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, and 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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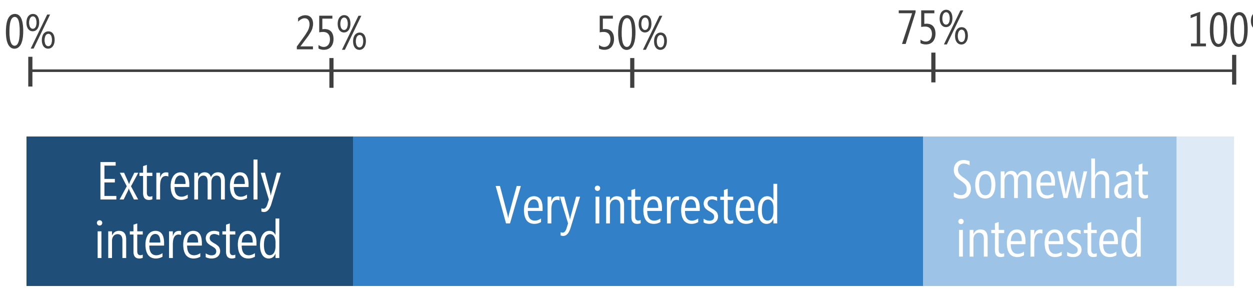
CONCEPTS

...n-centered computing → Empirical studies in ...ility.

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...

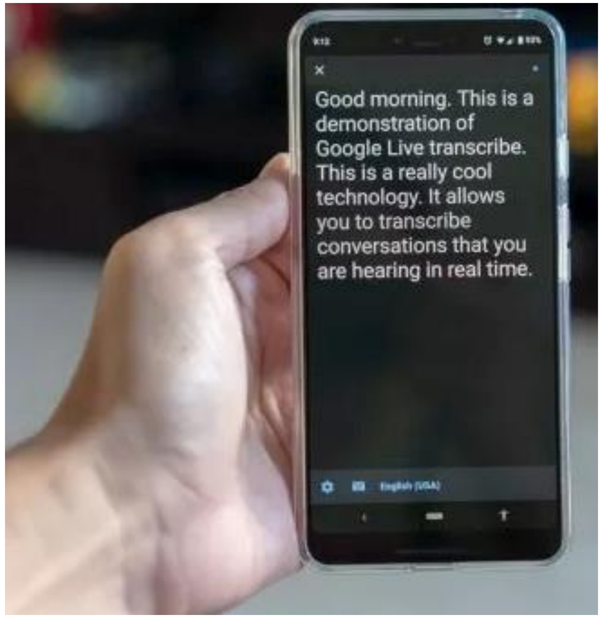


73.1%

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

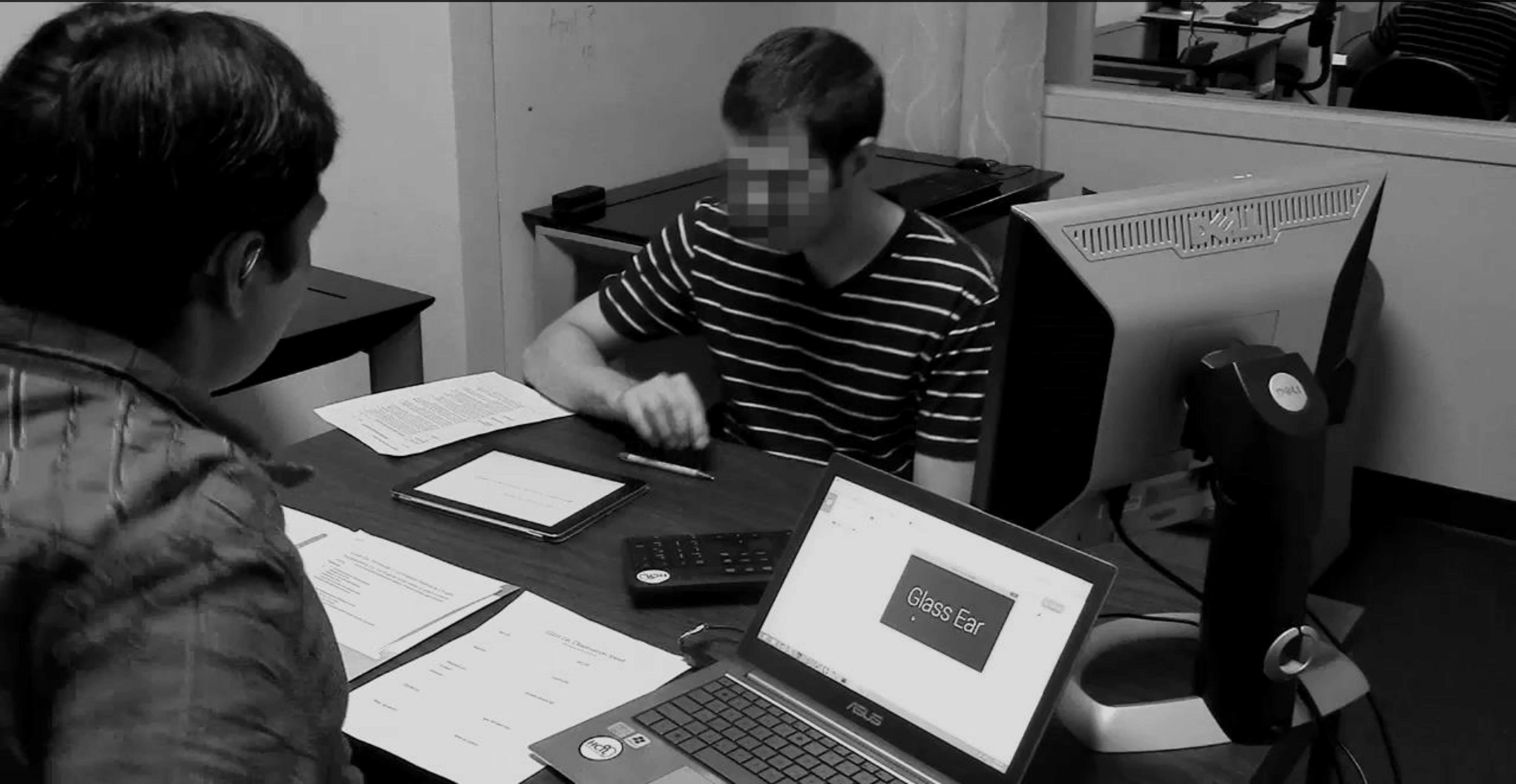
HEARING AID

COCHLEAR IMPLANT

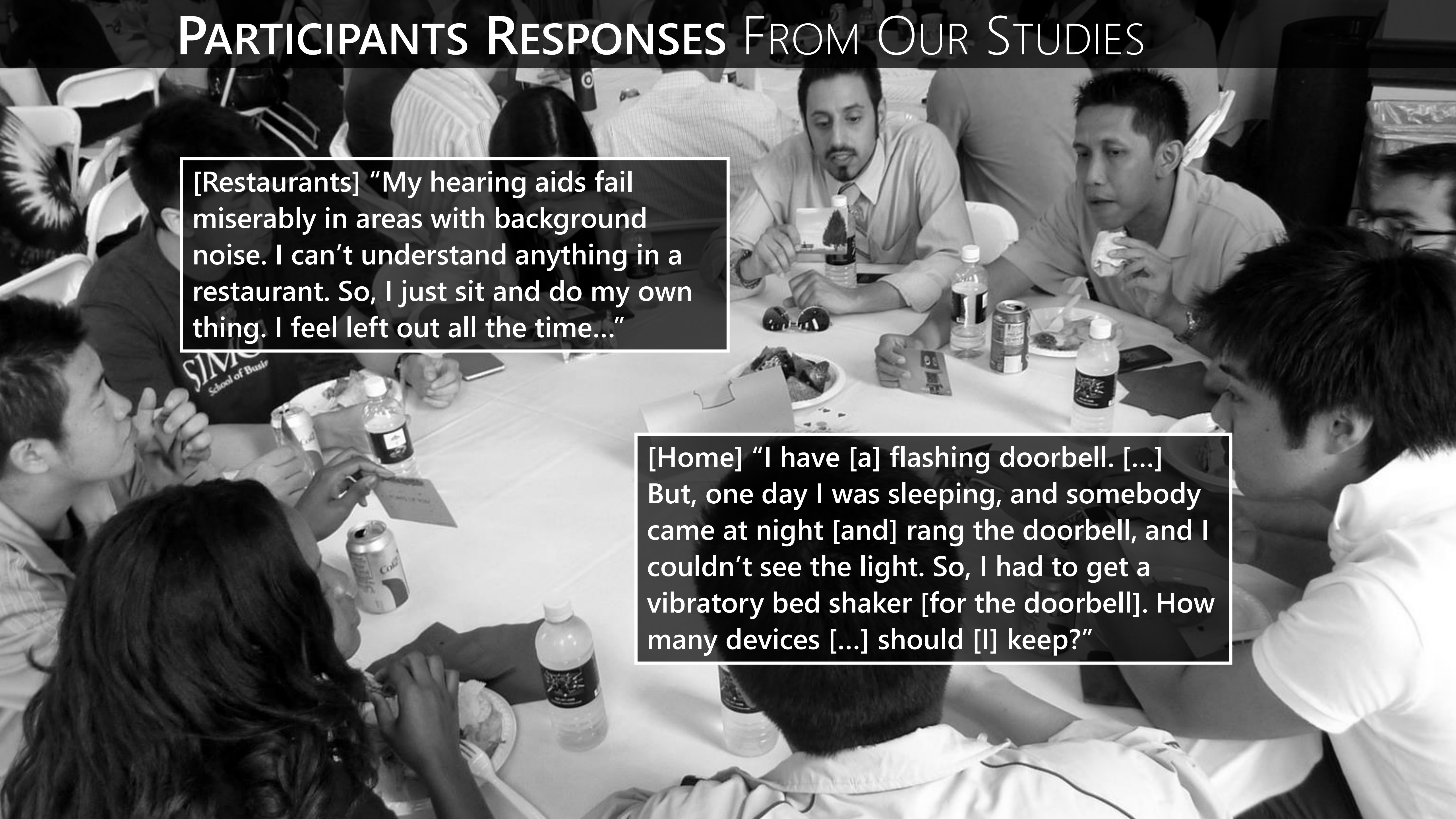


LIVE TRANSCRIBE

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

[Restaurants] "My hearing aids fail miserably in areas with background noise. I can't understand anything in a

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

[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 time you're unsure if you have understood the conversation well."

[Recreational activities] [In] martial arts: you have an instructor showing how to move the arms, hands, body, etc. while talking to describe it. Well, if they have to "talk" by signing, then how the [heck] do they also show you how to hold your arm 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...."

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

[Home] "I miss my kid crying upstairs"

vacuum cleaner running for 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!"

[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 I 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 ... if you have ... conversation well."

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

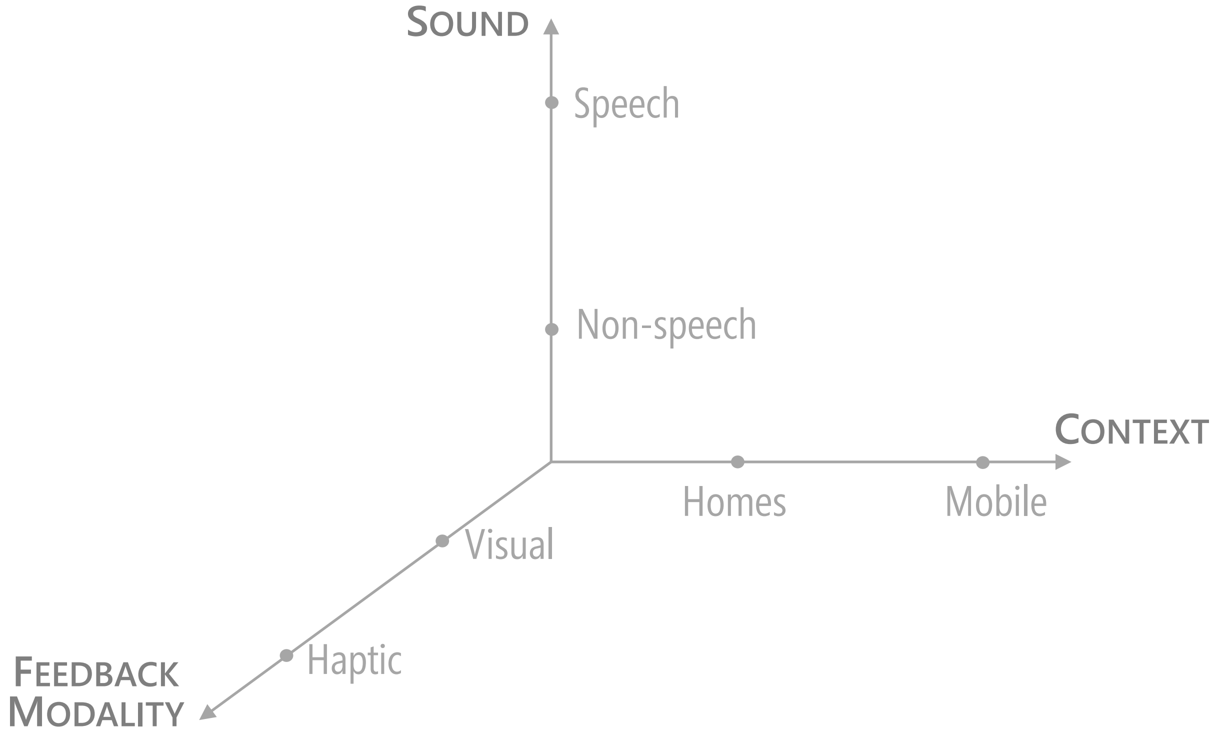
[In a group conversation] "Live Transcribe isn't perfect because it demands that I ... front [of me] and [also] have one [hand] holding the phone. It's hard to make the conversation smooth enough to go deep...."

