

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

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The home environment is filled with a
rich diversity of sounds



Door opening

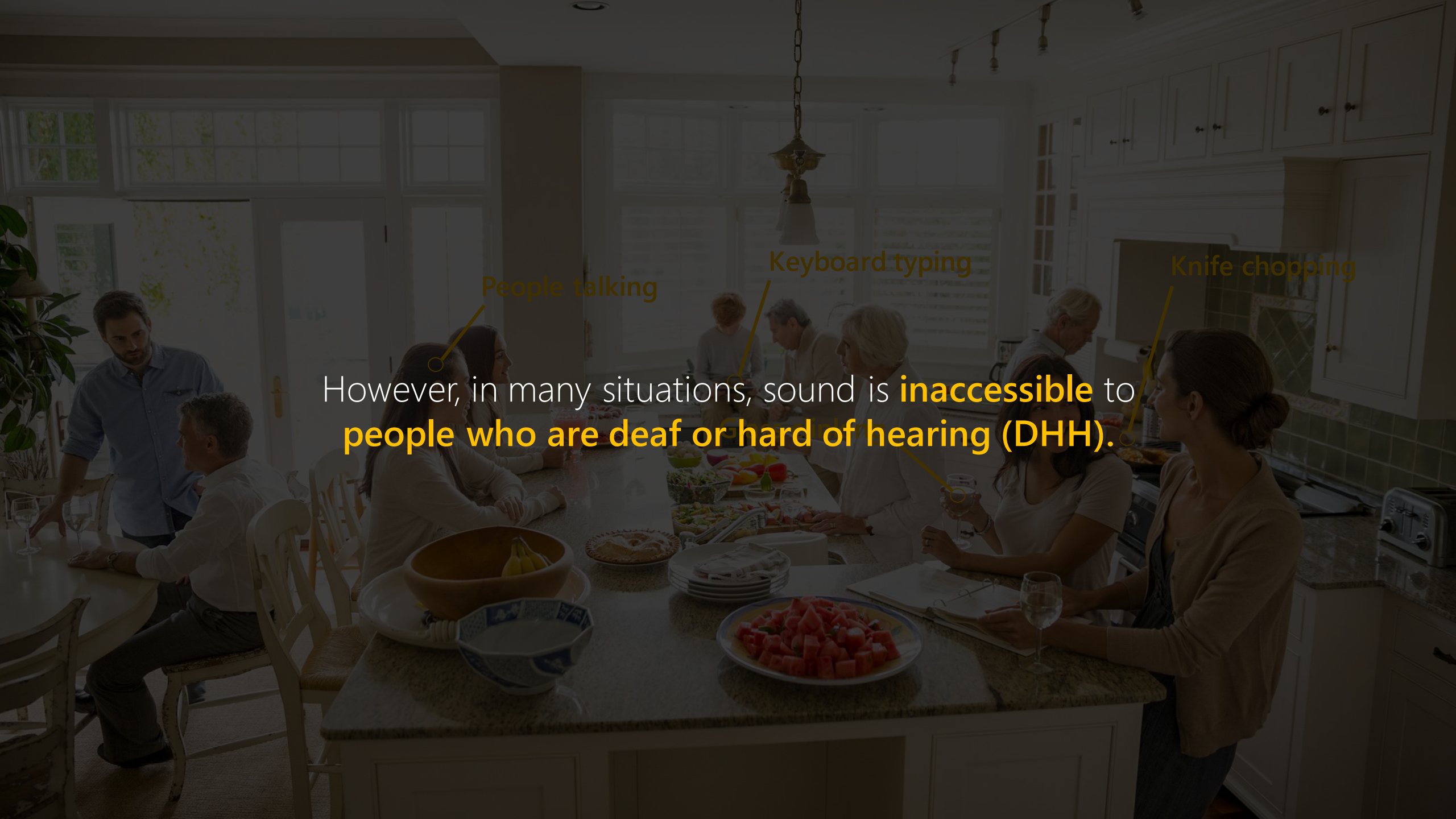
People talking

Knife chopping

Dog barking

Dryer whirring

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



People talking

Keyboard typing

Knife chopping

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



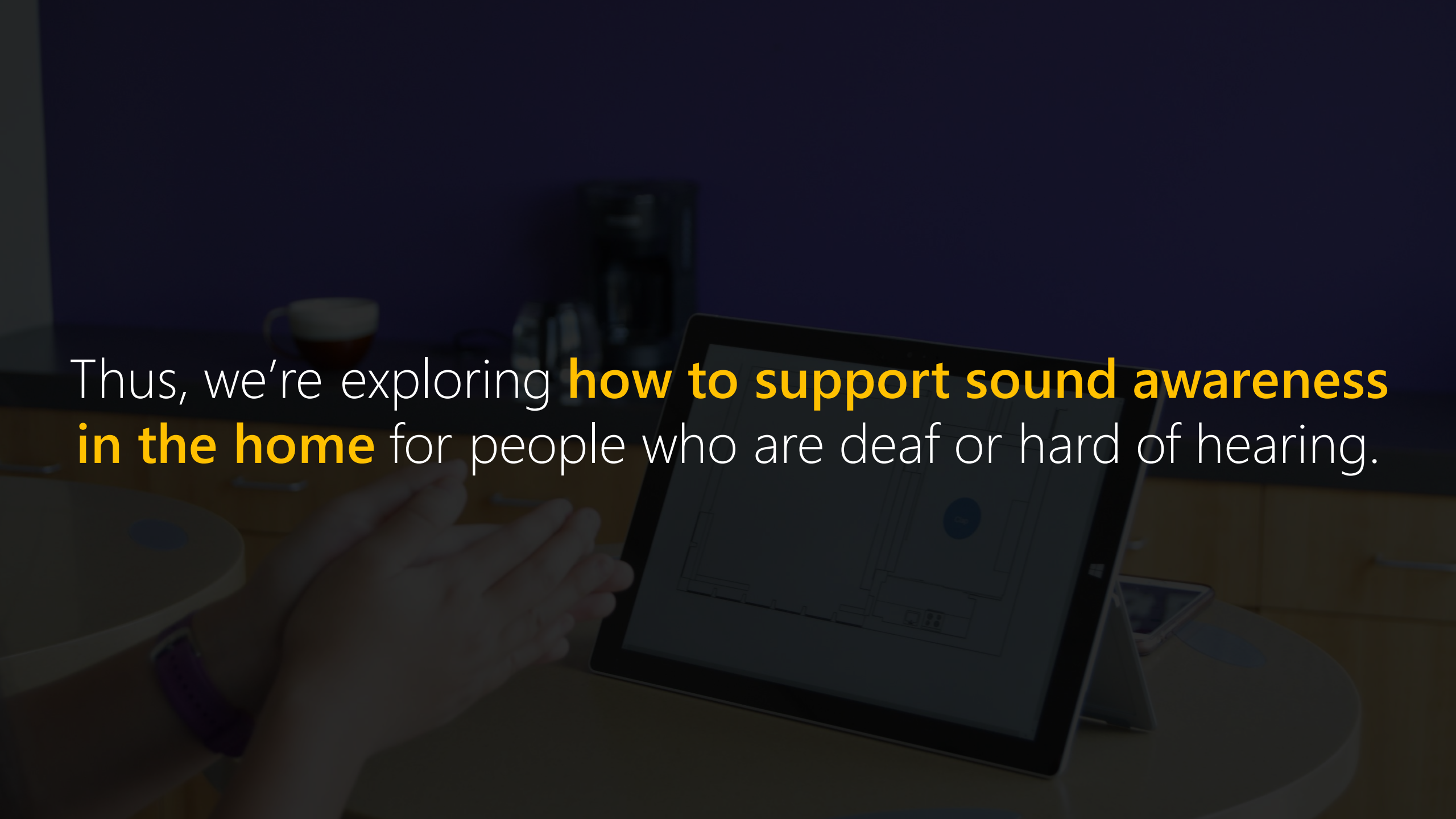
VIBRATORY BED ALARM

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

A person's hands are shown interacting with a tablet computer. The tablet screen displays a floor plan or architectural drawing. The scene is dimly lit, with a warm, low-key light source, possibly a lamp, creating a soft glow on the hands and the tablet. In the background, a cup and some other objects are visible on a table, but they are out of focus. The overall atmosphere is quiet and focused.

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 a 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**

Year 2

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

Published at CHI 2019

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

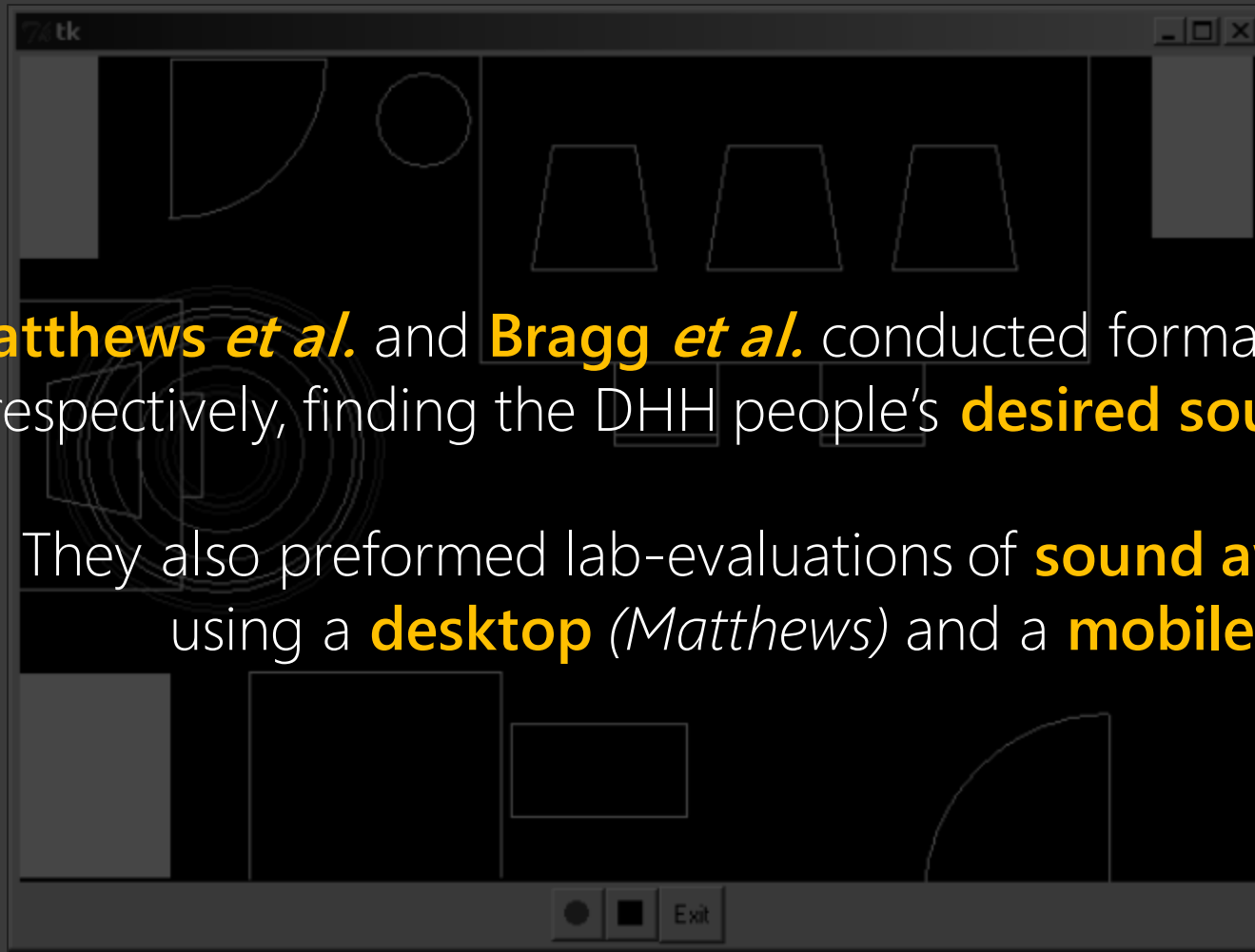
RELATED WORK

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

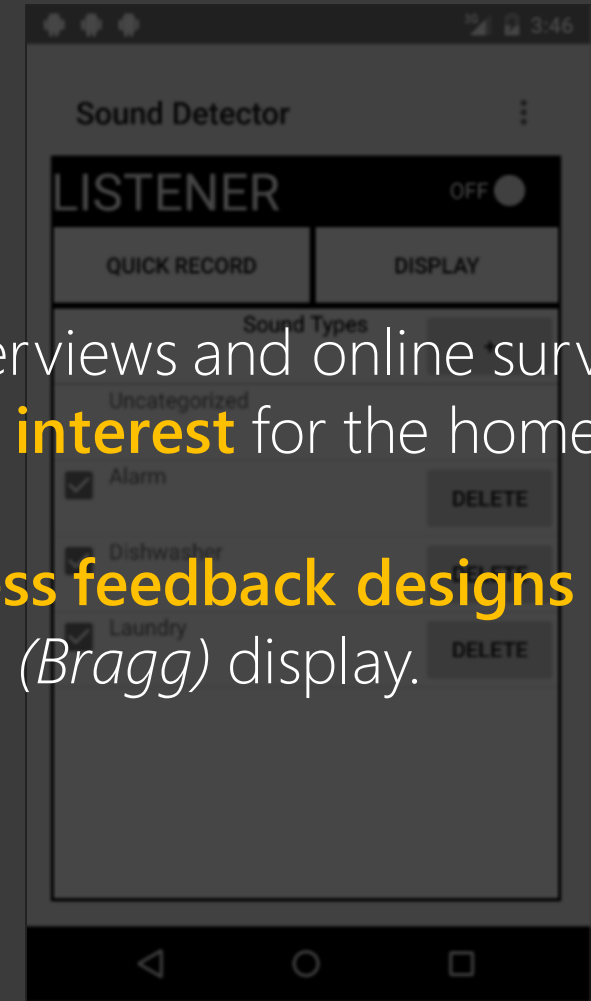
RELATED WORK

Matthews et al. 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 performed lab-evaluations of **sound awareness feedback designs** using a **desktop** (*Matthews*) and a **mobile phone** (*Bragg*) display.



