Head-Mounted Display Visualizations to Support Sound Awareness for the Deaf and Hard of Hearing

Dhruv Jain[1,2,5], Leah Findlater[1,5], Jamie Gilkeson[4], Benjamin Holland[4], Ramani Duraiswami[5], Dmitry Zotkin[5], Christian Vogler[3], Jon Froehlich[1,5]

Human Computer Interaction Laboratory

mit media lab

Gallaudet University

Montgomery Blair High School

University of Maryland

Deaf and Hard of Hearing Use Visual Signals

Body Language, Facial Expressions, Lip Movement (SpeechReading)

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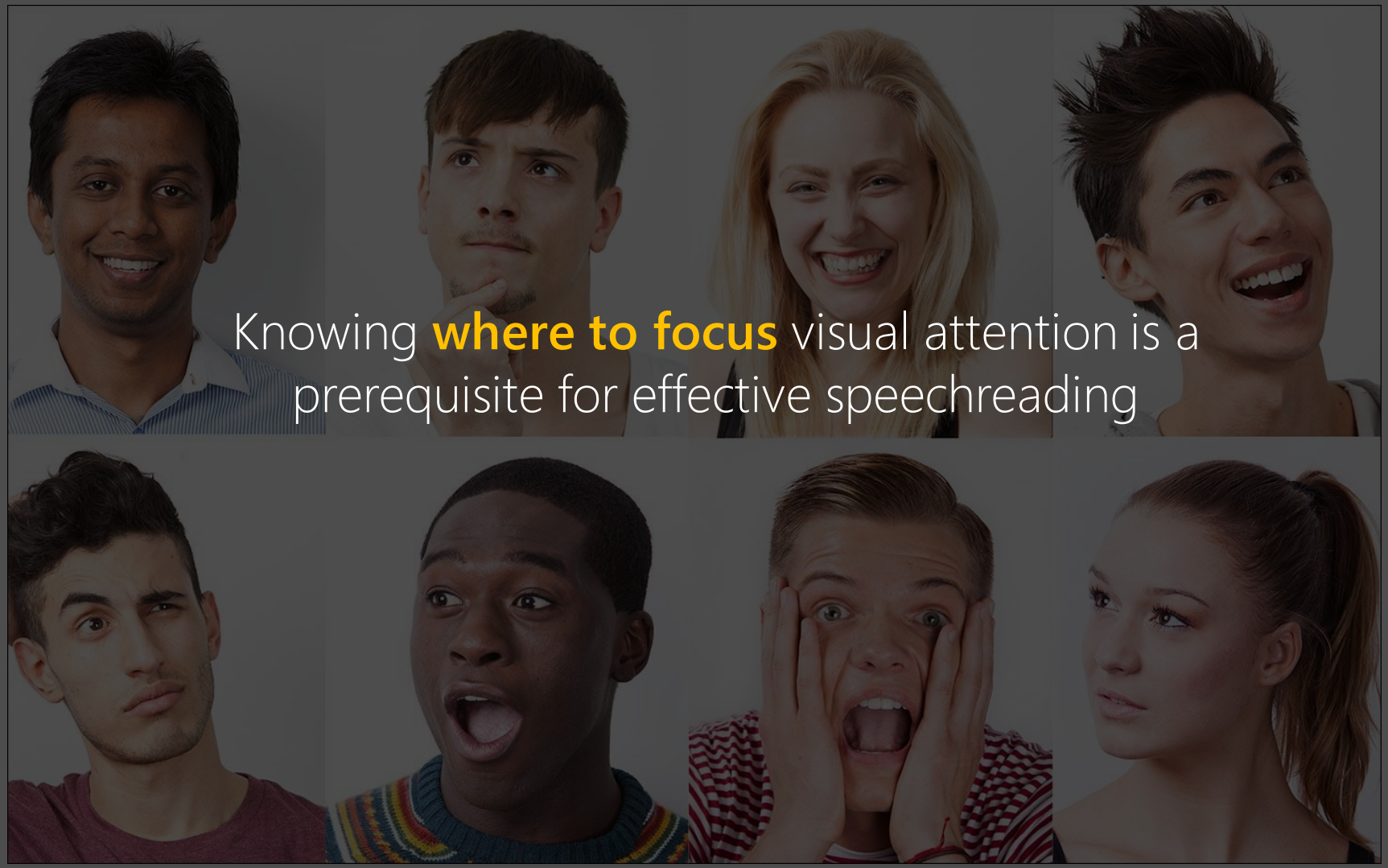