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

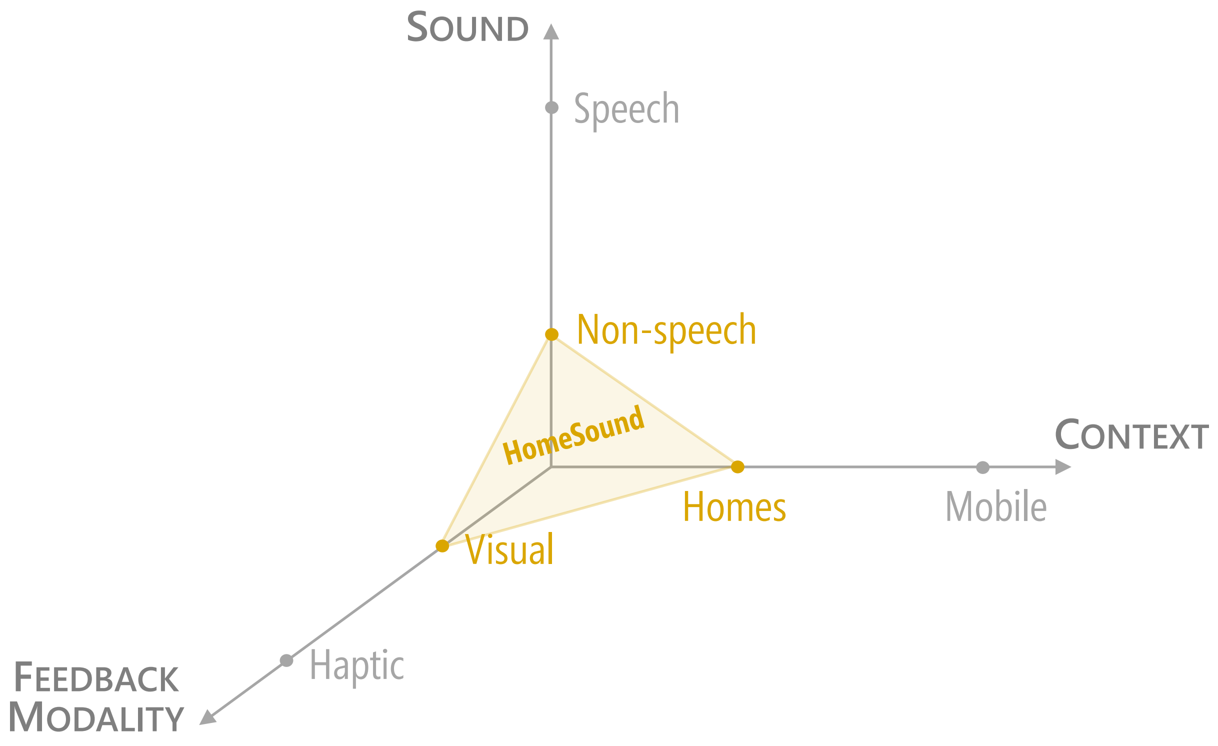
... vacuum cleaner running ... long, long time. The person next door got annoyed and came and told me that there is a terribly loud sound in my home. Gosh, it was running for three days!"

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

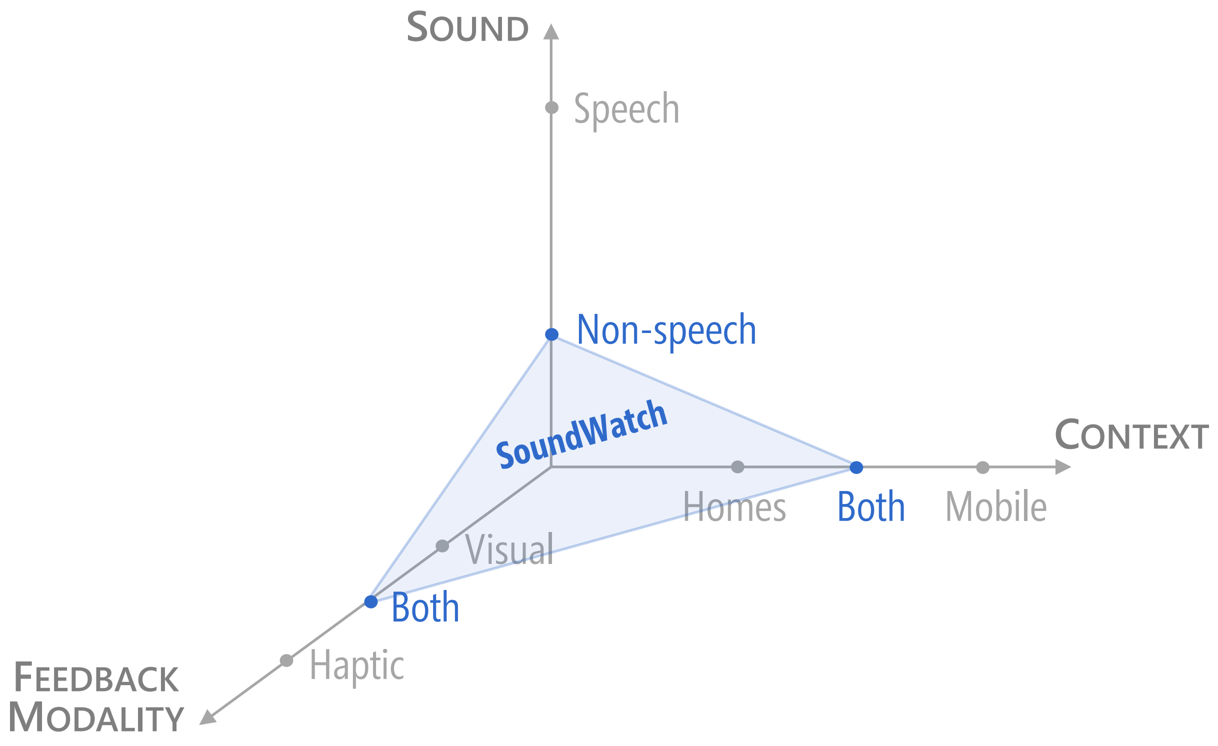
New approaches to enhance **sound awareness** for DHH people…

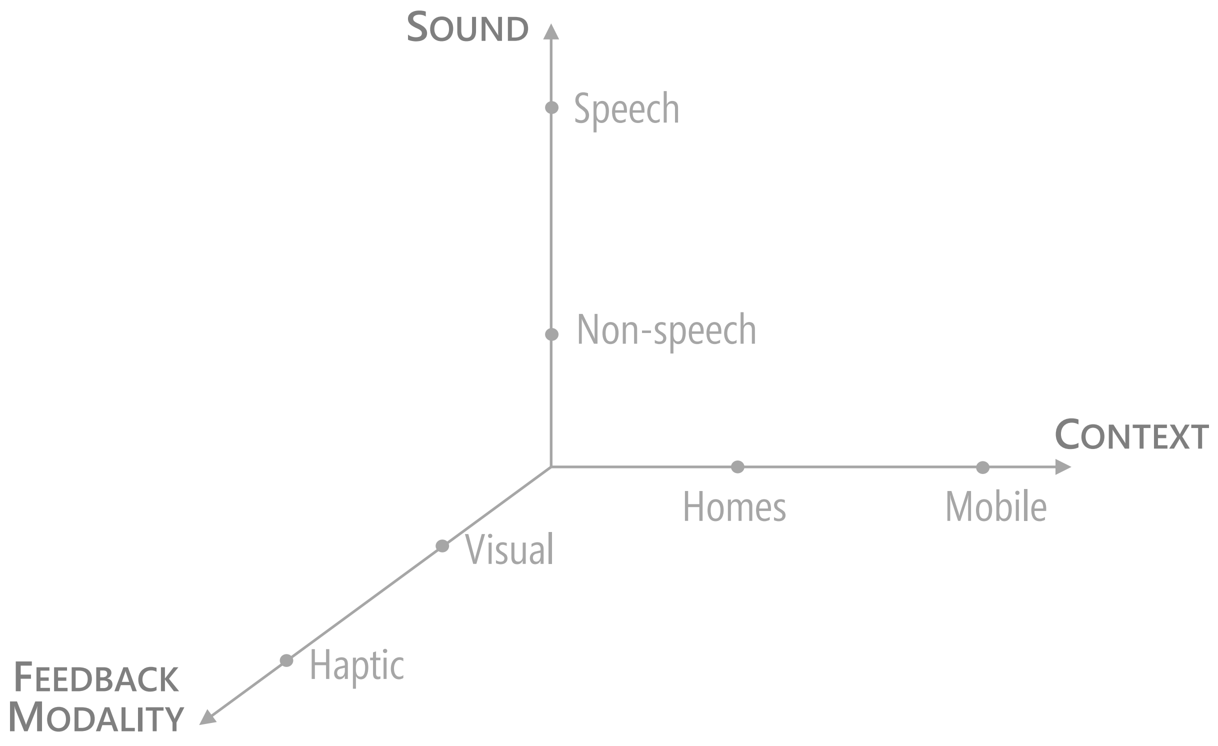


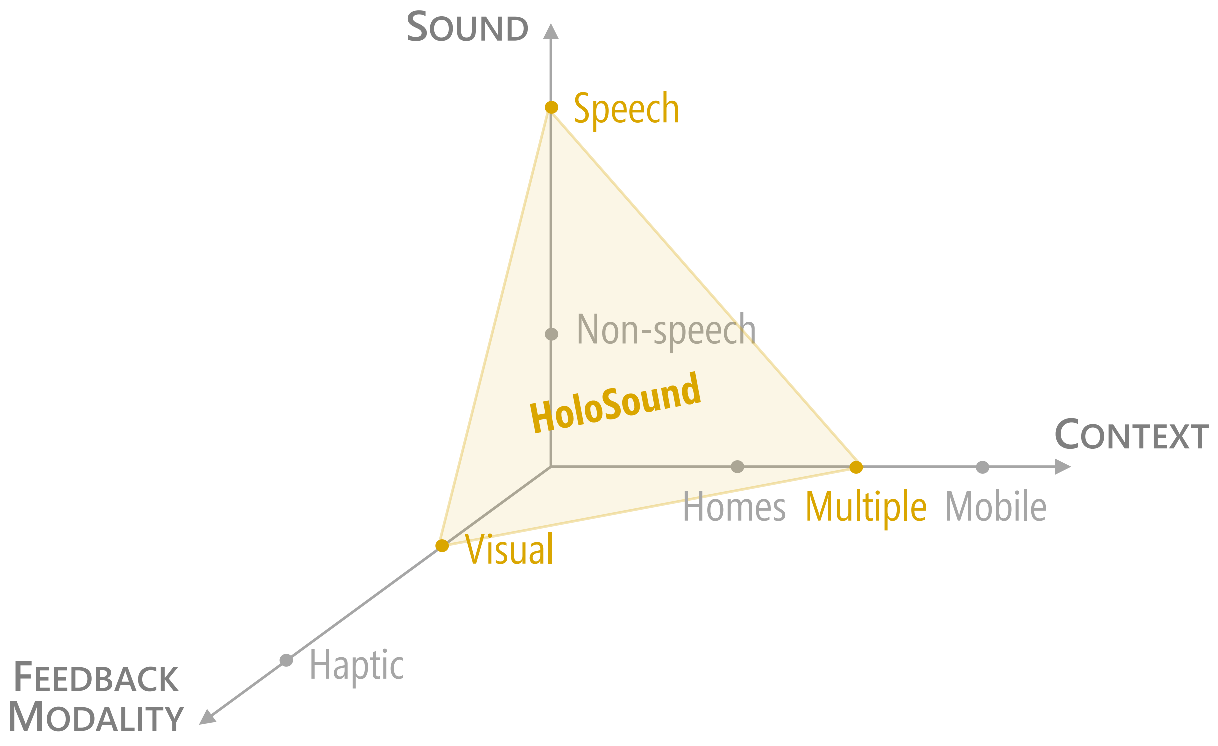
SOUND
Speech
Non-speech
CONTEXT
Homes
Mobile
Visual
Haptic
FEEDBACK MODALITY



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
Haptic
FEEDBACK
MODALITY

transform how DHH

think about,

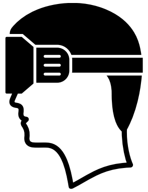
experience,

and engage

with the sound.

HomeSound

SoundWatch



HoloSound

Completed Work

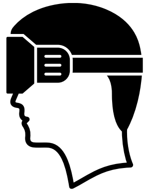
HomeSound

Two formative studies
(CHI'19)

Field studies
(CHI'20)

SoundWatch

Two studies
(ASSETS'20)



HoloSound

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

Proposed Work

HomeSound

Two formative studies
(CHI'19)

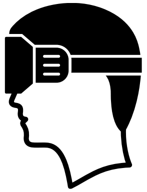
Field studies
(CHI'20)

SoundWatch

Two studies
(ASSETS'20)

End-user customization

Field study



HoloSound

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

Field study

Dissertation

HomeSound

Two formative studies

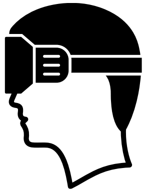
Field studies

SoundWatch

Two studies

End-user customization

Field study



HoloSound

Three initial explorations

Field study

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

End-user customization 1

Field study 2

HoloSound

Three initial explorations

Field study 3

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

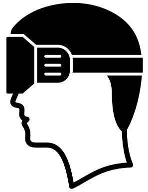
Field studies

SoundWatch

Two studies

End-user customization

Field study



HoloSound

Three initial explorations

Field study

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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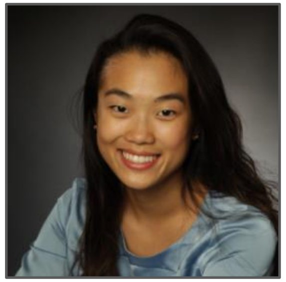

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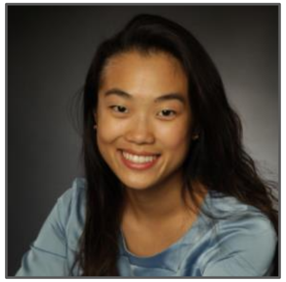
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design principles in developing and modifying
our prototypes
Sounds

