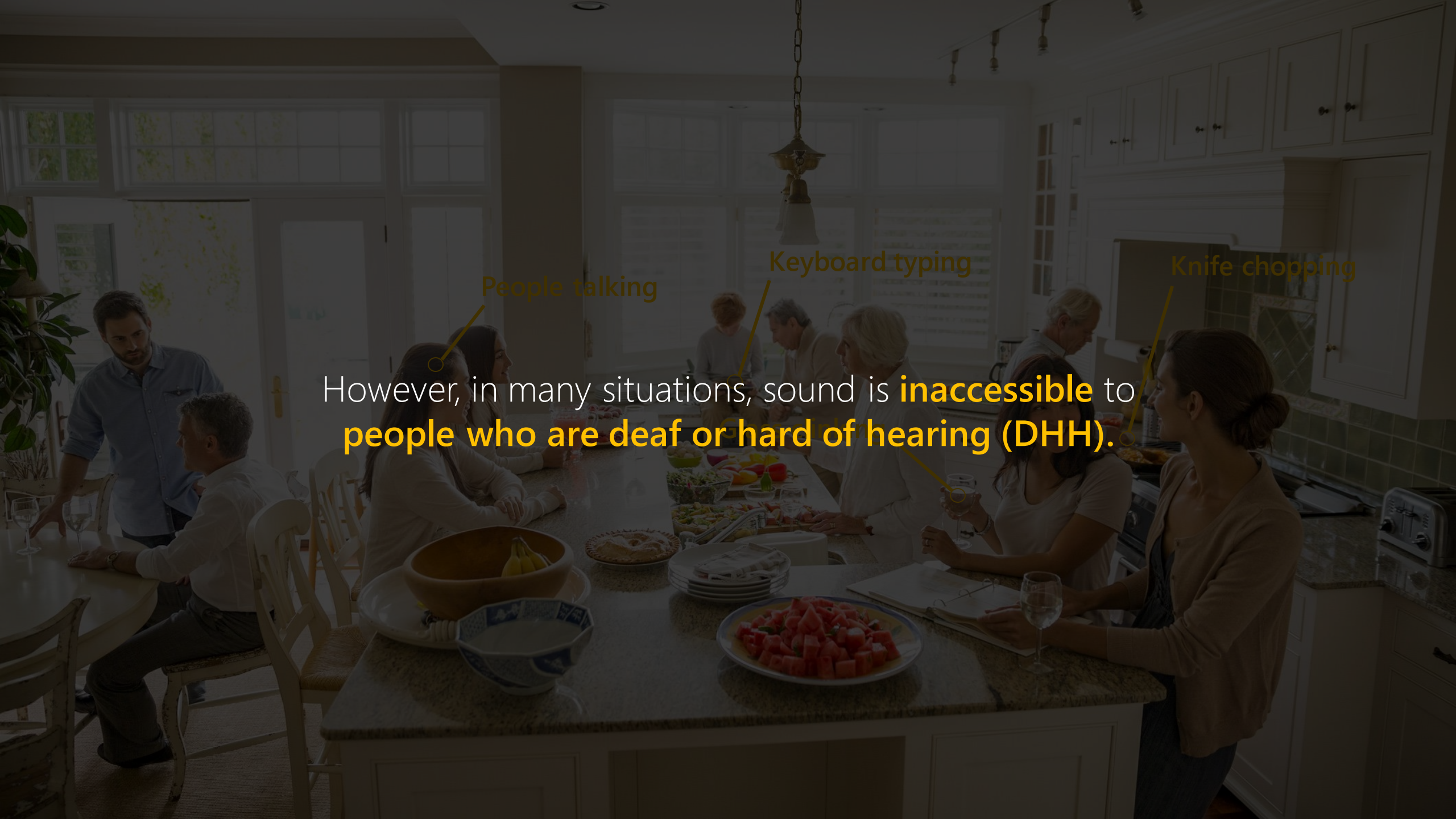
Field Deployment of a **Smarthome Sound Awareness System** for Deaf or Hard of Hearing Users

Dhruv Jain (DJ)
University of Washington, Seattle


The home environment is filled with a
rich diversity of sounds

These sounds inform us about the **home, home activities** and the **household members**.



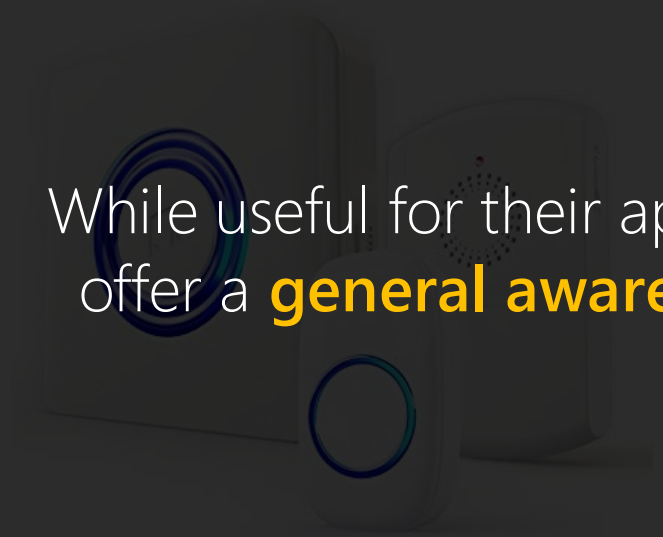
However, in many situations, sound is **inaccessible** to **people who are deaf or hard of hearing (DHH).**

Fortunately, DHH people use **visual** or **vibratory** alternatives…

Flashing Doorbell

Vibratory Bed Alarm

Fortunately, DHH people use **visual** or **vibratory** alternatives…



While useful for their applications, these products **do not** offer a **general awareness** about sounds in the home.

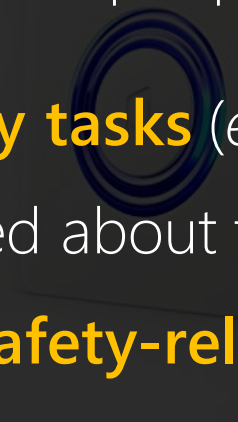
FLASHING DOORBELL

VIBRATORY BED ALARM

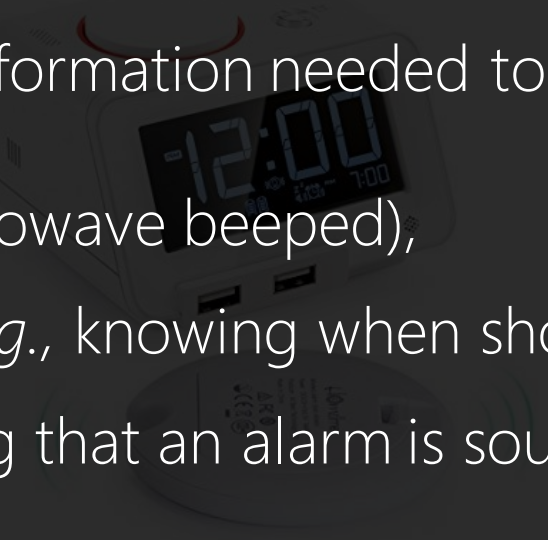
Fortunately, DHH people use **visual** or **vibratory** alternatives…

As a result, DHH people miss out on important information needed to:

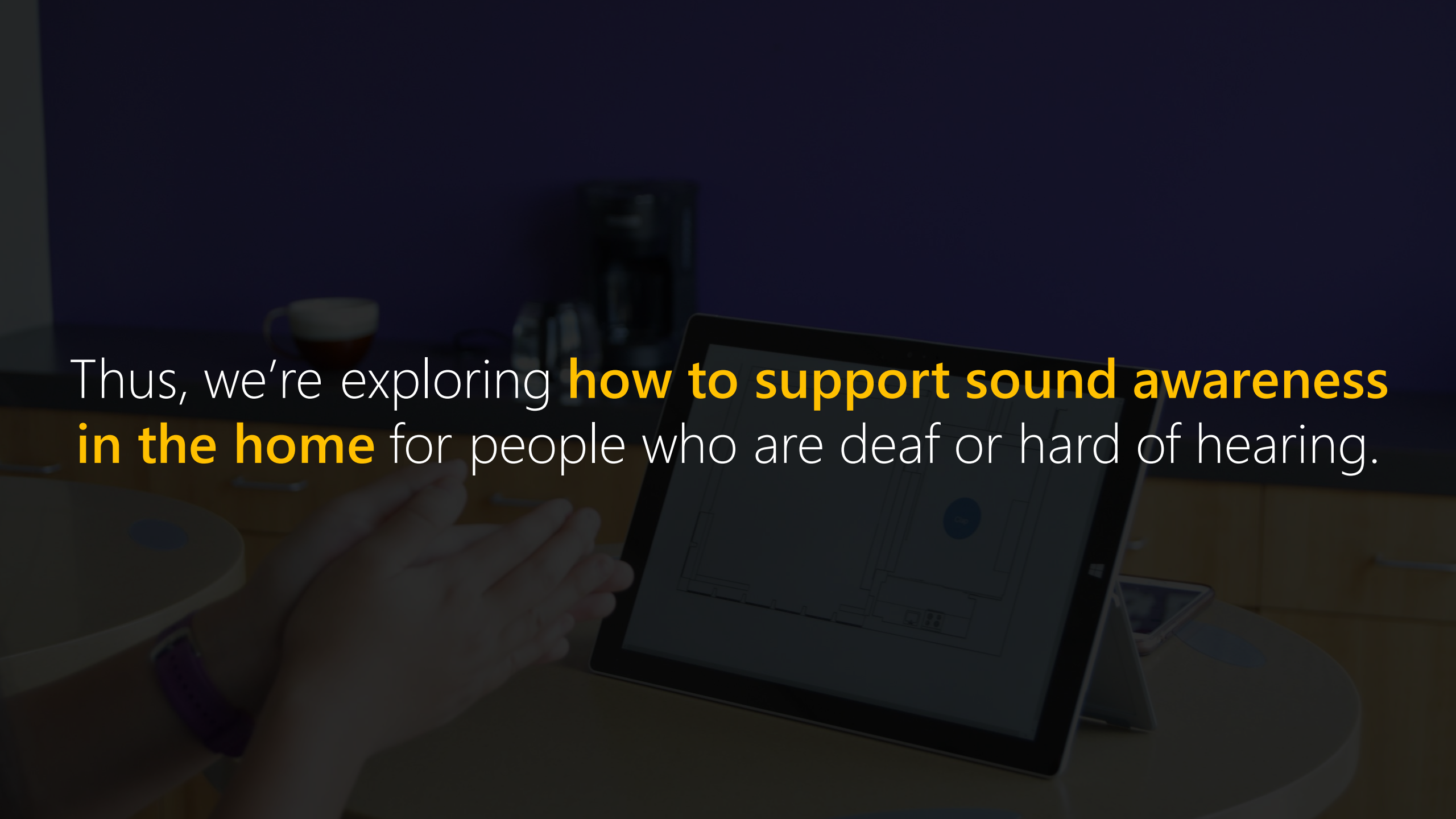
perform **daily tasks** (*e.g.*, knowing when the microwave beeped),
keep informed about the **state of their home** (*e.g.*, knowing when shower is running),
or perform **safety-related tasks** (*e.g.*, by knowing that an alarm is sounding).



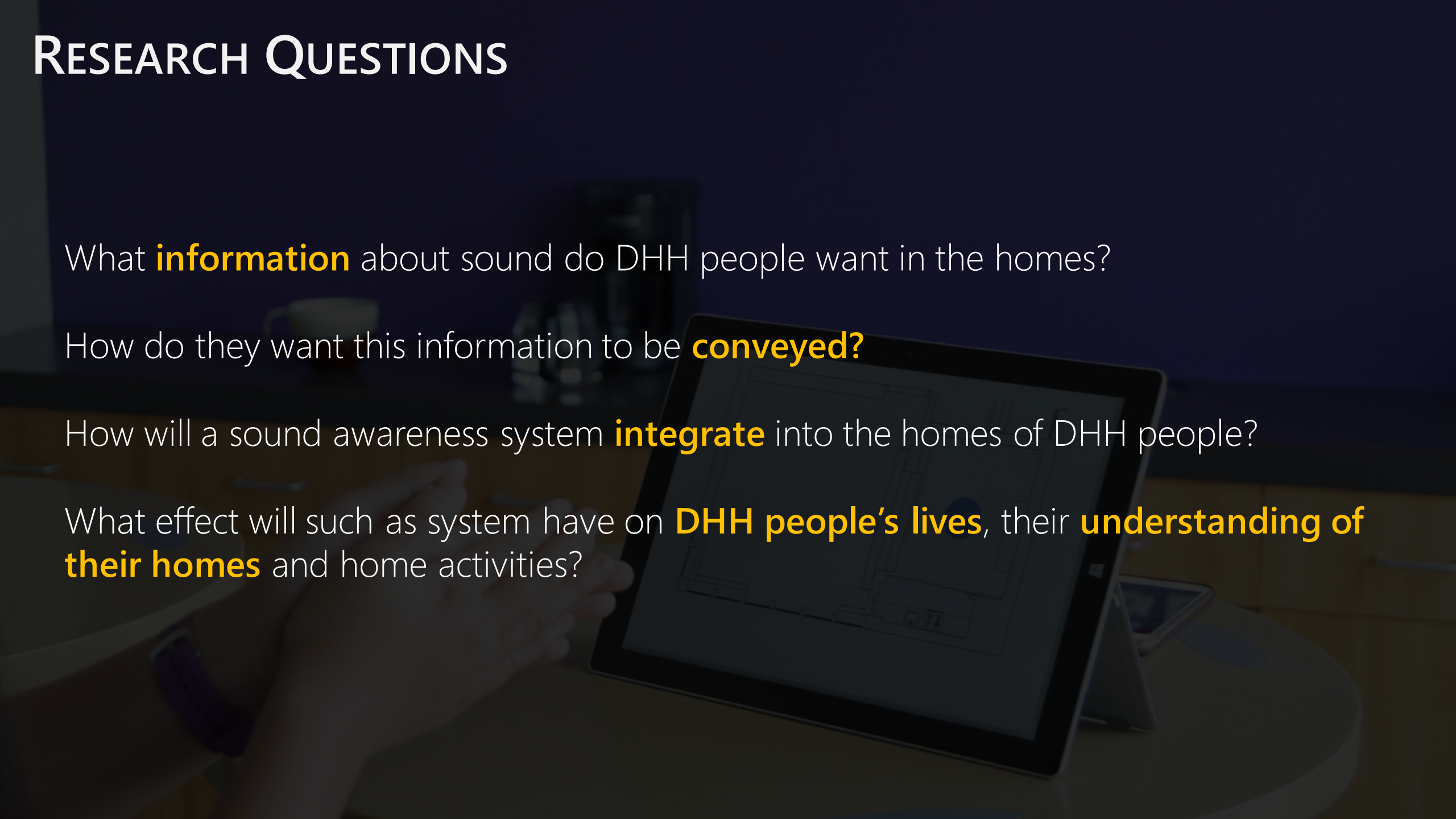
FLASHING DOORBELL



VIBRATORY BED ALARM


Thus, we're exploring **how to support sound awareness in the home** for people who are deaf or hard of hearing.

Research Questions



What **information** about sound do DHH people want in the homes?

How do they want this information to be **conveyed?**

How will a sound awareness system **integrate** into the homes of DHH people?

What effect will such as system have on **DHH people's lives**, their **understanding of their homes** and home activities?

Two Phase Project

Year 1 Investigating the **sound awareness needs** of DHH people and **designs of sound awareness** visualizations

Published at CHI 2019

Year 2 **Design** and **field evaluation** of two **iterative prototypes** of in-home sound awareness system

Today's talk

An Iterative Field Deployment of an In-Home Sound Awareness System for Deaf or Hard of Hearing Users

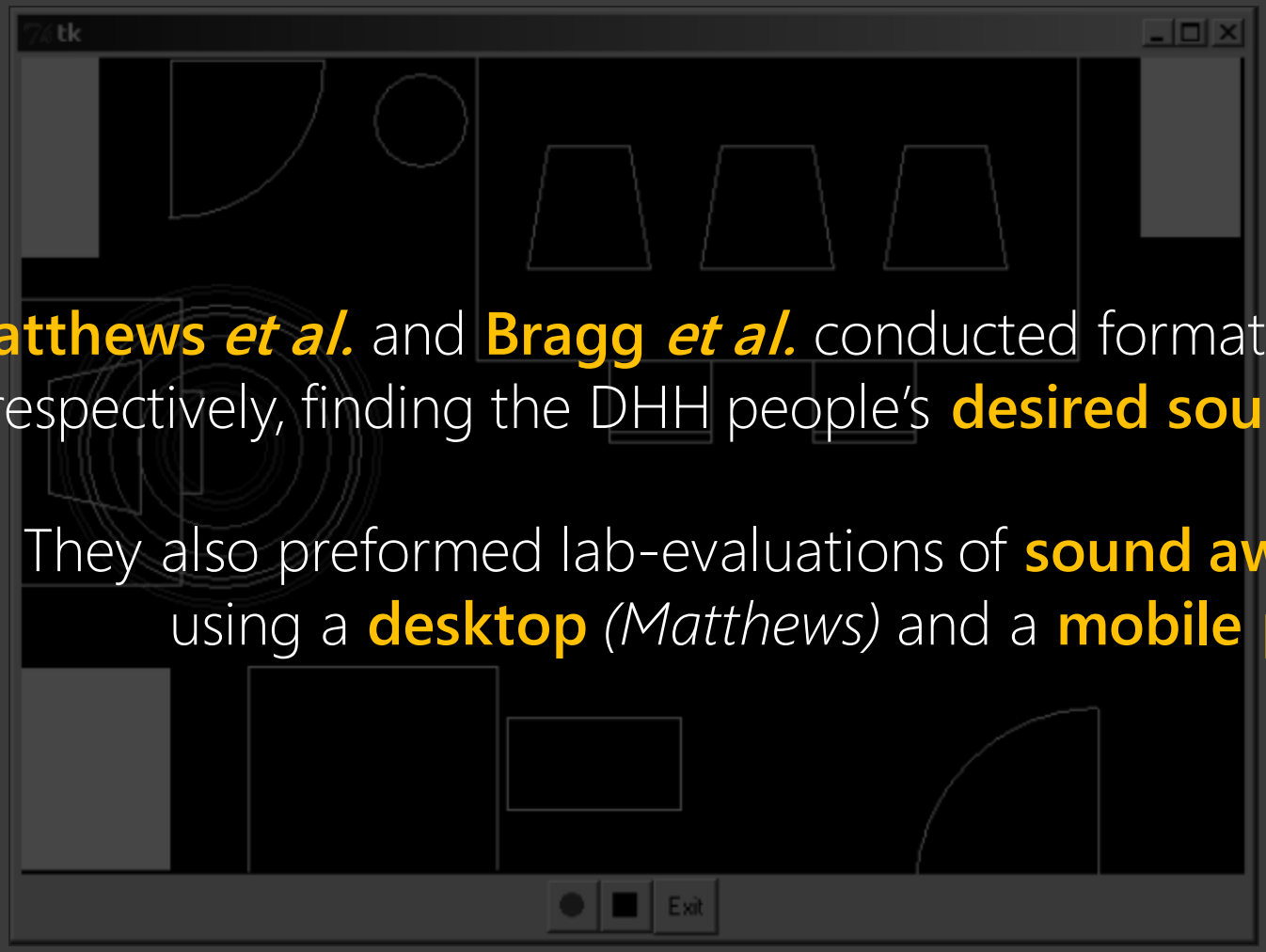
Dhruv Jain (DJ)
Advisers: Jon Froehlich, Leah Findlater
University of Washington, Seattle

Picture credit: Kelly Mack

Related Work

Several formative studies have explored the **needs and preferences of DHH people** for home-based sound awareness systems.

