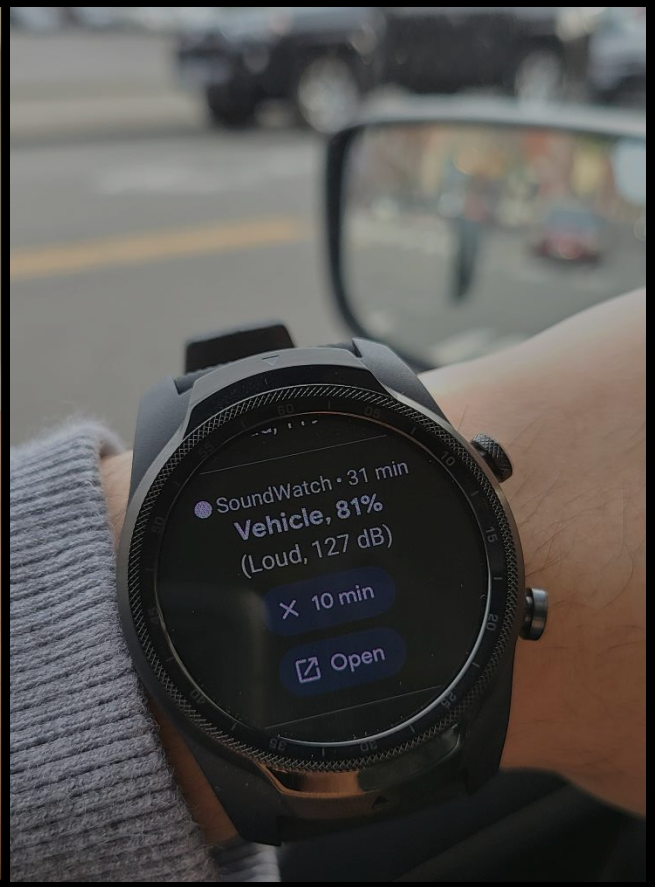
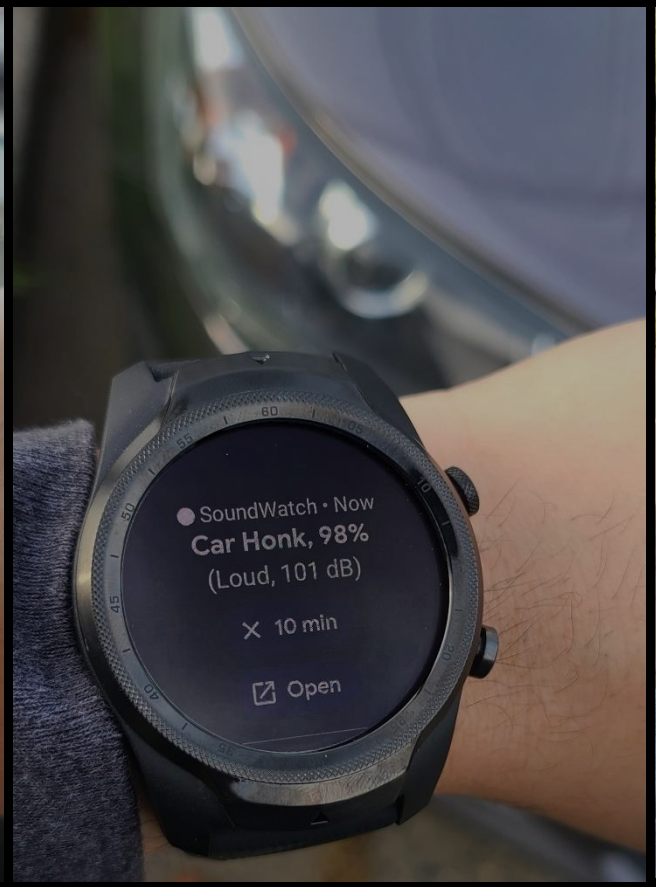
SoundWatch: Sound Awareness on a Smartwatch



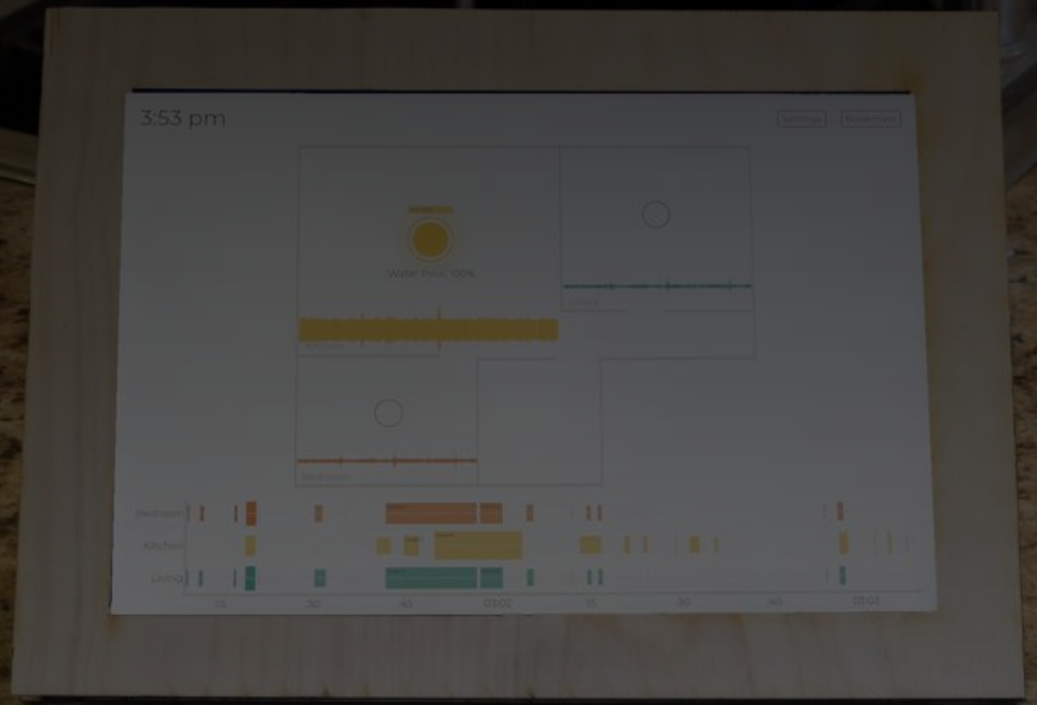


SoundWatch: Sound Awareness on a Smartwatch

SoundWatch is informed by **lived experiences** of many DHH people.