HEARING AID **AND** COCHLEAR IMPLANT

DO NOT IMPROVE SOUND LOCALIZATION

Common Problems in Group Communication

Common Problems in Group Communication

1. Speaker Transition

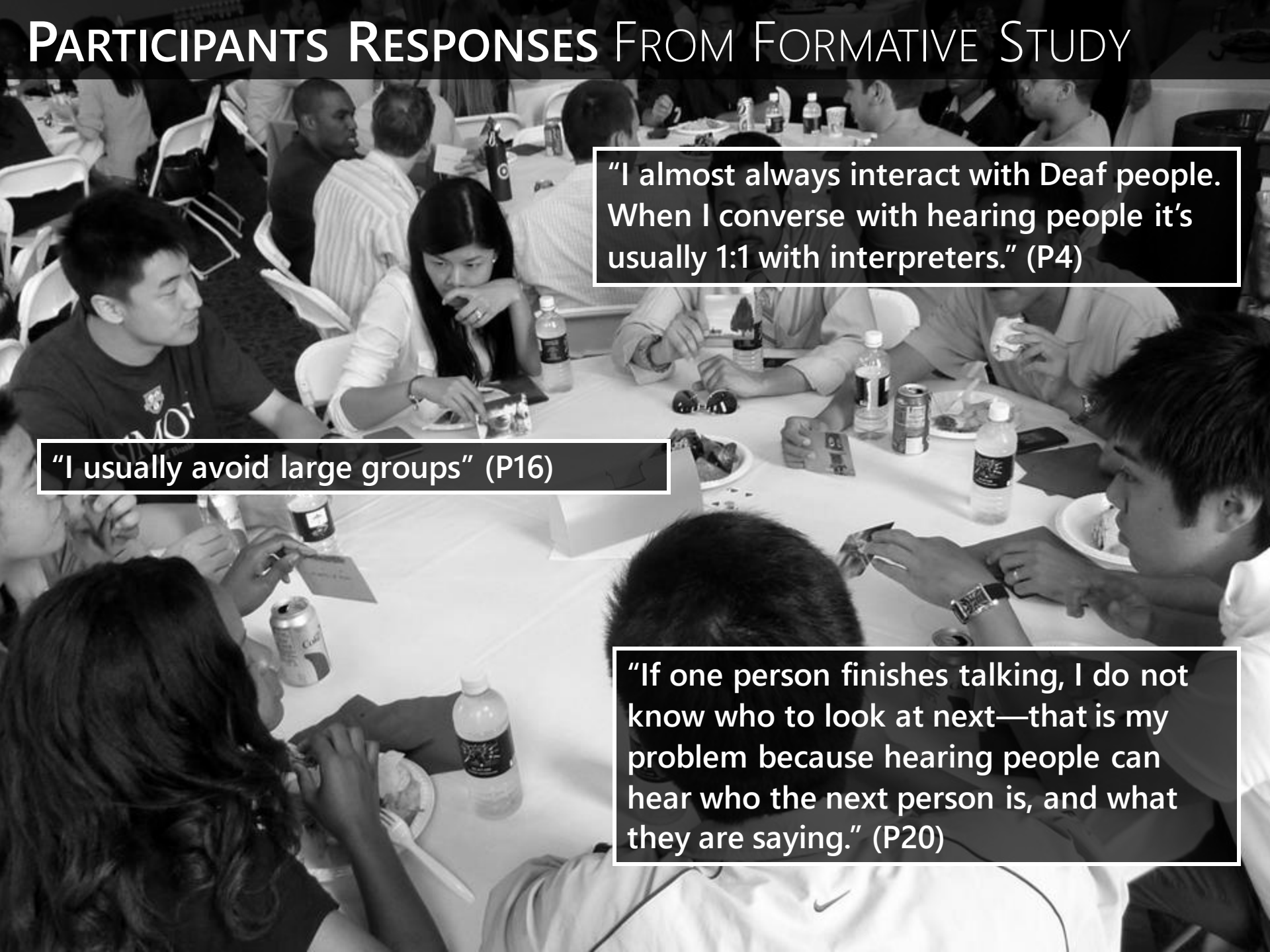
Video from Study 1: Part 1 (Formative Interview)