Related Work



(Matthews *et al.*, *ASSETS 2007*)

Matthews *et al.* and **Bragg *et al.*** conducted formative interviews and online survey respectively, finding the DHH people's **desired sounds of interest** for the home.

They also preformed lab-evaluations of **sound awareness feedback designs** using a **desktop** *(Matthews)* and a **mobile phone** *(Bragg)* display.

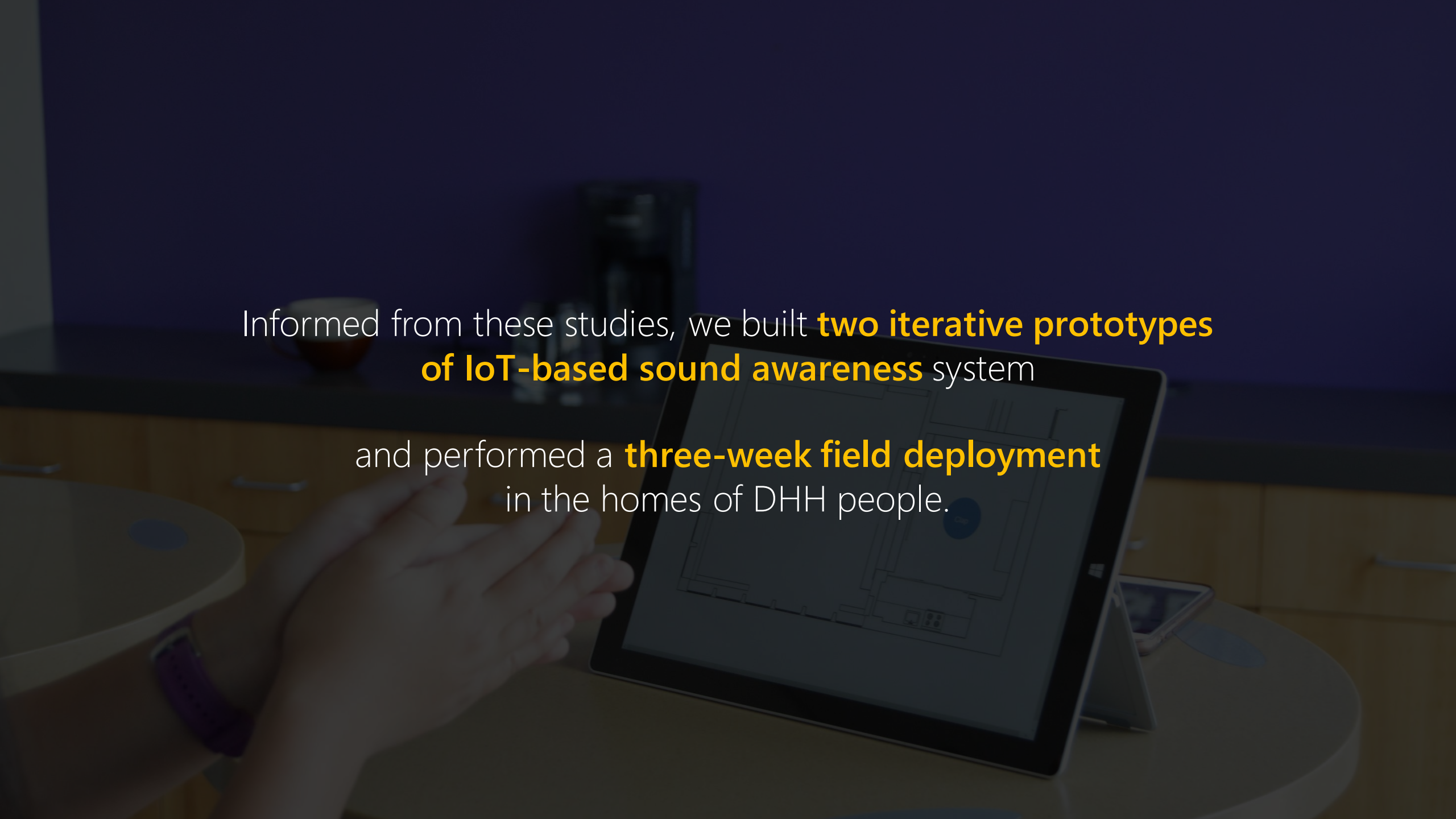
(Bragg *et al.*, *ASSETS 2016*)

Related Work

In our **CHI 2019 work,** we built and evaluated a **Wizard-of-Oz smarthome-based** sound awareness display with 22 DHH participants.

Our findings provide **several design suggestions**, including how to mitigate concerns that may arise while using a sound awareness technology at home (*e.g.*, issues of **privacy,** activitiy **tracking**).

(Jain *et al.*, CHI 2019)



Informed from these studies, we built **two iterative prototypes of IoT-based sound awareness** system

and performed a **three-week field deployment** in the homes of DHH people.

Outline

Prototype 1 → **Study 1** → **Prototype 2** → **Study 2**

Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

Prototype 1 deployment

Conveyed more complex sound features (e.g., sound identity)

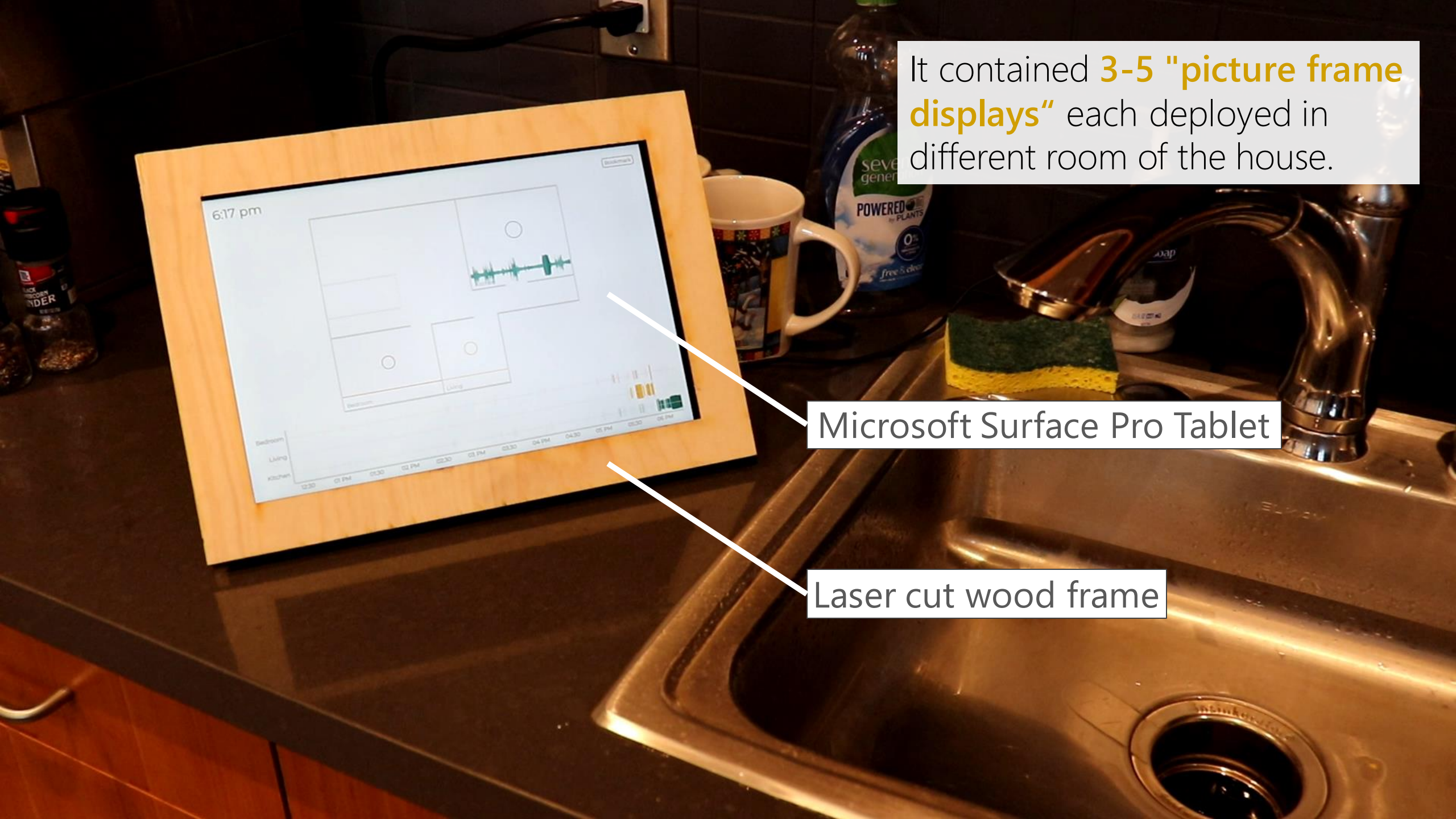
Prototype 2 deployment

Outline

Prototype 1
Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

Our goal was to examine how DHH users would react to a system which conveyed **"easy to sense" sound properties,** such as **loudness** and **pitch**, before exploring complex probabilistic characteristics (*e.g.*, sound type).

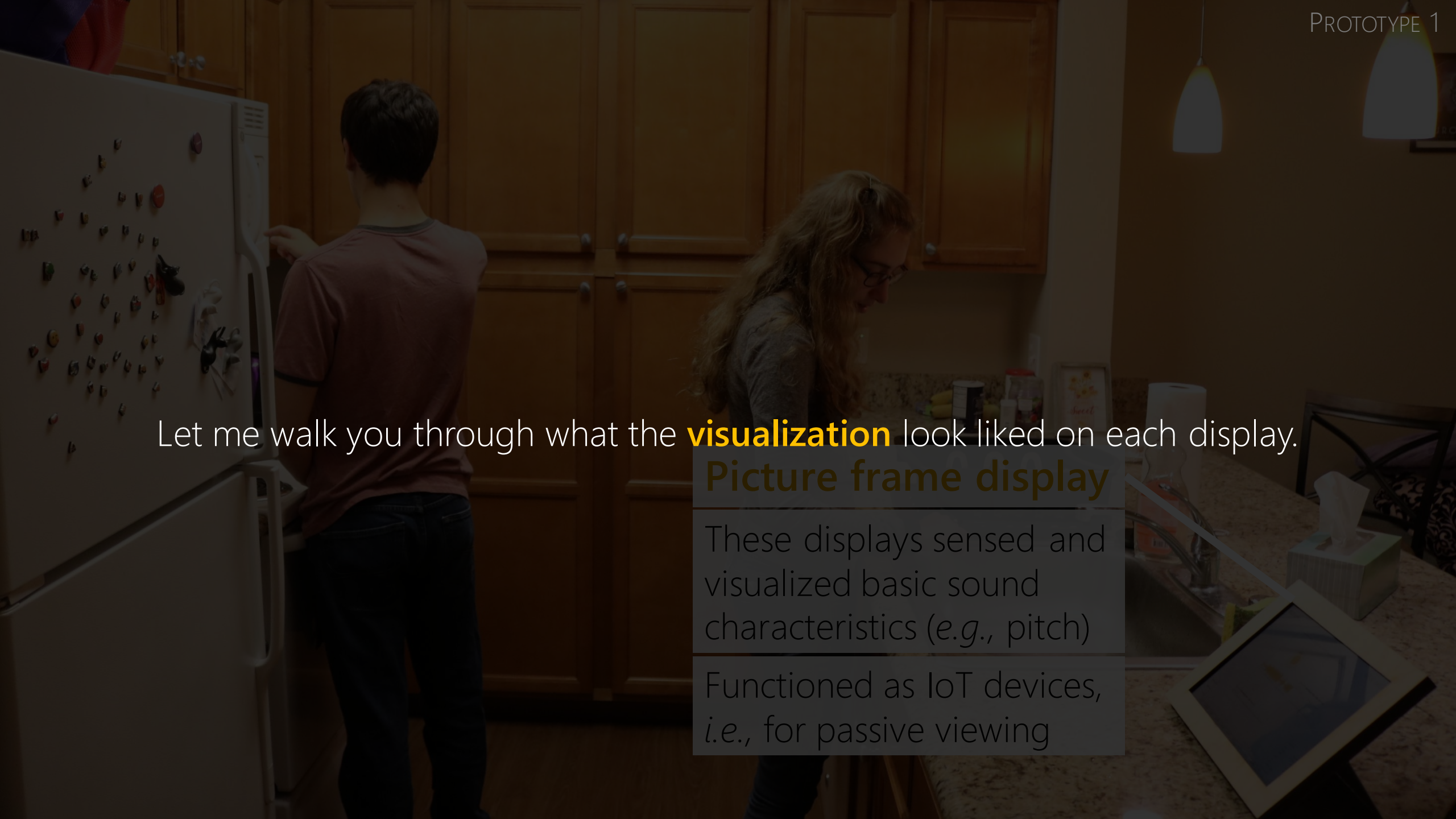
This prototype was inspired by the new commercially available **display-based IoT devices** like the Amazon Echo Show…


It contained 3-5 "picture frame displays" each deployed in different room of the house.
Microsoft Surface Pro Tablet
Laser cut wood frame
6:17 pm

Picture frame display

These displays sensed and visualized basic sound characteristics (*e.g.*, pitch)

Functioned as IoT devices, *i.e.*, for passive viewing



Let me walk you through what the **visualization** look liked on each display.

Picture frame display

These displays sensed and visualized basic sound characteristics (*e.g.*, pitch)

Functioned as IoT devices, *i.e.*, for passive viewing

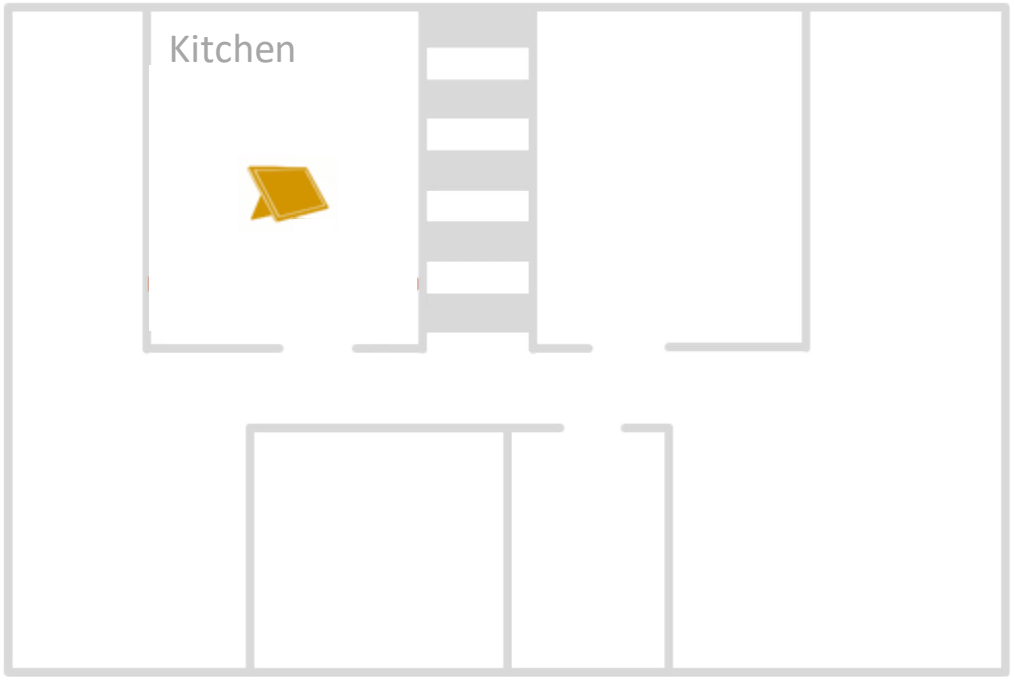
Imagine a **two-floor** home....

First floor

Second floor

And this is an **approximate floorplan** of the home...

First floor



Second floor

Say we **install our tablets in three rooms** of the house.