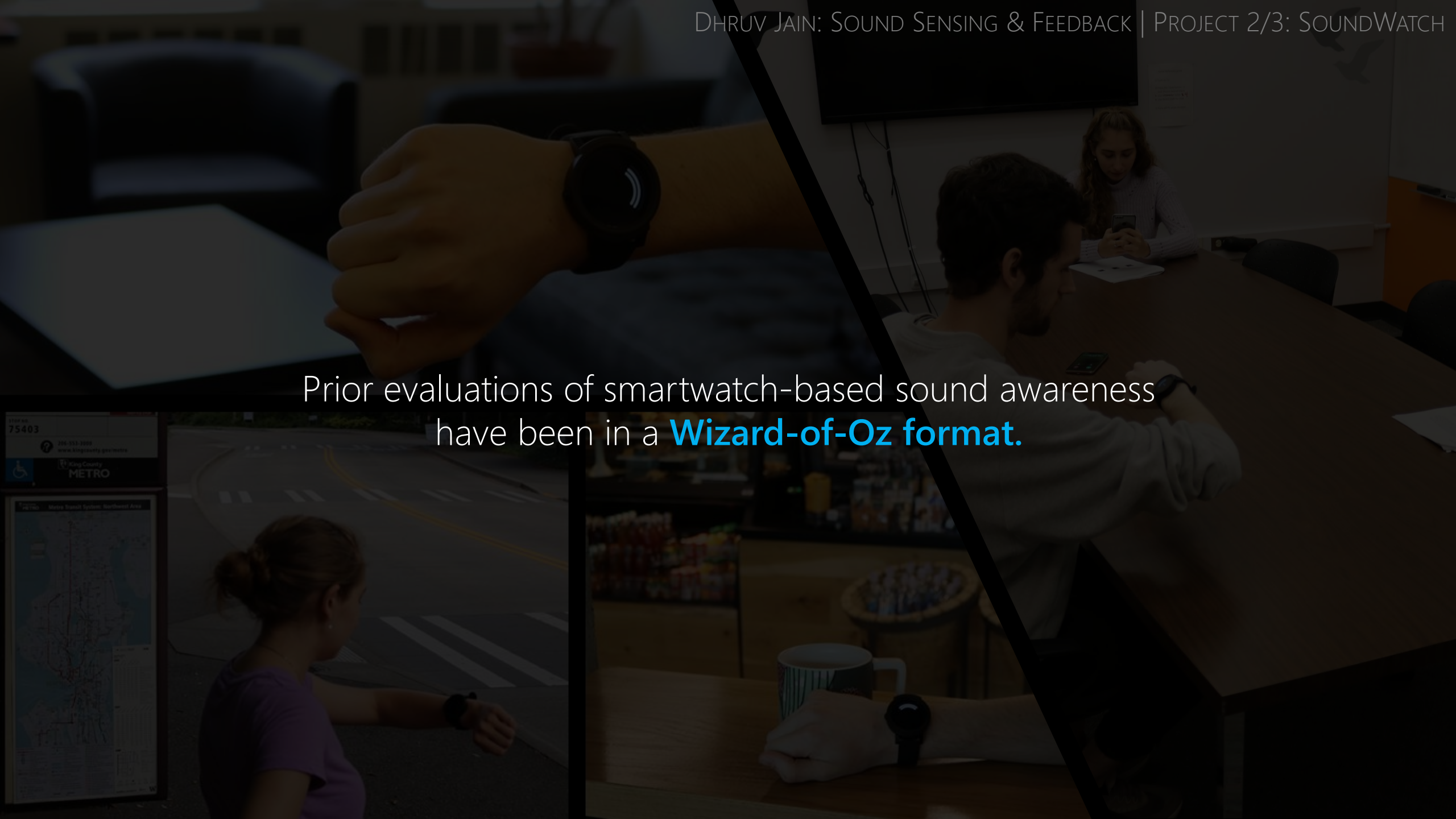
P4 in the **HomeSound** study:

"I want to be able to use this system when I am commuting to work, taking my kids to school, when I am hiking, going on a beach, in a movie theater, etc."



Our survey with 201 DHH participants showed that **smartwatch was the most preferred device** for non-speech sound feedback.

Using both visual and vibration modalities, smartwatch can provide **always-available** and **discreet** sound feedback in **multiple contexts.**



Prior evaluations of smartwatch-based sound awareness have been in a **Wizard-of-Oz format.**

Two Studies

Study 1 A **quantitative** comparison of small deep-learning models to classify sounds on portable devices.

Study 2 A **qualitative** evaluation of a smartwatch-based sound classification app in which 8DHH participants used the app in different locations on the campus.