(Matthews et al., ASSETS 2007)



(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**, activity **tracking**).

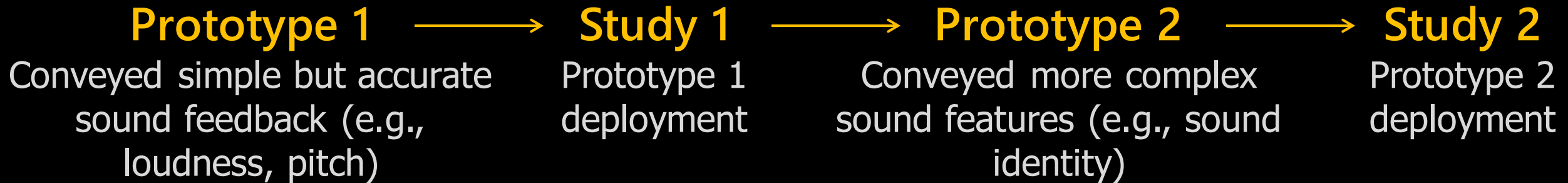
(Jain *et al.*, CHI 2019)

A person's hand is shown interacting with a tablet computer. The tablet screen displays a floor plan or architectural drawing. The background is a dimly lit room with a wooden table and some objects. The text is overlaid on the image.

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



OUTLINE

Prototype 1

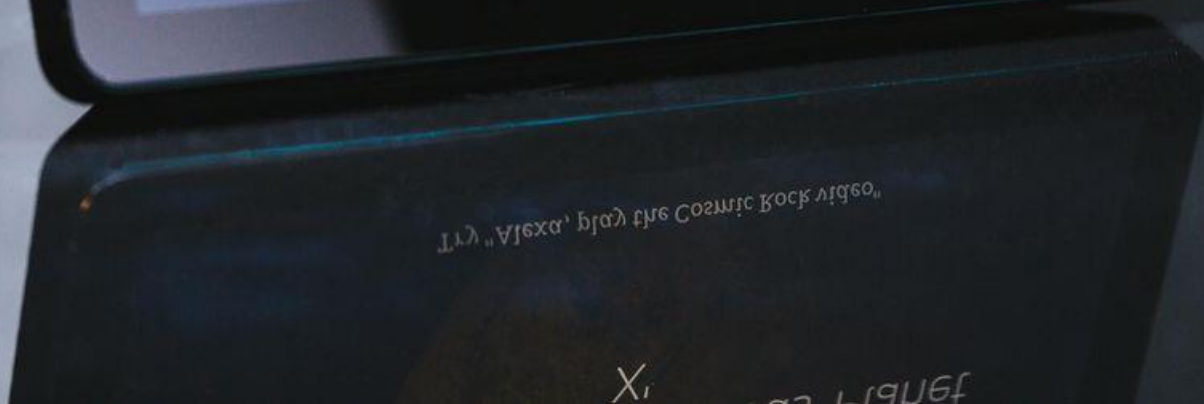
Conveyed simple but accurate sound feedback (e.g., loudness, pitch)



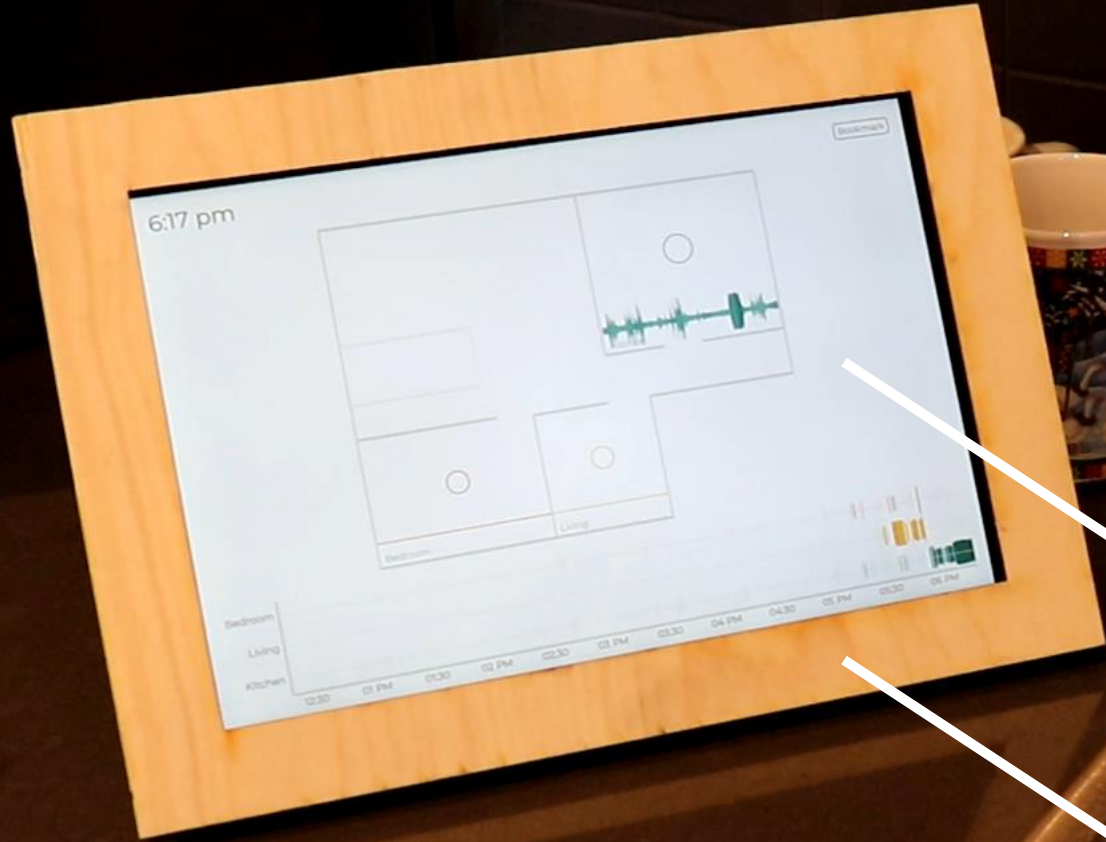
Our goal was to examine how DHH users would react to a system which conveyed **“easy to sense” sound properties**, such as **loudness** and **pitch**, before exploring complex probabilistic characteristics (e.g., sound type).



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



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.

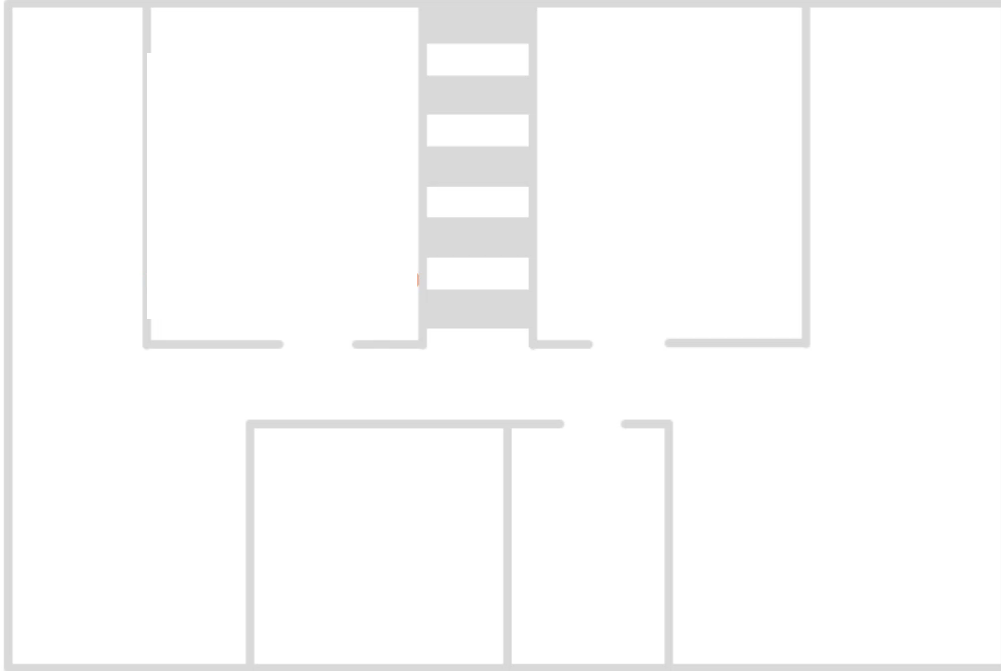
Picture frame display

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

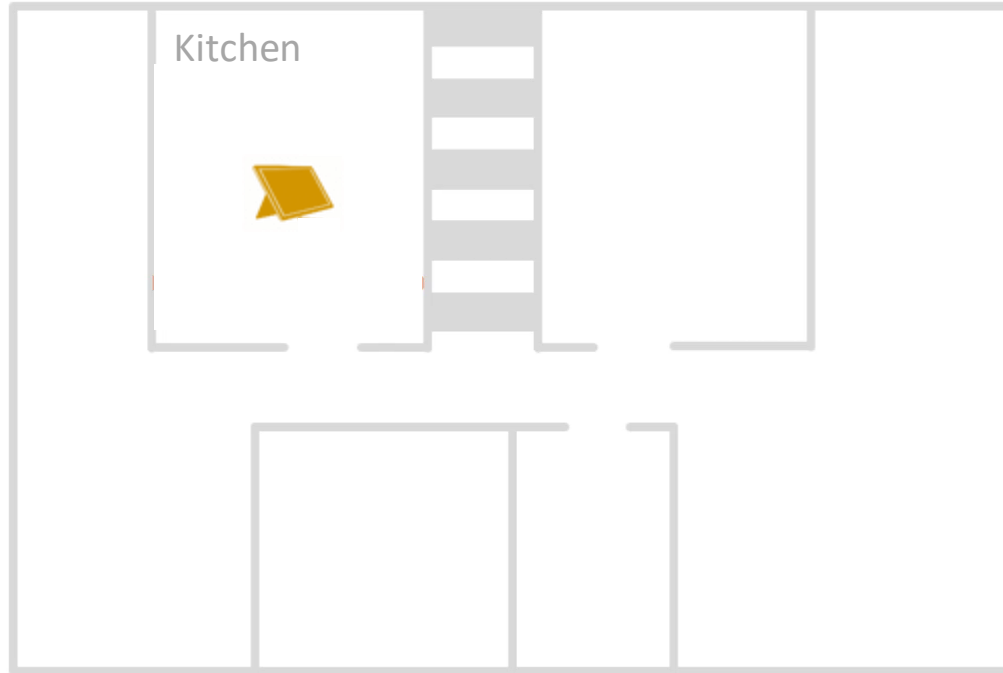


Second floor

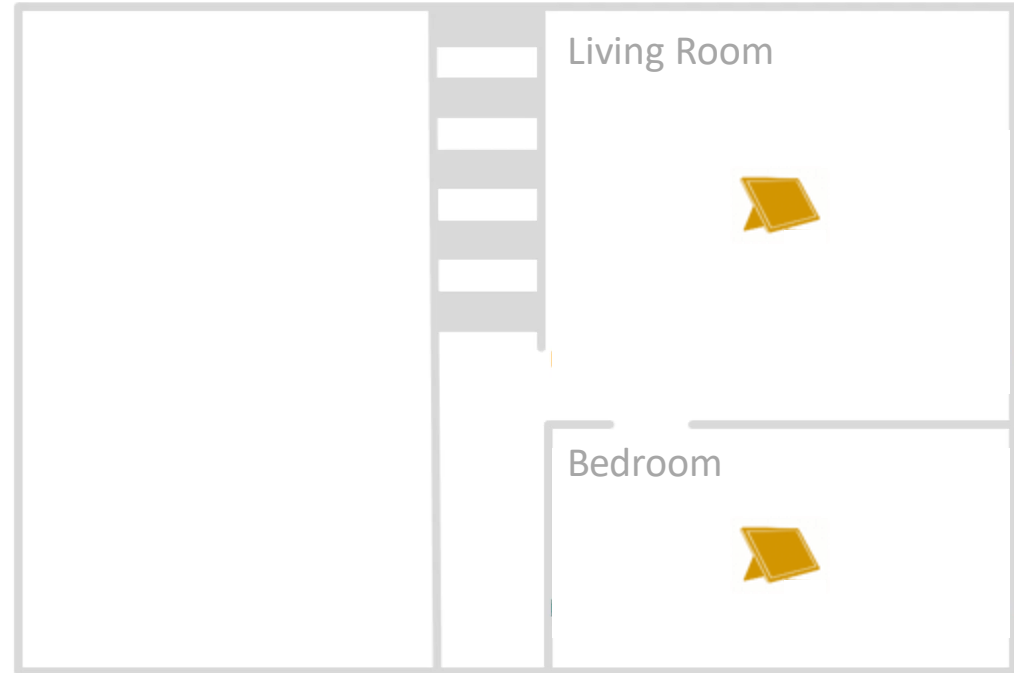


And this is an **approximate floorplan** of the home...