6:06 pm

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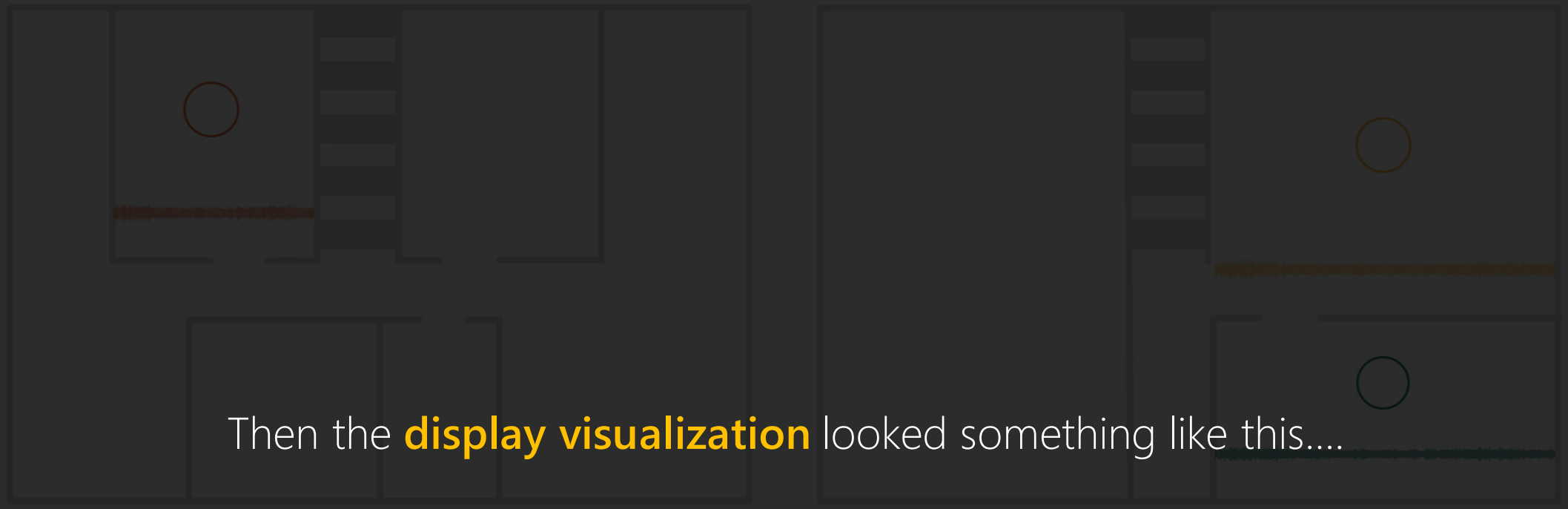
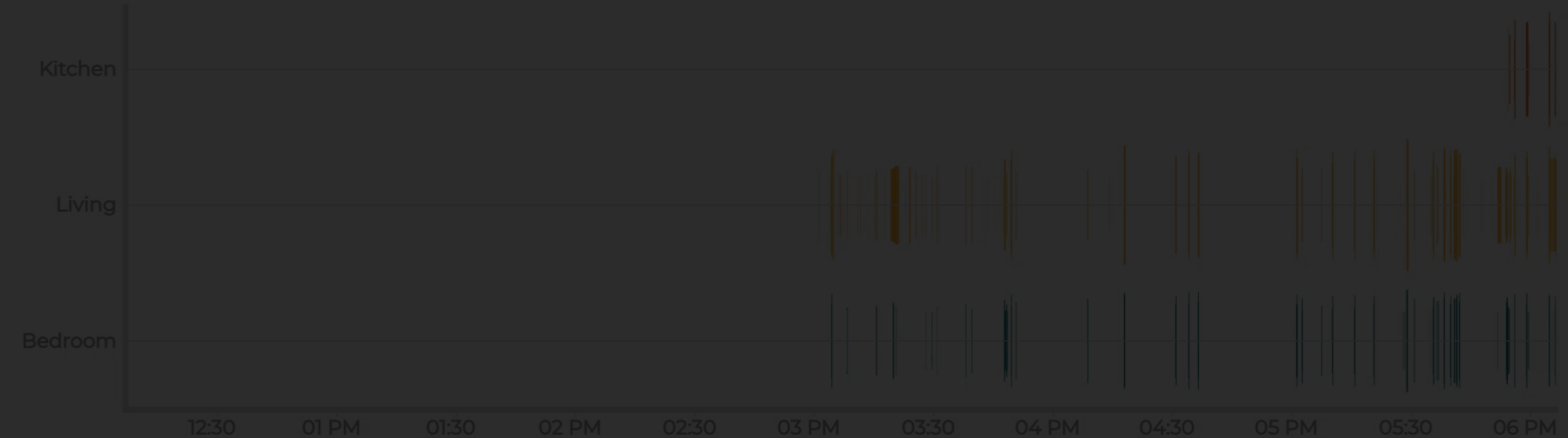


Then the **display visualization** looked something like this....



6:06 pm

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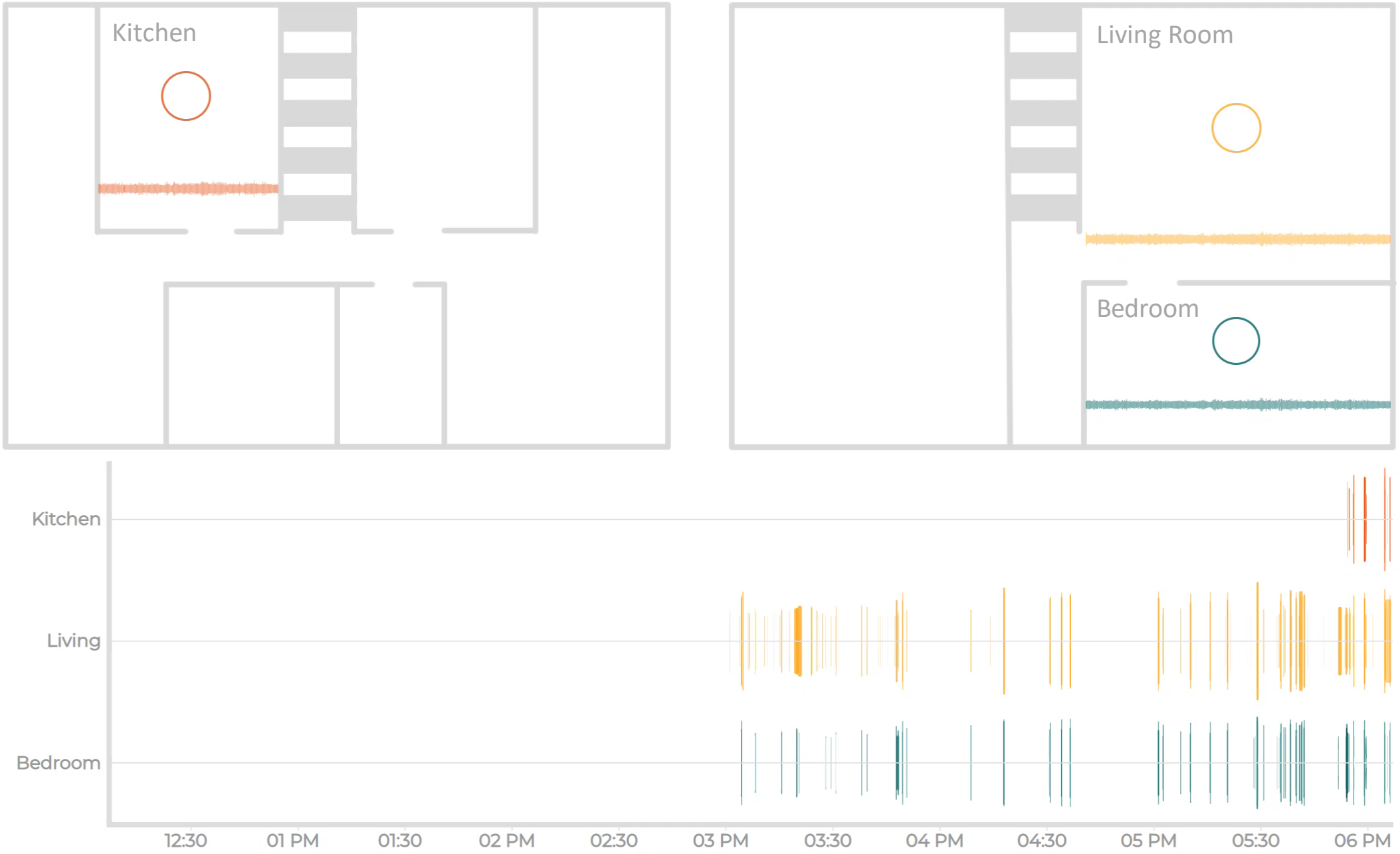
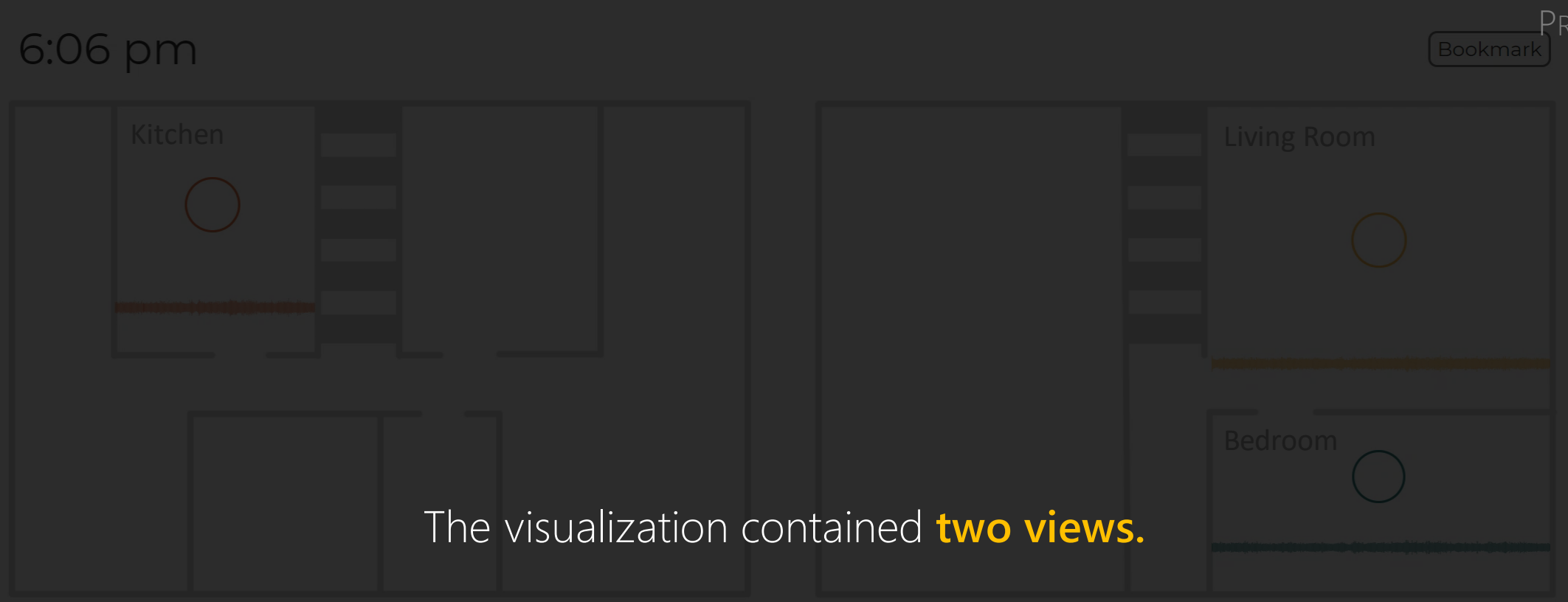
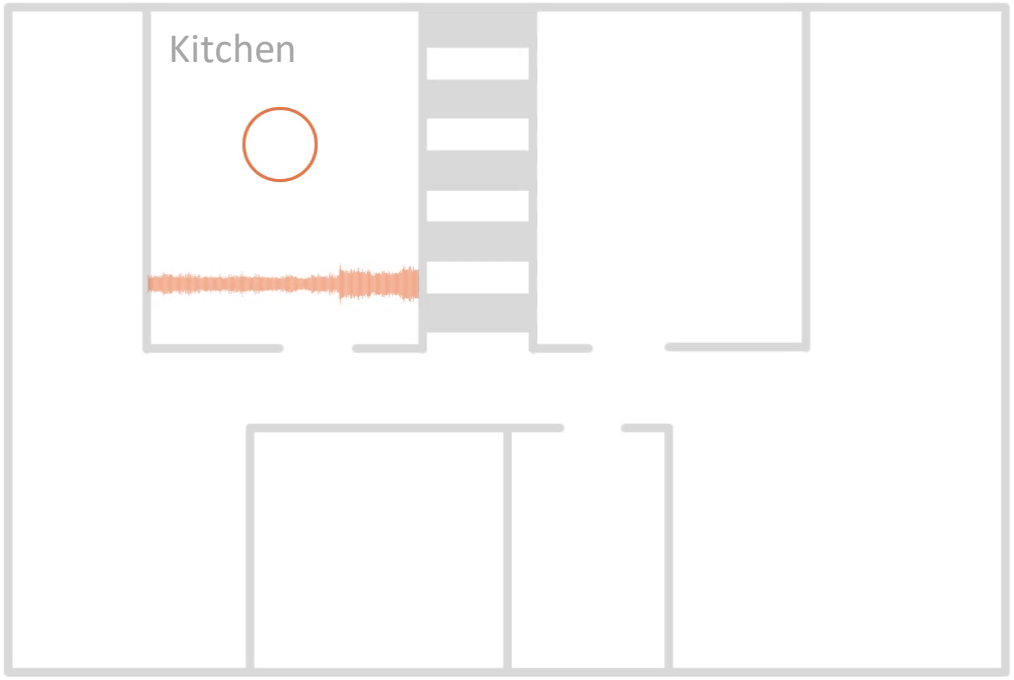
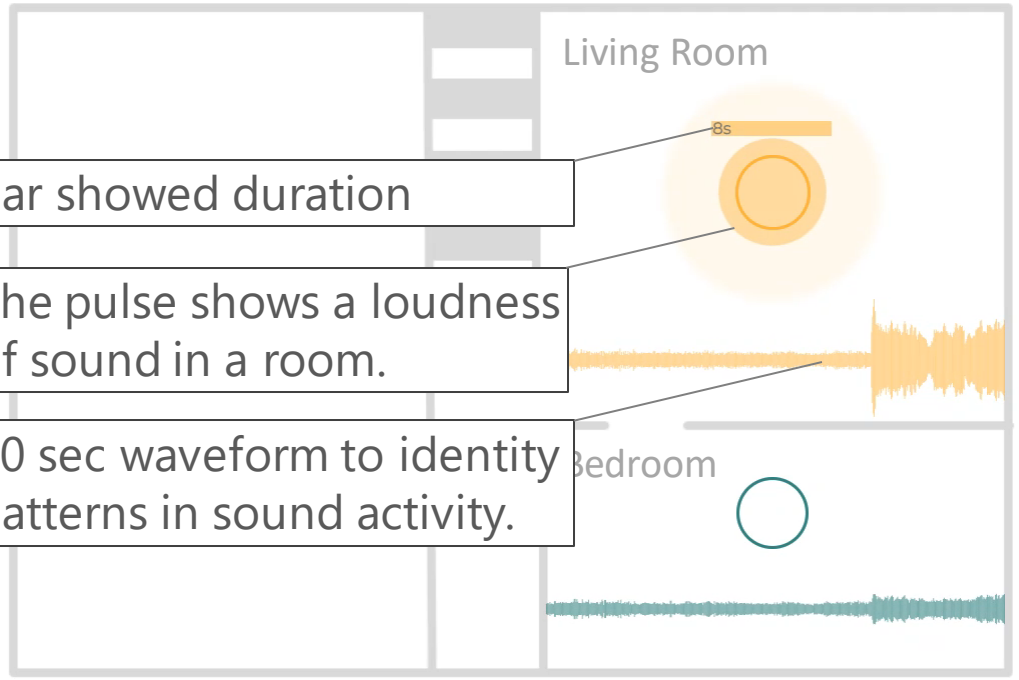



6:06 pm
Bookmark
Kitchen
Living Room
Bedroom
The visualization contained two views.
Kitchen
Living
Bedroom
12:30
01 PM
01:30
02 PM
02:30
03 PM
03:30
04 PM
04:30
05 PM
05:30
06 PM

6:07 pm

Bookmark

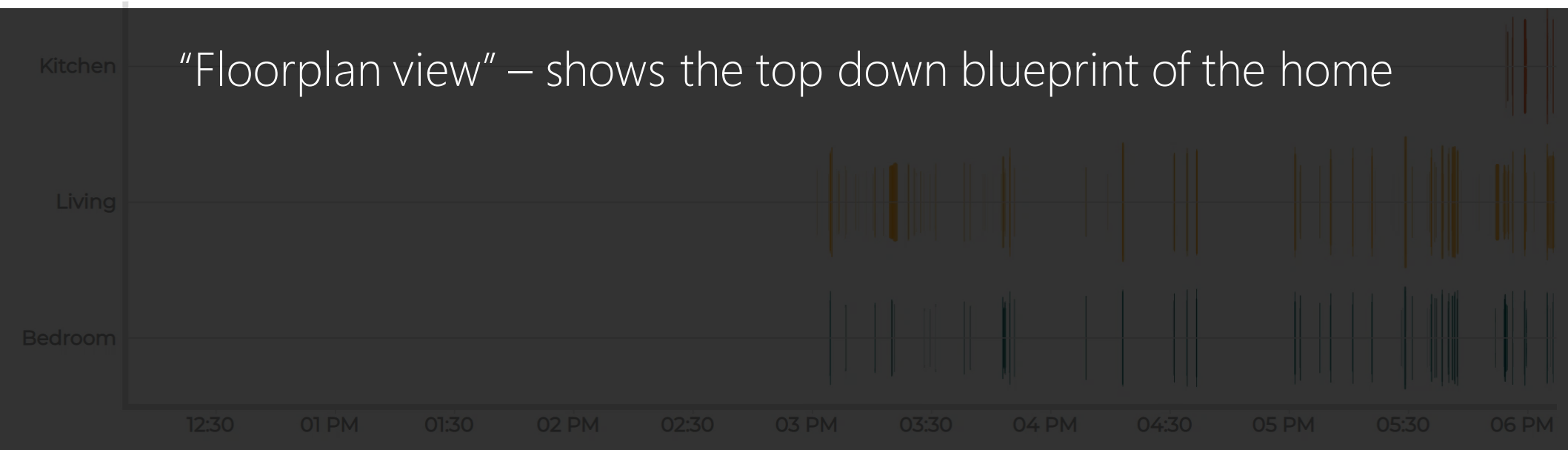




Bar showed duration

The pulse shows a loudness of sound in a room.