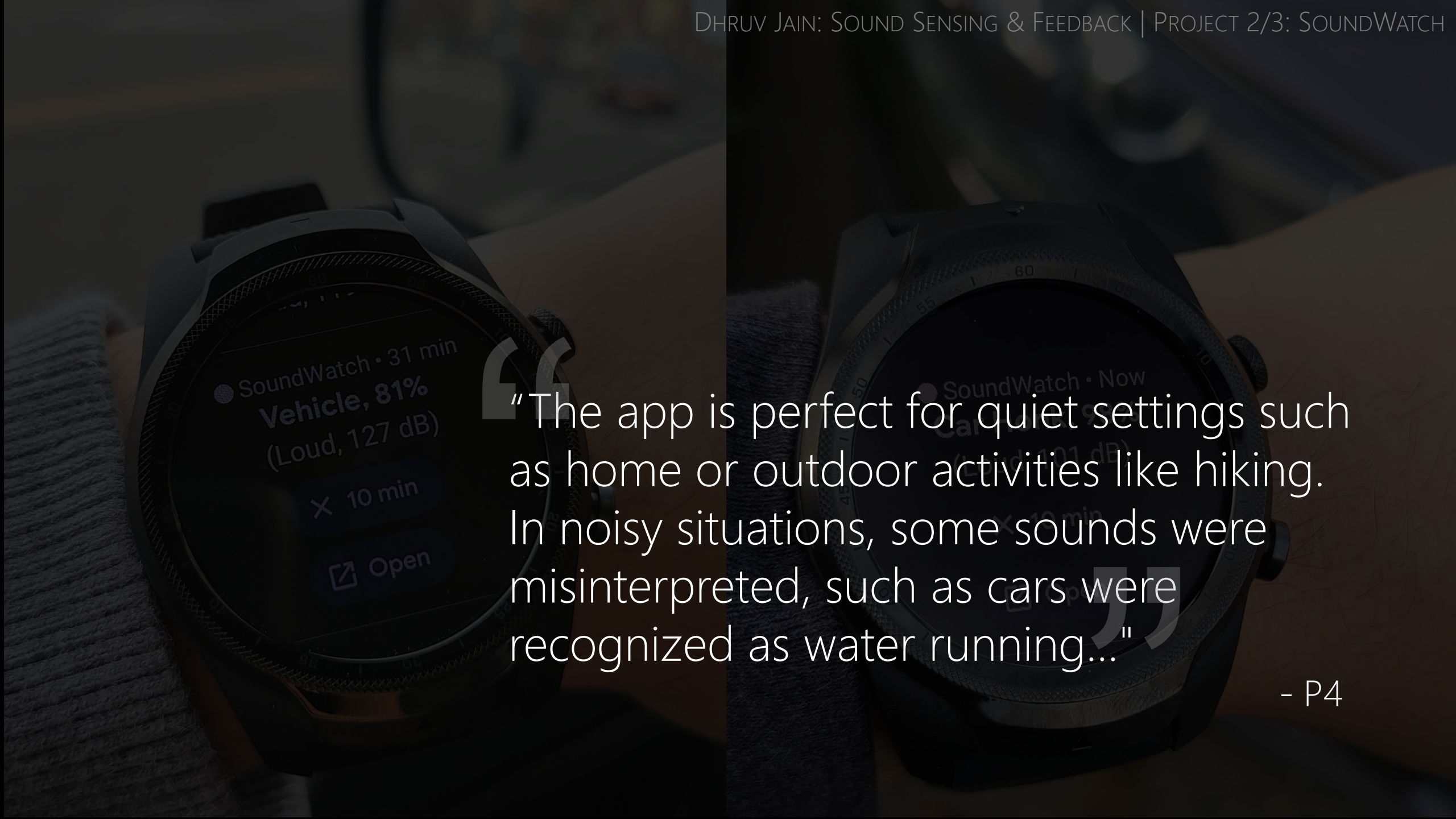
Findings

Study 1

Our best classification model had **similar accuracy** as the state-of-the-art for non-portable devices (81.2%) but required **much less memory** (~1/3rd).