Common Problems in Group Communication

1. Speaker Transition
2. Inability To Follow Simultaneous Speakers

Video from Study 1: Part 1 (Formative Interview)

Participants Responses From Formative Study

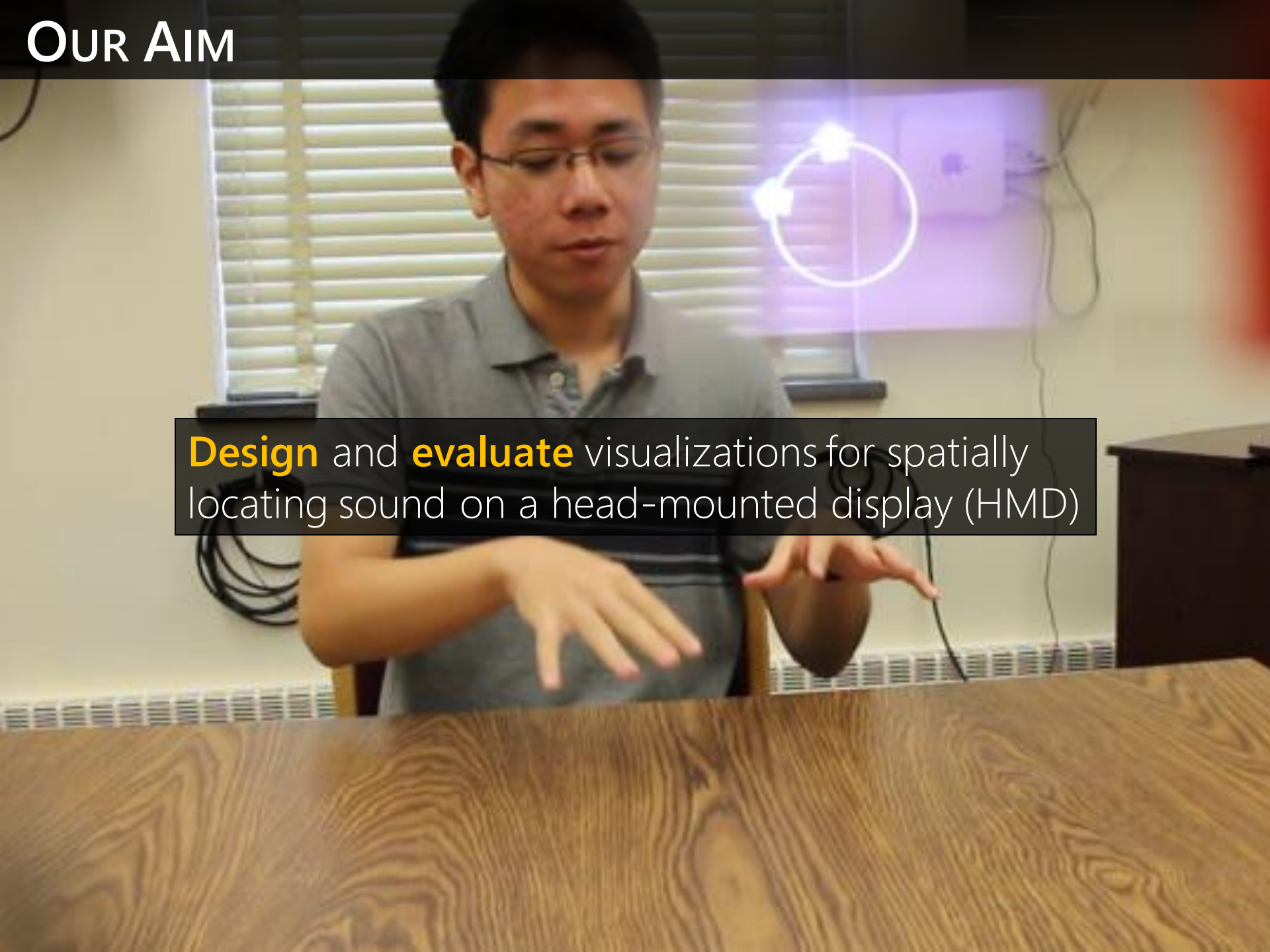


"I almost always interact with Deaf people. When I converse with hearing people it's usually 1:1 with interpreters." (P4)