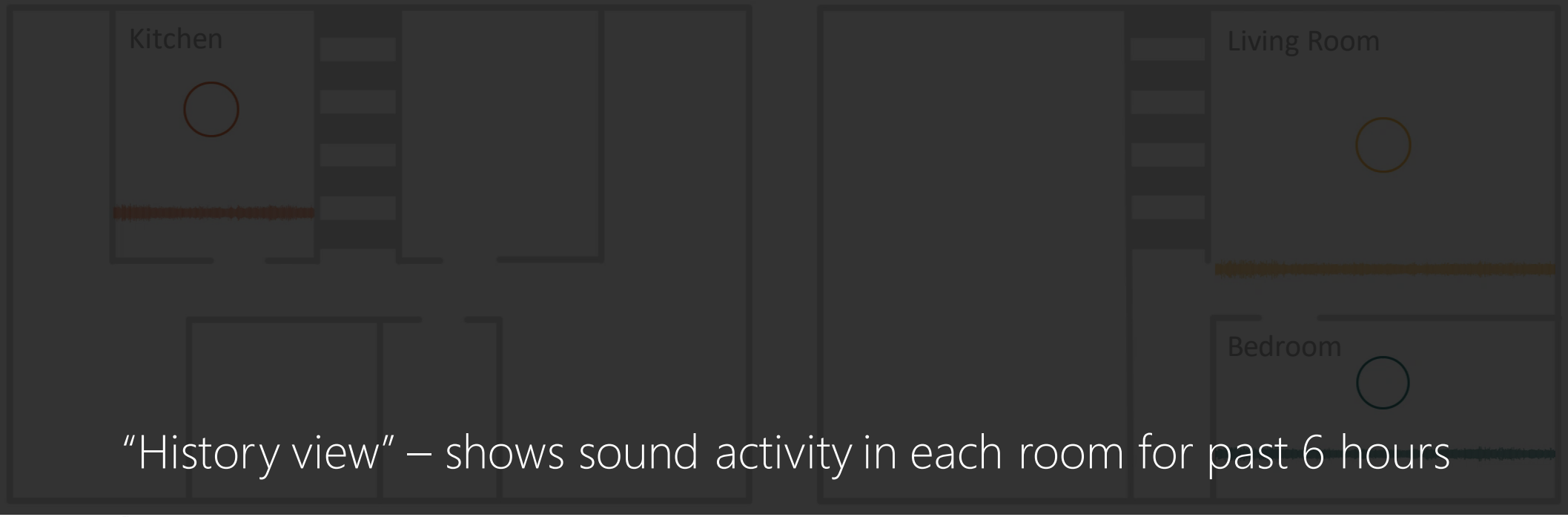
30 sec waveform to identity patterns in sound activity.



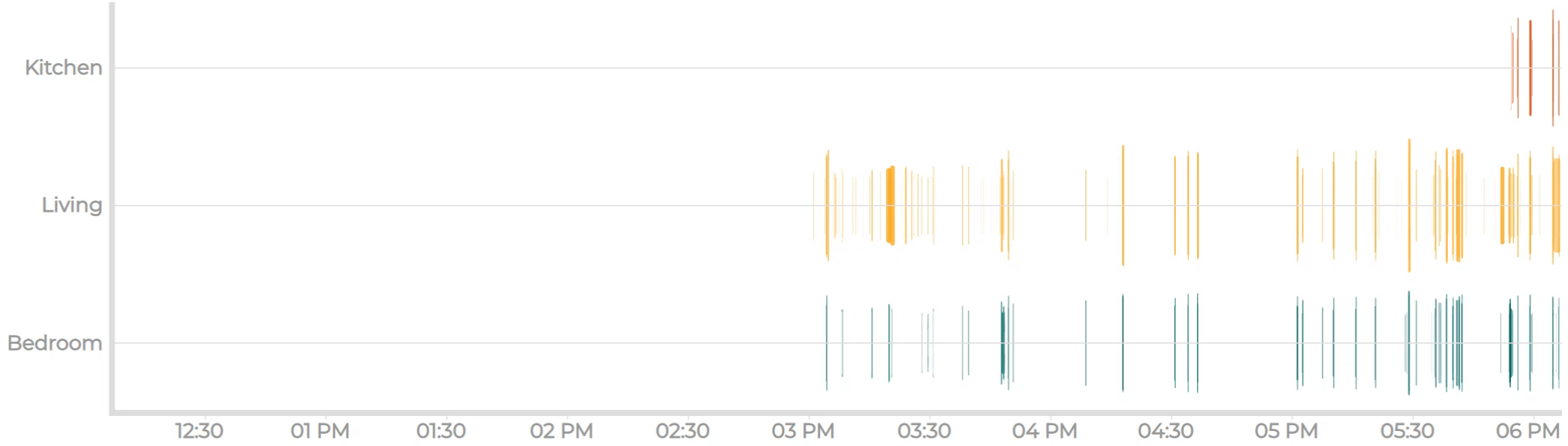
"Floorplan view" – shows the top down blueprint of the home

6:06 pm

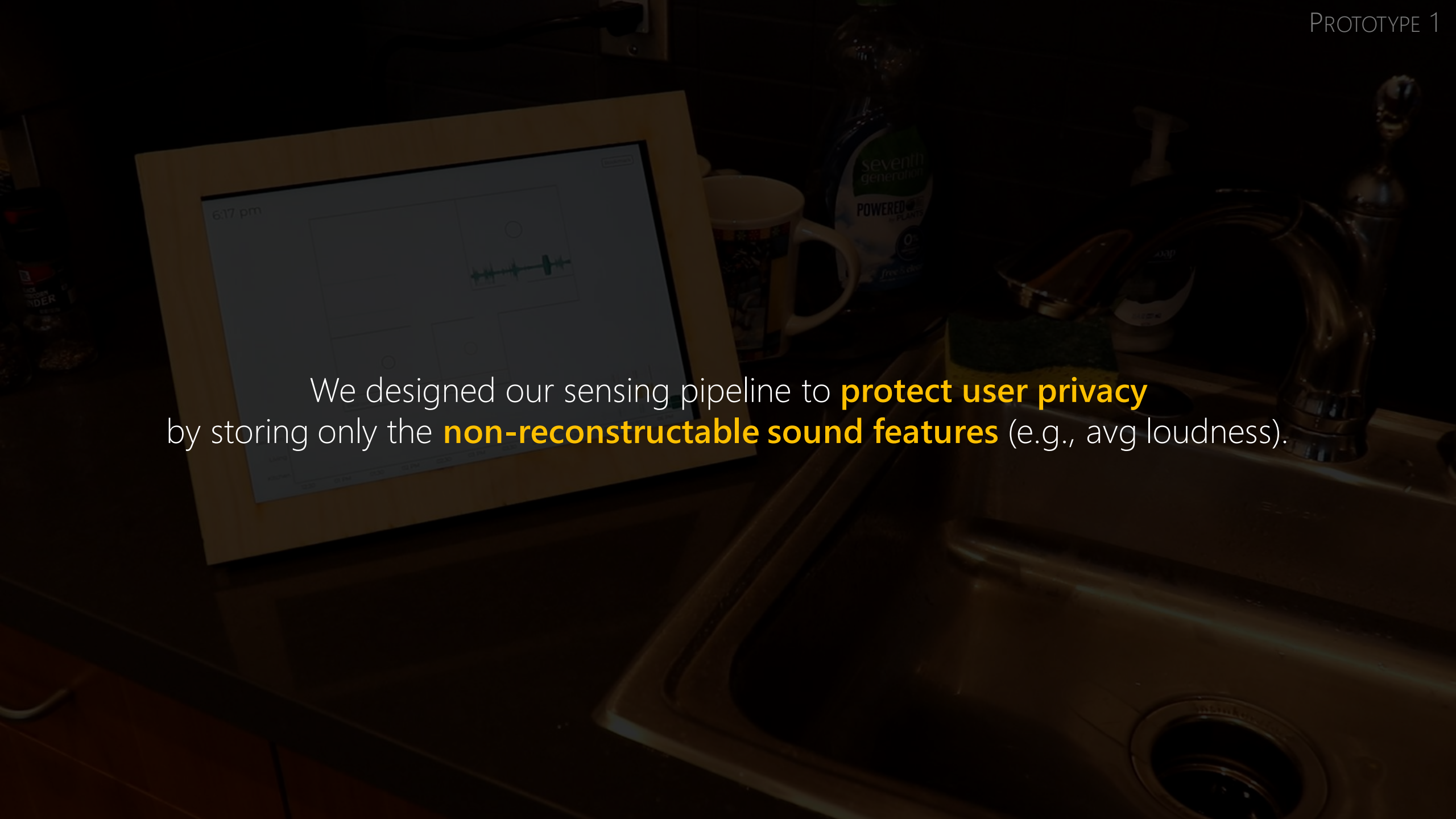
Bookmark



"History view" – shows sound activity in each room for past 6 hours




6:17 pm
Bookmark
Bedroom
Living
Kitchen
12:30
01 PM
01:30
02 PM
02:30
03 PM
03:30
04 PM
04:30
05 PM
05:30
06 PM
seventh generation
POWERED by PLANTS



We designed our sensing pipeline to **protect user privacy**
by storing only the **non-reconstructable sound features** (e.g., avg loudness).

Outline

Prototype 1

Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

Outline

Prototype 1 → **Study 1**

Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

Prototype 1 deployment

Study 1

Goal

- To examine how DHH users reacted to an in-home sound awareness system that showed simple features

Participants

- 4 Homes; 6 DHH and 1 hearing individual

Study Method

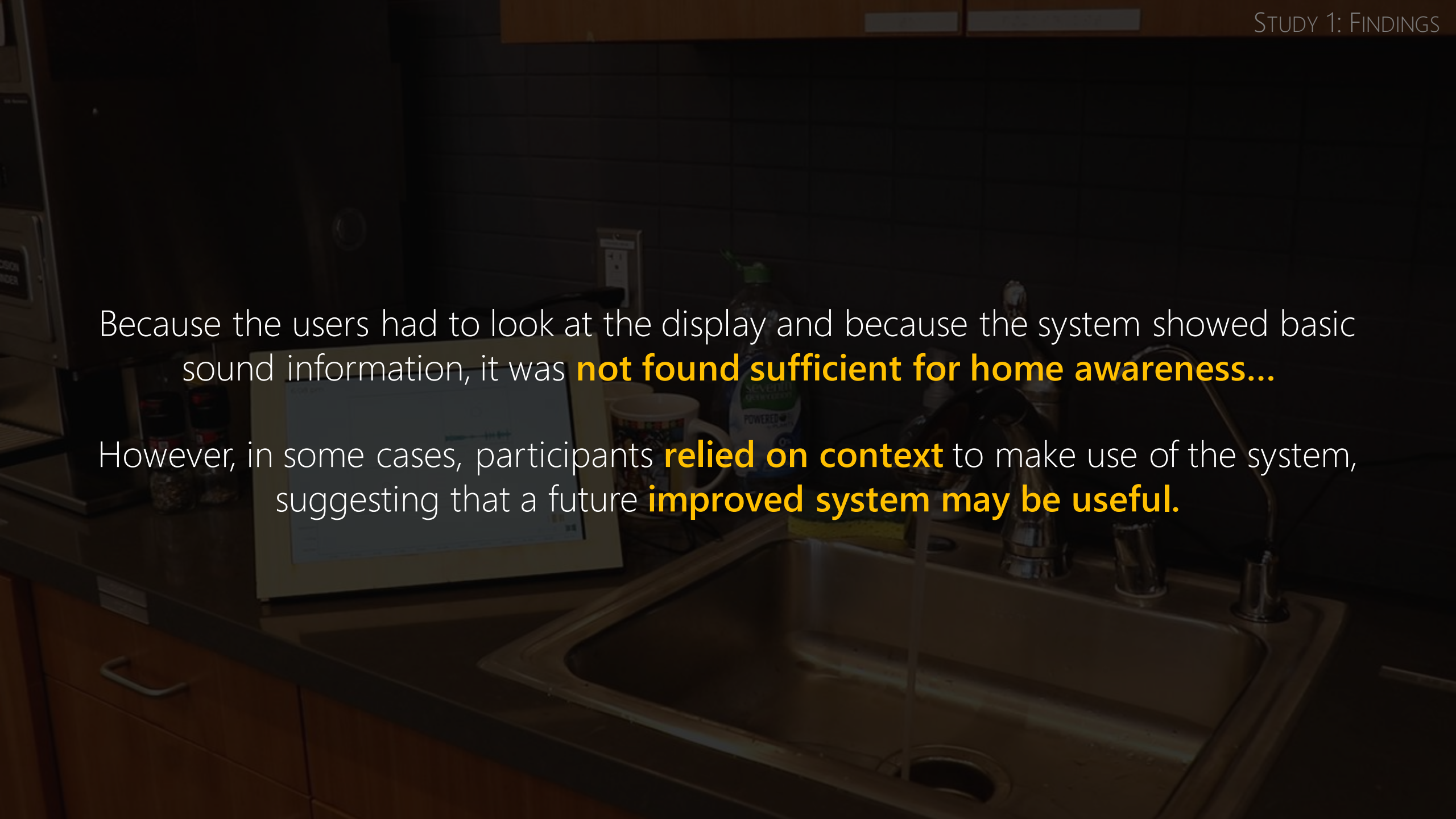
- Initial Interview about experience with sound
- 3 week deployment: 3 weekly surveys + system logs
- Post trial interview about experience with Prototype 1

Data Analysis

- Thematic analysis of interview transcripts + surveys
- Two coders; IRR was 0.66, raw agreement was 86.3%
- Disagreements were resolved through consensus

Study 1 Findings

All DHH participants looked at the displays **at least a few times a day.**

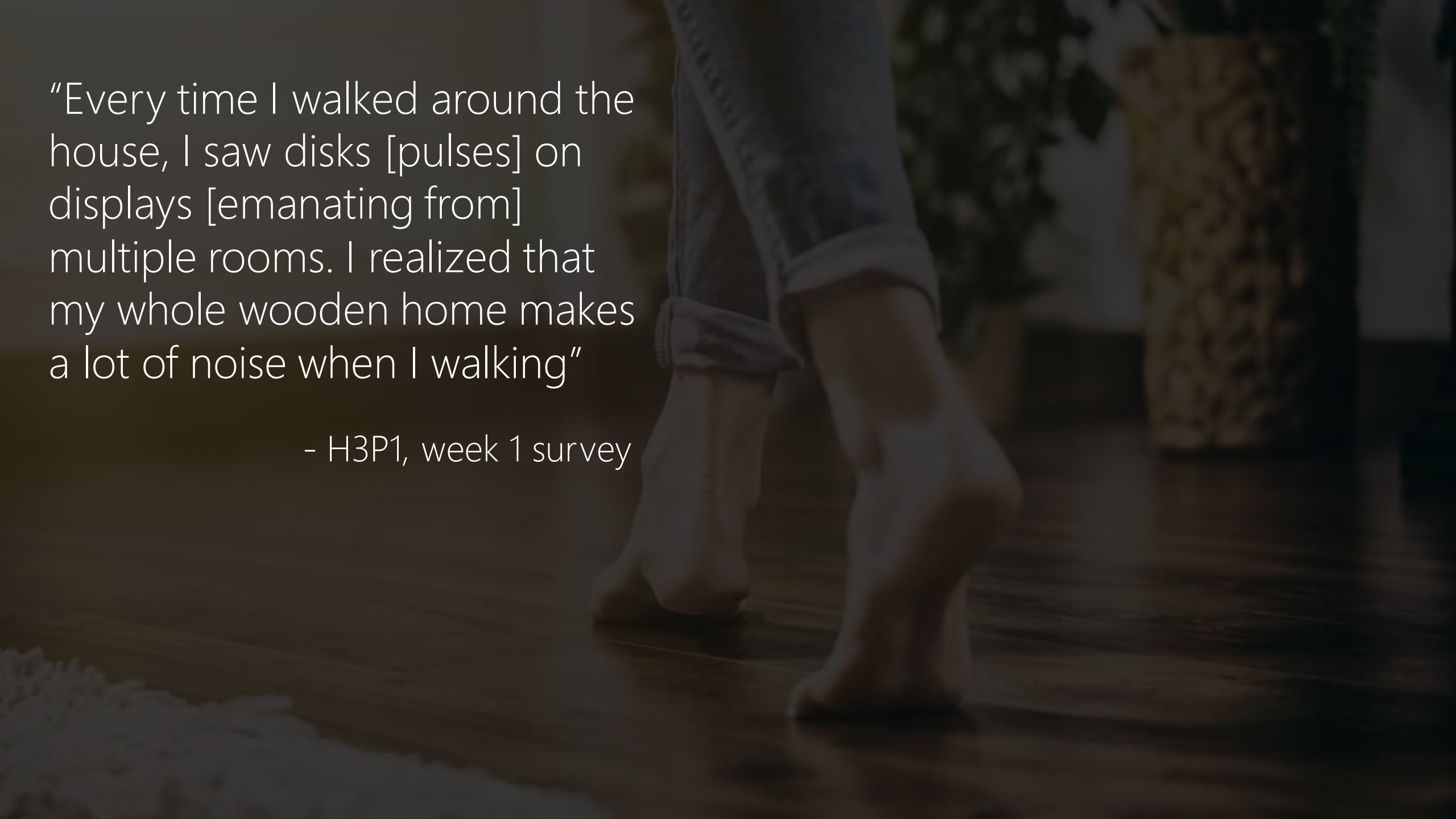


Because the users had to look at the display and because the system showed basic sound information, it was **not found sufficient for home awareness...**

However, in some cases, participants **relied on context** to make use of the system, suggesting that a future **improved system may be useful.**