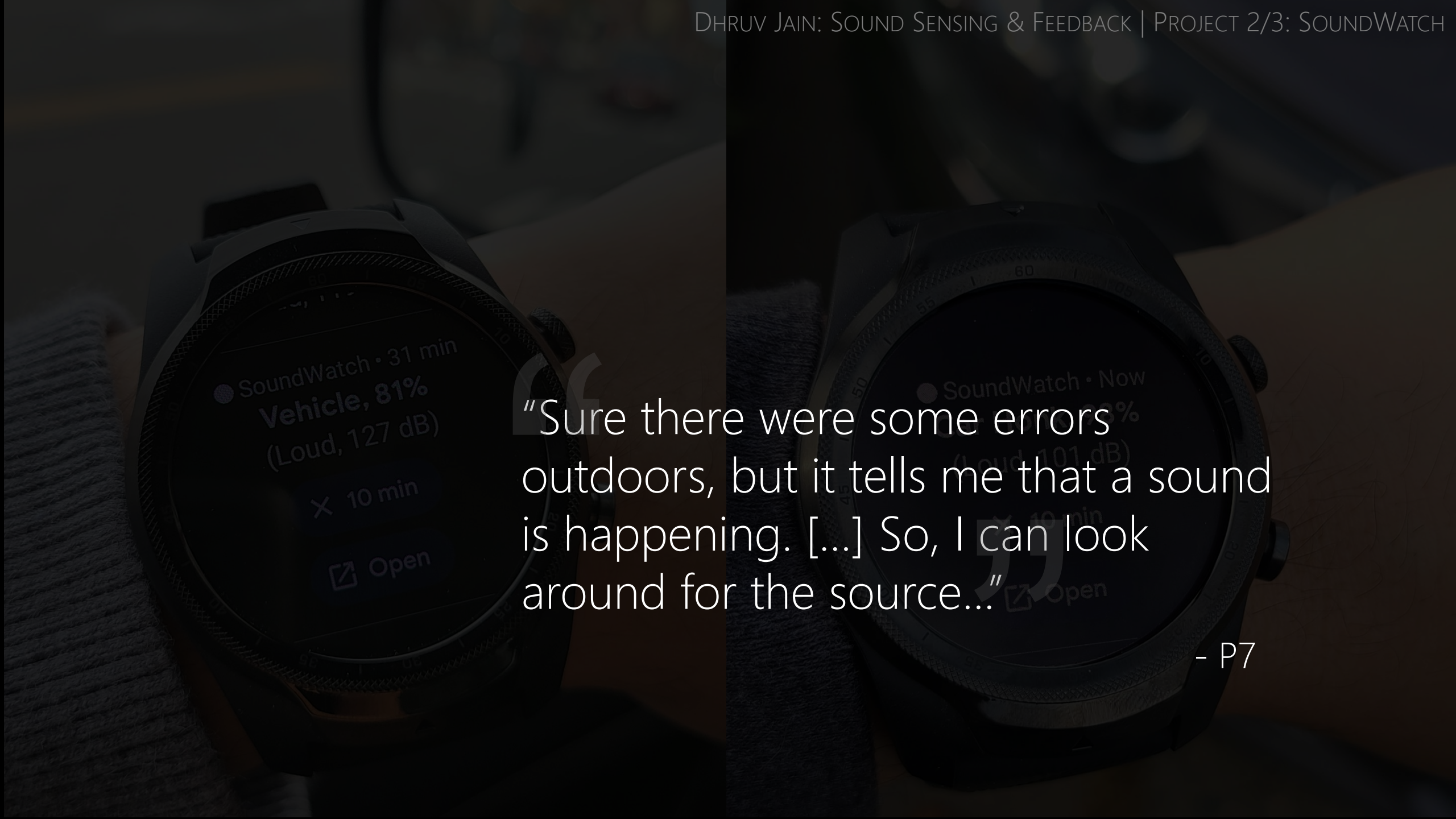
Study 2

All participants generally liked SoundWatch but were concerned with **errors in noisy environments.**



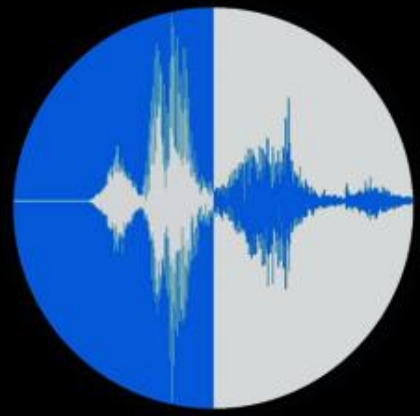
"The app is perfect for quiet settings such as home or outdoor activities like hiking. In noisy situations, some sounds were misinterpreted, such as cars were recognized as water running..."

- P4



"Sure there were some errors outdoors, but it tells me that a sound is happening. [...] So, I can look around for the source..."

- P7



SoundWatch

Always-available sound feedback

Released on Google store!