"I usually avoid large groups" (P16)

"If one person finishes talking, I do not know who to look at next—that is my problem because hearing people can hear who the next person is, and what they are saying." (P20)

Our Aim



Design and **evaluate** visualizations for spatially locating sound on a head-mounted display (HMD)

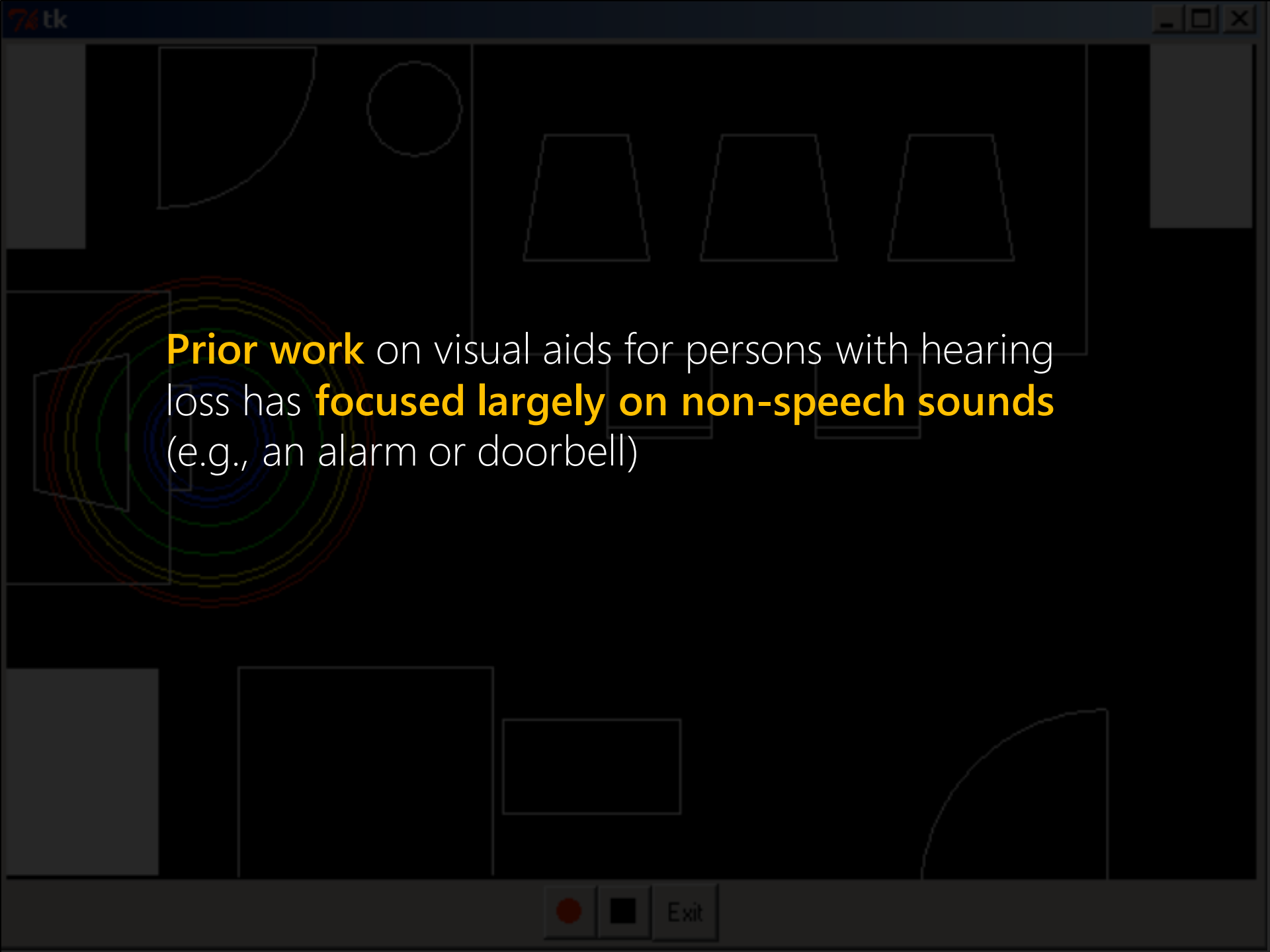
Traditional Techniques

Talking pillow....