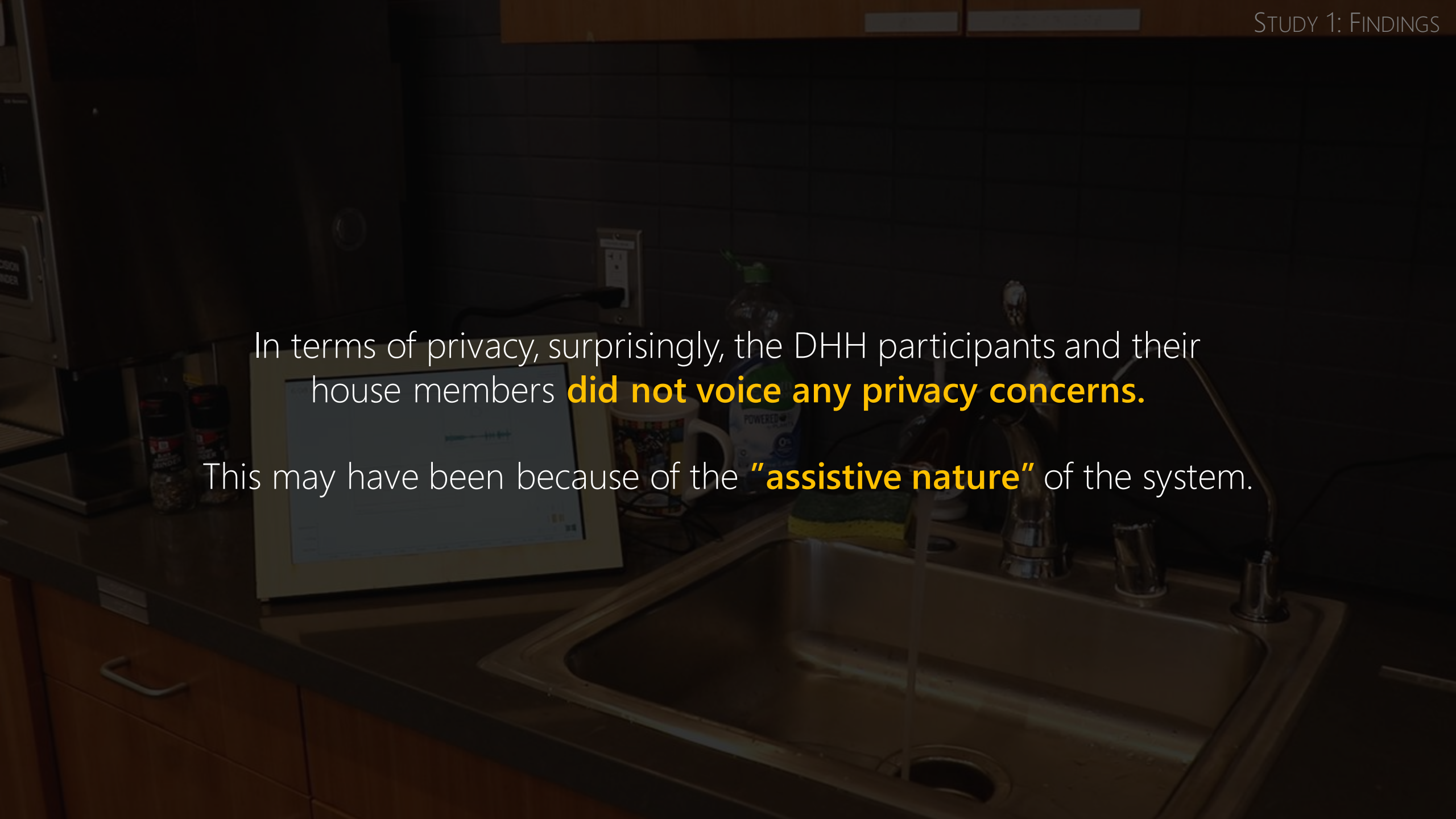
H4P1 – snapshot taken in week 2

"The peaks in the waveform from Kitchen meant that the microwave must have beeped, and my food was ready. [Because] no one else [was] in the home."



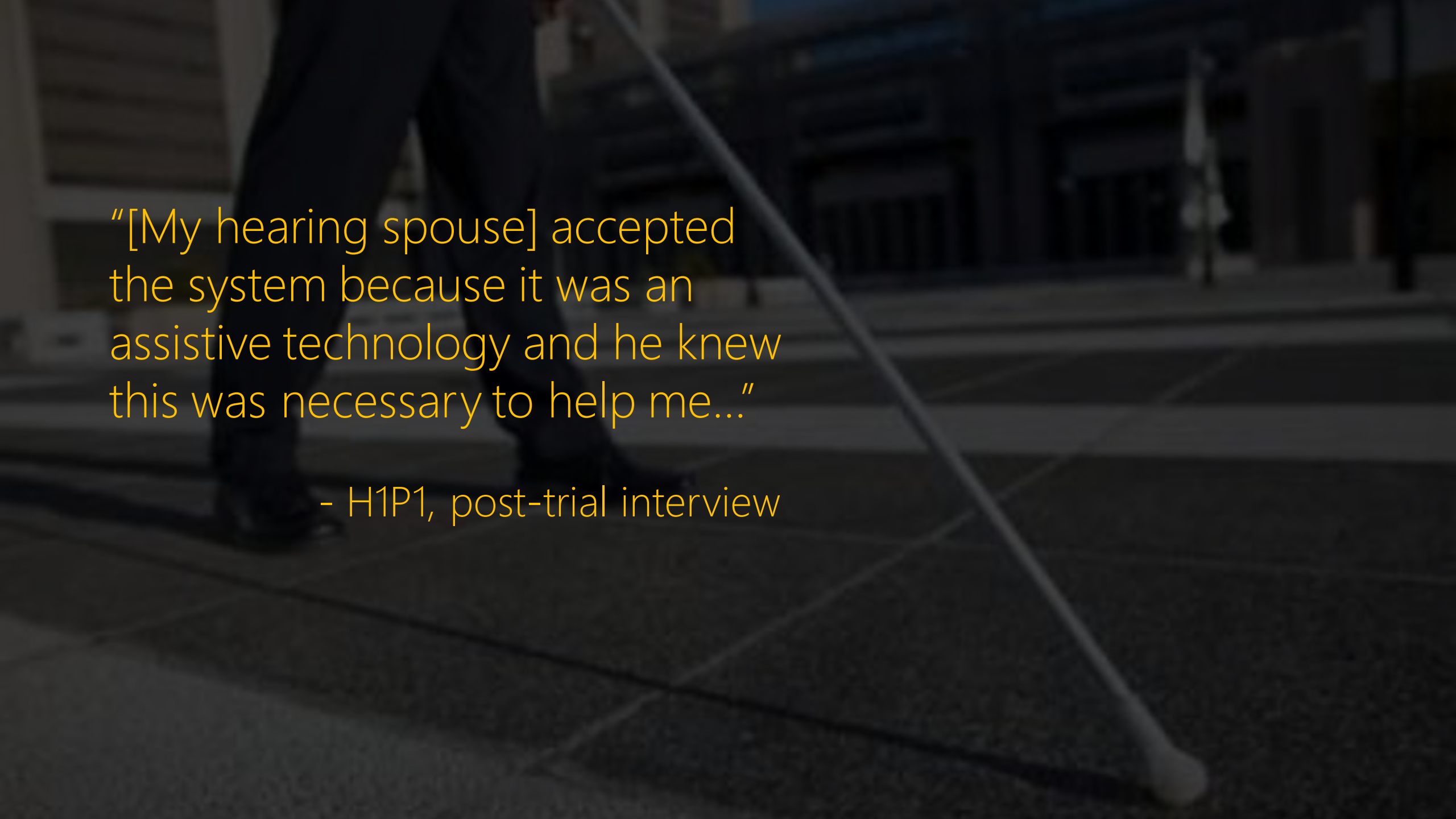
"Every time I walked around the house, I saw disks [pulses] on displays [emanating from] multiple rooms. I realized that my whole wooden home makes a lot of noise when I walking"

- H3P1, week 1 survey



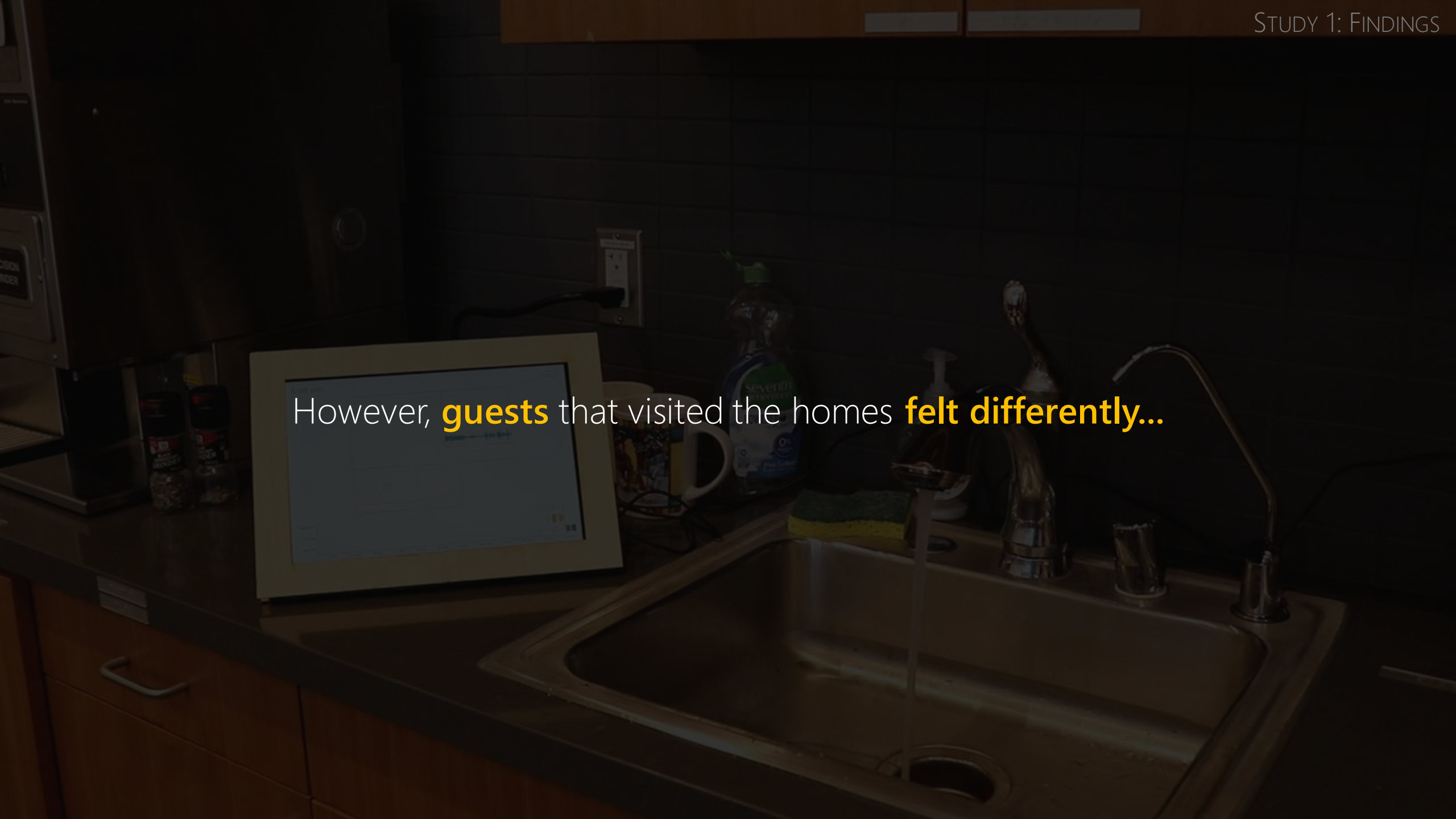
In terms of privacy, surprisingly, the DHH participants and their house members **did not voice any privacy concerns.**

This may have been because of the **"assistive nature"** of the system.



"[My hearing spouse] accepted the system because it was an assistive technology and he knew this was necessary to help me..."

- H1P1, post-trial interview



However, **guests** that visited the homes **felt differently...**

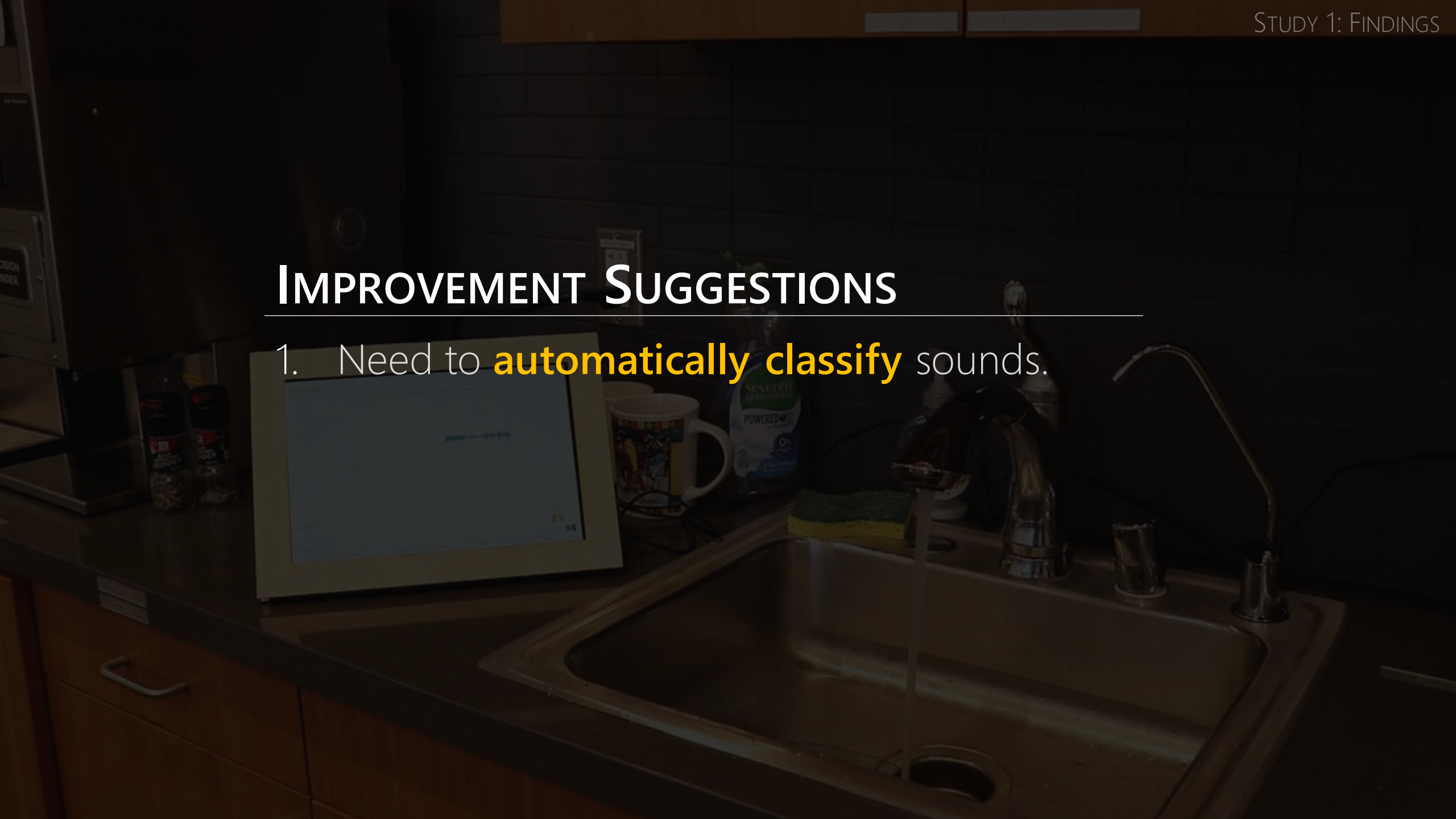
"My friend asked his wife to not hold a conversation near a tablet [...] Then I explained that this [system] cannot display words and he seemed to be ok with it then. Although I must say he was a little put off initially."