First floor

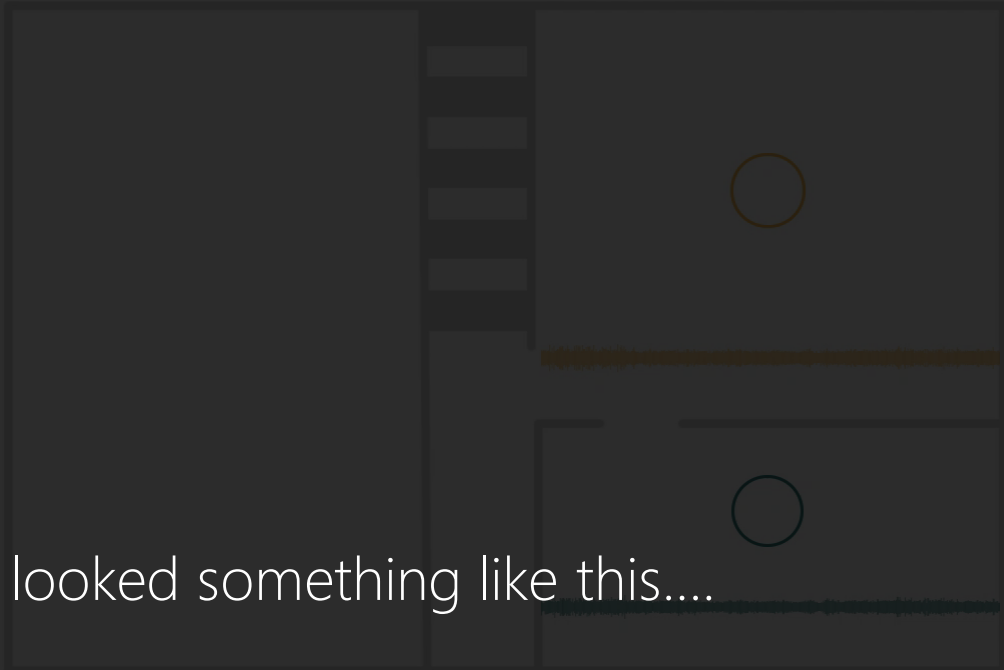
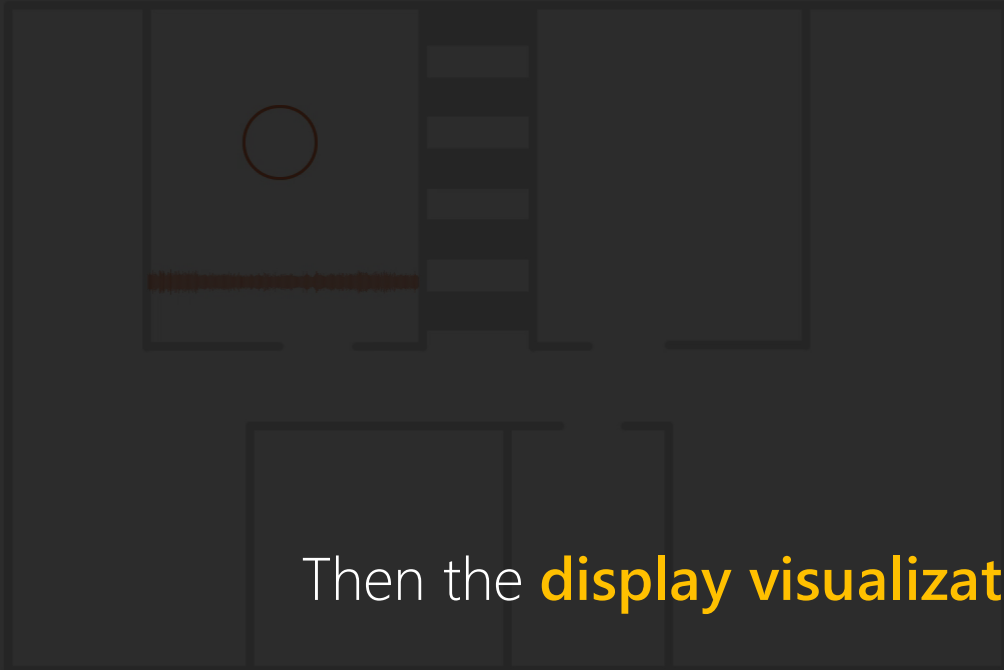


Second floor

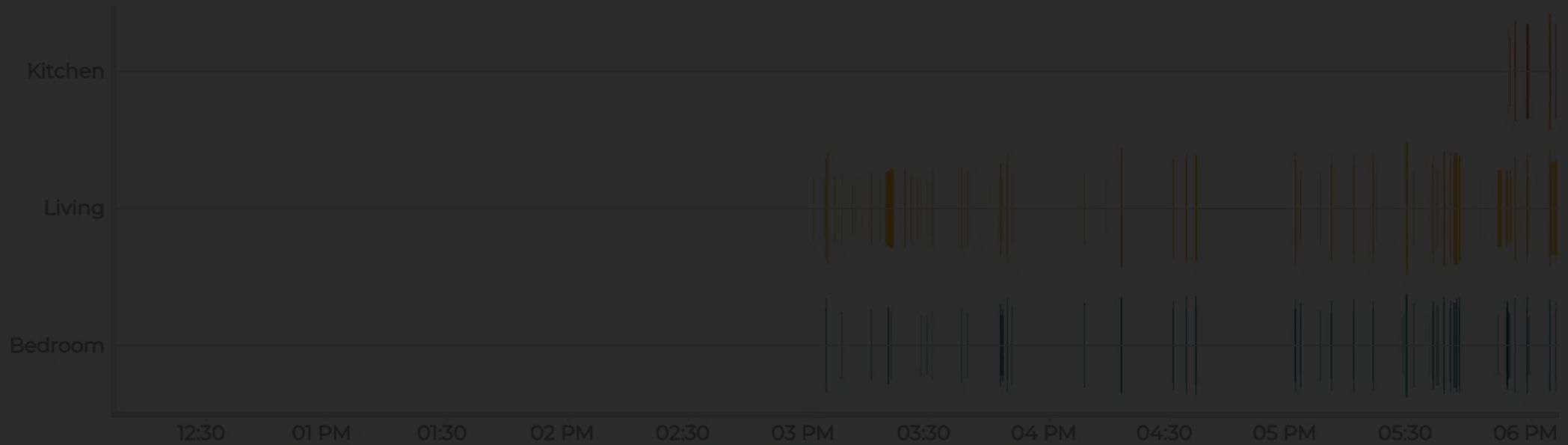


Say we **install our tablets in three rooms** of the house.

6:06 pm

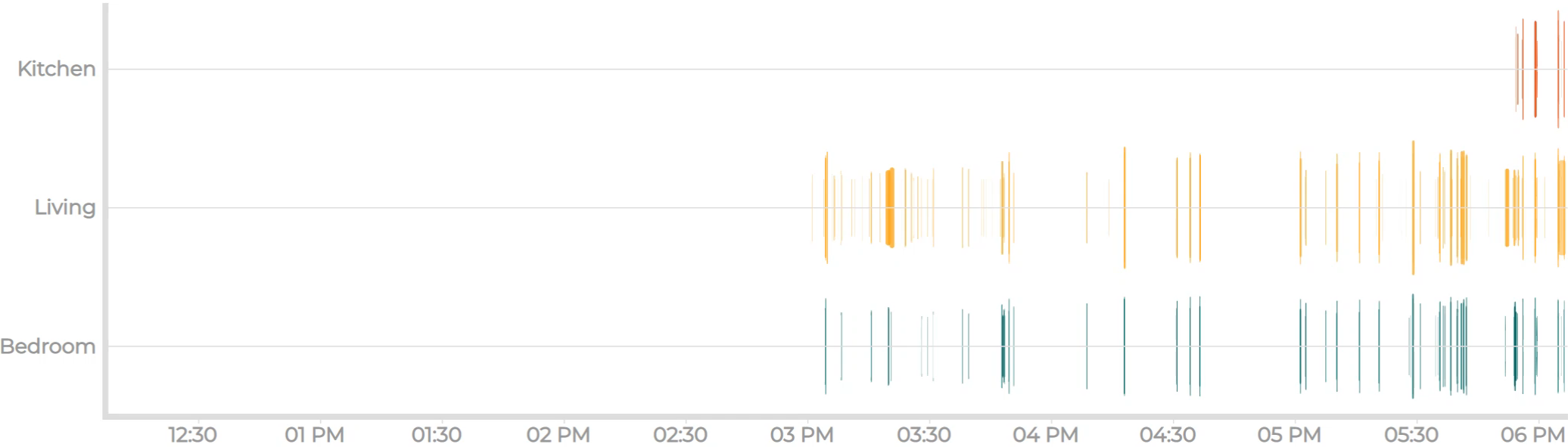
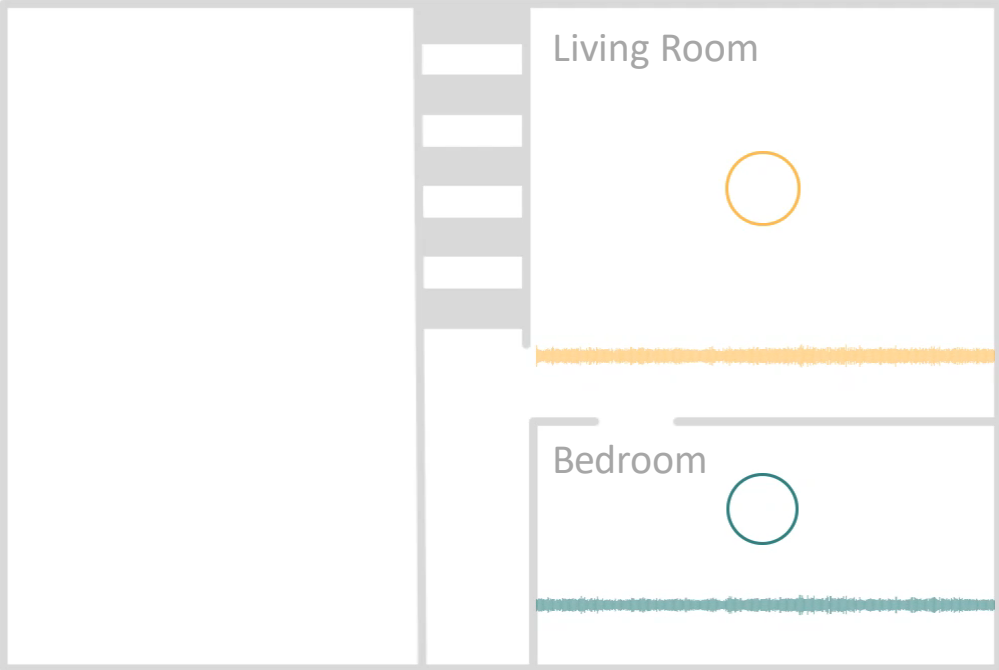
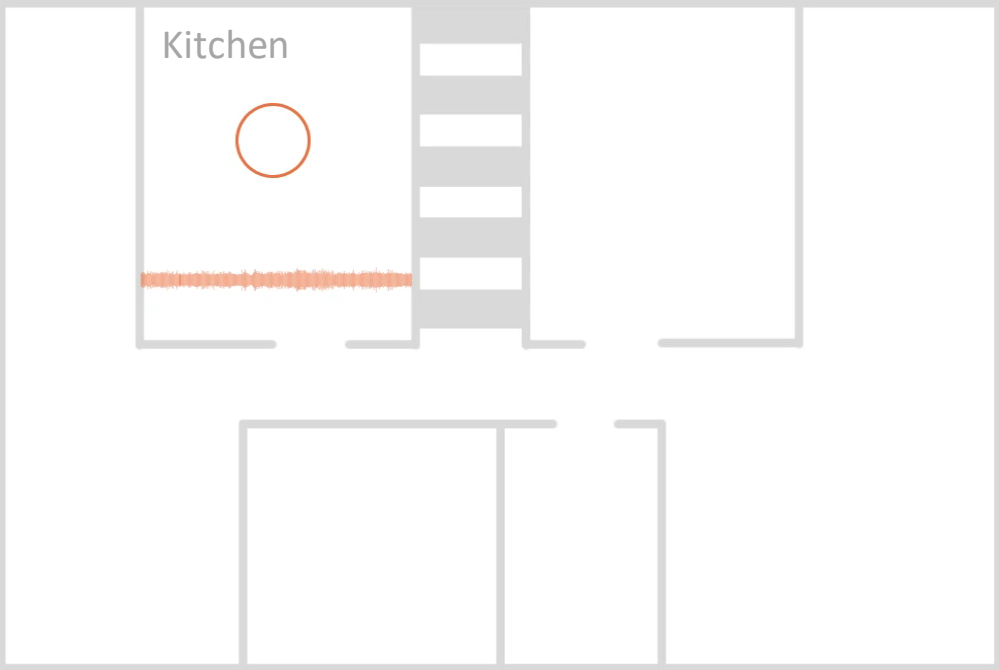


Then the **display visualization** looked something like this....