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

End-user customization

Field study

HoloSound

Three initial explorations

Field study

Yellow: proposed work

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

End-user customization

Field study

HoloSound

Three initial explorations

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Yellow: proposed work

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Three initial explorations

Field study

Yellow: proposed work

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

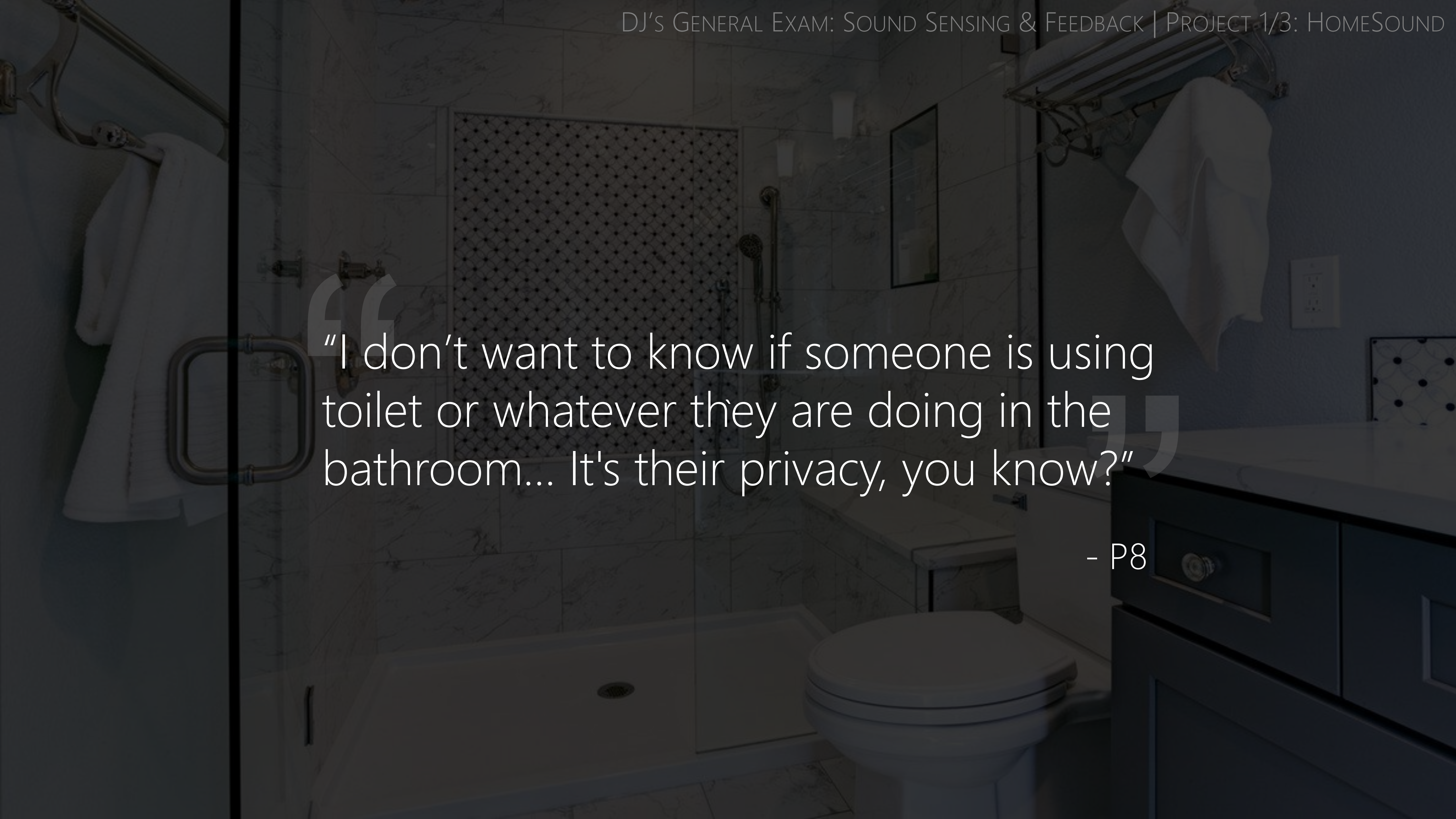
Study 2 A **scenario-based evaluation** of three initial sound awareness prototypes with 10 DHH participants

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

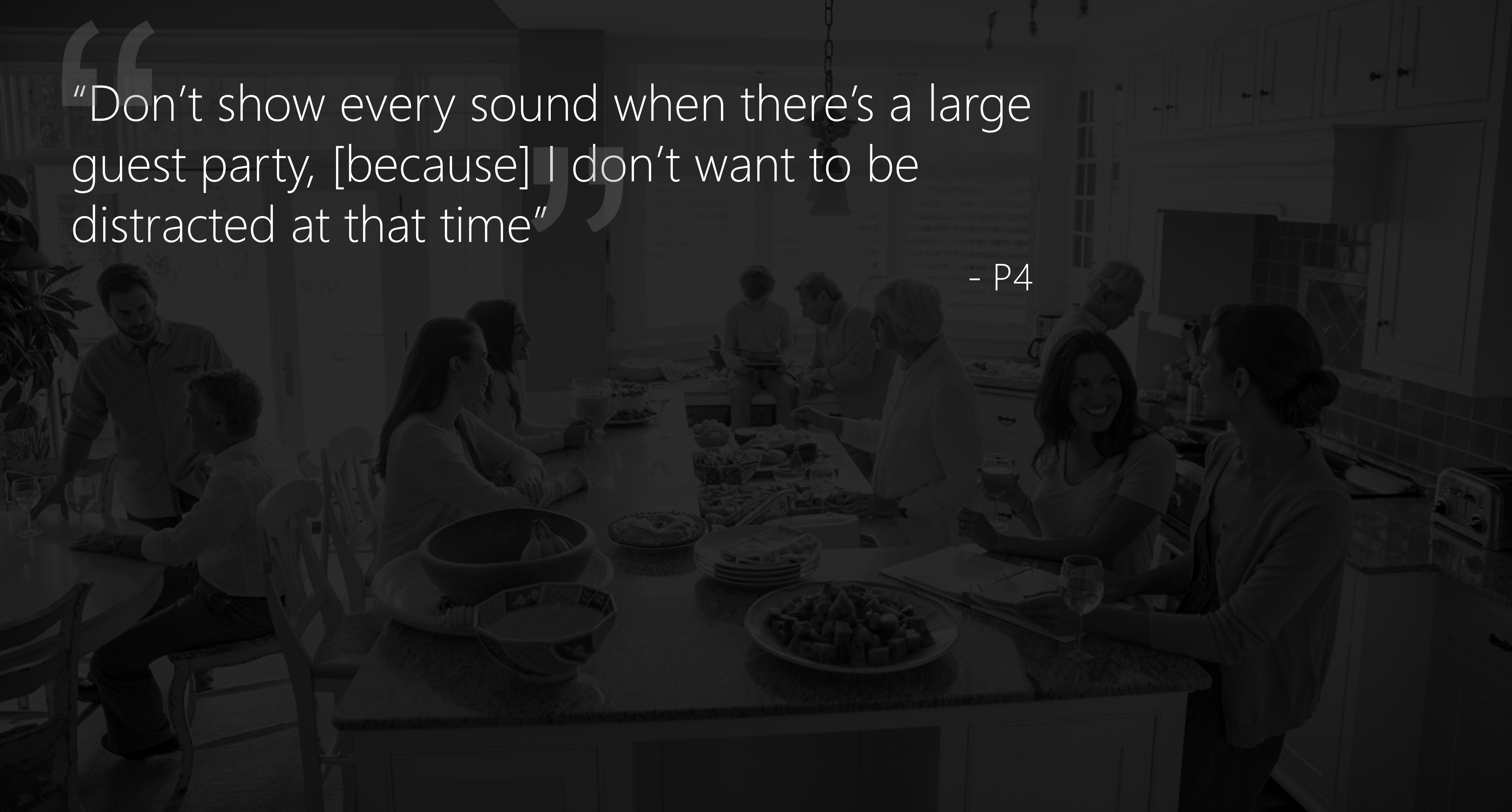


"I don't want to know if someone is using toilet or whatever they are doing in the bathroom... It's their privacy, you know?"

- 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

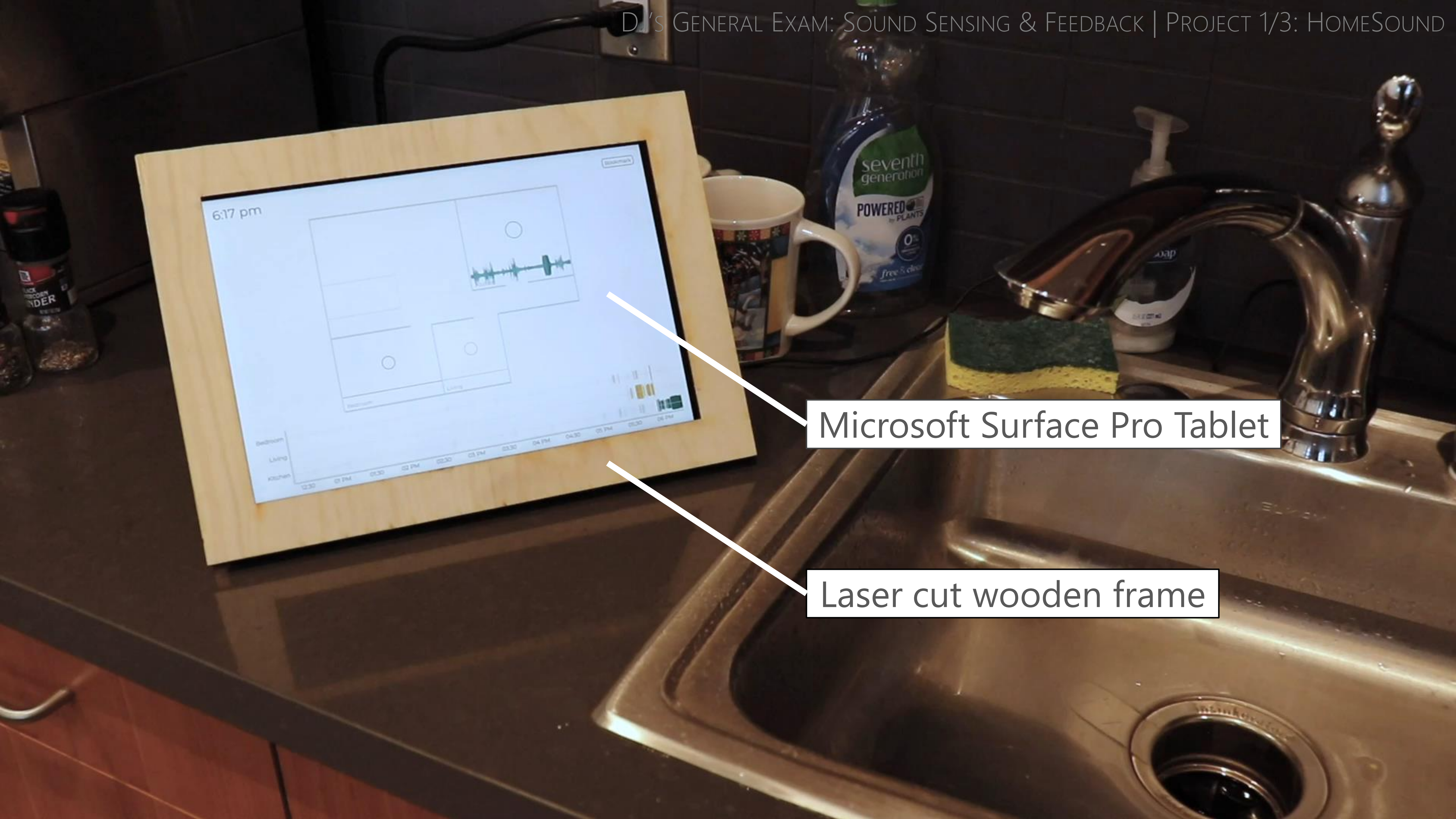
Field study

HoloSound

Three initial explorations

Field study

Yellow: proposed work


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


echo show 8
10:10
21°
alexa
12:38

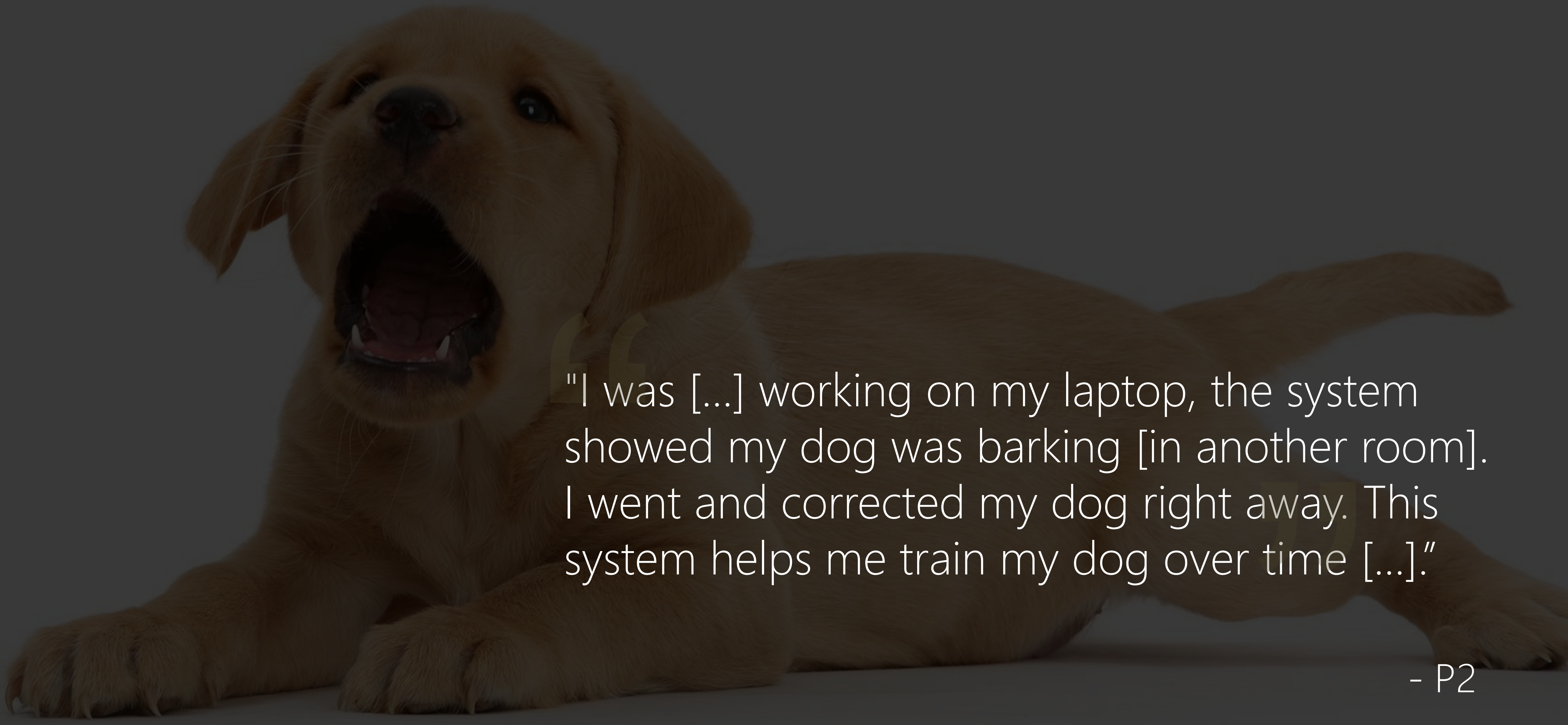
Live Demo!