- H3P1, post-trial interview

IMPROVEMENT SUGGESTIONS

IMPROVEMENT SUGGESTIONS

1. Participants wanted **more specific information** about sounds.

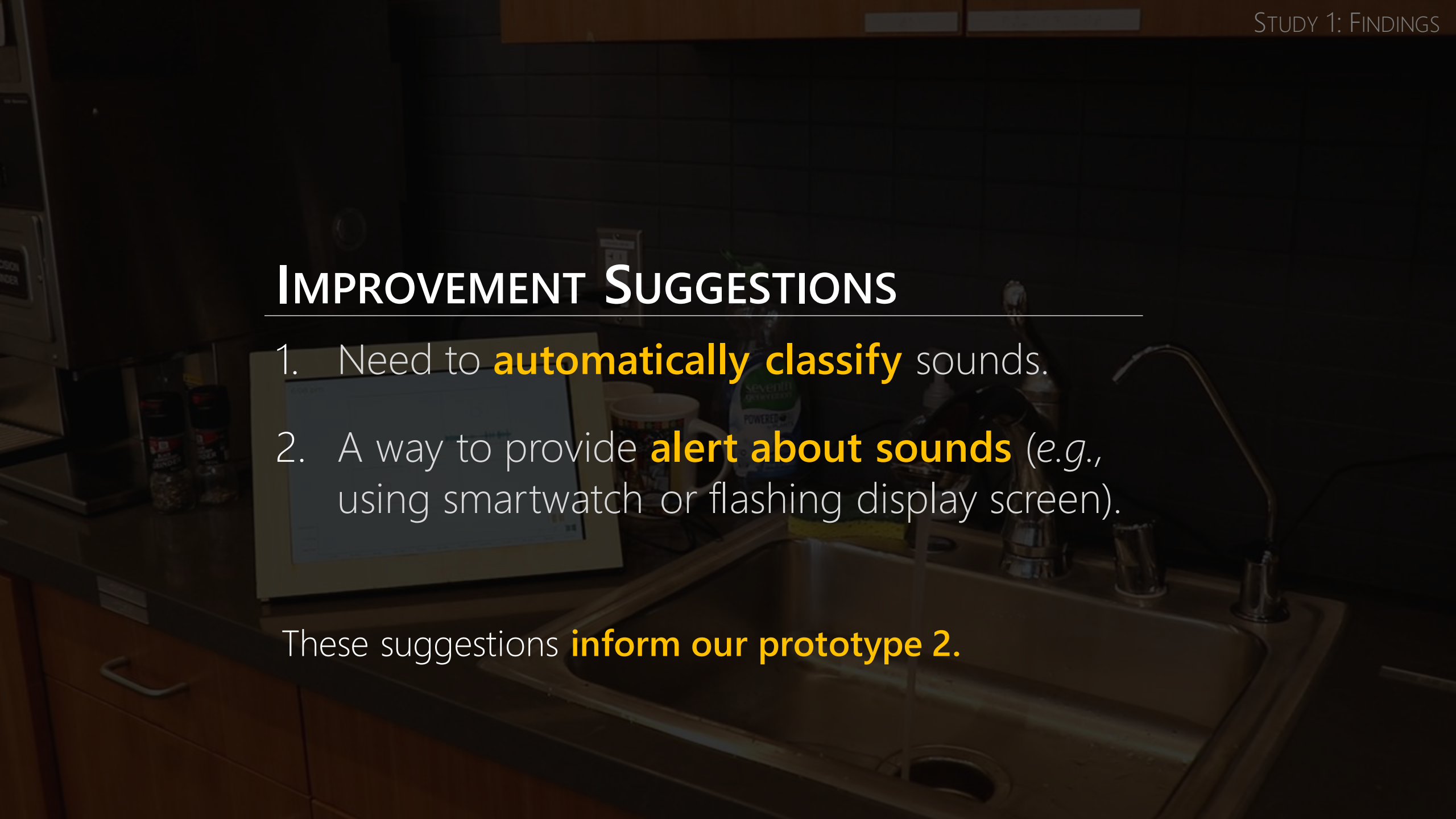


Improvement Suggestions

1. Need to **automatically classify** sounds.

Improvement Suggestions

1. Need to **automatically classify** sounds.
2. Participants got **tired of having to look at the displays** from time to time.



Improvement Suggestions

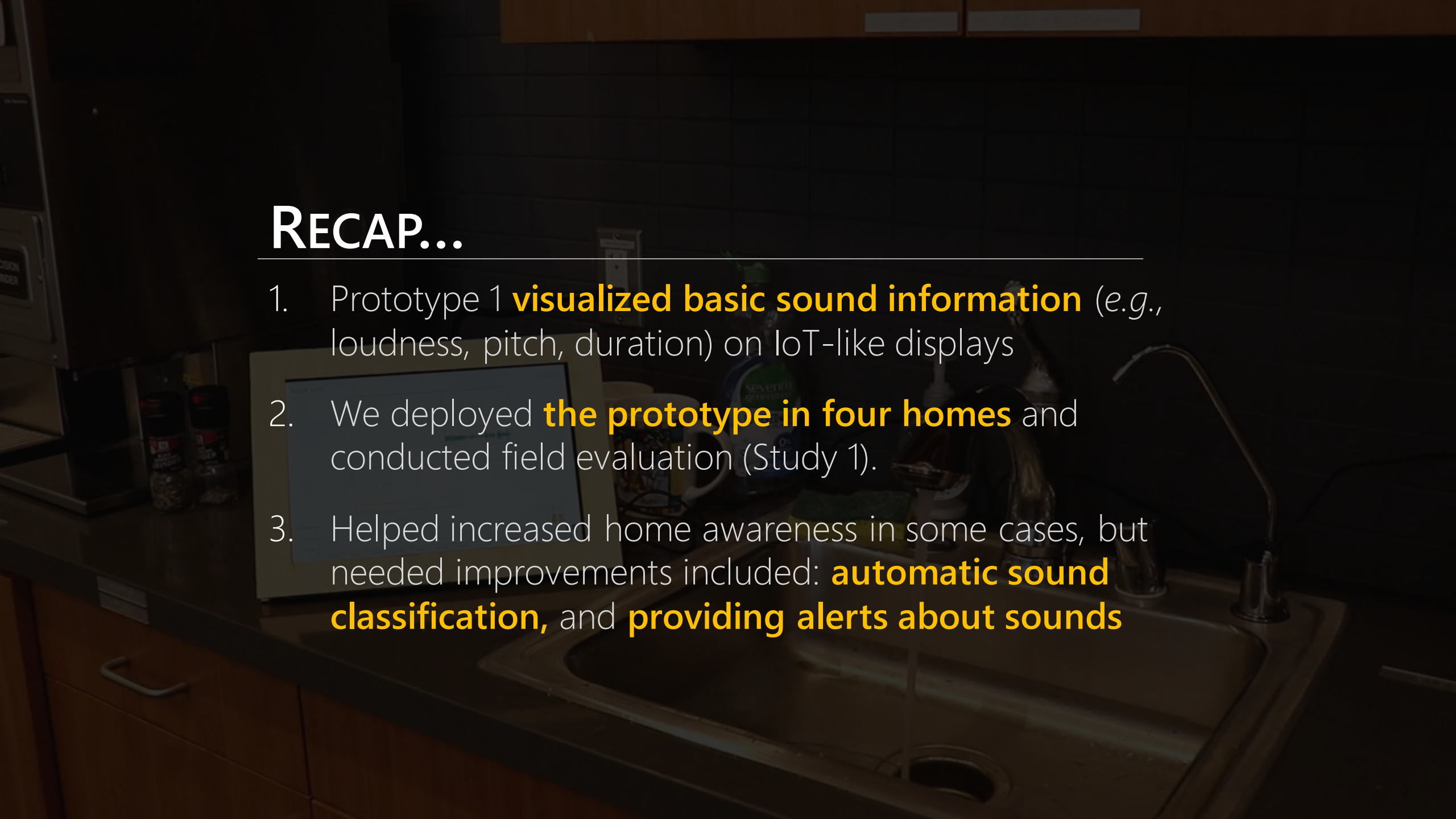
1. Need to **automatically classify** sounds.
2. A way to provide **alert about sounds** (*e.g.*, using smartwatch or flashing display screen).

These suggestions **inform our prototype 2.**

Break Time

Any questions?

https://tinyurl.com/DJ-quals



Recap…

1. Prototype 1 **visualized basic sound information** (*e.g.*, loudness, pitch, duration) on IoT-like displays
2. We deployed **the prototype in four homes** and conducted field evaluation (Study 1).
3. Helped increased home awareness in some cases, but needed improvements included: **automatic sound classification,** and **providing alerts about sounds**

Outline

Prototype 1 → **Study 1**

Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

Prototype 1 deployment

Outline

Prototype 1
Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

→

Study 1
Prototype 1 deployment

→

Prototype 2
Conveyed more complex sound features (e.g., sound identity)

Two Extensions To Prototype 1

1. **Sound classification engine** for 19 common home sounds
2. **Smartwatch** to provide sound alerts using visual + vibration notifications.

Two Extensions To Prototype 1

1. **Sound classification engine** for 19 common home sounds

Sound Classification

SOUND CLASSIFICATION

Using **transfer learning**, we adapted this model for our task (sound classification)

VGG16 Architecture Pre-trained on 8M YouTube videos

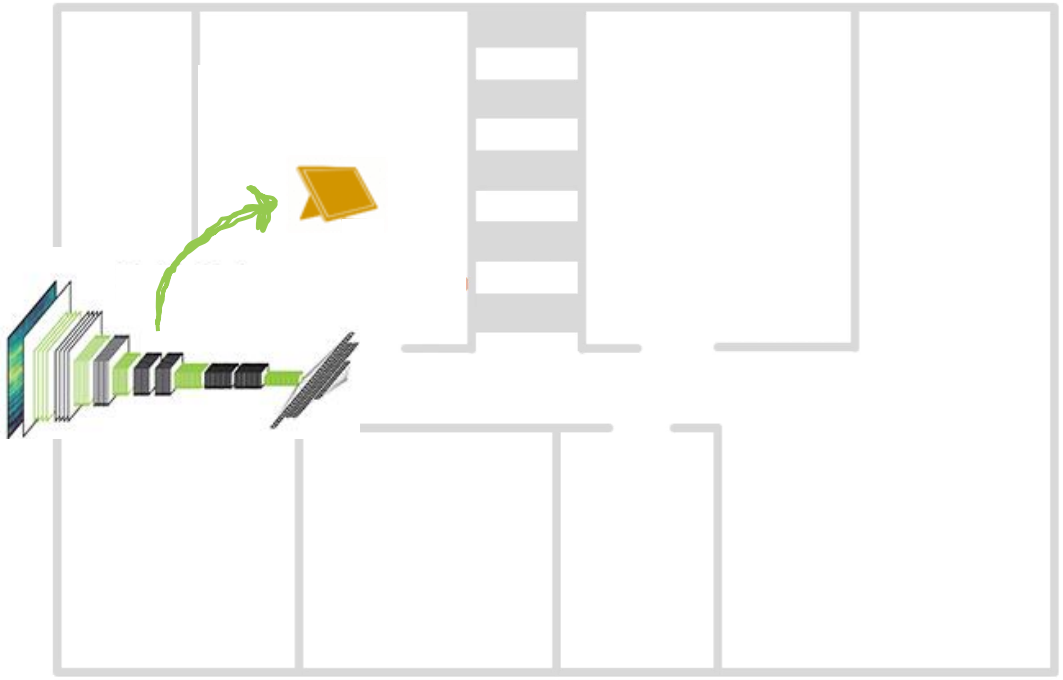
SOUND CLASSIFICATION

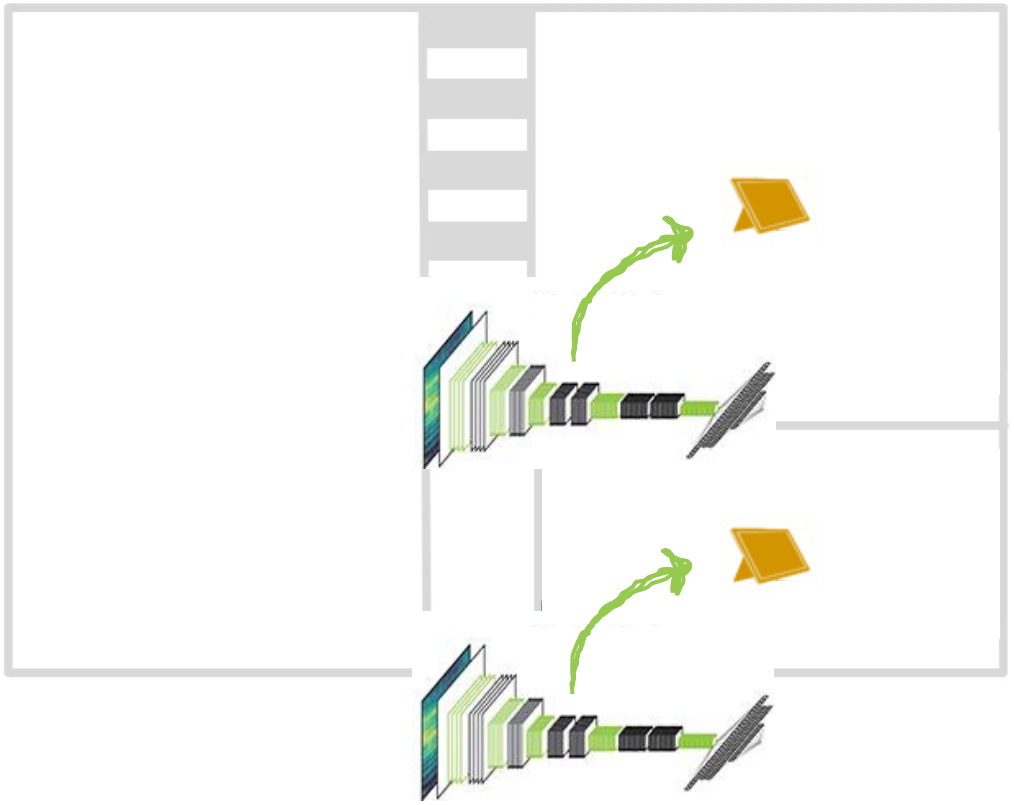
Clips from online libraries for 19 sound classes

VGG16 Architecture Pre-trained on 8M YouTube videos

Average test accuracy on sounds recorded in homes of 5 research team members =

85.9% (*SD*=4.1%)

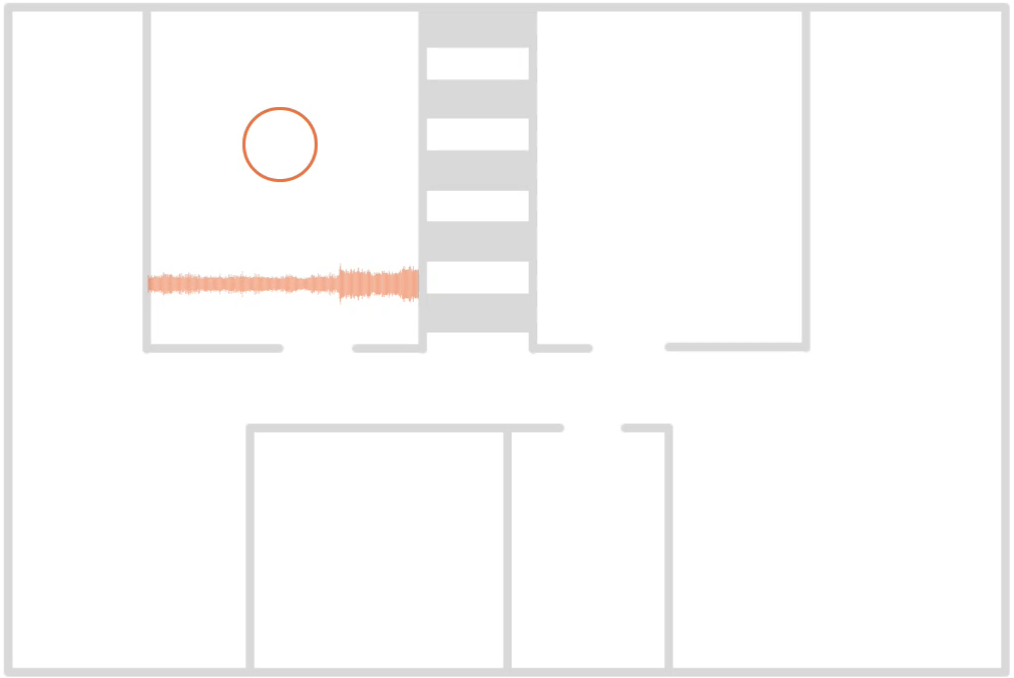


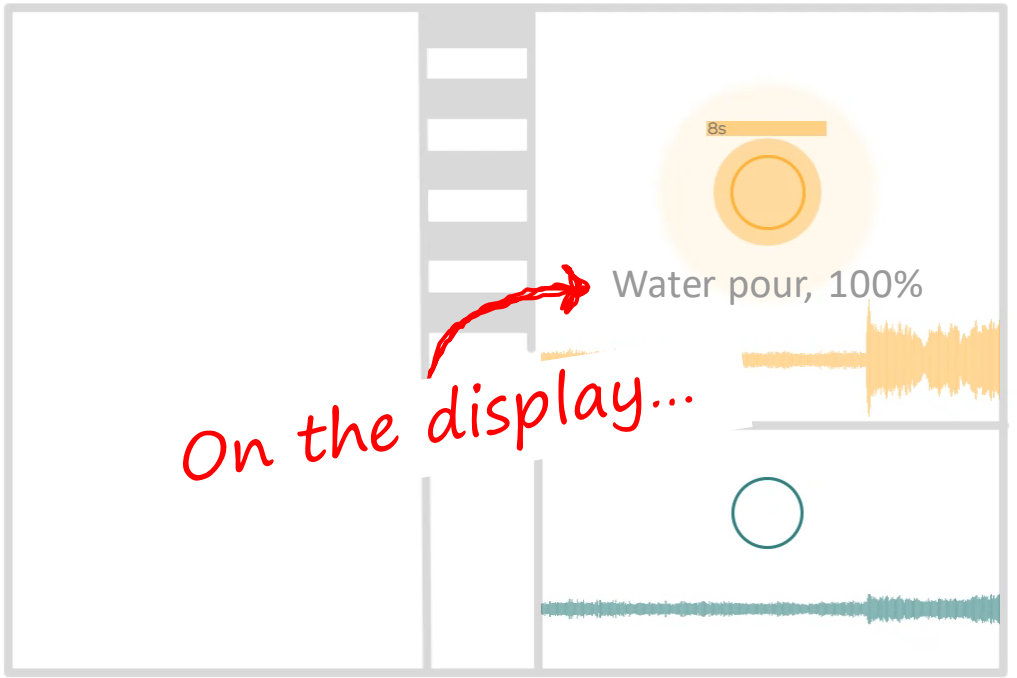


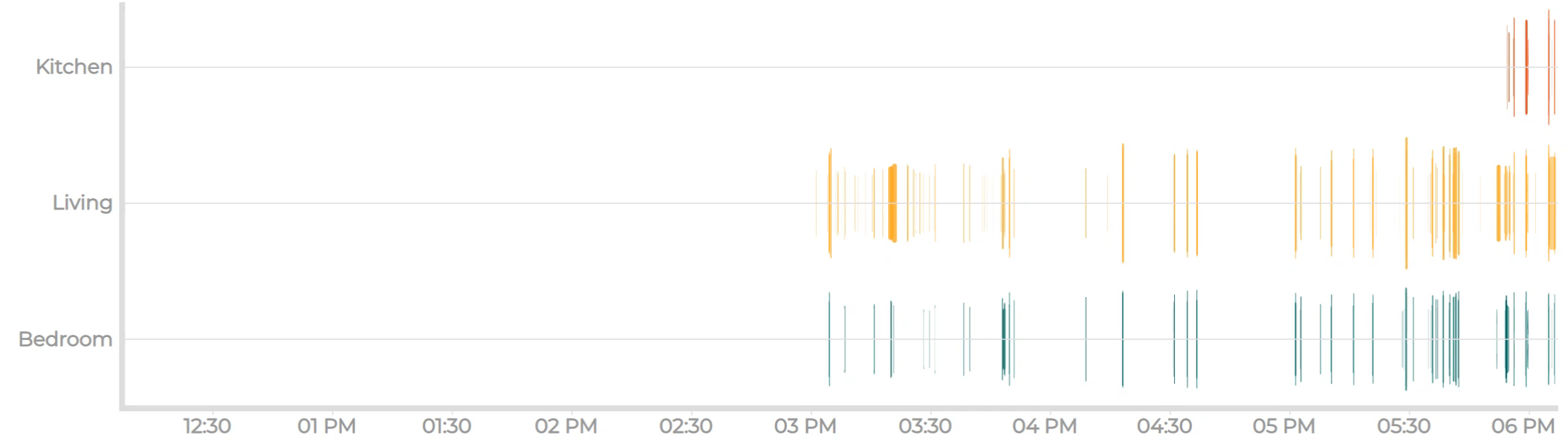
The model was uploaded to **each IoT display.**