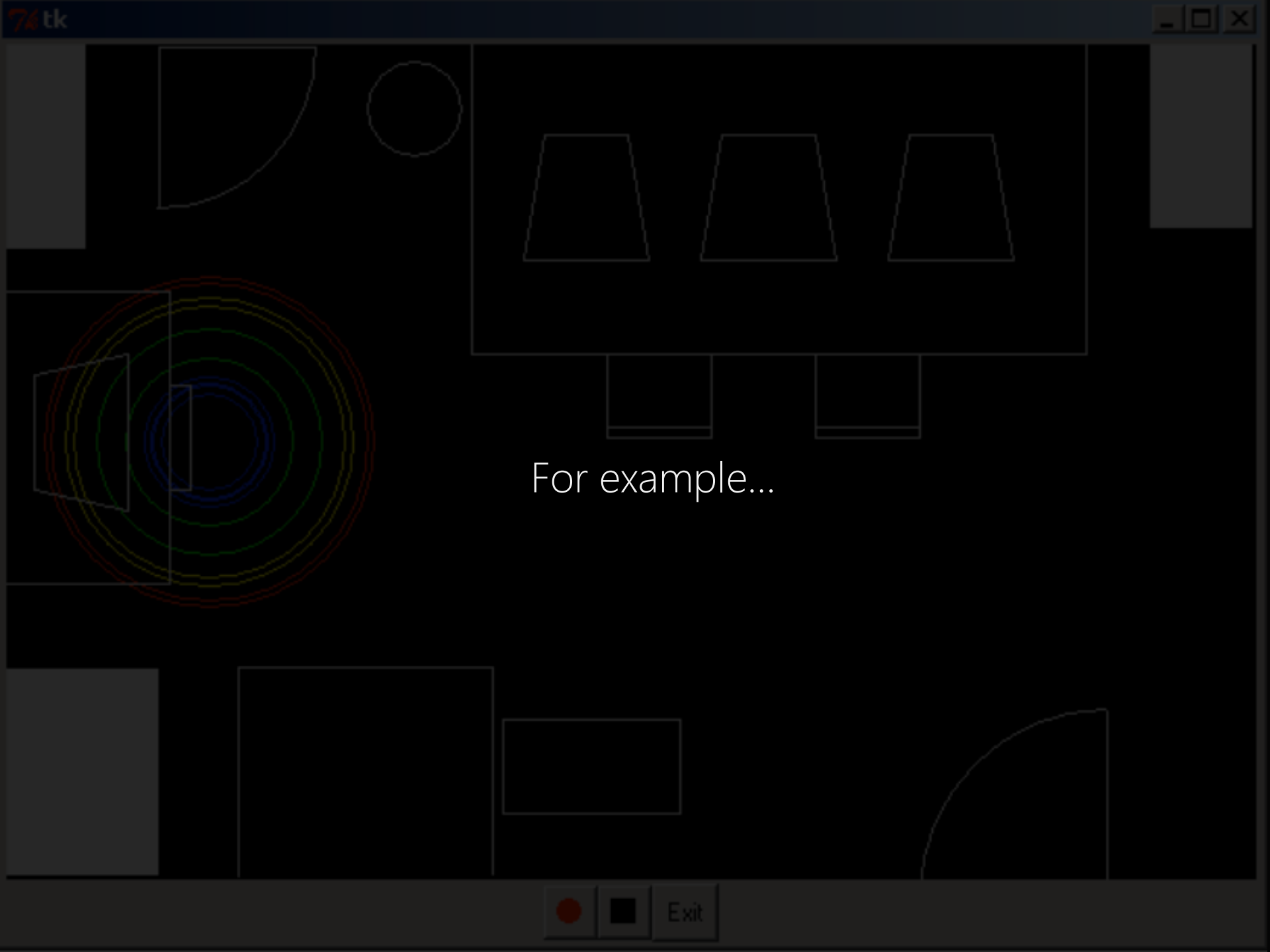

Pillow
Talking pillow....