GET IT ON Google Play

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Sponsors

NSF

Google Faculty Research

Non-speech sound feedback

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

HoloSound

Three initial explorations

Non-speech sound feedback

HomeSound

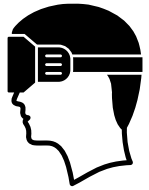
Two formative studies

Field studies

SoundWatch

Two studies

Speech feedback



HoloSound

Three initial explorations

HoloSound: Head-Mounted Displays for Speech Feedback

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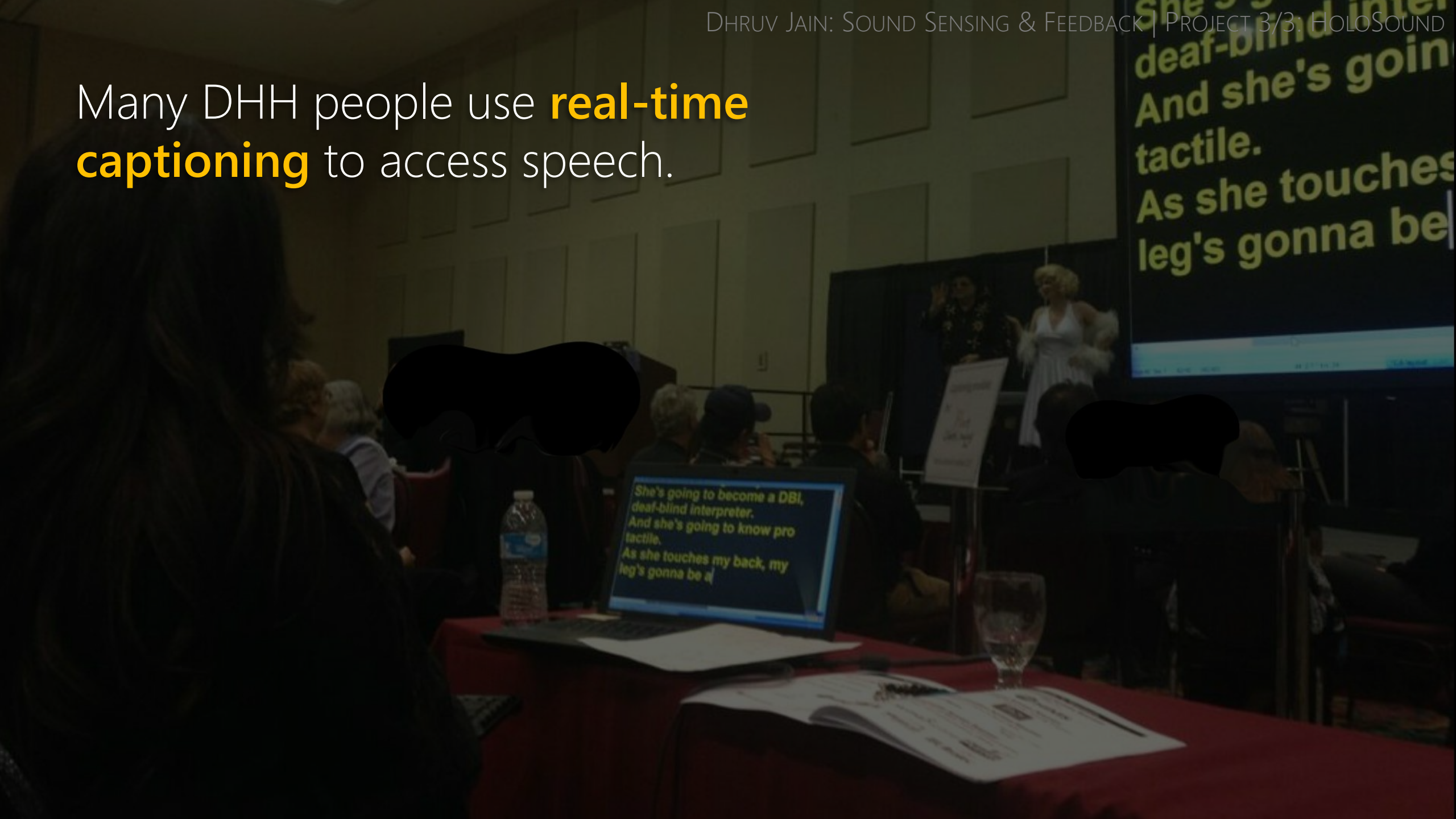
UW Reality Lab