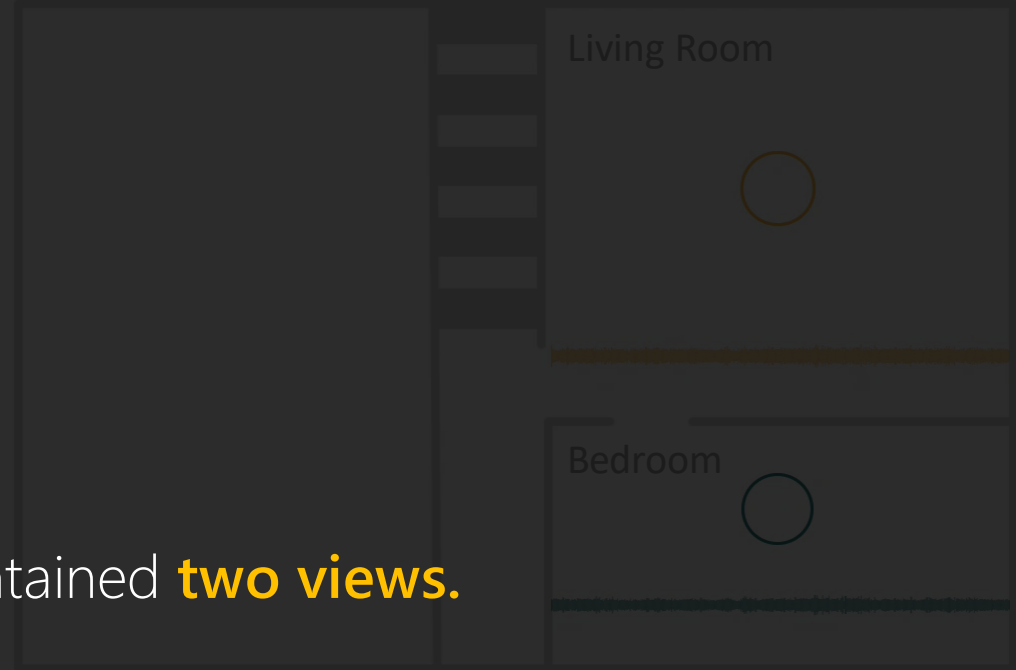
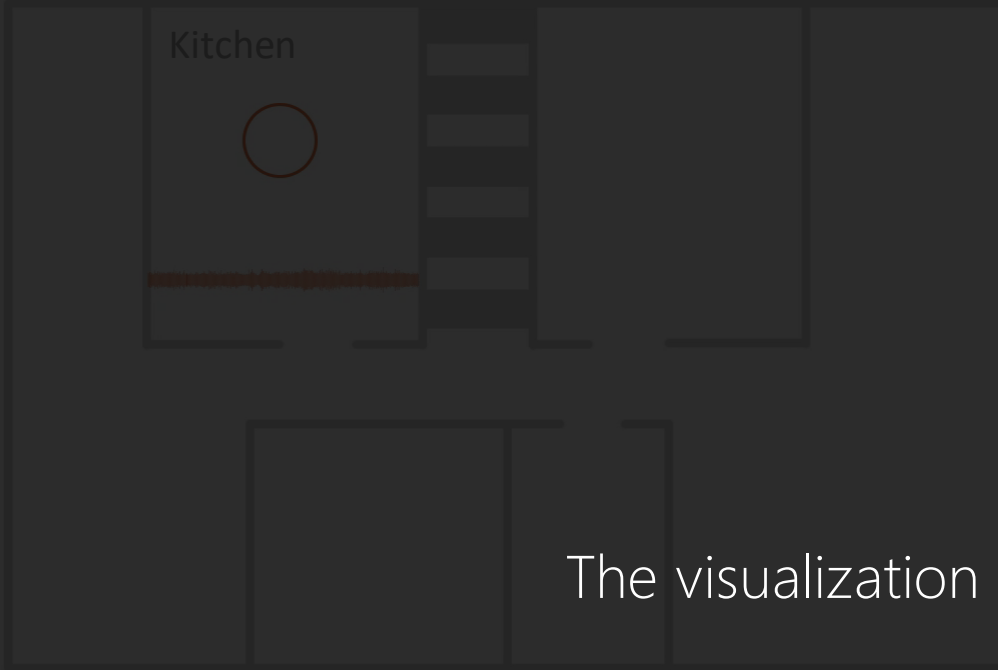
6:06 pm

Bookmark

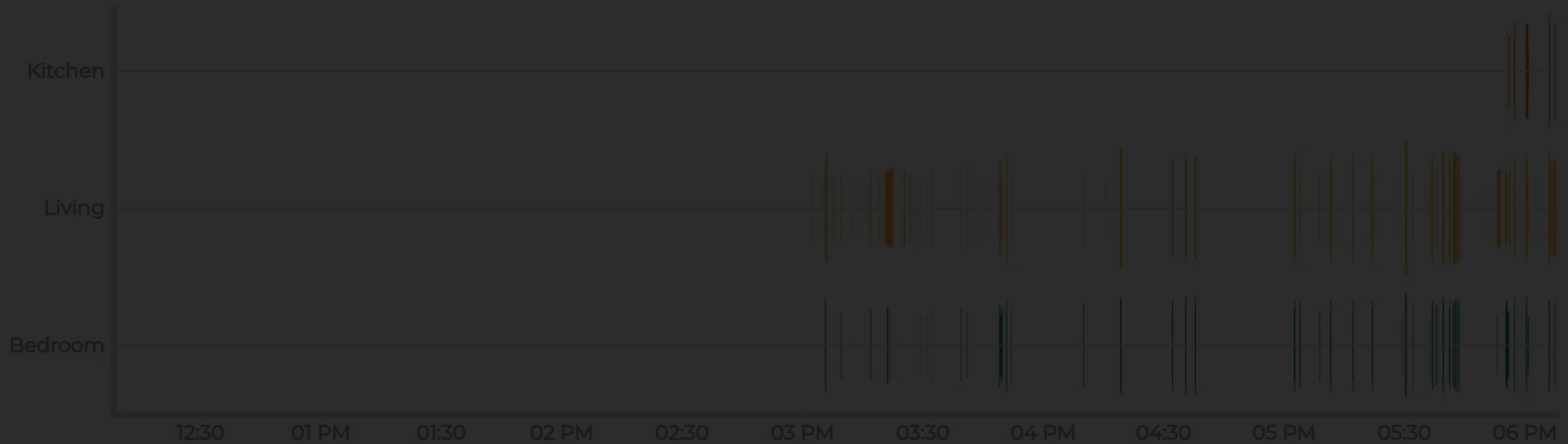


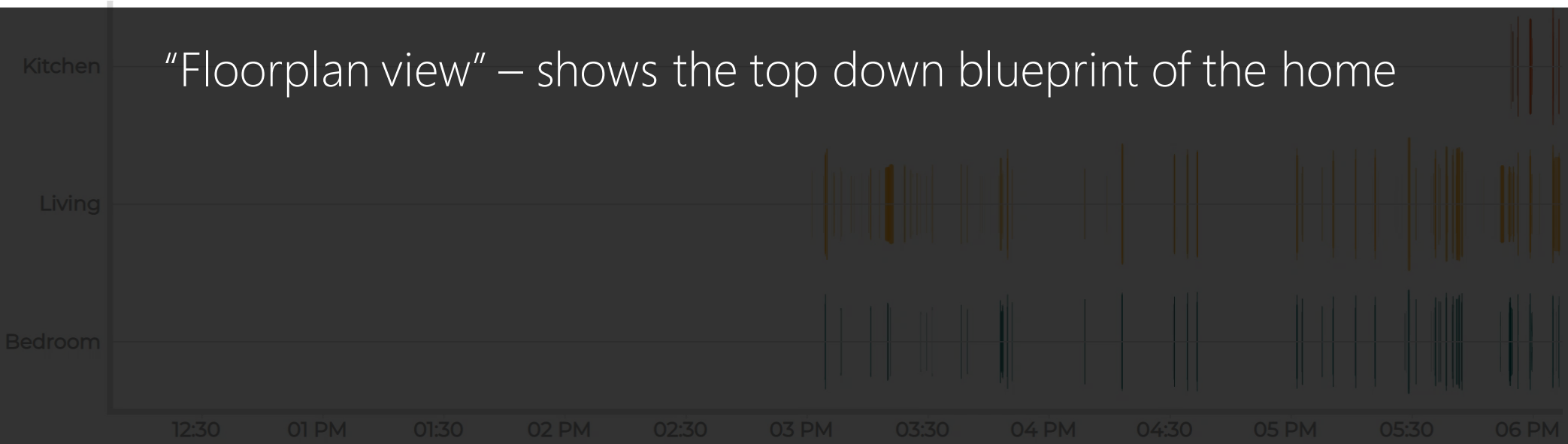
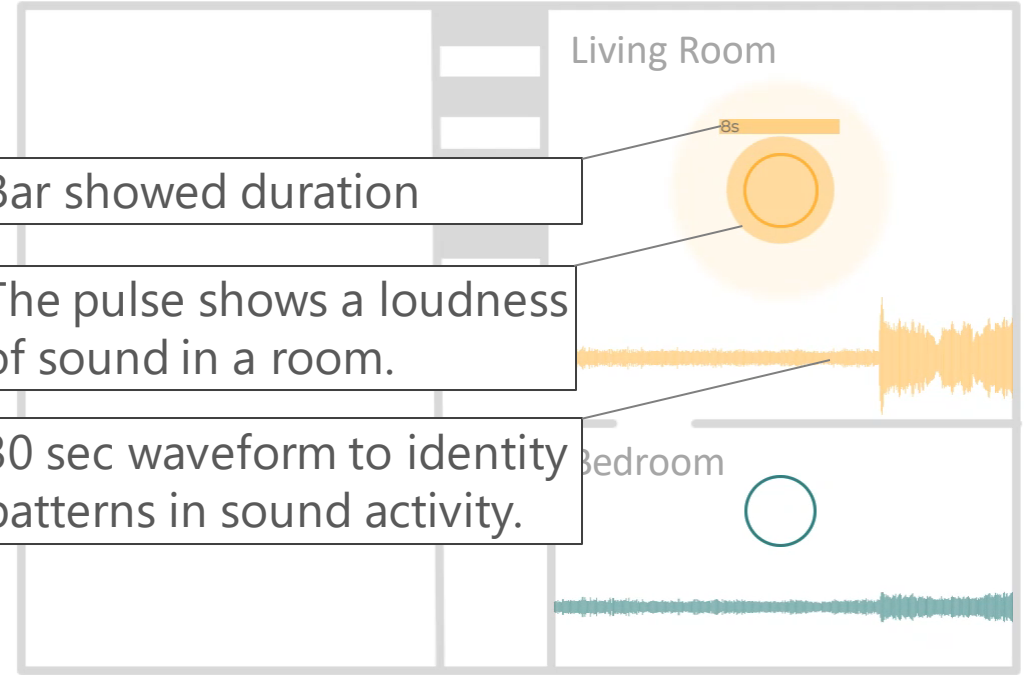
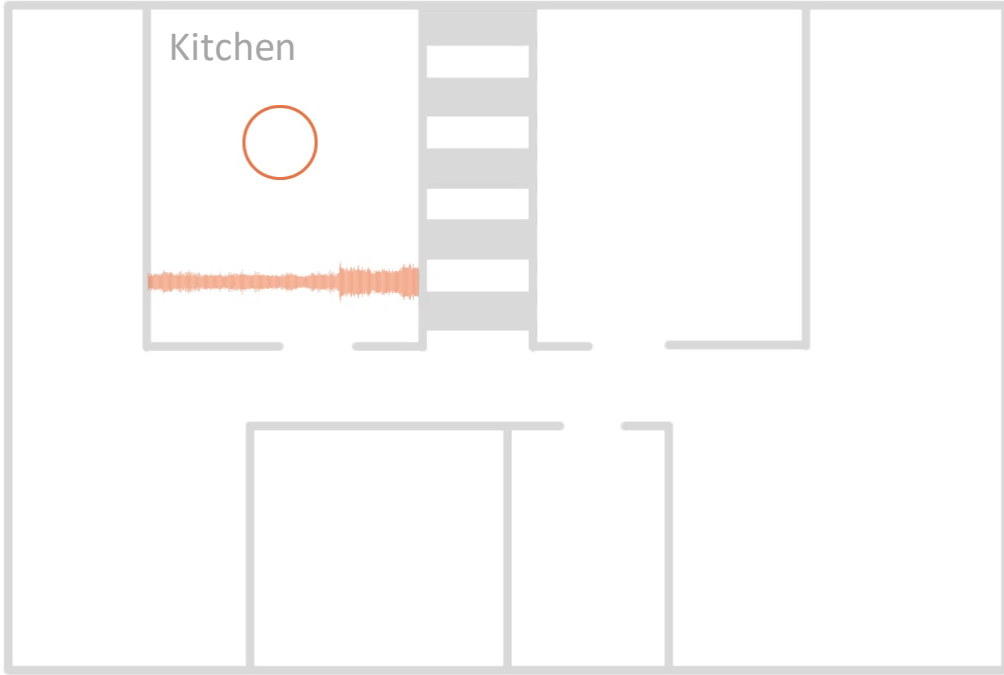
6:06 pm

Bookmark



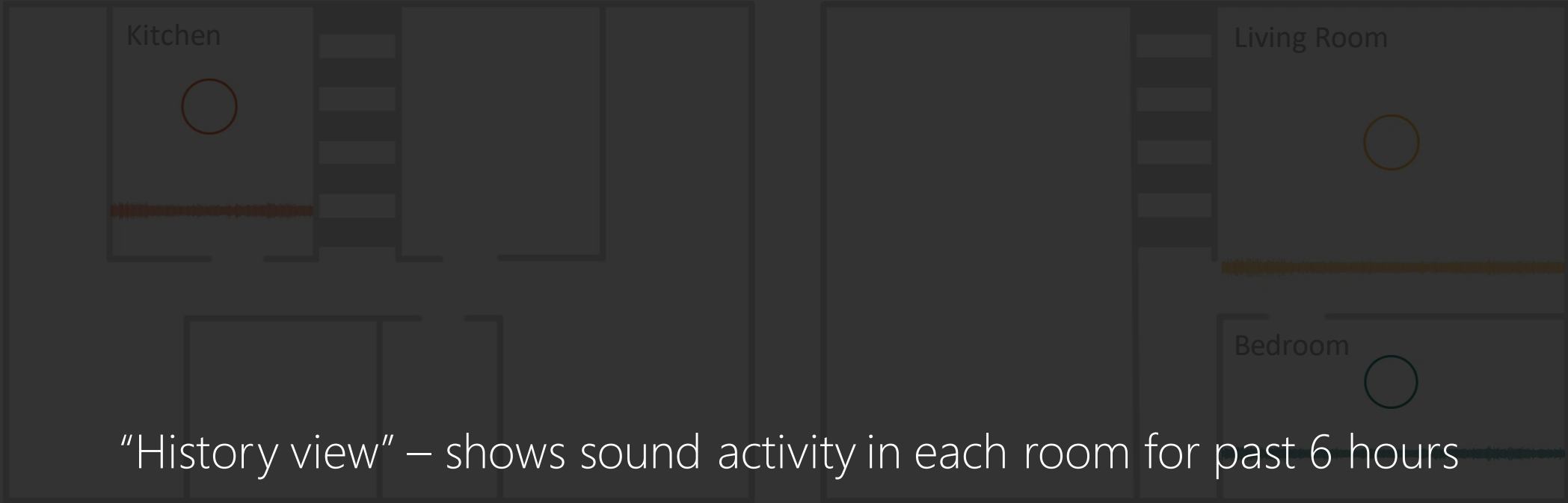
The visualization contained **two views**.