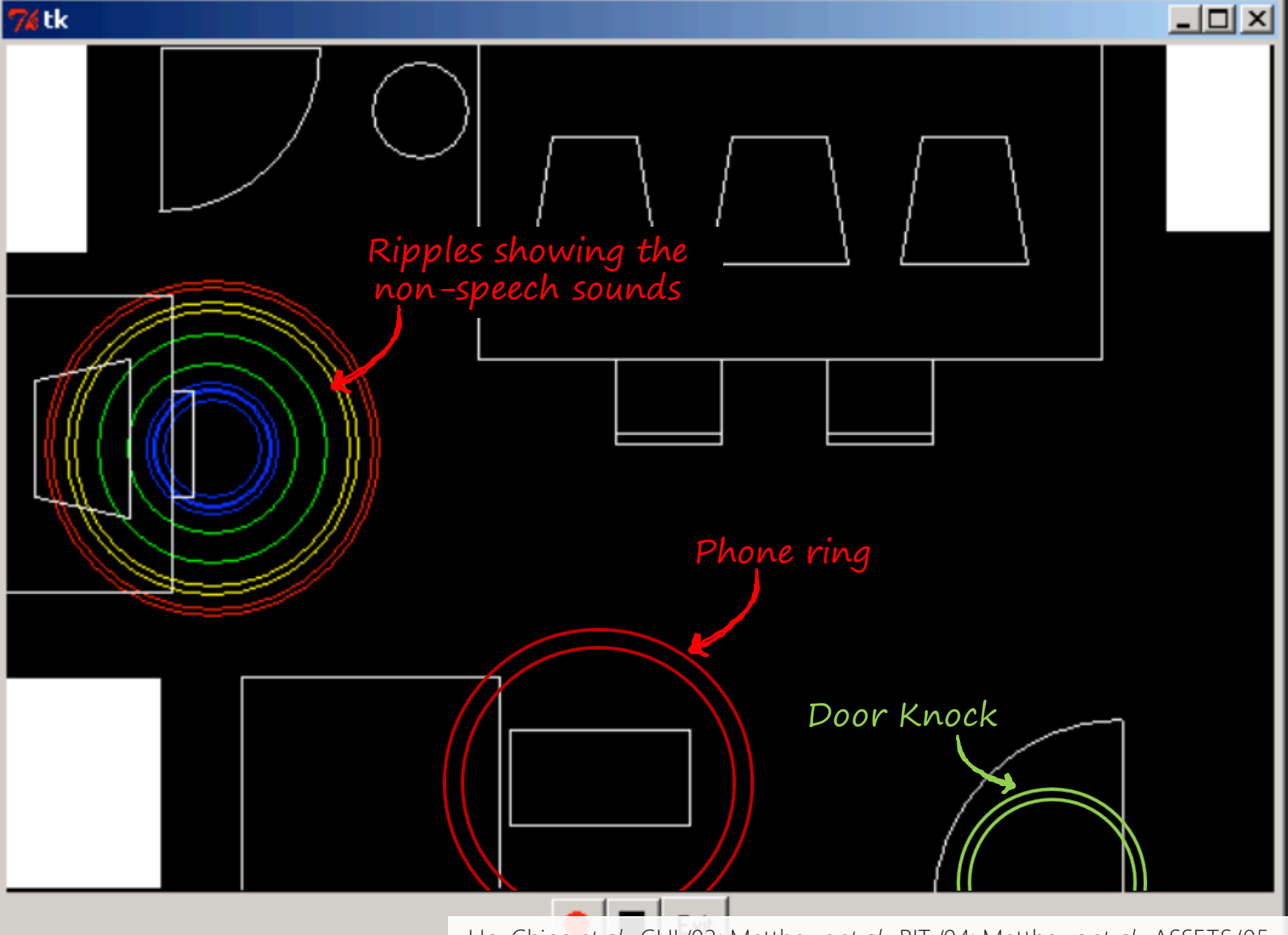

Speaker
Talking pillow....