4:10 pm
Settings
Bookmark
Dining
Entryway
Office
Living
Water Pour, 100%
Kitchen
Dining
Entryway
Living
Office
Kitchen
10:30
11 AM
11:30
12 PM
12:30
01 PM
01:30
02 PM
02:30
03 PM
03:30


Each home contained
3-5 displays.
Kitchen display

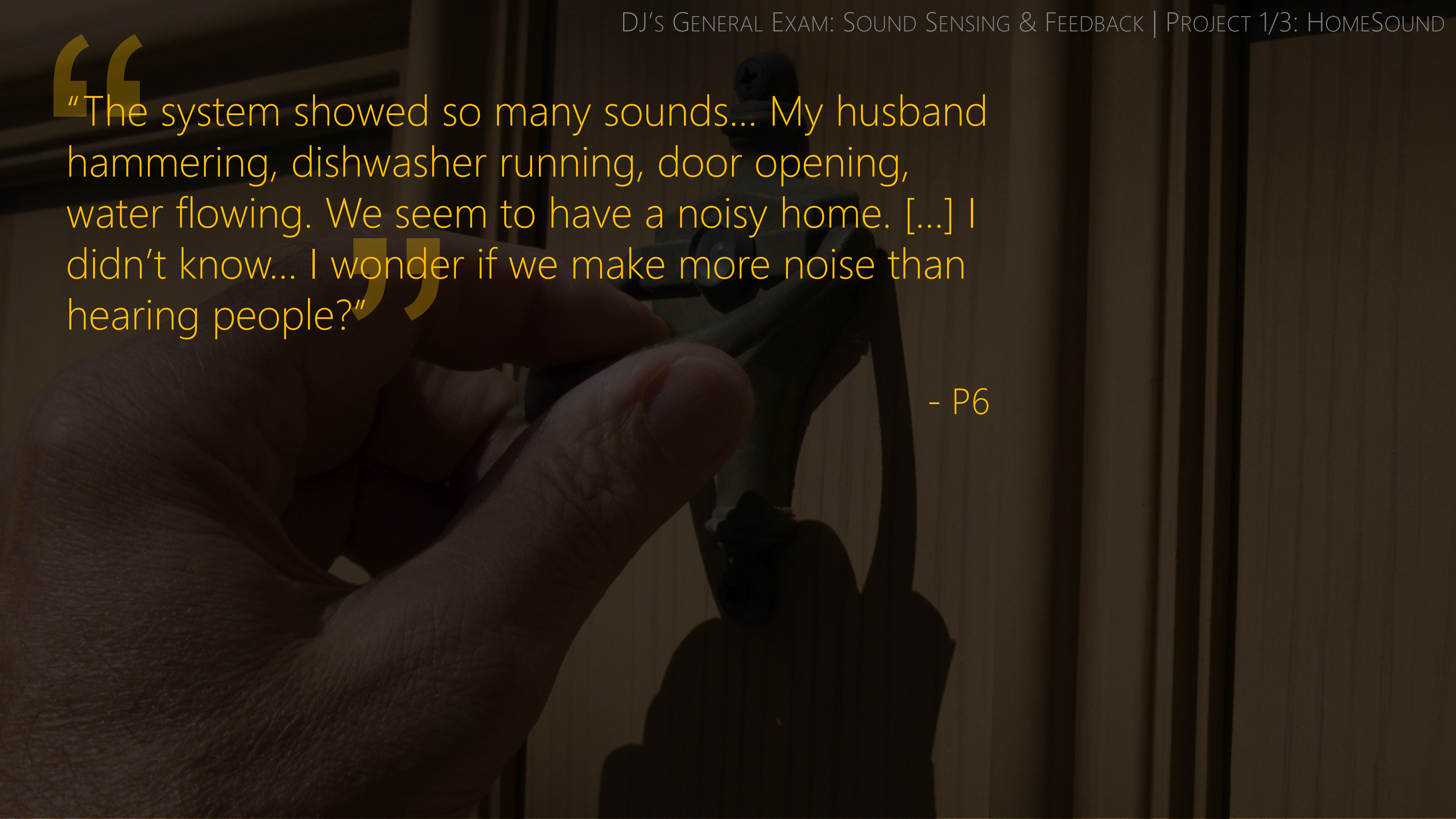
"Every time I walked around the house, I saw disks [pulses] on displays [emanating from] multiple rooms. I realized that my whole wooden home makes a lot of noise when I walking"

- P1



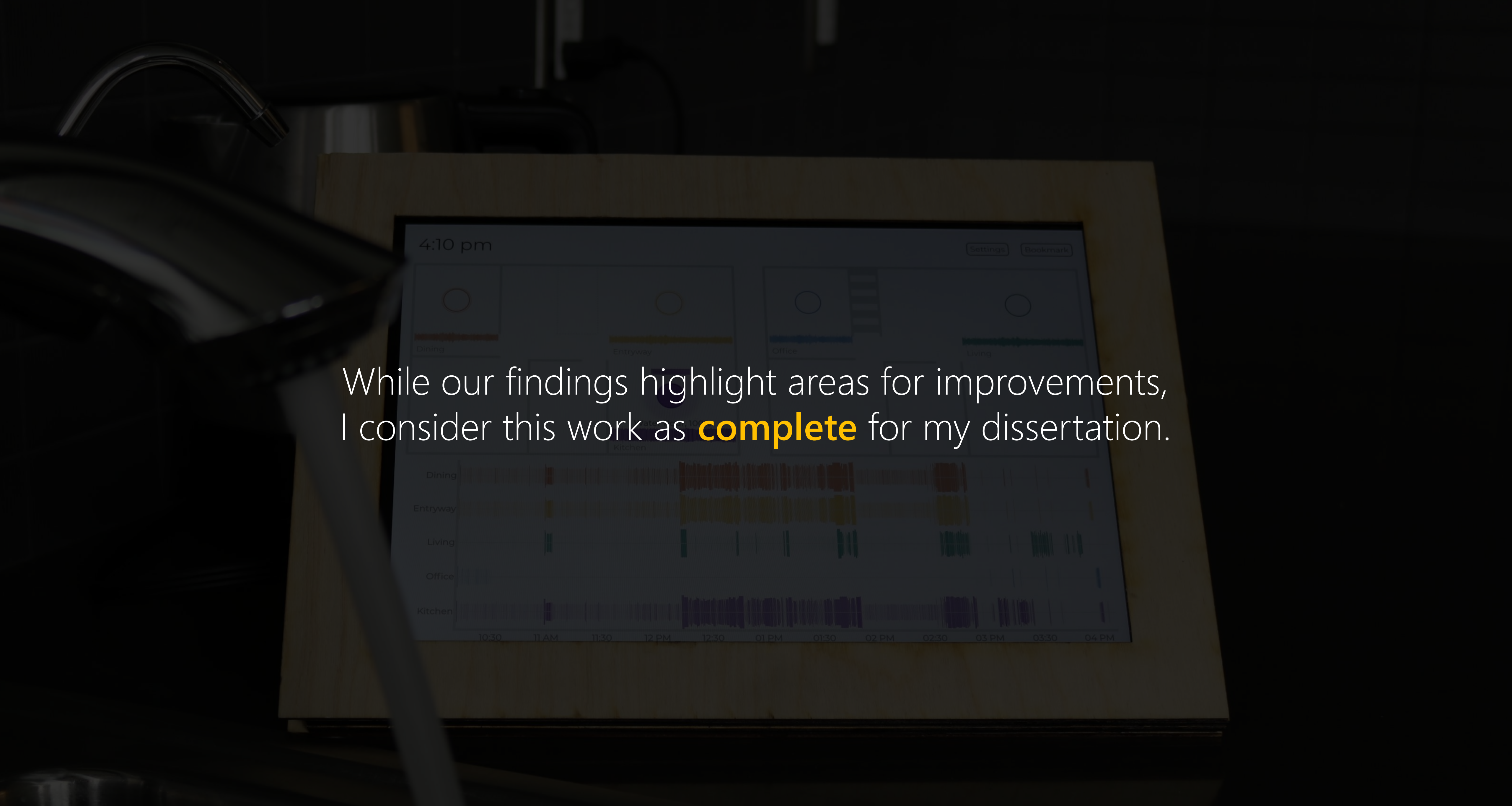
"I was […] working on my laptop, the system showed my dog was barking [in another room]. I went and corrected my dog right away. This system helps me train my dog over time […]."

- P2



"The system showed so many sounds… My husband hammering, dishwasher running, door opening, water flowing. We seem to have a noisy home. […] I didn't know… I wonder if we make more noise than hearing people?"

- P6



While our findings highlight areas for improvements,
I consider this work as **complete** for my dissertation.

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

End-user customization

Field study

HoloSound

Three initial explorations

Field study

Yellow: proposed work

HomeSound

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Field study

Yellow: proposed work

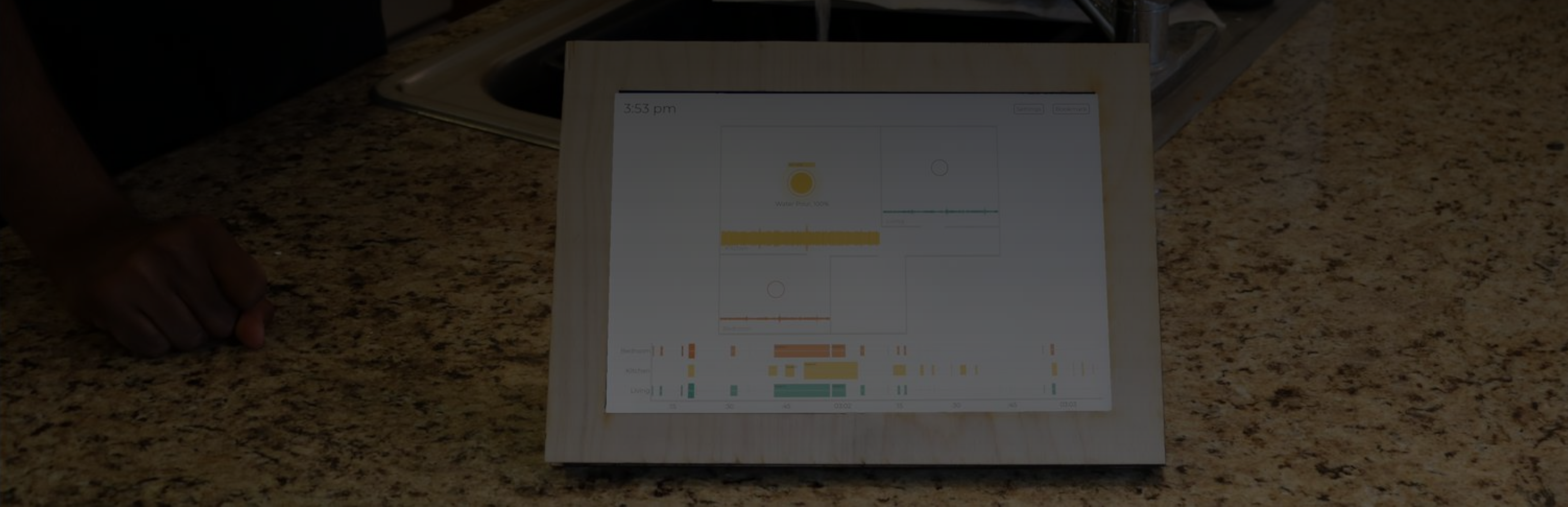
SoundWatch: Sound Awareness on a Smartwatch

SoundWatch: Sound Awareness on a Smartwatch

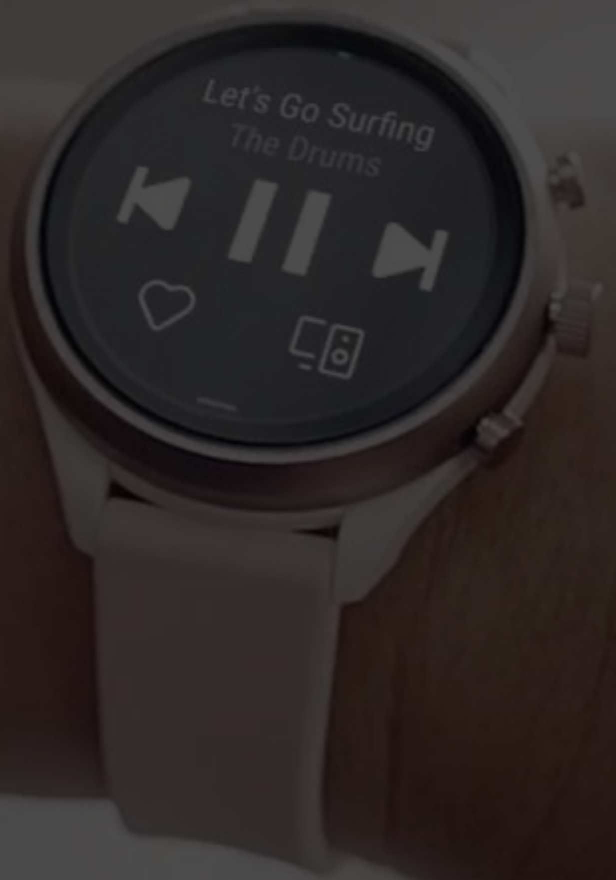
SoundWatch is informed by **lived experiences** of many DHH people.