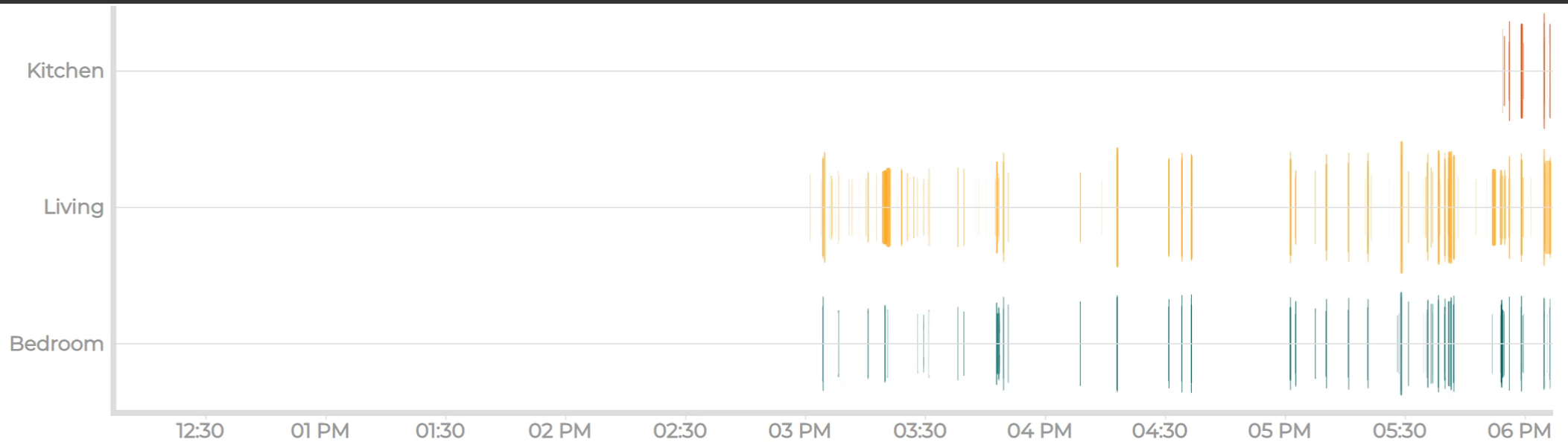


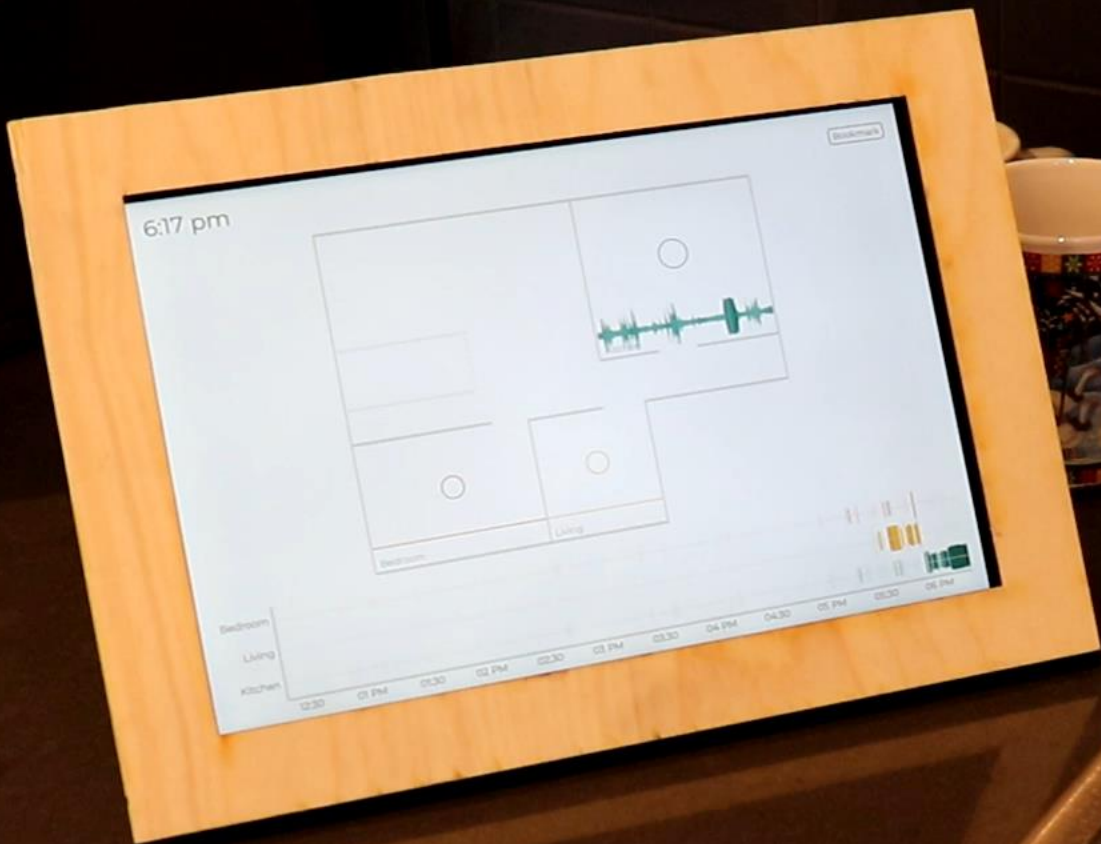
6:06 pm

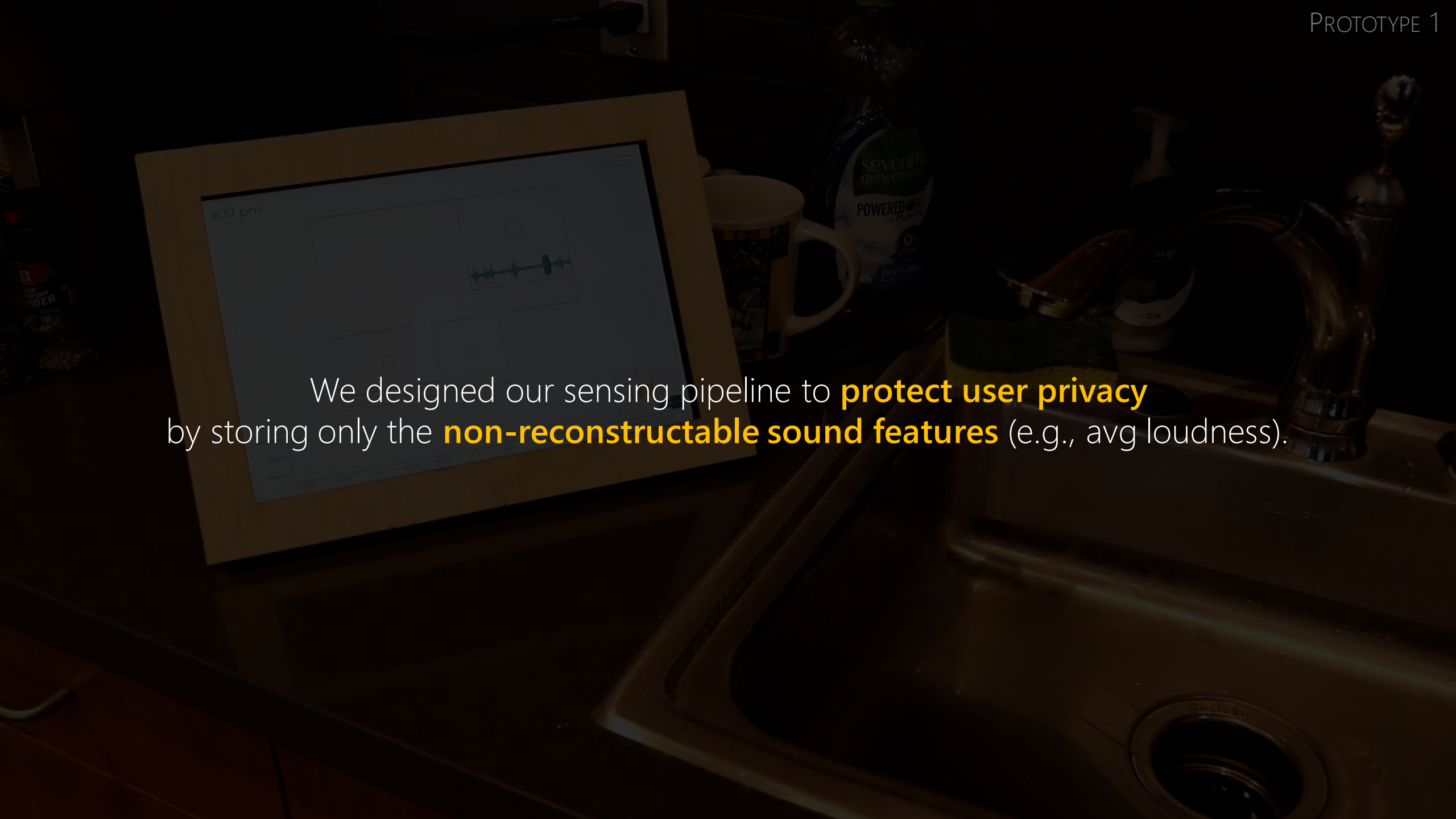
Bookmark



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





A photograph of a kitchen sink area. In the foreground, a tablet is propped up, displaying a waveform graph with a time stamp of 6:17 pm. The graph shows a series of peaks and troughs. In the background, there is a sink with a faucet, a bottle of Seventh Generation dish soap, and a mug. The scene is dimly lit, with the tablet screen providing the main source of light.

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

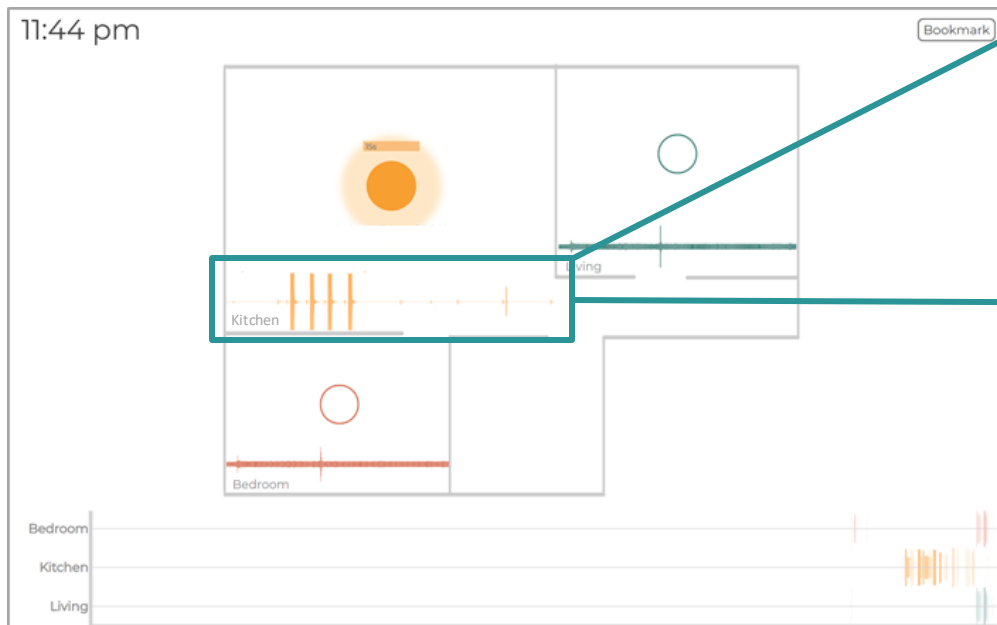
All DHH participants looked at the displays **at least a few times a day.**

A photograph of a kitchen sink area. A computer monitor is placed on the countertop to the left of the sink. The sink is a double-basin stainless steel sink with a chrome faucet. A yellow and green sponge is on the edge of the sink. In the background, there is a white mug, a bottle of dish soap, and a wall outlet. The entire image is dimly lit and has a dark overlay.