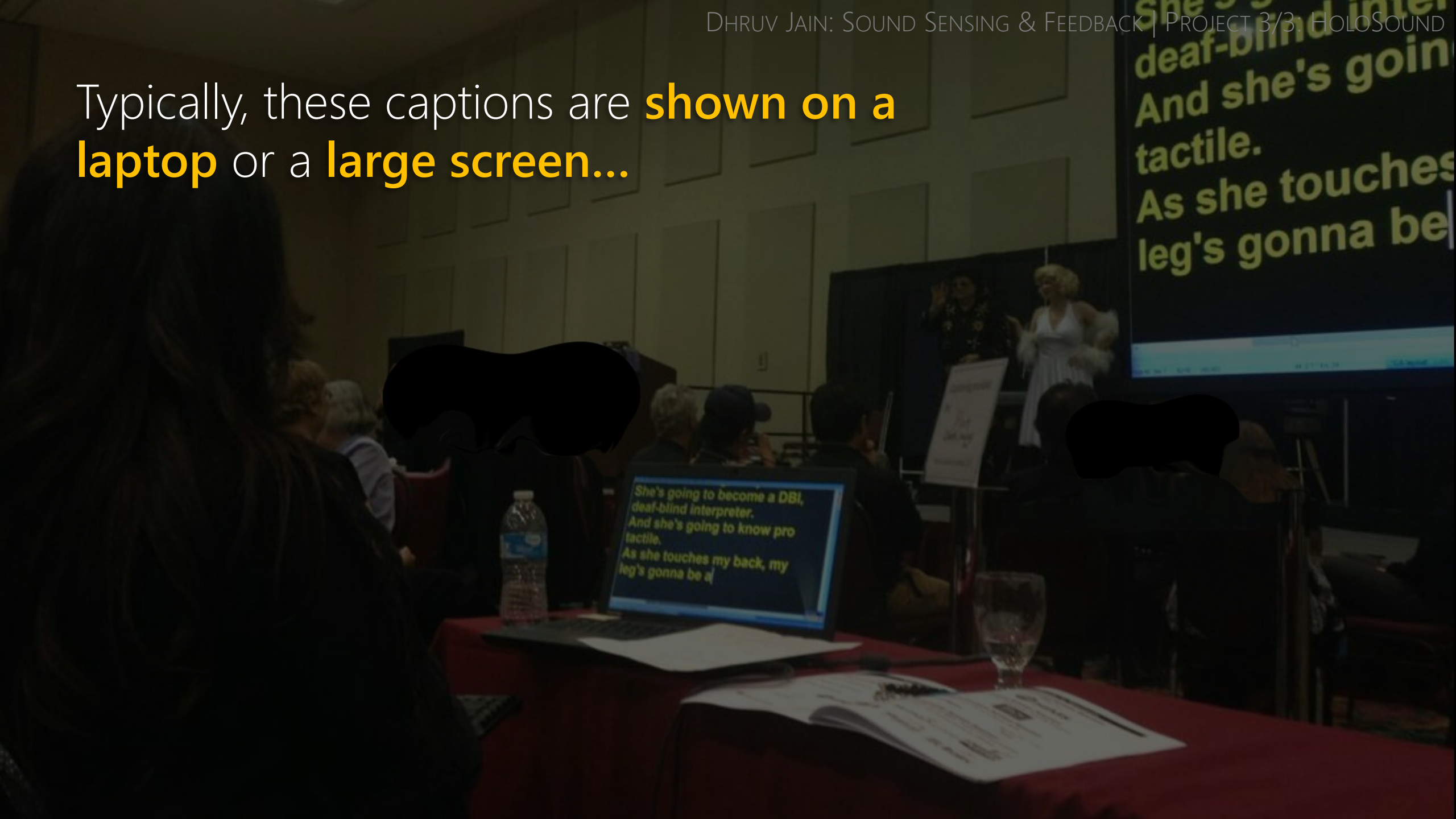
Google Faculty Research Awards

Microsoft

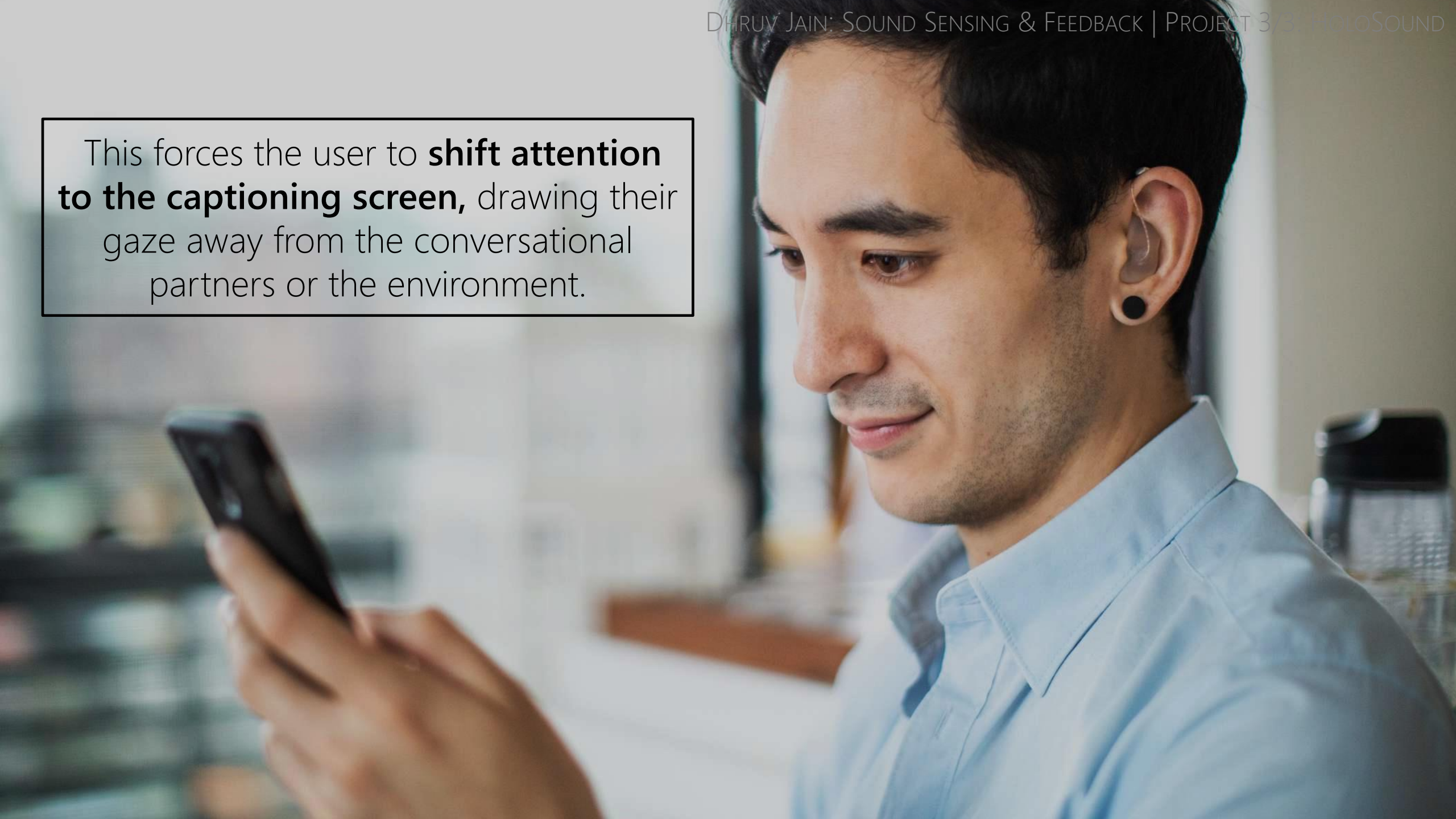
Many DHH people use **real-time captioning** to access speech.