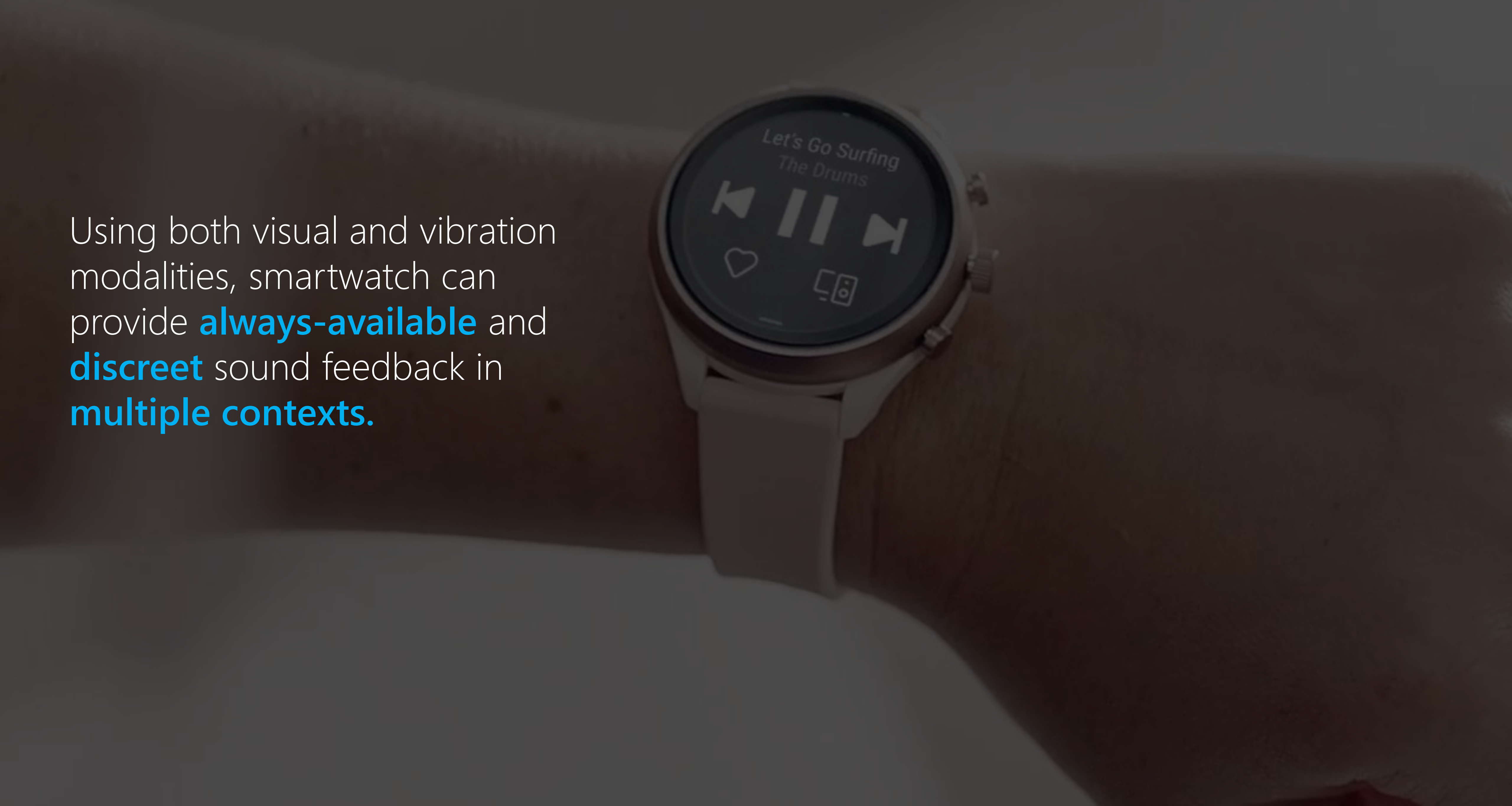
P4 in the **HomeSound** study:

"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."

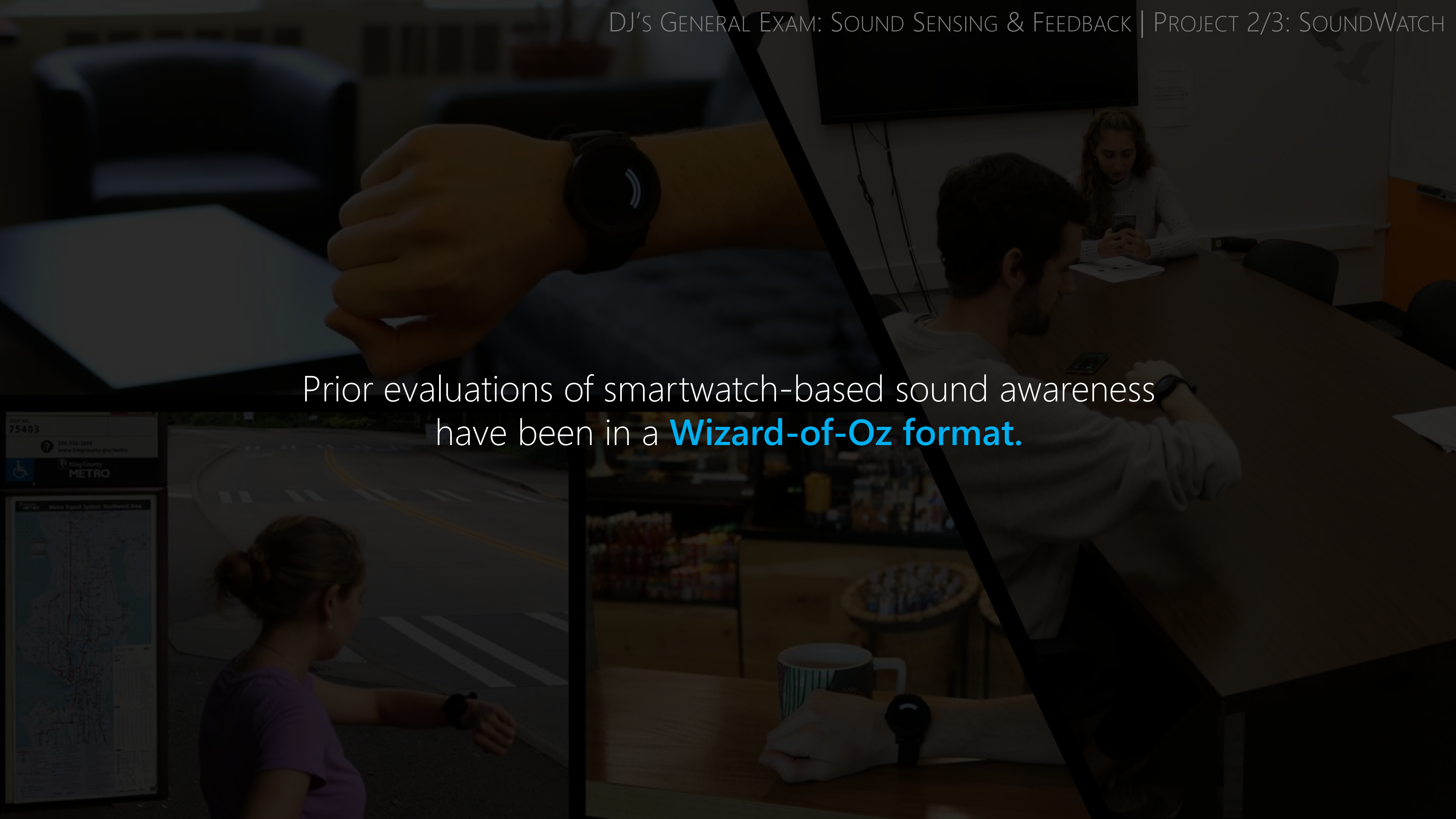


Our survey with 201 DHH participants showed that **smartwatch was the most preferred device** for non-speech sound feedback.





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.

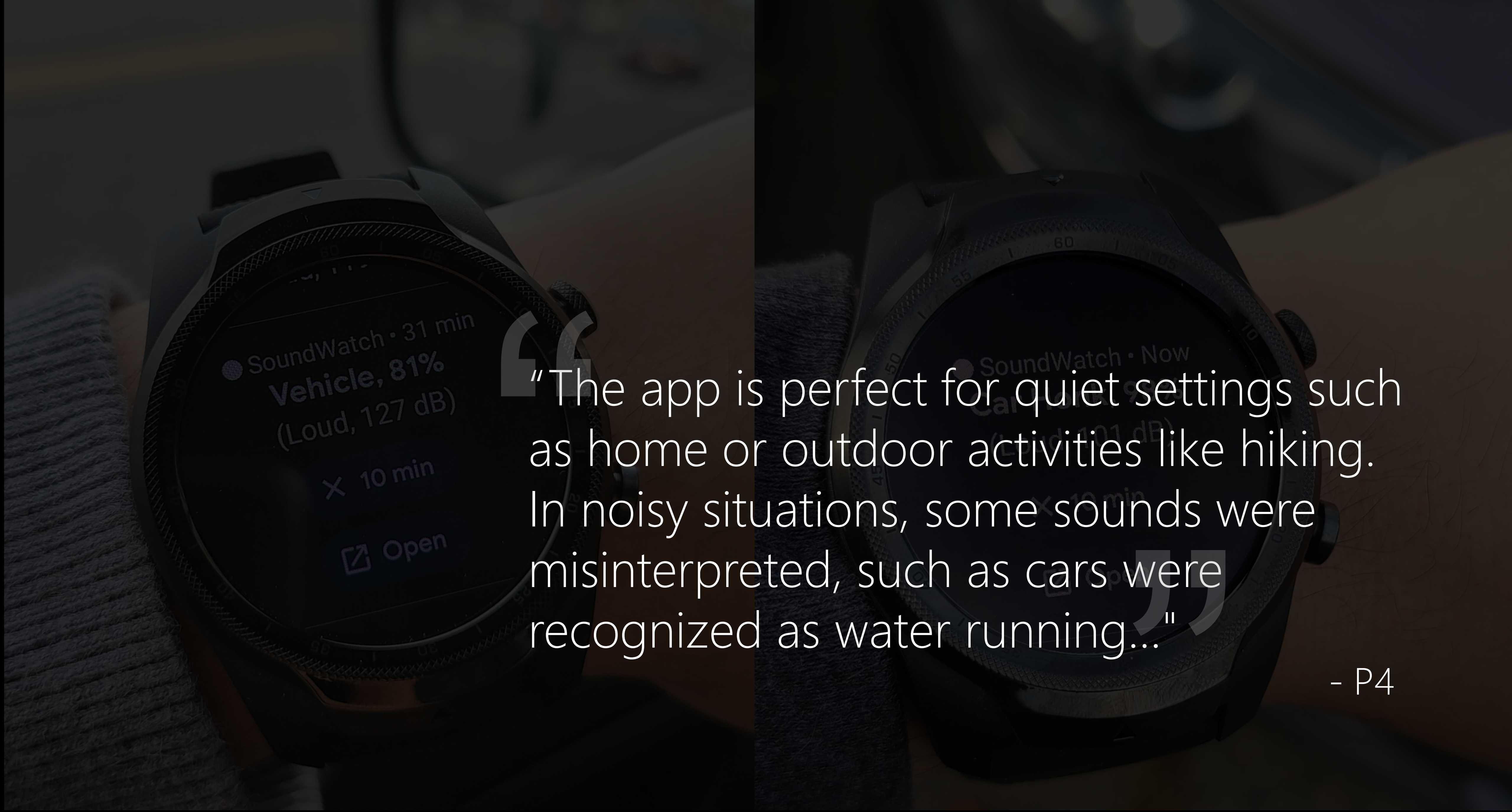
Findings

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).