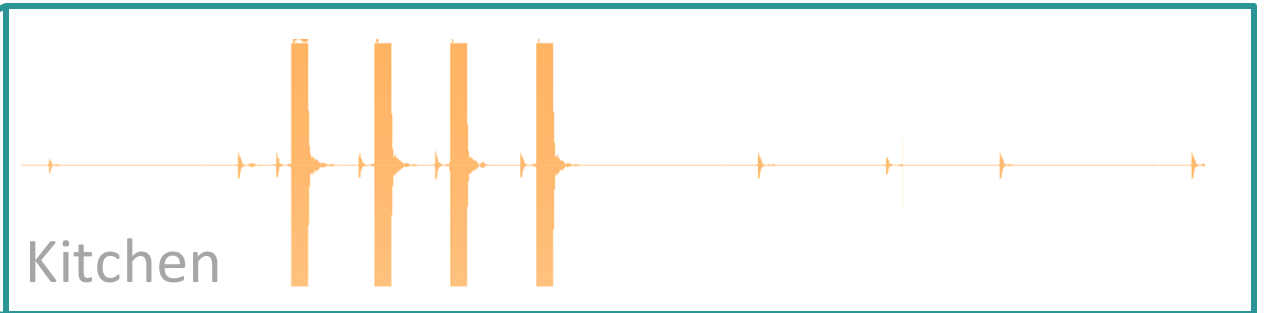
A photograph of a kitchen sink area. A tablet computer is propped up on the counter to the left of the sink, displaying a line graph with a rising trend. The sink is a double-basin stainless steel sink with a chrome faucet. A bottle of dish soap and a mug are visible on the counter behind the sink. The background shows a tiled wall and a power outlet.

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...**

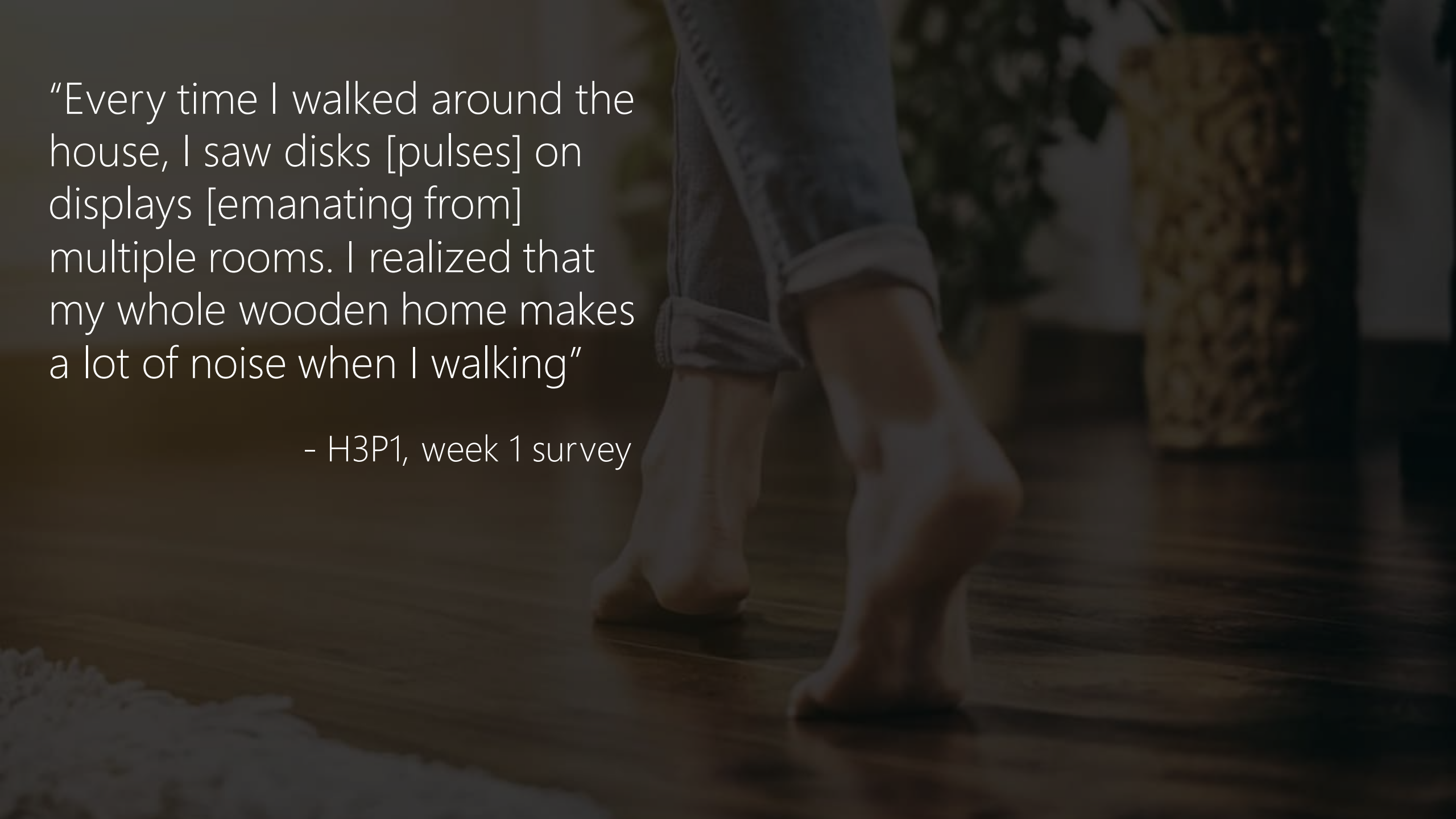
However, in some cases, participants **relied on context** to make use of the system, suggesting that a future **improved system may be useful.**



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.”



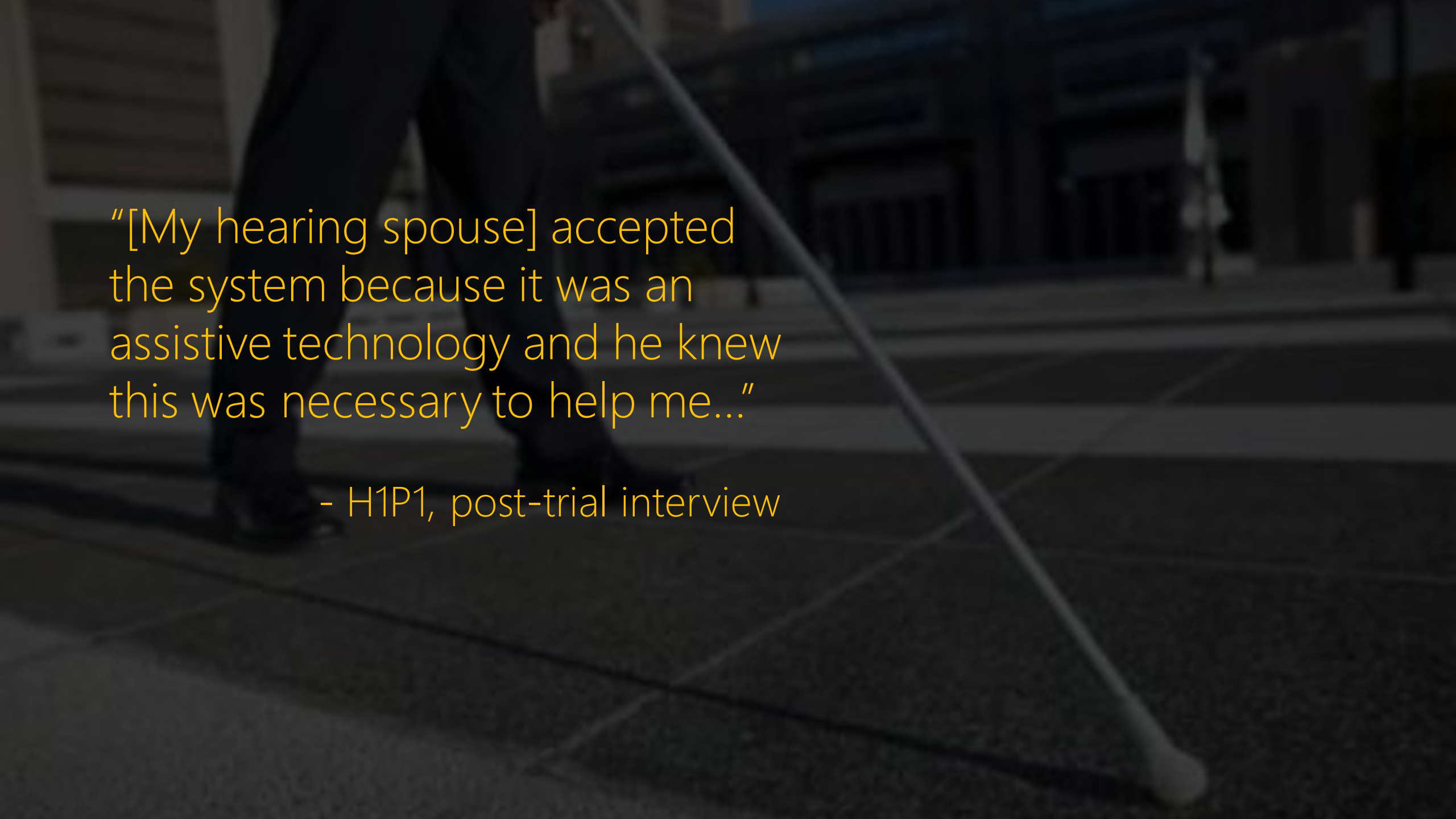
“Every time I walked around the house, I saw disks [pulses] on displays [emanating from] multiple rooms. I realized that my whole wooden home makes a lot of noise when I walking”

- H3P1, week 1 survey

A photograph of a kitchen sink area. A computer monitor is placed on the countertop to the left of the sink. The sink is a double-basin stainless steel sink with a chrome faucet. There are various items on the counter, including a mug and a bottle of dish soap. The background shows a tiled wall and a power outlet.

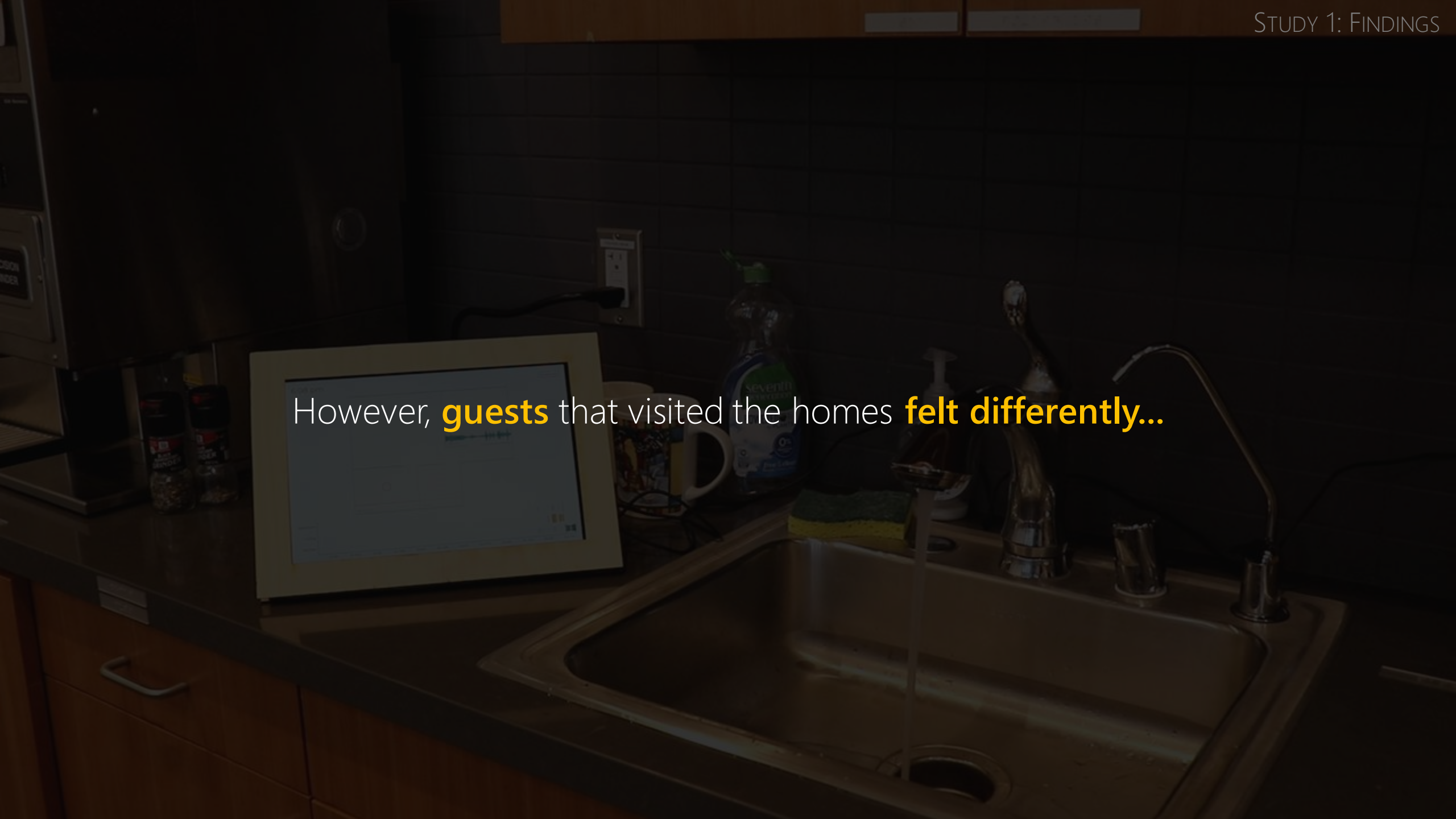
In terms of privacy, surprisingly, the DHH participants and their house members **did not voice any privacy concerns.**

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

A dark, low-angle photograph of a person's legs and feet walking on a city sidewalk. The person is using a white cane, which is visible as a diagonal line from the top right towards the bottom center. The background shows a blurred city street with buildings and a traffic light.