Using interpreter….

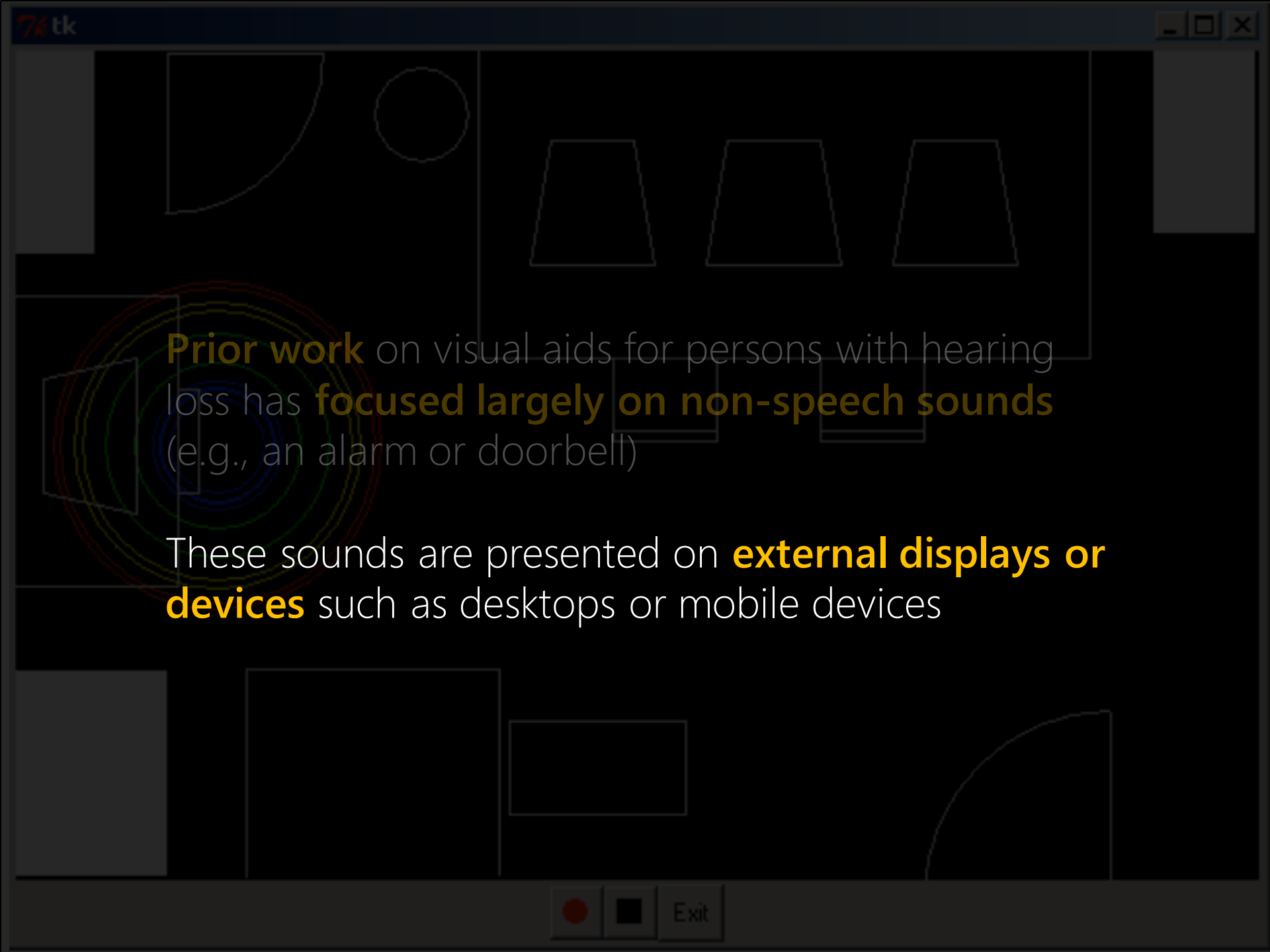


Prior work on visual aids for persons with hearing loss has **focused largely on non-speech sounds** (e.g., an alarm or doorbell)