Typically, these captions are **shown on a laptop** or a **large screen…**

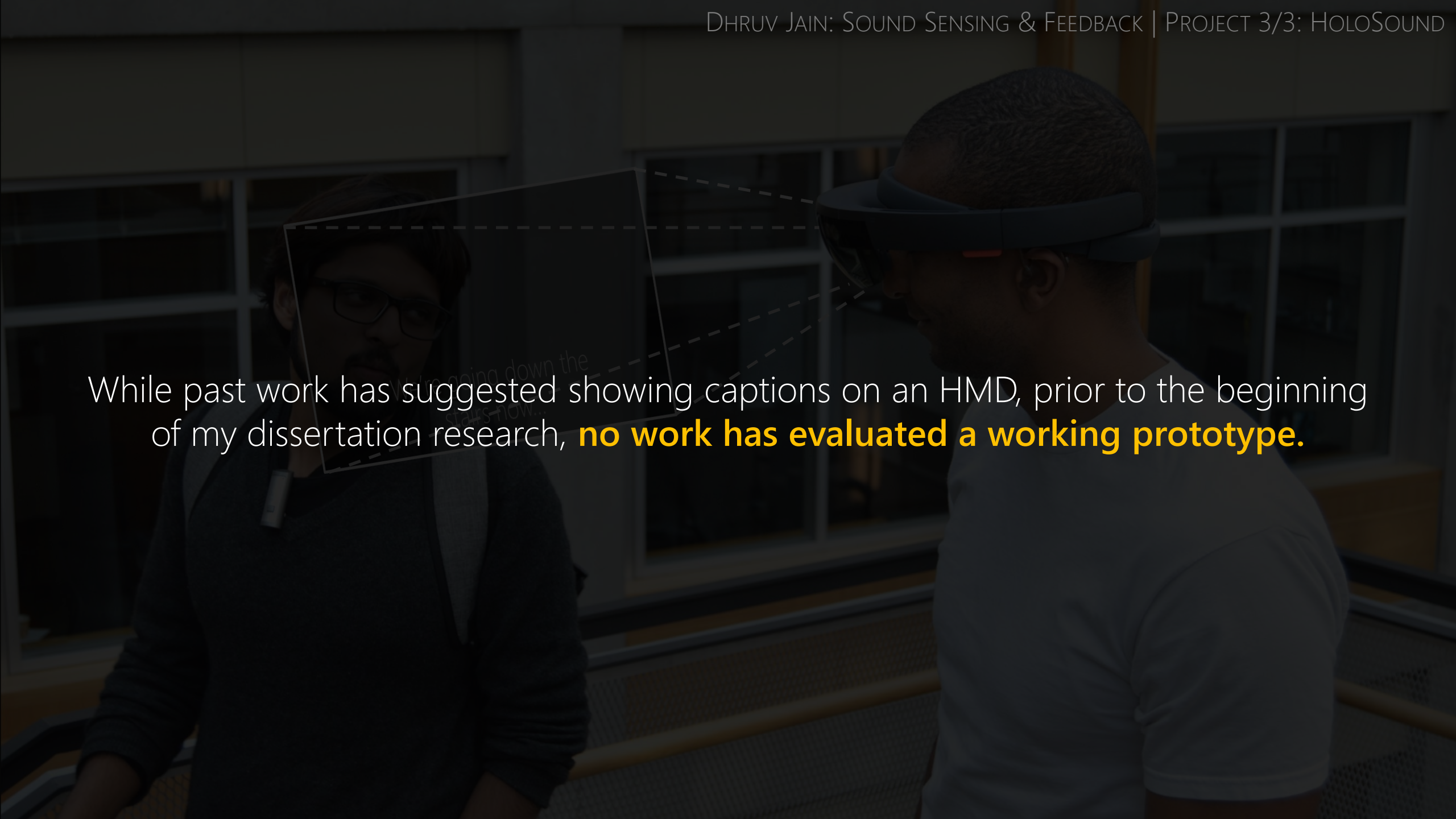


or on a smartphone…



This forces the user to **shift attention to the captioning screen,** drawing their gaze away from the conversational partners or the environment.

Display captions directly in the **user's field of view** using a head-mounted display.



While past work has suggested showing captions on an HMD, prior to the beginning of my dissertation research, **no work has evaluated a working prototype.**

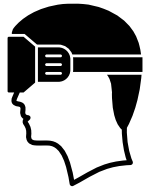
HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

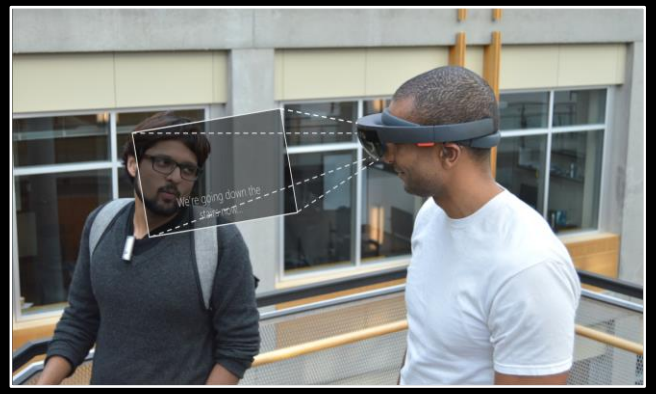


HoloSound

Three initial explorations

Three Initial Explorations of HMD-captioning

A 45-day autoethnographic evaluation



A semi-controlled evaluation with 10 DHH participants

A preliminary prototype that displays captioning with speaker location and non-speech sounds

Three Initial Explorations of HMD-captioning

Current HoloSound prototype

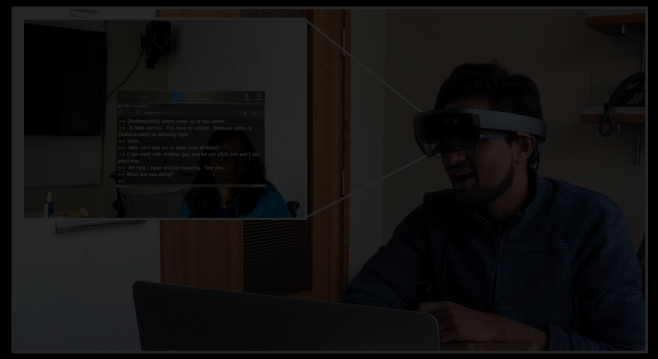
A preliminary prototype that displays captioning with speaker location and non-speech sounds

HoloSound

Combining Speech and Sound Identification for Deaf or Hard of Hearing Users on a Head-Mounted Display