“[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

A photograph of a kitchen sink area. The sink is stainless steel and has a chrome faucet. A yellow and green sponge is on the edge of the sink. To the left of the sink, a tablet computer is propped up on the counter. The background is a tiled wall with a power outlet. The image is dimly lit and has a dark overlay.

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
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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



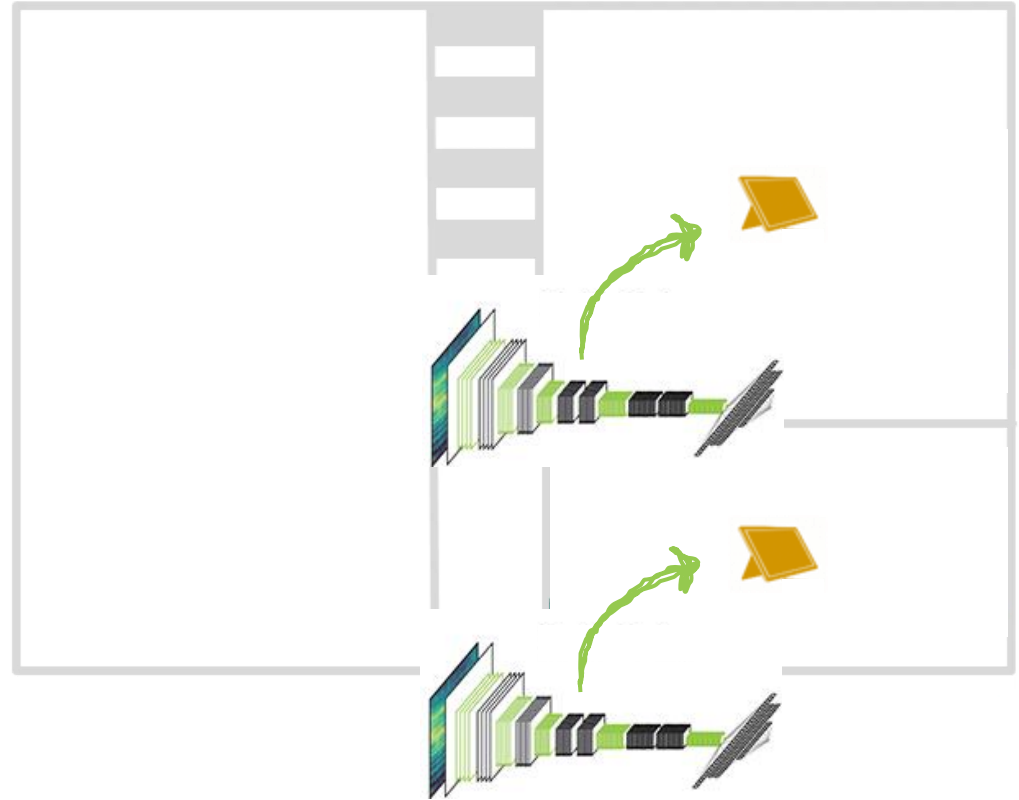
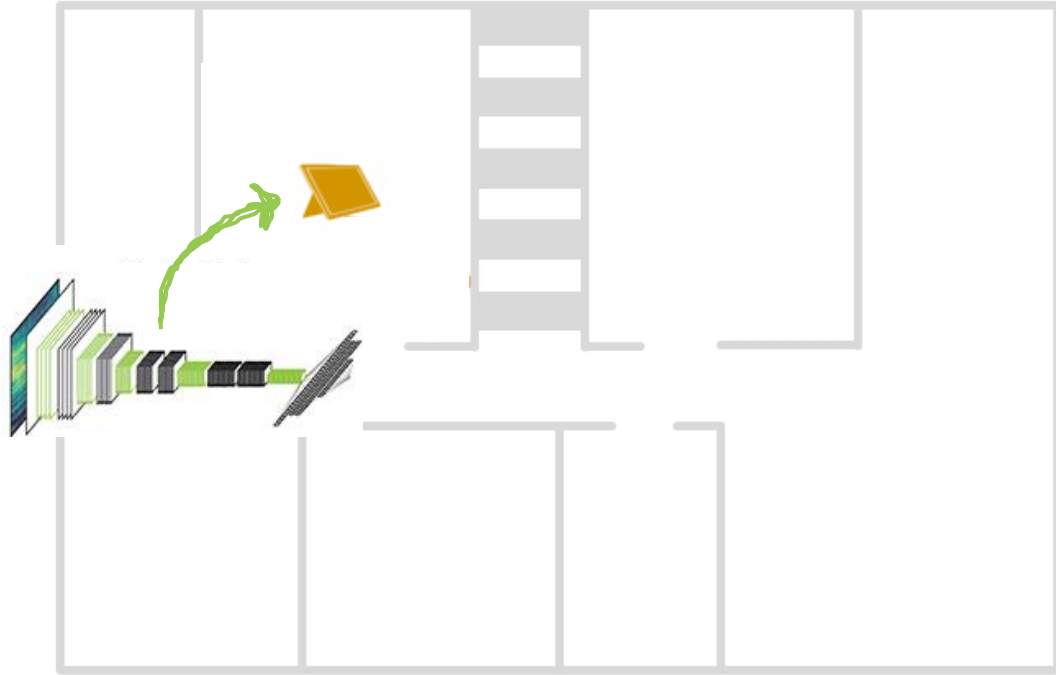
**Clips from online
libraries for 19
sound classes**



**VGG16 Architecture
Pre-trained on 8M
YouTube videos**

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

85.9% ($SD=4.1\%$)

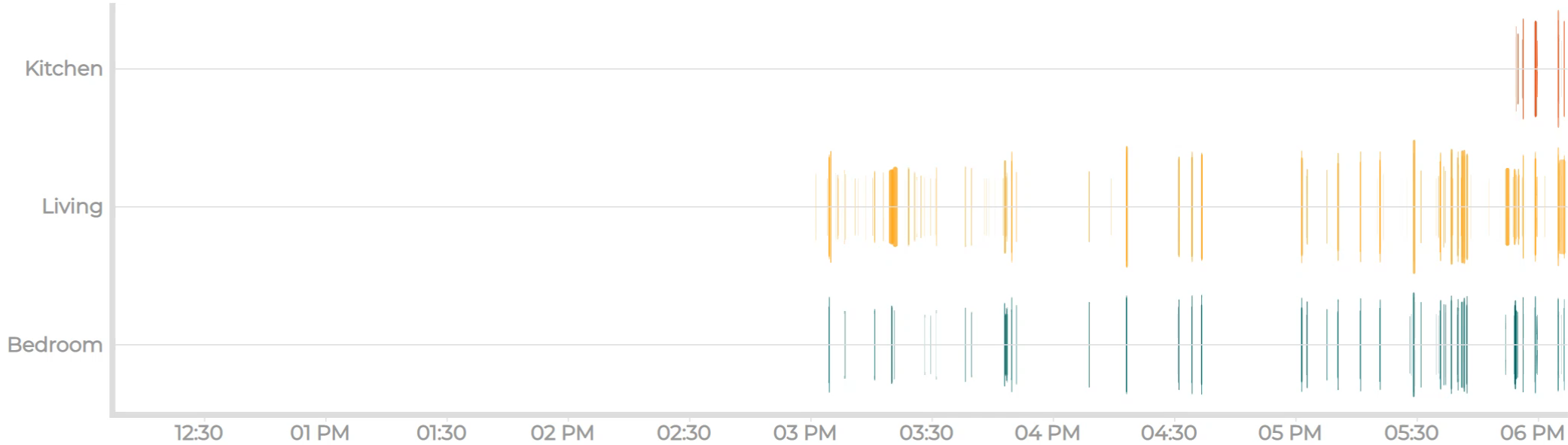
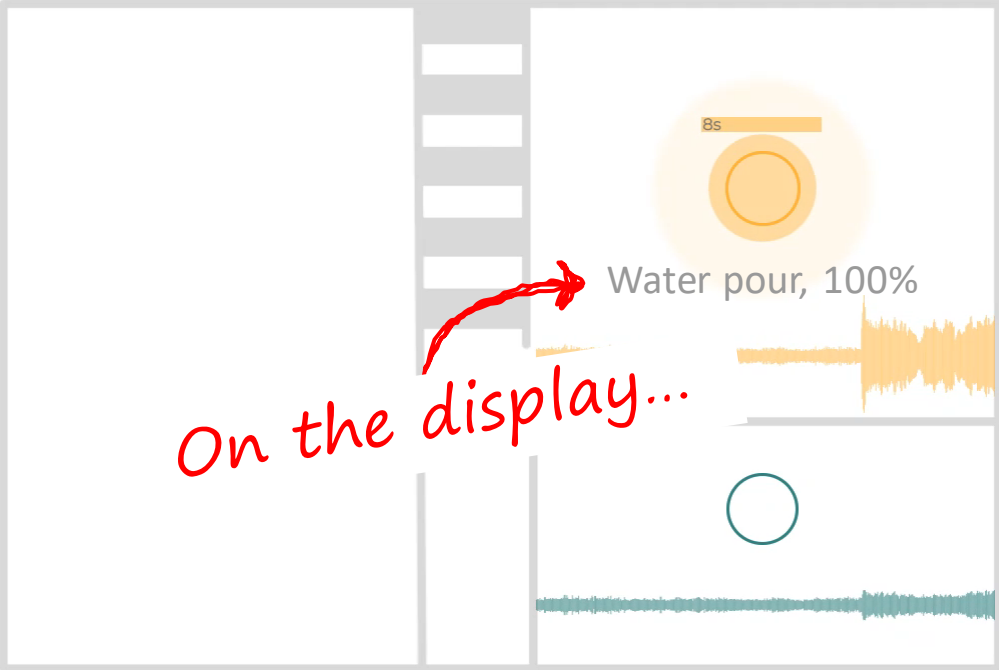
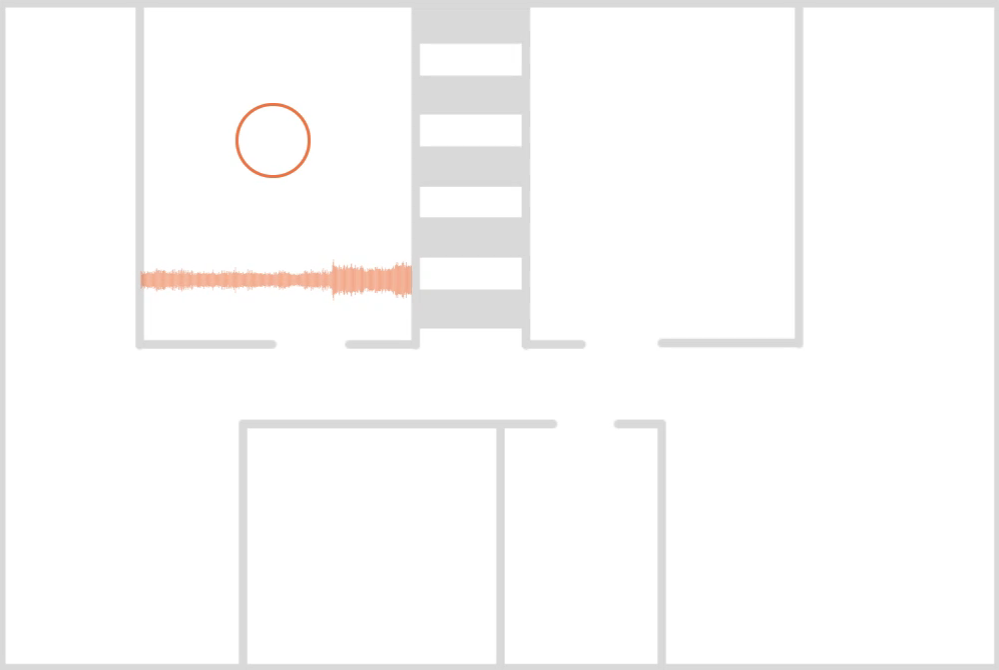