6:07 pm

Settings Bookmark



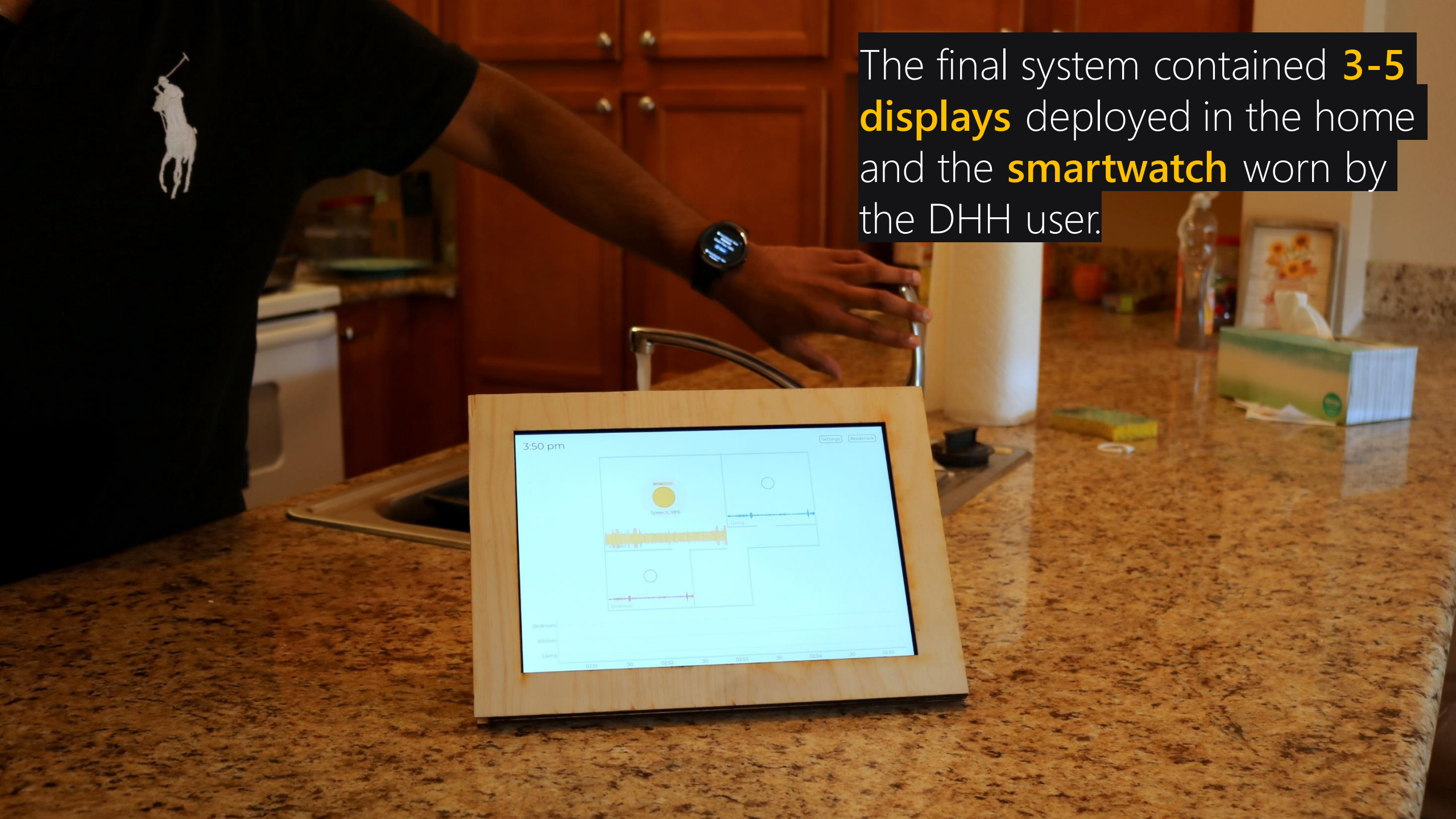




Two Extensions To Prototype 1

1. **Sound classification engine** for 19 common home sounds
2. **Smartwatch** to provide sound alerts using visual + vibration notifications.

SMARTWATCH APP



The final system contained **3-5 displays** deployed in the home and the **smartwatch** worn by the DHH user.

Outline

Prototype 1
Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

→

Study 1
Prototype 1 deployment

→

Prototype 2
Conveyed more complex sound features (e.g., sound identity)

Outline

Prototype 1 → **Study 1** → **Prototype 2** → **Study 2**

Conveyed simple but accurate sound feedback (e.g., loudness, pitch)

Prototype 1 deployment

Conveyed more complex sound features (e.g., sound identity)

Prototype 2 deployment

Study 2

Goal

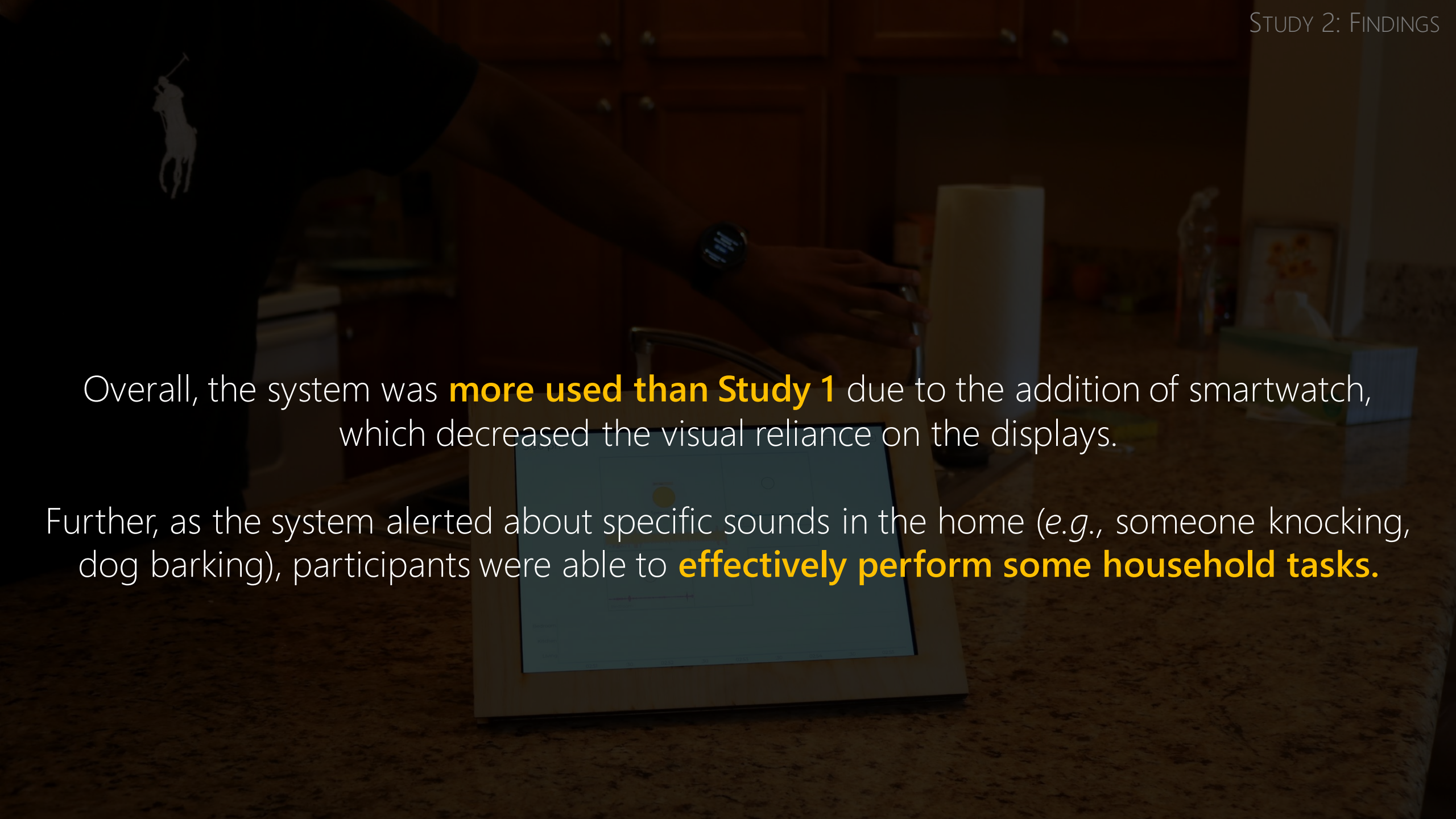
- To evaluate Prototype 2

Participants

- 4 Homes; 2 repeats from Study 1
- 6 DHH and 2 hearing individual

Method And Data Analysis

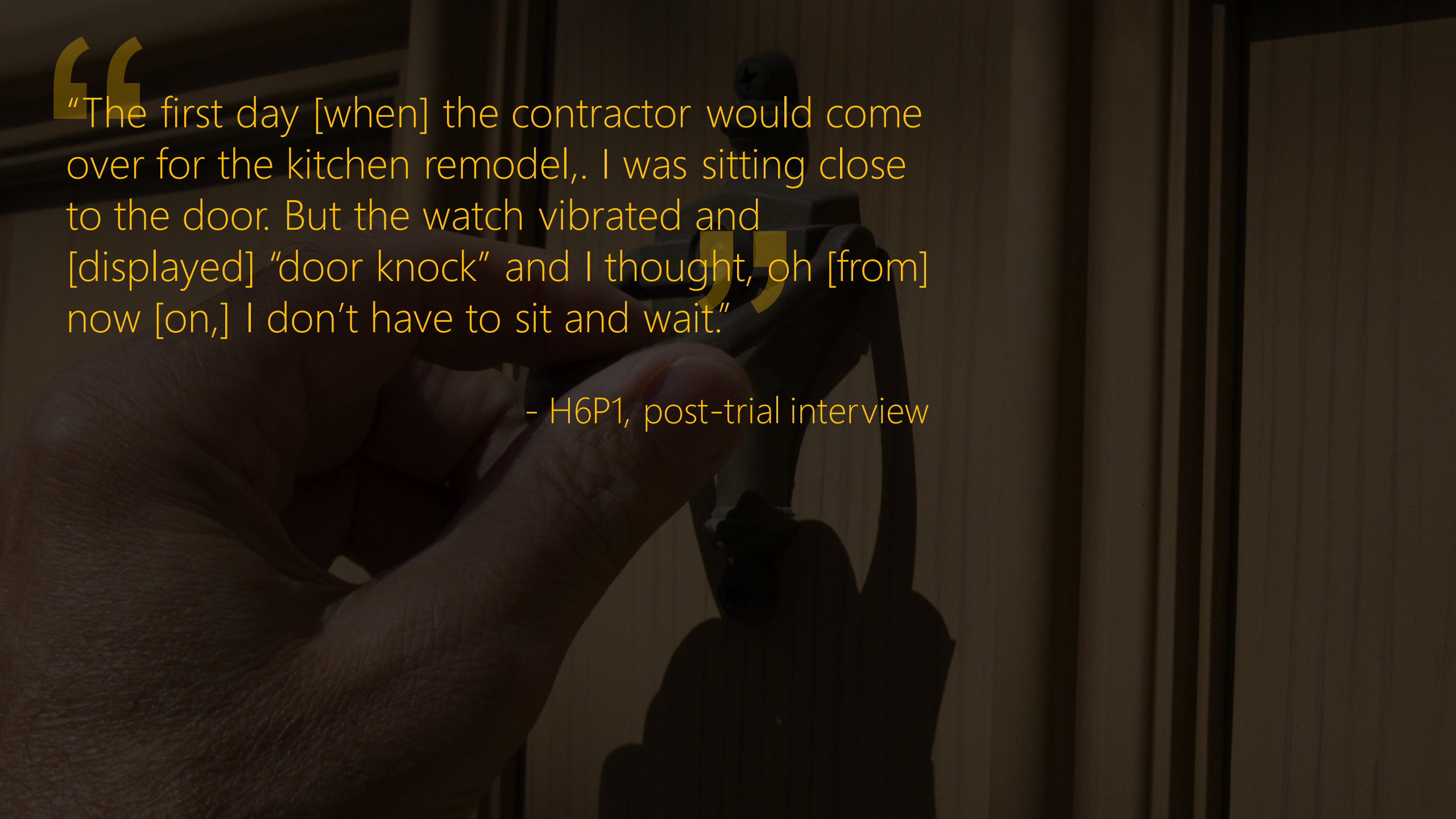
- Similar procedure as Study 1
- Two coders; IRR=0.78, raw agreement=91.7%
- Disagreements were resolved through consensus



Overall, the system was **more used than Study 1** due to the addition of smartwatch, which decreased the visual reliance on the displays.

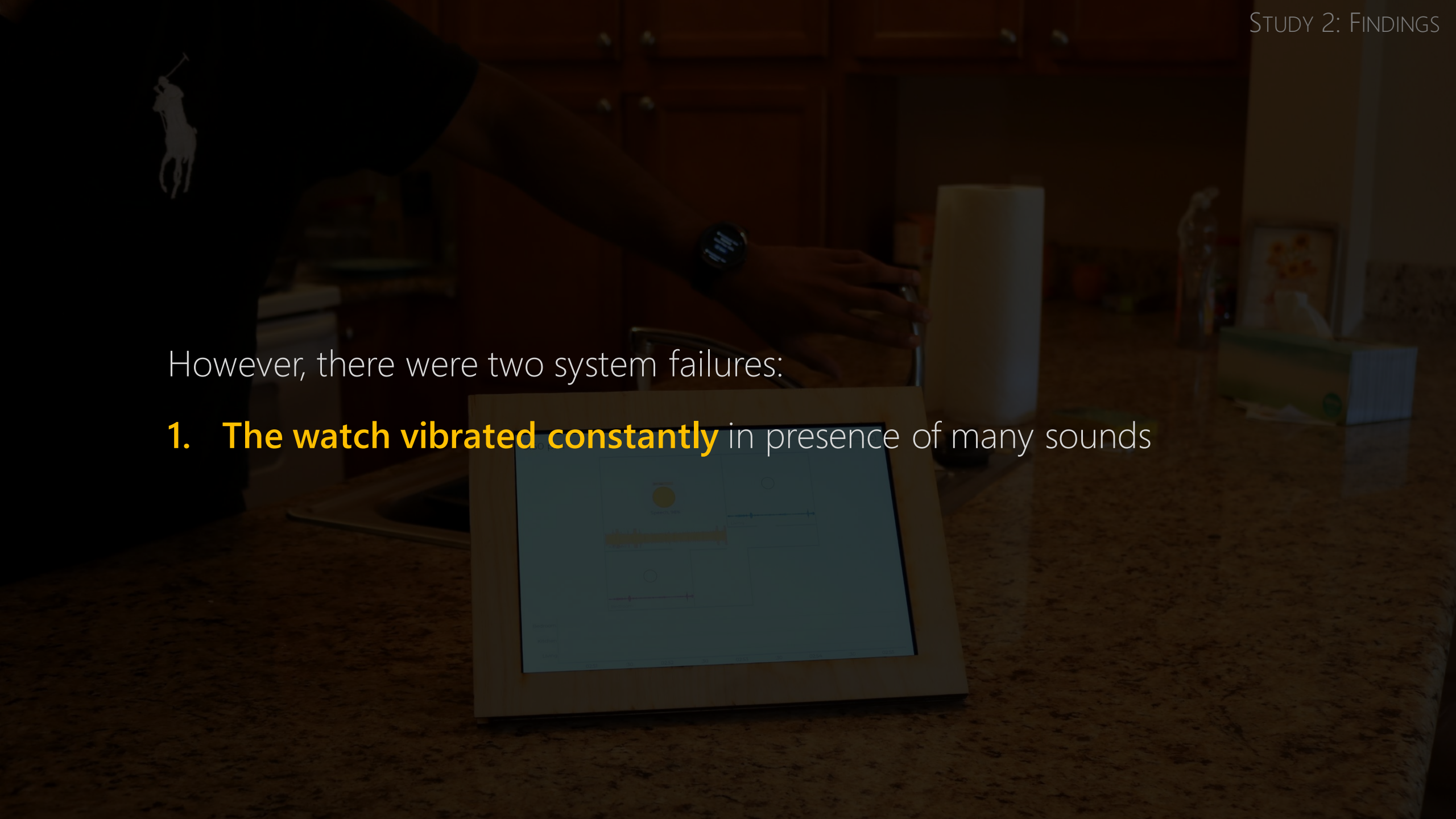
Further, as the system alerted about specific sounds in the home (*e.g.*, someone knocking, dog barking), participants were able to **effectively perform some household tasks.**


"I was [...] working on my laptop, the watch showed my dog was barking [in another room]. I went and corrected my dog right away. This helps me train the dog over time [...] Also, the watch lets me know when the washer is done."
- H2P2, week 2 survey



“The first day [when] the contractor would come over for the kitchen remodel,. I was sitting close to the door. But the watch vibrated and [displayed] “door knock” and I thought, oh [from] now [on,] I don’t have to sit and wait.”