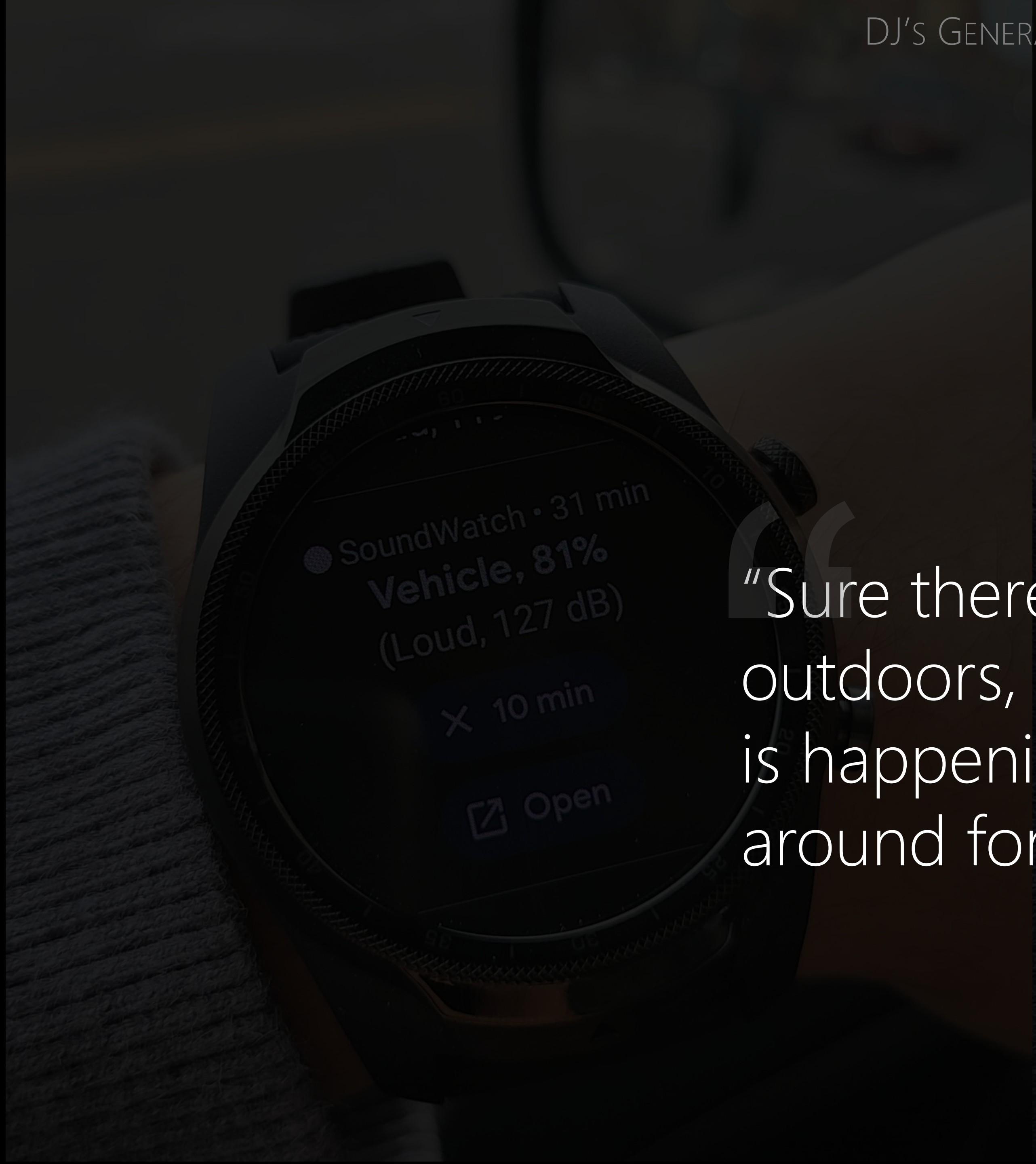
Study 2

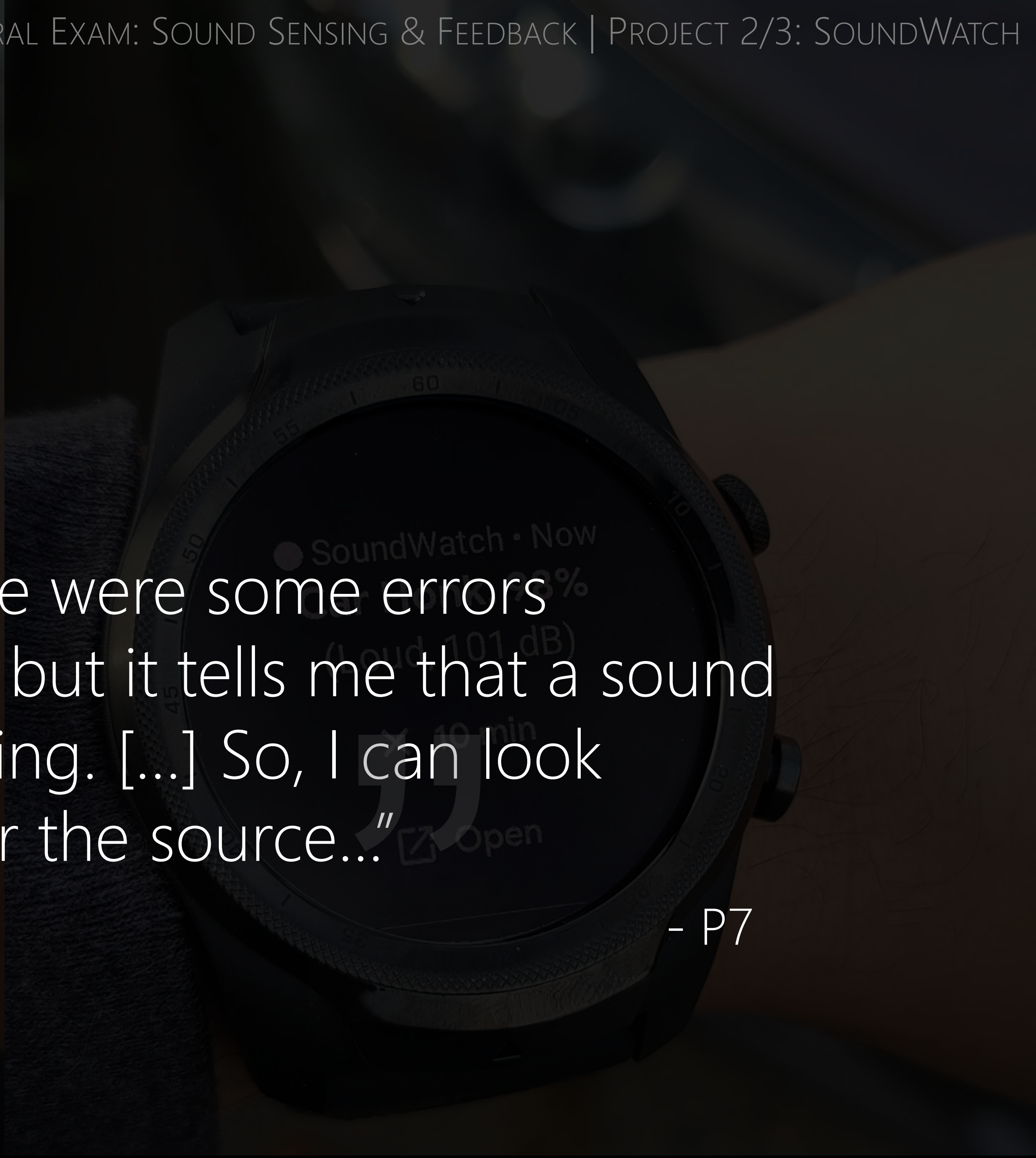
All participants generally liked SoundWatch but were concerned with **errors in noisy environments.**



"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

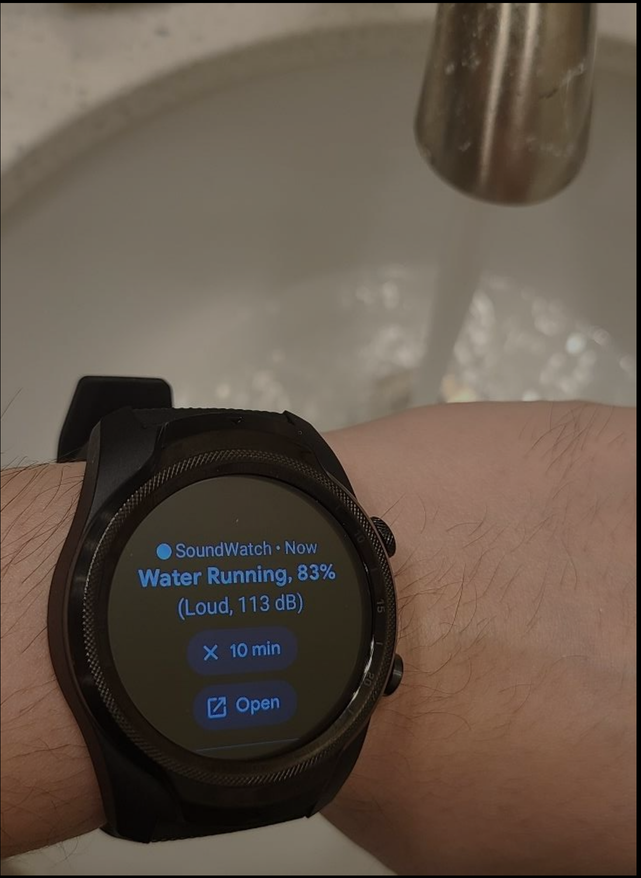


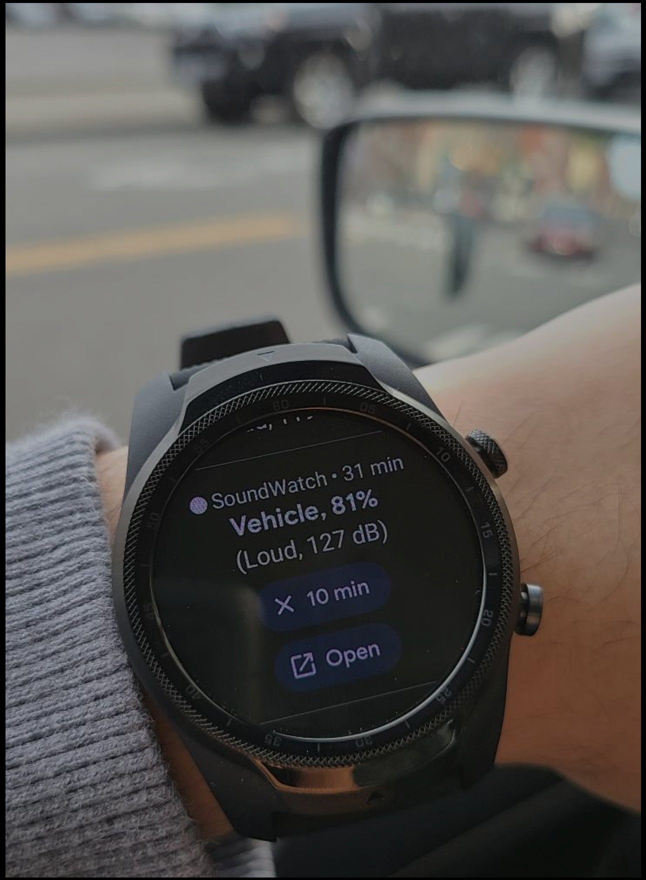


"Sure there were some errors outdoors, but it tells me that a sound is happening. [...] So, I can look around for the source..."

- P7

Demo Time!


SoundWatch • Now
Water Running, 83%
(Loud, 113 dB)
10 min
Open


SoundWatch • 31 min
Vehicle, 81%
(Loud, 127 dB)
10 min
Open


SoundWatch • Now
Car Honk, 98%
(Loud, 101 dB)
10 min
Open

SoundWatch

Always-available sound feedback

Released on Google store!

GET IT ON Google Play

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HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

End-user customization

Field study

HoloSound

Three initial explorations

Field study

Yellow: proposed work

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

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Field study

HoloSound

Three initial explorations

Field study

Yellow: proposed work

Two Drawbacks of Initial SoundWatch Work

1. A generic model trained on online sound corpora.
   End-user should be able to customize the model in-situ.

2. Evaluation was done in the lab.
   How people may use SoundWatch in the field remains to be studied.

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Proposed work 1

Field study

Proposed work 2

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Proposed Work 1: **End-User Customization**

Proposed Work 1: **Few-Shot Learning**

Imagine...

"Before remodeling the kitchen, we had a porcelain sink. And the [HomeSound] system will recognize if we leave the water running. Now, we have a stainless-steel sink and the sound of water hitting it is very different. So, I want to be able to tell the system: here are some sounds from my new sink and it should then be able to recognize it..."

- P6


TableGPT: Few-shot Table-to-Text Generation with Table Structure Reconstruction and Content Matching

Heng Gong[1*], Yawei Sun[1*], Xiaocheng Feng[1,2], Bing Qin[1,2], Wei Bi, Xiaojiang Liu, Ting Liu[1,2]

This CVPR paper is the Open Access version, provided by the Computer Vision Foundation. Except for this watermark, it is identical to the accepted version; the final published version of the proceedings is available on IEEE Xplore.

Few-Shot Learning with Localization in Realistic Settings

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Abstract

Traditional recognition methods typically require large, artificially-balanced training classes, while few-shot learning methods are tested on artificially small ones. In contrast to both extremes, real world recognition problems exhibit heavy-tailed class distributions, with cluttered scenes and a mix of coarse and fine-grained class distinctions. We show that prior methods designed for few-shot learning do not work out of the box in these challenging conditions, based on a new "meta-iNat" benchmark. We introduce three parameter-free improvements: (a) better training procedures based on adapting cross-validation to meta-learning, (b) novel architectures that localize objects using limited bounding box annotations before classification, and (c) simple parameter-free expansions of the feature space based on bilinear pooling. Together, these improvements double the accuracy of state-of-the-art models on meta-iNat while generalizing to prior benchmarks, complex neural architectures, and settings with substantial domain shift.

1. Introduction

Image recognition models have purportedly reached human performance on benchmarks such as ImageNet, but depend critically on large, balanced, labeled training sets with hundreds of examples per class.

Figure 1. Discrepancies between existing benchmarks and real world problems. Top: Traditional recognition benchmarks use many, equally large classes, while few-shot benchmarks use few, equally small classes. Natural problems tend to be heavy-tailed. Bottom: Clockwise from top left: relevant objects may be overlapping, tiny, occluded,

Past efforts in few-shot learning for real-life settings have been focused on **computer vision and NLP**.

Proposed Work 1: **Few-Shot Sound Classification**

Phase 1: Algorithmic Experiments

- **Three approaches:** MAML, Meta-Opt, prototypical networks
- **Baselines:** FT-last, FT-all, NN
- **Dataset:** field recordings from SoundWatch work
- **Metrics:** top-1, top-3 accuracy, AUC

Phase 2: Short In-Situ Evaluation

- **Participants:** 5-10 DHH
- **Tasks:** record a few sounds, then evaluate the trained model on SoundWatch for 1-3 days
- **Data collection:** pre-/post- interviews, brief in-situ questionnaires, device logs

PROPOSED WORK 1: **EXPECTED CONTRIBUTIONS**

1 Quantification of several "few-shot" personalization approaches for real-life sound classification.

2 Preliminary insights from an in-situ evaluation.

HomeSound

Two formative studies

Field studies

SoundWatch

Two studies

End-user customization

Field study

HoloSound

Three initial explorations

Field study

Yellow: proposed work

Proposed Work 2: **SoundWatch Field-Deployment**

1. How do DHH people use smartwatch-based sound awareness technology in diverse contexts (e.g., at home, while waking, in transit)?

2. How does long-term use of this technology change the users' understanding of sounds and information conveyed through sounds?

3. What privacy or social implications arise with an always-on sound recording app in different contexts?

Proposed Work 2: **SoundWatch Field-Deployment**

Participants

- 30-40 DHH
- Recruited using opt-in form, emails, & social media

Protocol

- Pre-and post-interviews
- Weekly surveys
- A lightweight in-situ feedback form
- Usage logs

Proposed Work 2: **Expected Contributions**

1	Characterization of real-world usage of smartwatch-based sound awareness across a variety of contexts.

2	Design guidelines for future wearable sound awareness systems.

...and an improved SoundWatch app for the world!