The model was uploaded to **each IoT display.**

6:07 pm

Settings

Bookmark



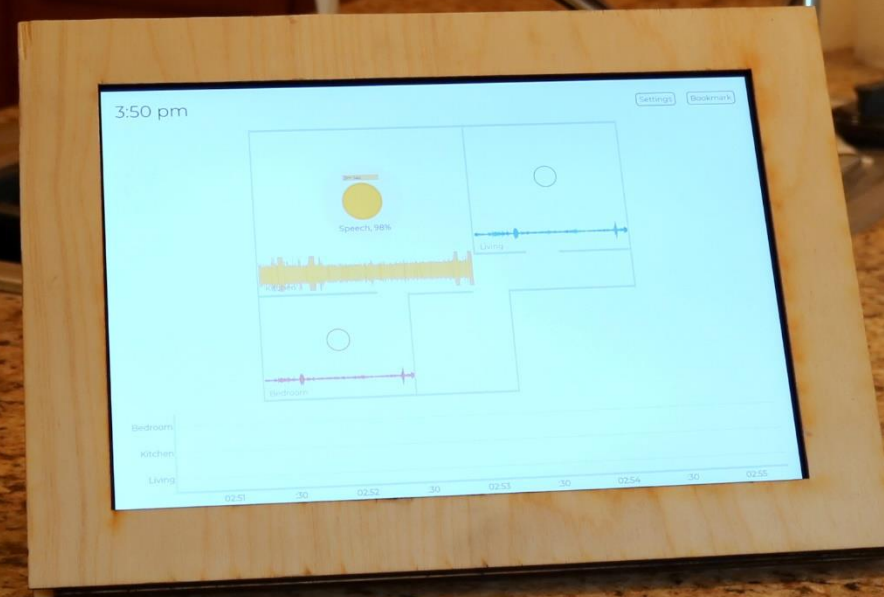
TWO EXTENSIONS TO PROTOTYPE 1

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

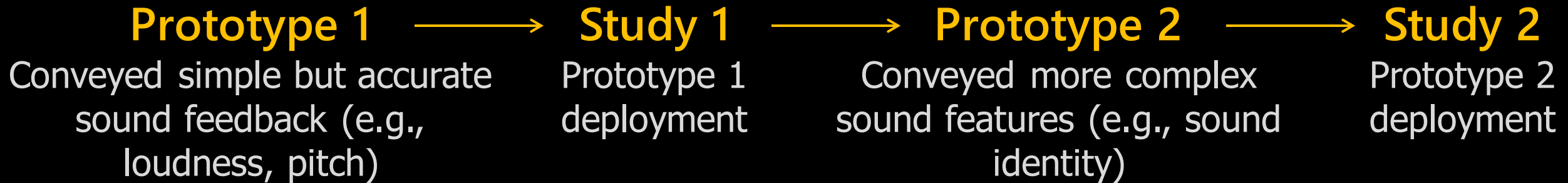
Prototype 1
deployment



Prototype 2

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

OUTLINE



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

A person's hand is shown interacting with a smartwatch on a kitchen counter. The background is a dimly lit kitchen with wooden cabinets and a countertop. The smartwatch is the central focus, and the person's hand is positioned over it. The overall scene is dark, with the smartwatch and the person's hand being the primary light sources.

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

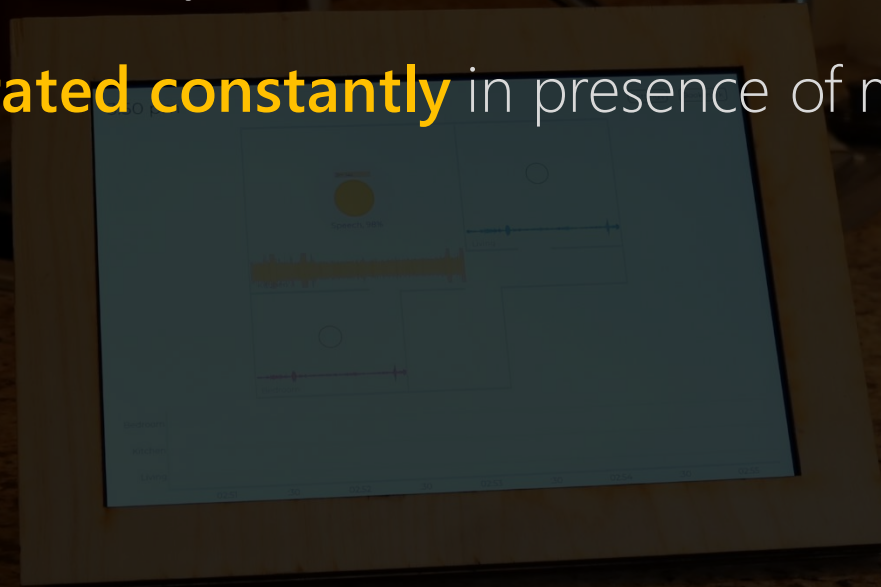
“


“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



A group of five people are seated around a dining table in a restaurant. A woman, likely a waiter, stands behind the table, holding a bottle and looking towards the seated guests. The guests are engaged in conversation and eating. The scene is dimly lit, suggesting an evening setting. The text is overlaid on the left side of the image.

“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.

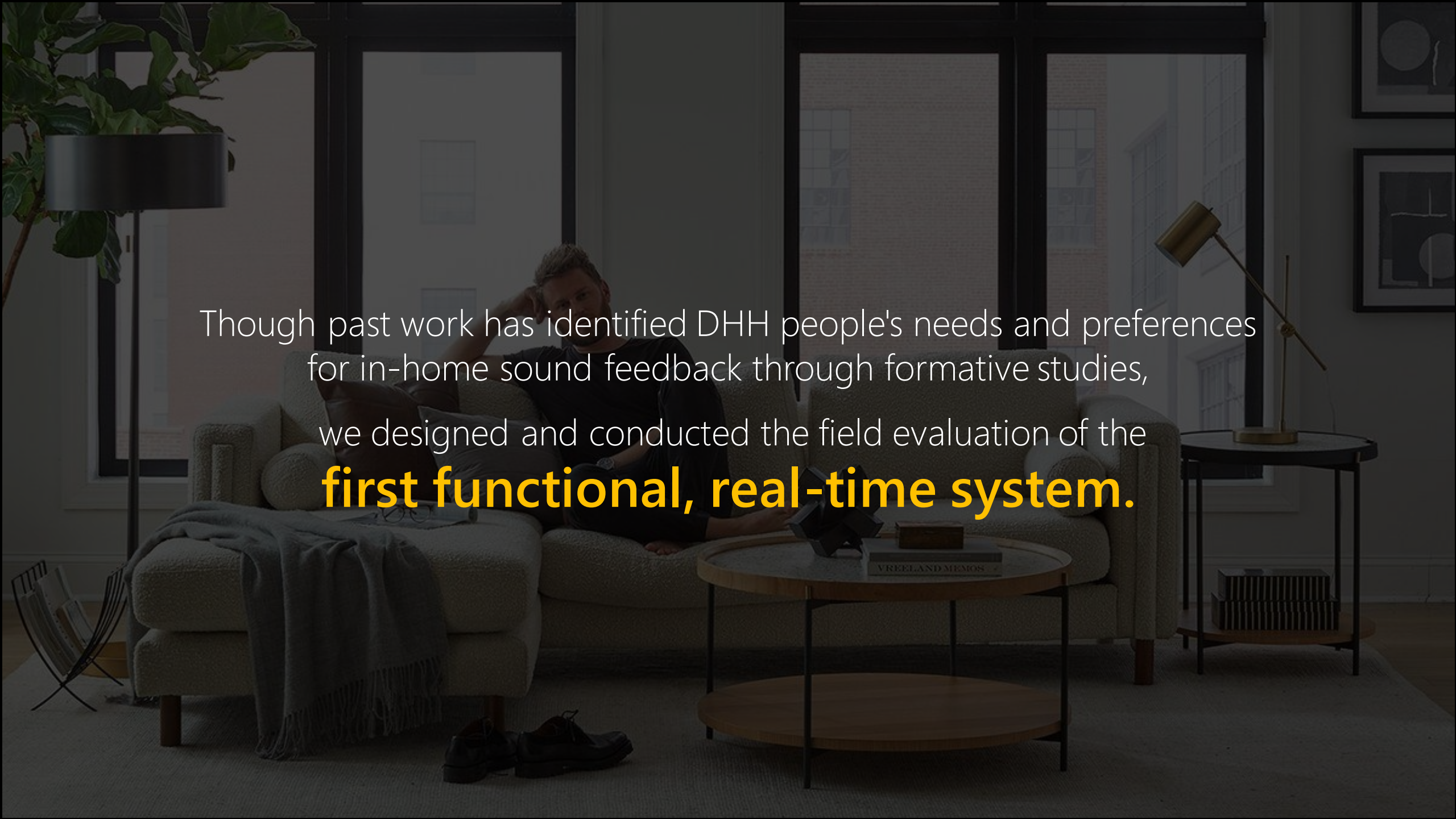
These are future work.

A person's hand is shown interacting with a tablet device. The tablet displays a control interface with various sliders and buttons, likely for adjusting sound settings. The background is a kitchen with wooden cabinets and a countertop. The overall scene is dimly lit, with the tablet screen providing the primary light source.

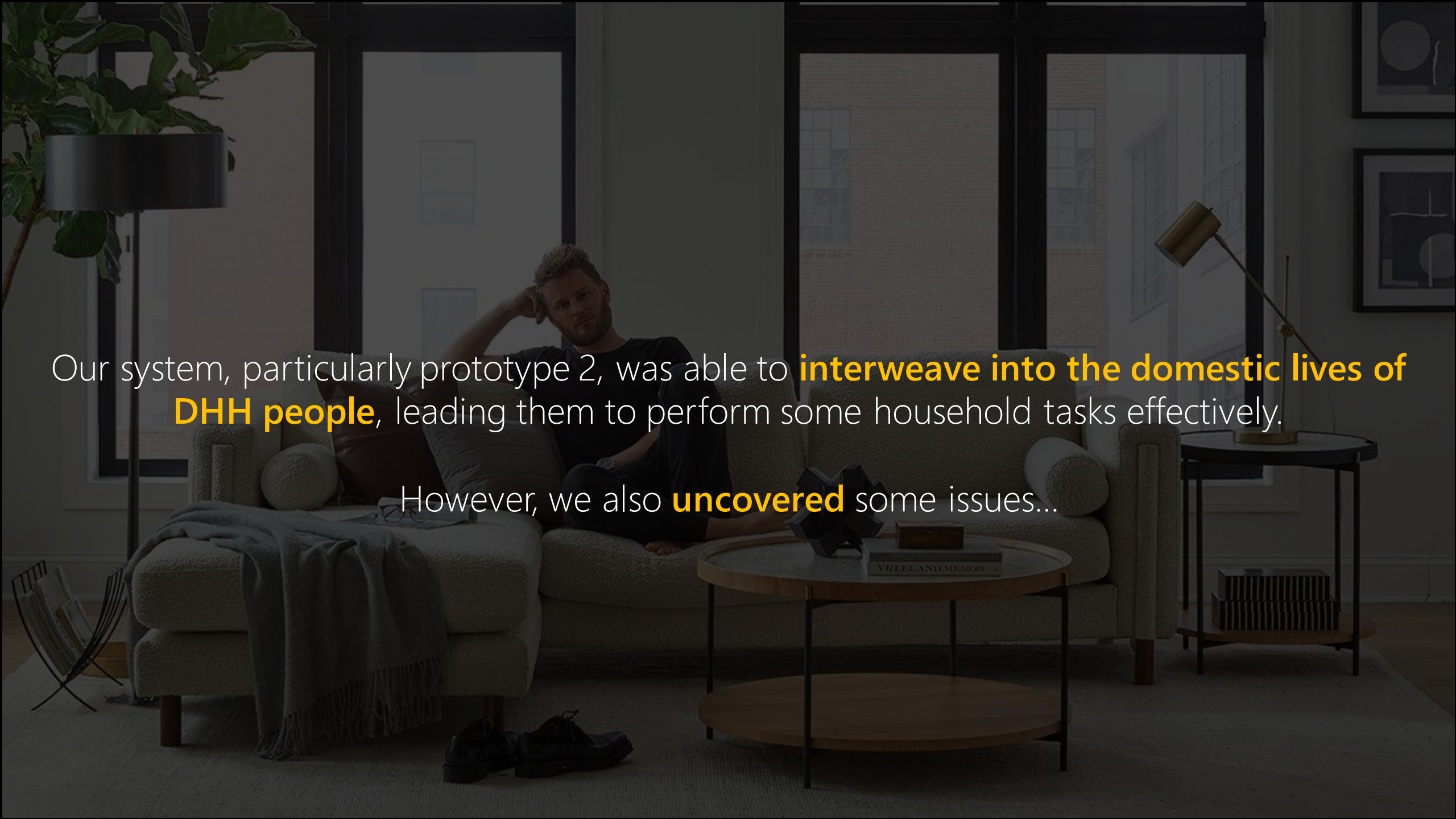
Other findings related to **self-awareness, privacy, culture, display placement and play** provide guidance for future home sound awareness technology.



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.**

A man with short hair and a beard is sitting on a light-colored sofa in a modern living room. He is leaning back with his right hand on his head, looking towards the camera. The room features large windows with black frames, a round coffee table with a book titled 'VREELAND MEMOS', a floor lamp with a large shade, and a side table with a brass lamp. The overall atmosphere is calm and contemporary.

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

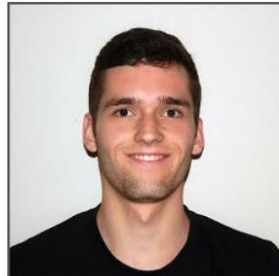
THE TEAM



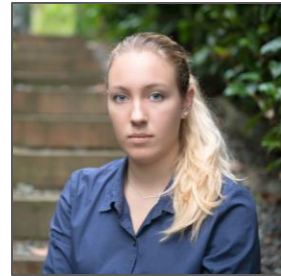
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Exploring Sound Awareness in the Home for People who are Deaf or Hard of Hearing

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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.