- H6P1, post-trial interview

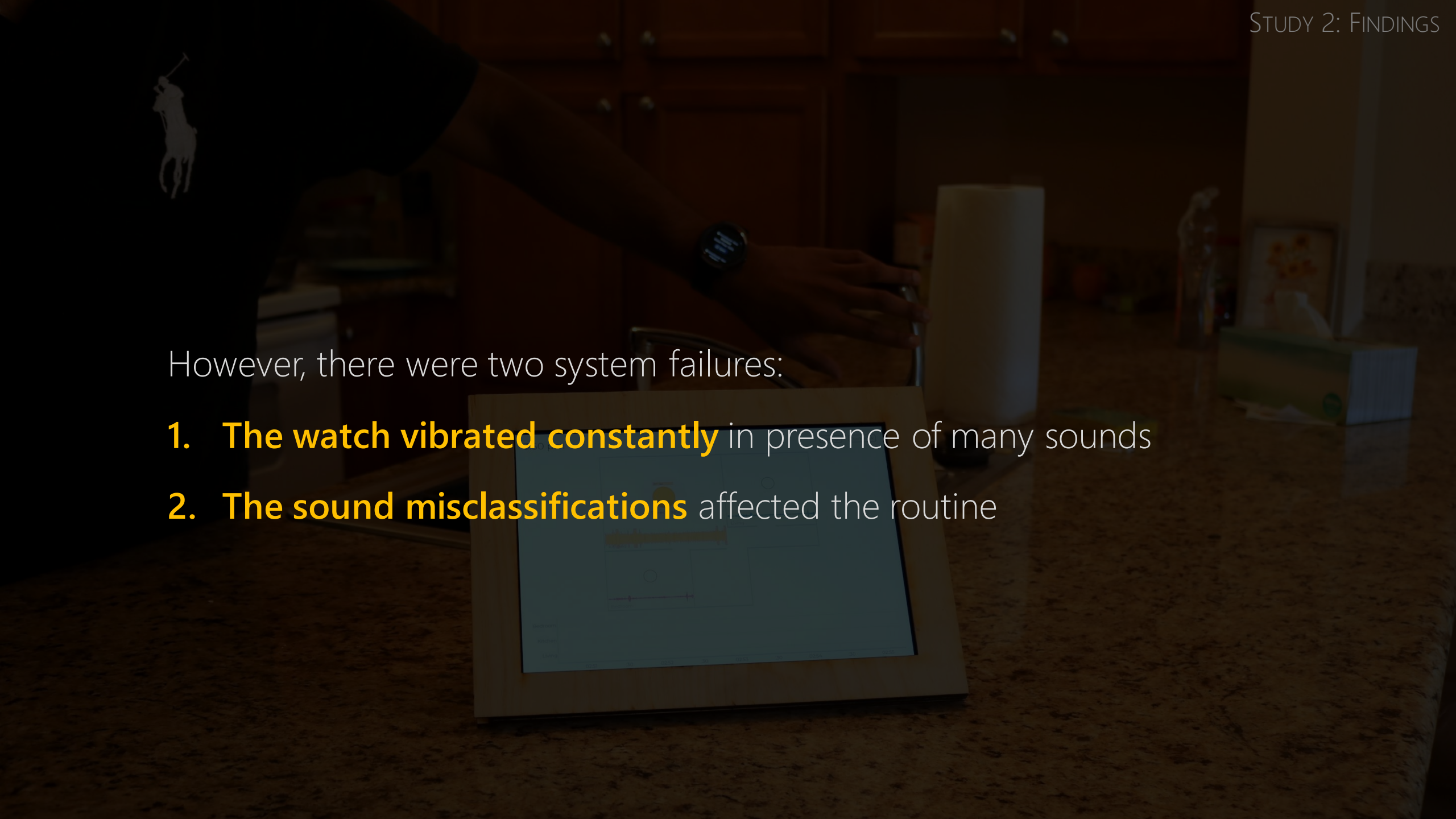


However, there were two system failures:

1. **The watch vibrated constantly** in presence of many sounds

"I had company last Sunday. All of a sudden it began [vibrating] constantly. I couldn't take away my attention off because I didn't want to be rude to my company."

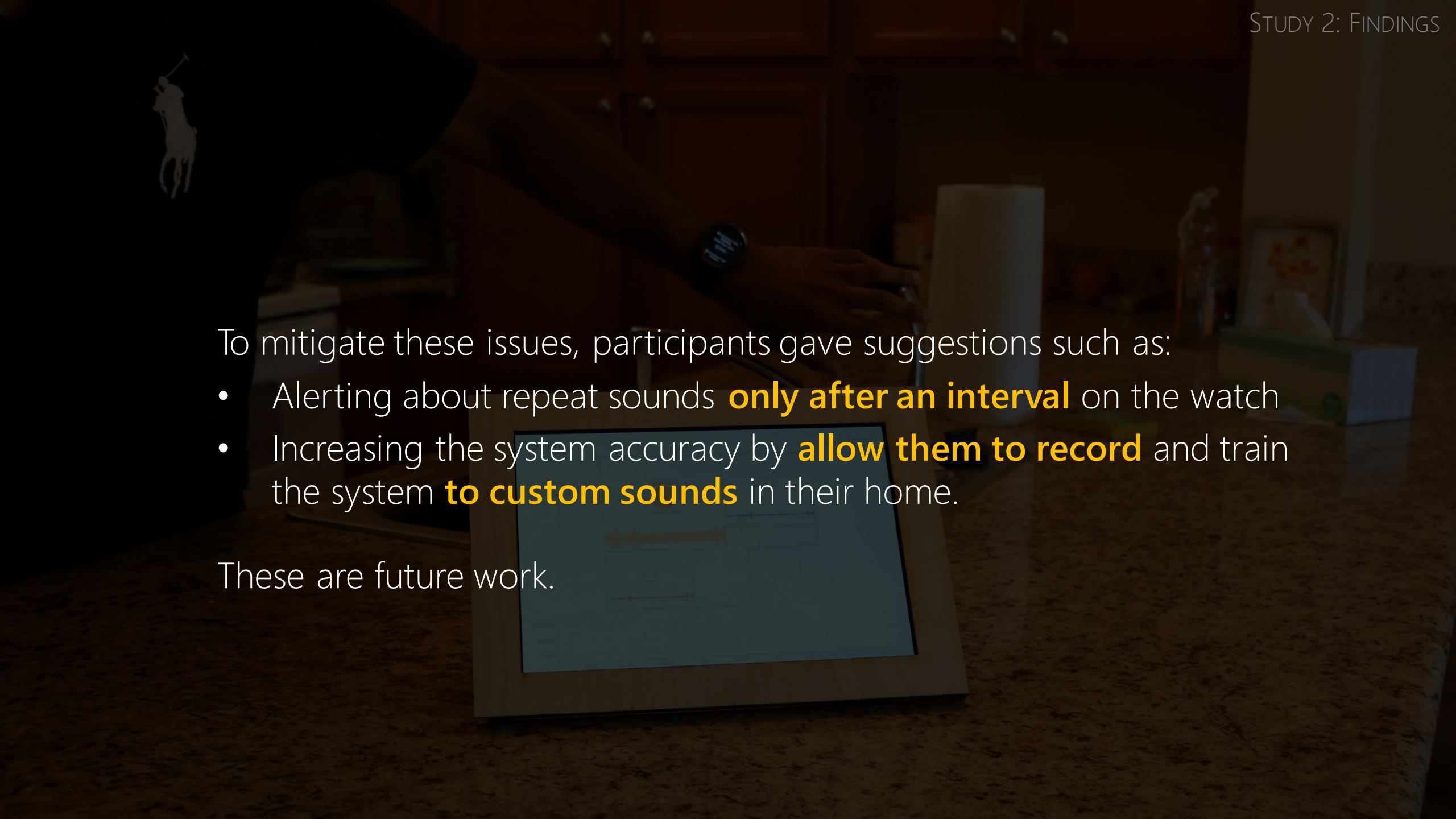
- H1P1, post-trial interview



However, there were two system failures:

1. **The watch vibrated constantly** in presence of many sounds
2. **The sound misclassifications** affected the routine


“A fan running in the kitchen kept identifying as microwave [….] and I had to go and check again and again.”
- H2P1, post-trial interview



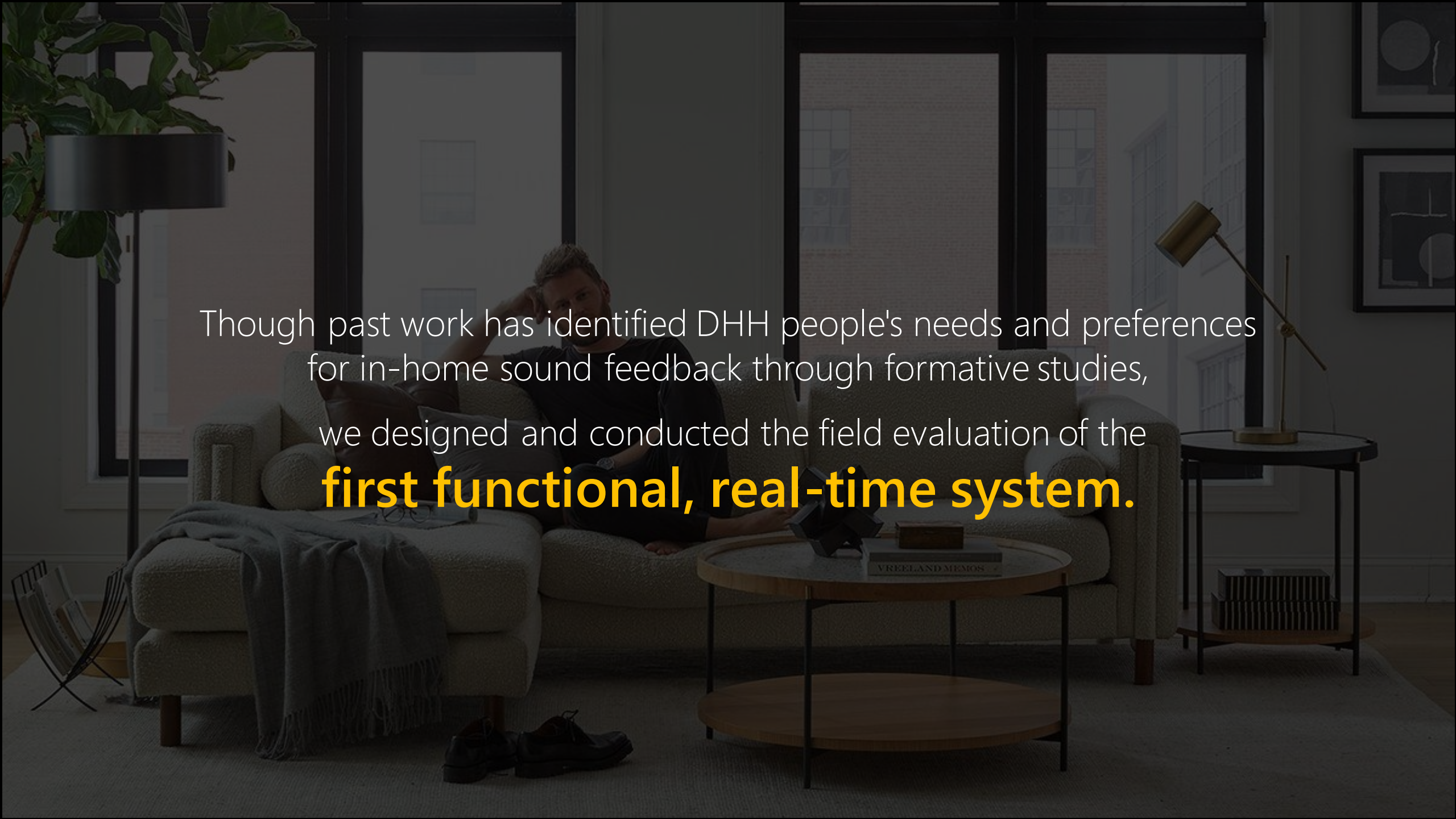
To mitigate these issues, participants gave suggestions such as:

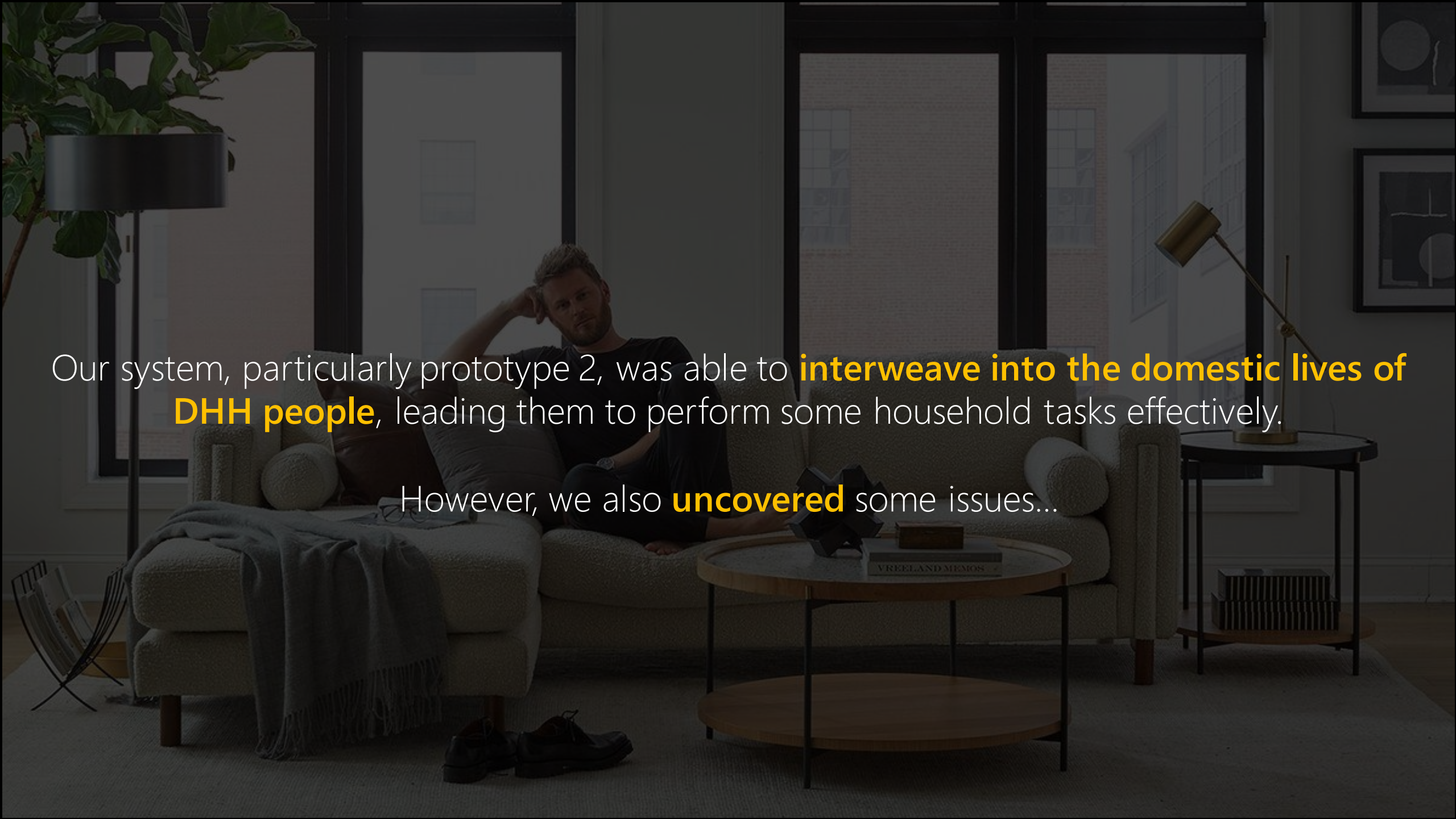
- Alerting about repeat sounds **only after an interval** on the watch
- Increasing the system accuracy by **allow them to record** and train the system **to custom sounds** in their home.

These are future work.

Other findings related to **self-awareness, privacy, culture, display placement and play** provide guidance for future home sound awareness technology.

Reflection


Though past work has identified DHH people's needs and preferences
for in-home sound feedback through formative studies,
we designed and conducted the field evaluation of the
first functional, real-time system.



Our system, particularly prototype 2, was able to **interweave into the domestic lives of DHH people**, leading them to perform some household tasks effectively.

However, we also **uncovered** some issues...

Future Considerations

Handling misclassifications

- Sound misclassifications were reported as an issue.
- To mitigate, participants suggested using a customization approach, by allowing them **to train the system for the sounds** in their home.
- However, this training may be **tedious** and difficult if the **sound is inaccessible** to DHH users. Future work should consider this.
- Another possibility is to **adapt the information based on classification confidence**, *e.g.*, when the confidence is low, show "a motor sound", instead of a microwave, as in our design.

Future Considerations

Handling information overload

- Constant vibrations on the watch were annoying.
- To control for overload, instead of showing every recognized sound on the watch, **use context cues** such as **daily rhythm** (e.g., night vs. day), **user's location and activity** (*e.g.*, not doing high-focused tasks) to select what to display.

Future Considerations

Handling activity tracking

- While the home occupants accepted the system, guests showed concerns with the sound recording.
- Future work should continue to be mindful of **what sound information is being listened to, and where the displays are installed** in the home
- For example, consider carefully: should the displays be installed in a **public area** like a living room or not?

Exploring Sound Awareness in the Home for People who are Deaf or Hard of Hearing

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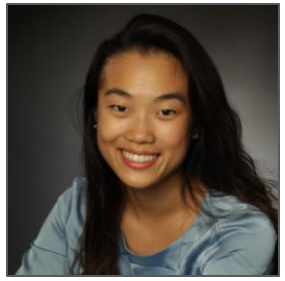

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Exploring Sound Awareness in the Home for People who are Deaf or Hard of Hearing

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Recent proliferation of **screen-based** smarthome devices offer a rich opportunity to **design for DHH people**, who have trouble interacting with voice-based devices.

By identifying **key benefits, challenges** and **concerns** of an in-home sound awareness system, our work has **implications for the design** of such future "smarthome" displays.