Non-speech sound feedback

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Yellow: proposed work

Non-speech sound feedback

Speech feedback

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Field study

HoloSound

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Field study

Yellow: proposed work

HoloSound: Head-Mounted Displays for Speech Feedback

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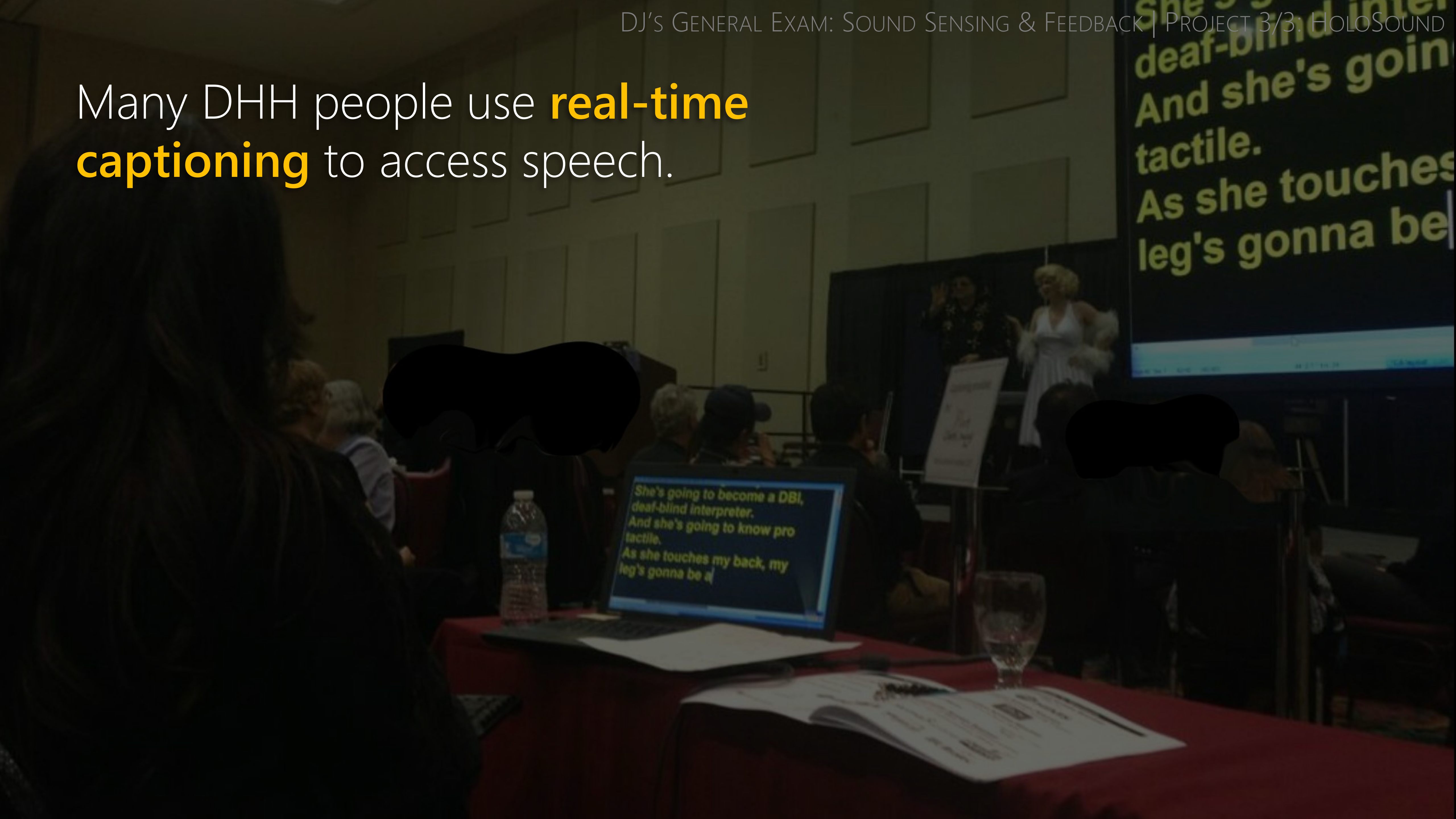
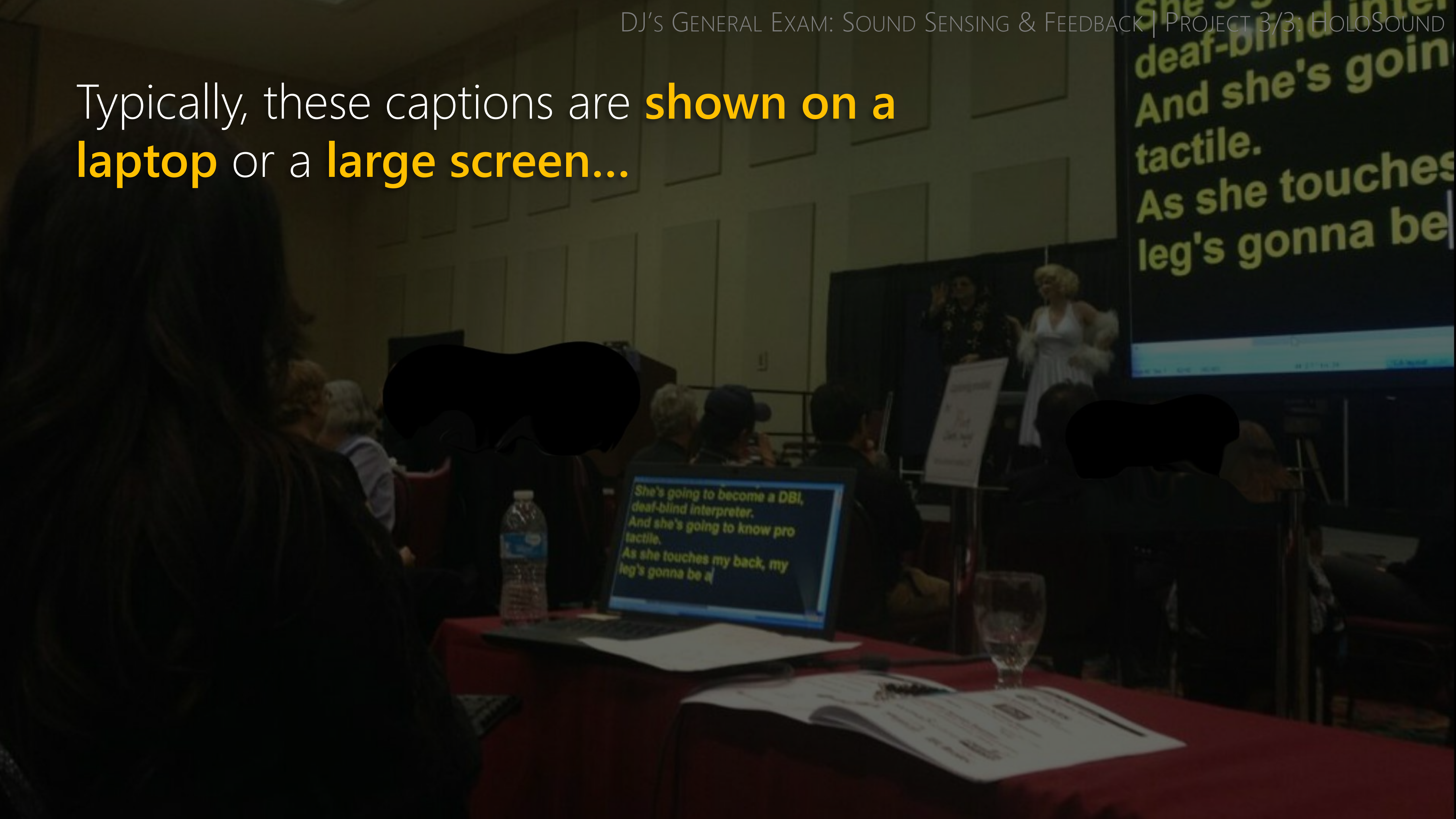
Microsoft

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

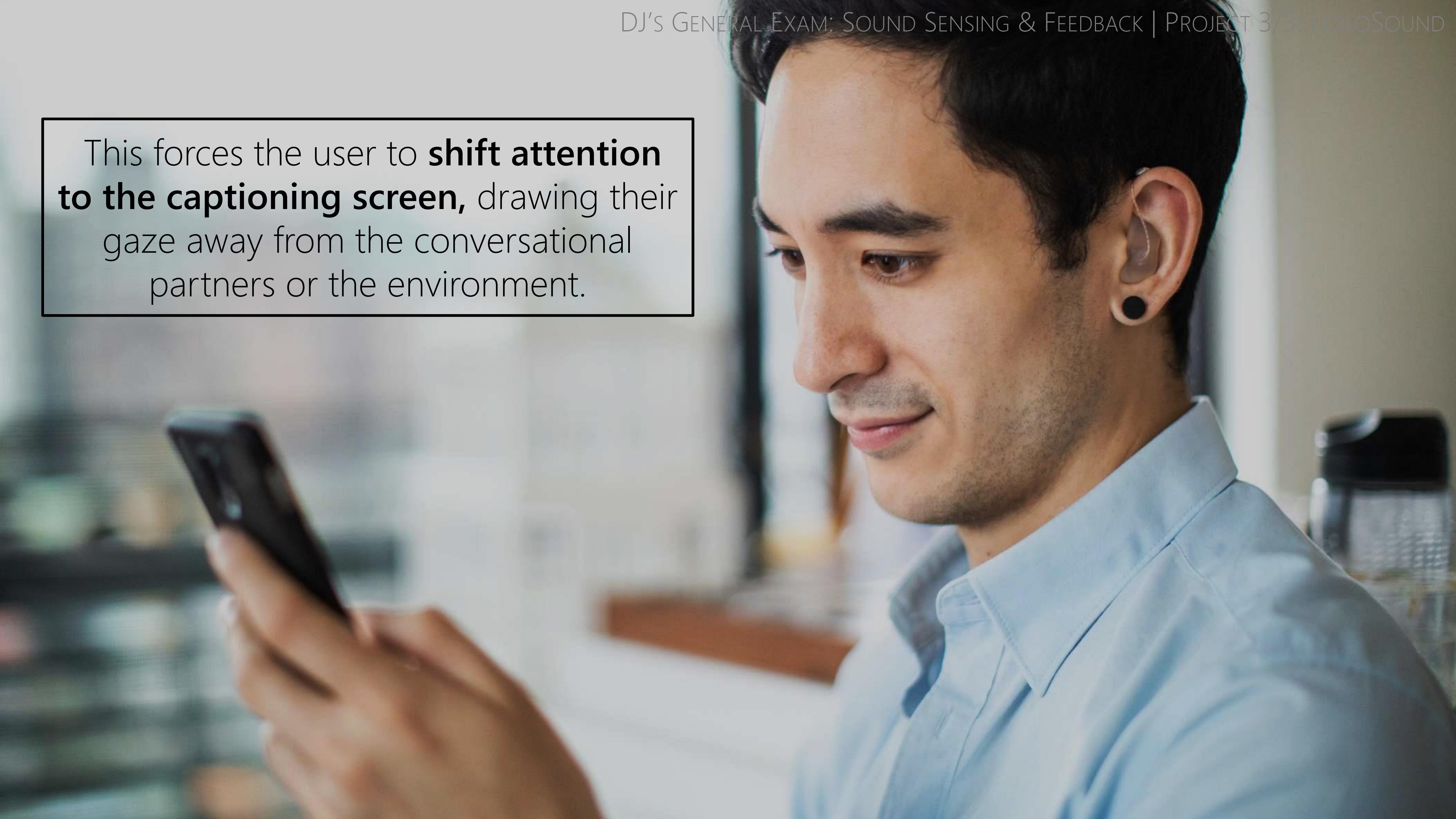


Typically, these captions are **shown on a laptop** or a **large screen...**

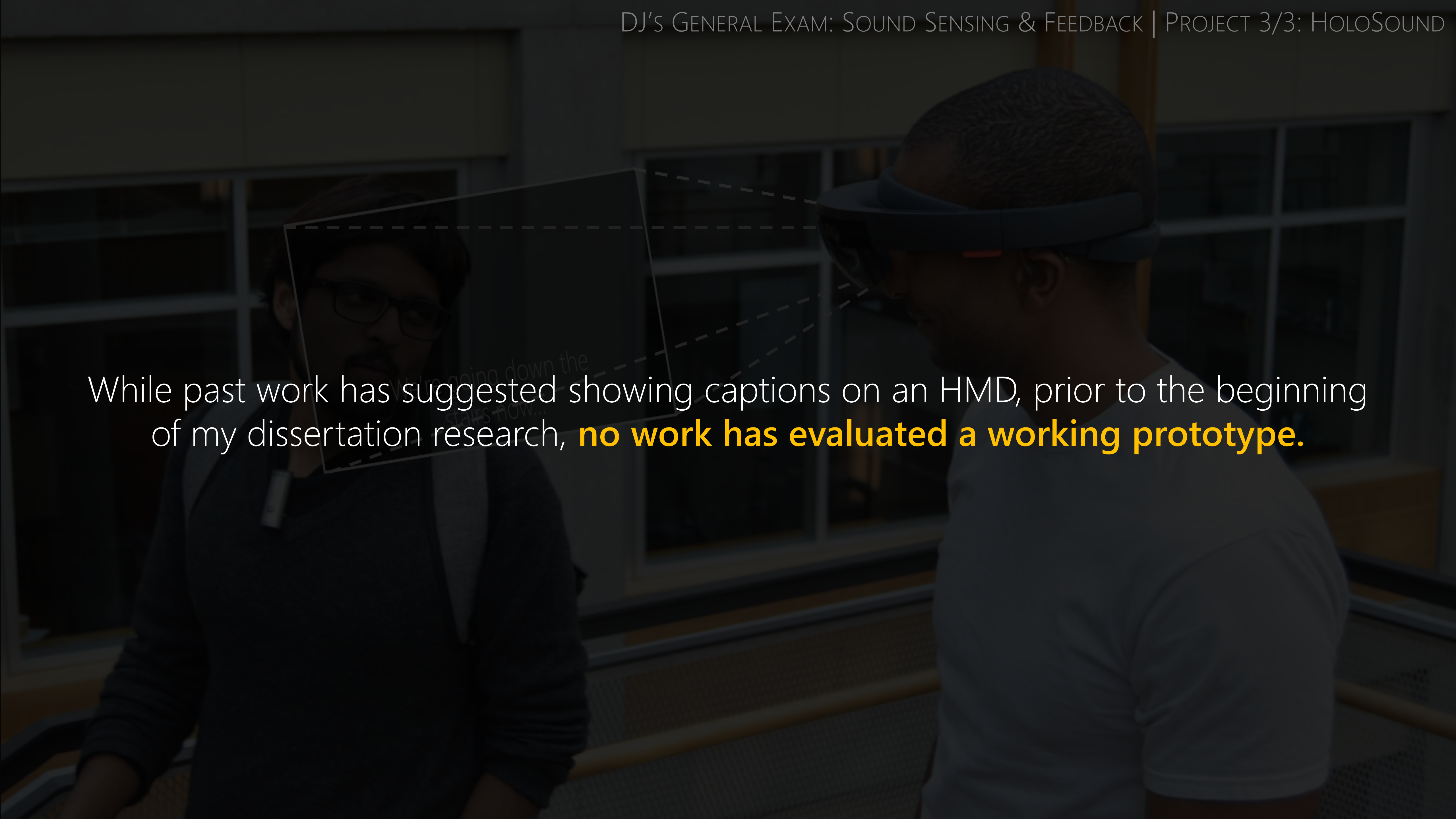


or on a smartphone...