ASSETS 2020 supplementary video

Three Initial Explorations of HMD-captioning



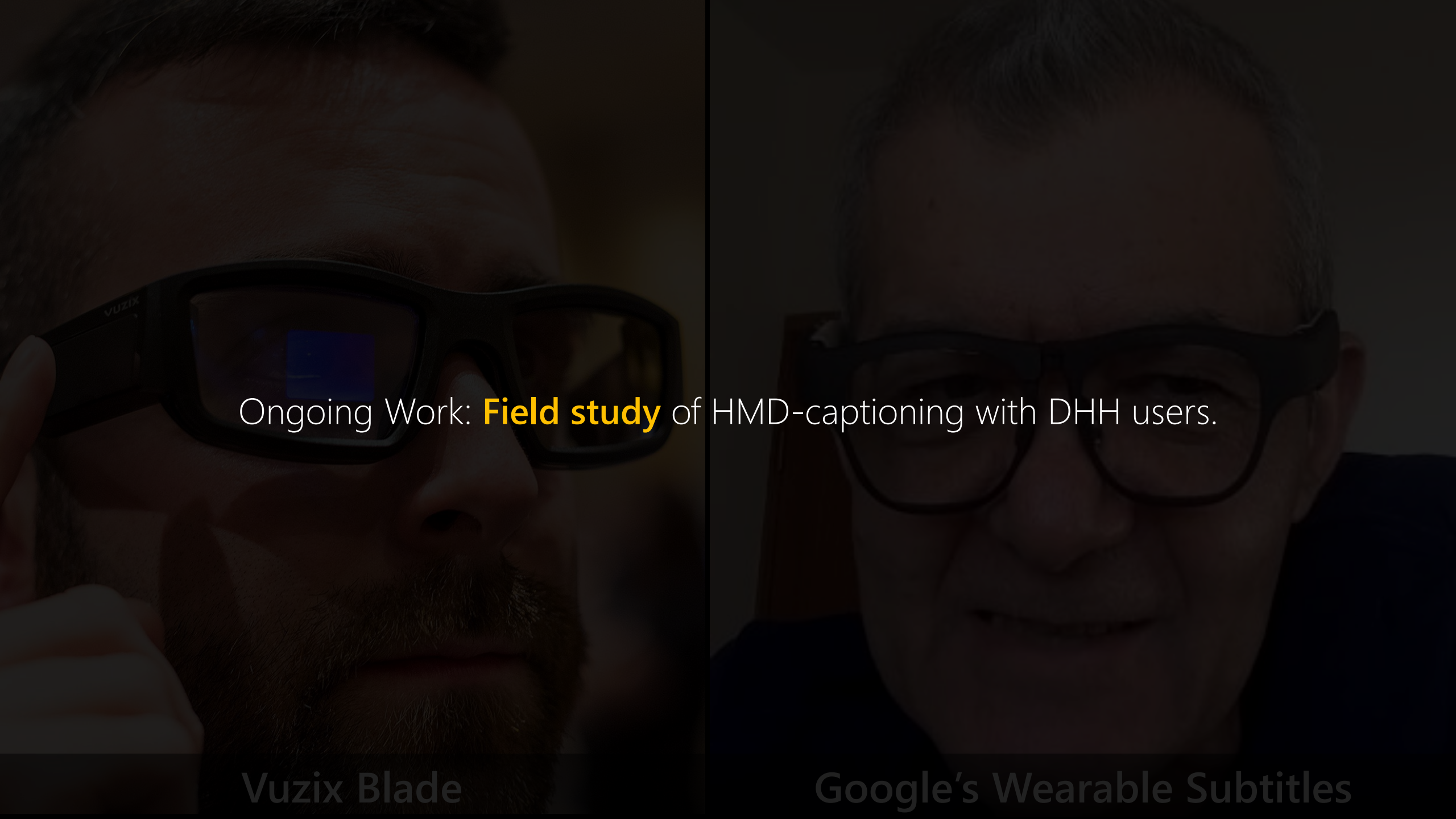
A 45-day autoethnographic evaluation

A semi-controlled evaluation with 10 DHH participants

A preliminary prototype that displays captioning with speaker location and non-speech sounds

While past studies inform the design of future HMD conversation support, **longer-term, more ecologically-valid field studies** are necessary.


Too Bulky!
Microsoft Edge
>> [Indiscernible] which made up of the cotton.
>> It feels narrow. You have to extend. Because cotton is [indiscernible] at defusing light.
>> Yeah.
>> Why can't you try to pitch both of them?
>> I can work with another guy and he can pitch one and I can pitch one.
>> All right I have another meeting. See you.
>> What are you doing?
>>



Ongoing Work: **Field study** of HMD-captioning with DHH users.

Vuzix Blade

Google's Wearable Subtitles

Summary

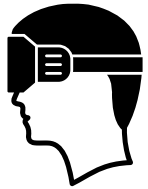
HomeSound

Two formative studies

Field studies

SoundWatch

Two studies



HoloSound

Three initial explorations

Reflections

Reflections

I largely explore providing sound information to take an action.

How can we design for “experiential” sound awareness?

I largely explore visual feedback.

How best to provide haptic feedback?

I provide transcription verbatim.

How to summarize topics of a conversation?

Broader Impacts

SoundWatch is released. Used by **more than 400 people daily**.

For HoloSound, we're collaborating with **Google**.

My work can benefit a **large** DHH population.

Can also benefit hearing people, e.g., when **wearing headphones**, or for **home surveillance**.

Wide applications for **other domains** as well such as wildlife survey, ocean surface mapping, game audio debugging, mechanical appliance repairs, and military.

Broader Impacts

Any Questions?

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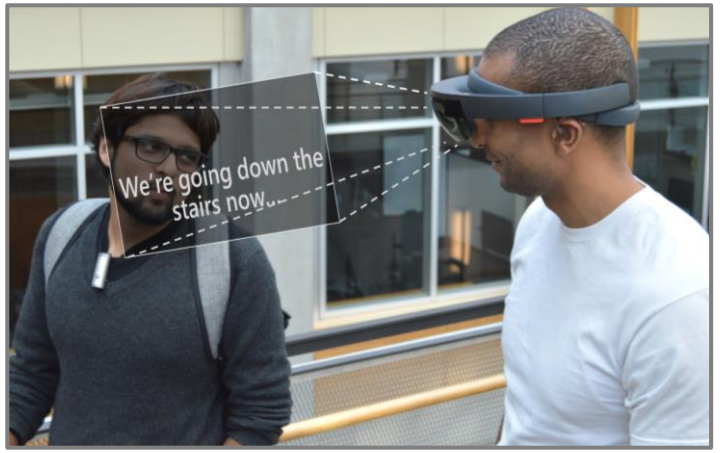
dj_hci

HomeSound

SoundWatch



HoloSound