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.**

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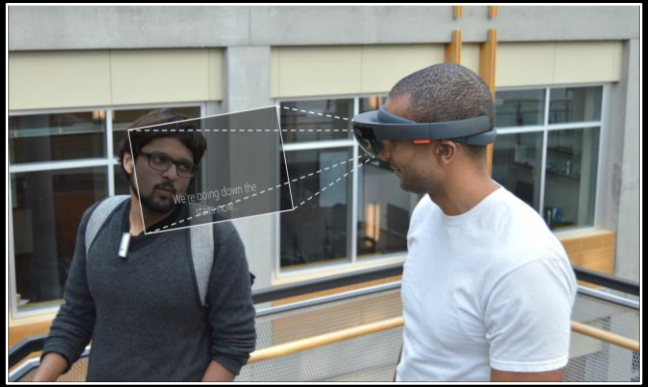
Yellow: proposed work

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

Non-speech sound feedback

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Yellow: proposed work

Non-speech sound feedback

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Field study

HoloSound

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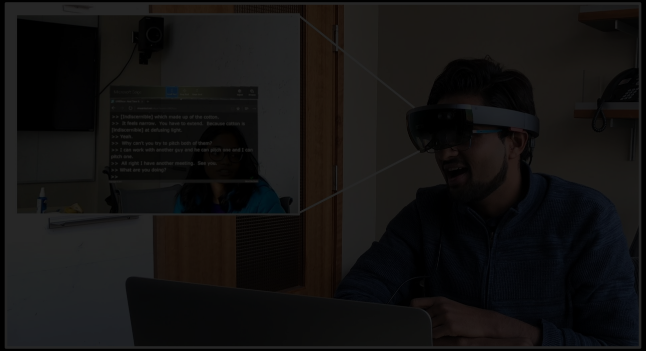
Field study

Proposed work 3

Yellow: proposed work

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.


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?
>>
Too Bulky!

Vuzix Blade


Google's Wearable Subtitles

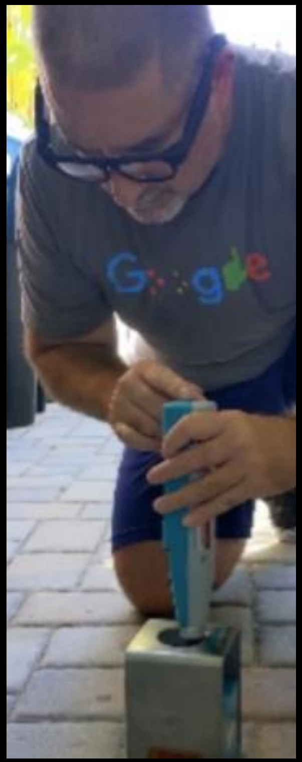
Proposed Work 3: **HMD-Captioning Field-Deployment**

1. How do DHH users use HMD-based captioning in uncontrolled settings? Does the usage change over time or with context (e.g., at home vs. while mobile)?

2. How does the long-term use of the device affect communication?

3. What social implications exist when using HMD captioning in different settings, such as alone, with friends, or with unfamiliar conversation partners.

Proposed Work 3: **Hmd-Captioning Field-Deployment**



Phase 1: Pilot Testing

- 3-5 DHH participants for one week each
- Protocol: Pre/post interviews, weekly surveys, a lightweight in-situ feedback form, usage logs

Phase 2: One-month Deployment

- 10-12 DHH participants
- Protocol: Pre/post interviews, weekly surveys, a lightweight in-situ feedback form, usage logs

Proposed Work 3: **Expected Contributions**

1 Characterization of real-world usage of HMD-based captioning across a variety of contexts

2 Design guidelines for future HMD-based sound awareness systems

...and improved HMD-captioning prototypes for the world!

Summary

HomeSound

Two formative studies

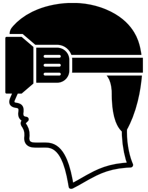
Field studies

SoundWatch

Two studies

End-user customization

Field study



HoloSound

Three initial explorations

Field study

Blue: completed work
Yellow: proposed work

Technical Novelty

HomeSound

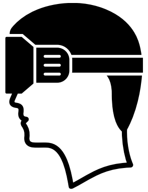
System development

Sound recognition

SoundWatch

On-device sound recognition

Meta learning

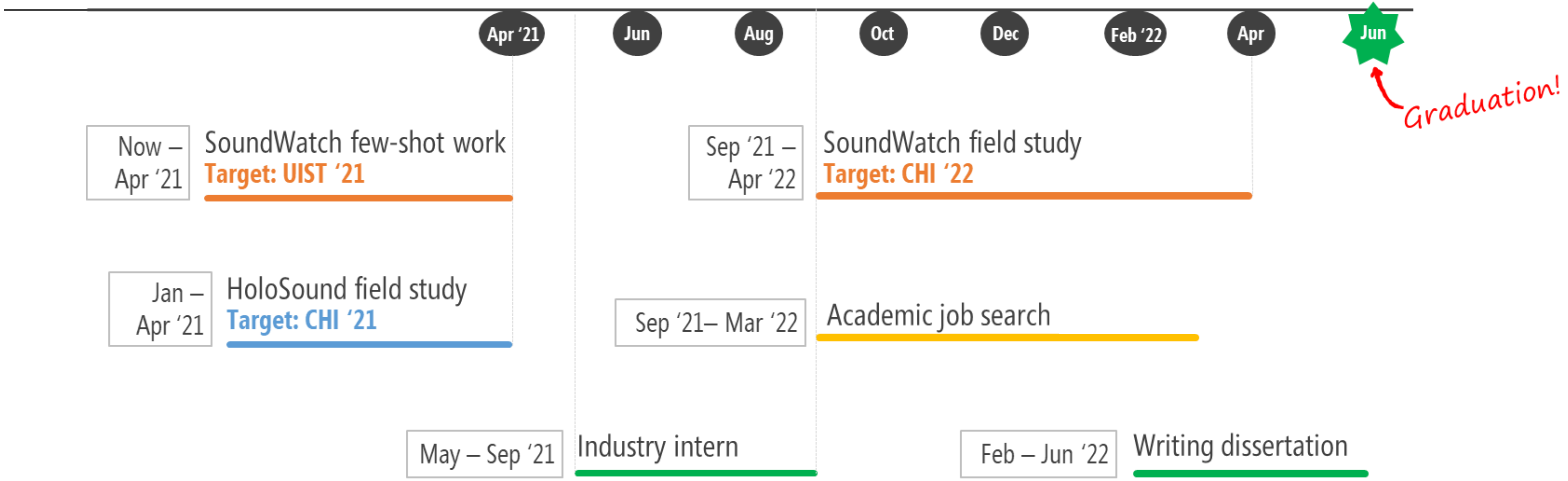


HoloSound

Hardware design

Blue: completed work
Yellow: proposed work

Timeline



Apr '21
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Feb '22
Apr
Jun
Graduation!
Now – Apr '21
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Target: UIST '21
Sep '21 – Apr '22
SoundWatch field study
Target: CHI '22
Jan – Apr '21
HoloSound field study
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Academic job search
May – Sep '21
Industry intern
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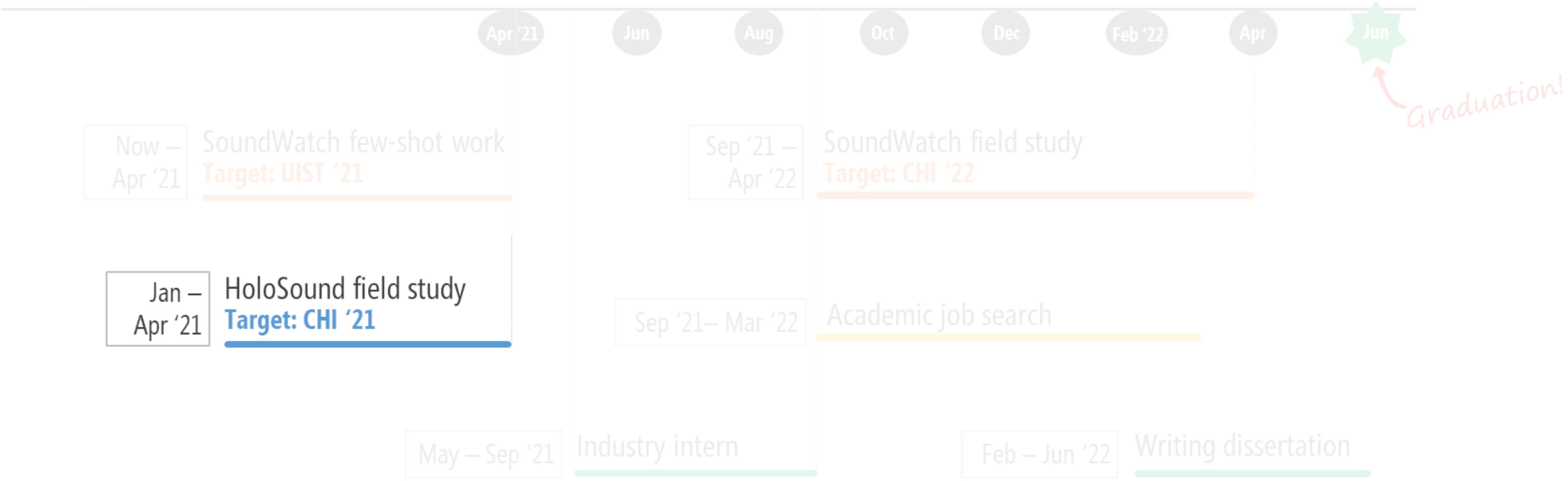

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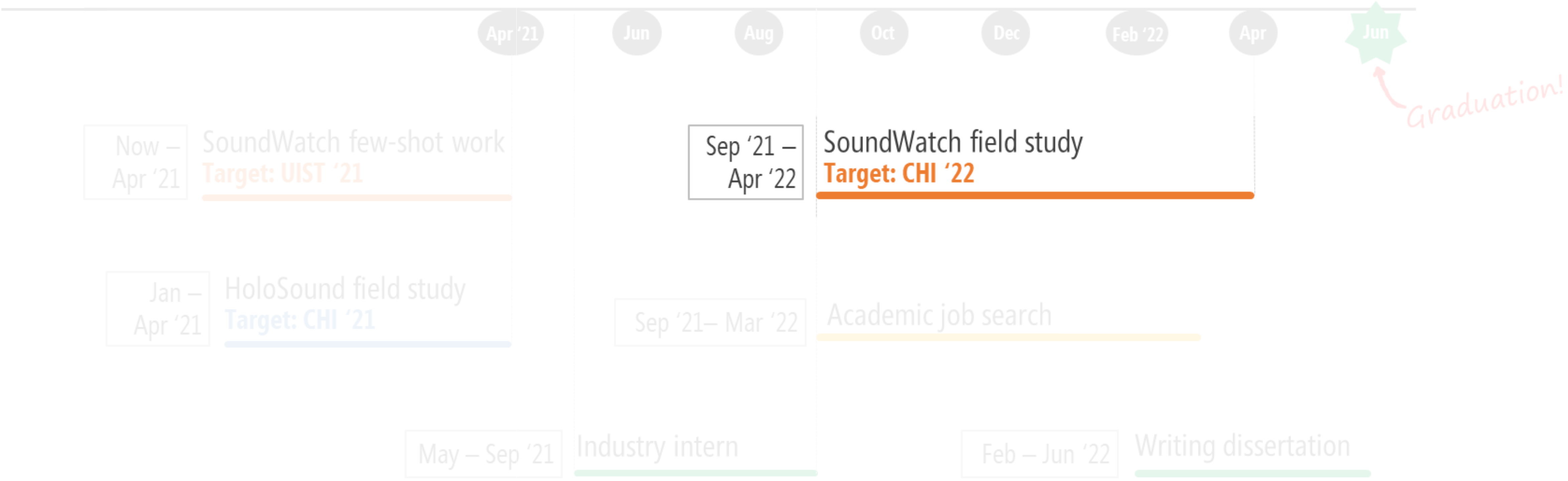
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Reflections

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

Advisors


Jon Froehlich


Leah Findlater

You're all awesome!

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Jon Froehlich


Leah Findlater


Jacob Wobbrock


Jen Mankoff


Richard Ladner


Jeffrey Bigham

Friends, Family, and Colleagues

Steven Goodman, Emma McDonnell, Venkatesh Potluri, Kelly Mack, Liang He, Manaswi Saha, Rose Guttman, Ana Liu, Pratyush Patel, Sudheesh Singanamalla, Aditya Kusupati, Tapan Chugh, Raghav Somani, Tanu, Arjun Bhatia, Sophie Tian, Ruchi Gupta, Alok Jain, Kunal Jain, Aaron Timms, Emma Gebben, Elise Dorough, Elle Brown, Brianna Blaser, Aileen Zeng, Marcus Amalachandran, Angela Lin, Raja Kushalnagar, Christian Vogler, Greg Goodman, Robin Yang, Hung Ngo, Khoa Nguyen, AccessComputing and many more…

Any Questions?

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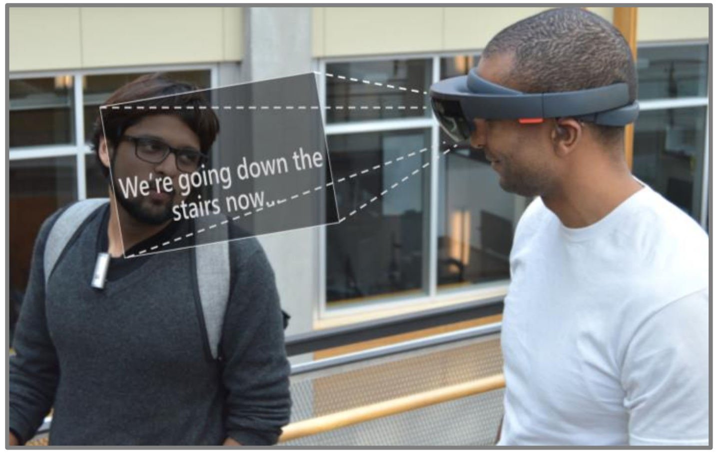
HomeSound

SoundWatch



HoloSound