tk
For example...
Exit



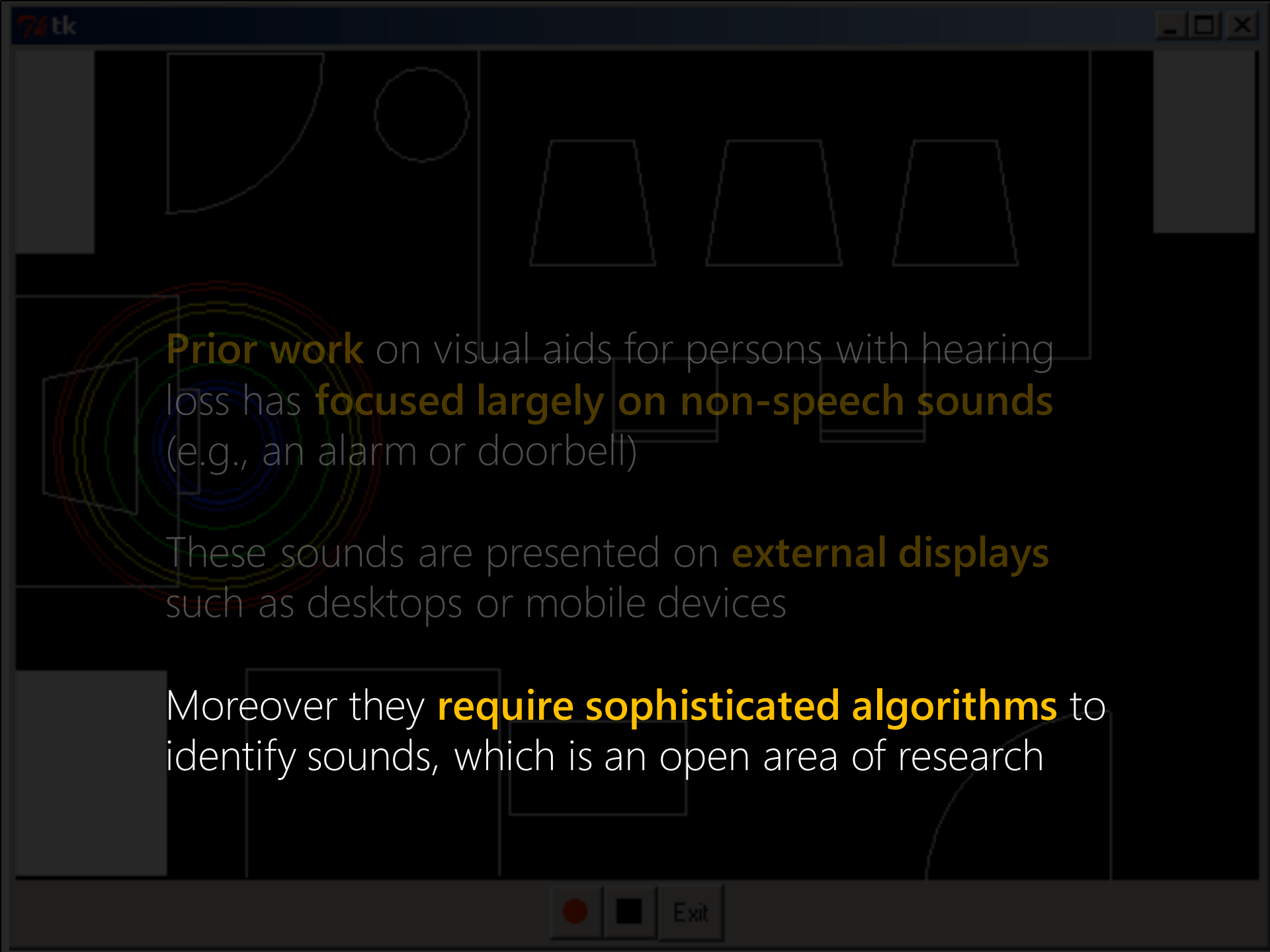
Ho-Ching *et al.*, CHI '03; Matthews *et al.*, BIT '04; Matthews *et al.*, ASSETS '05



Prior work on visual aids for persons with hearing loss has **focused largely on non-speech sounds** (e.g., an alarm or doorbell)

These sounds are presented on **external displays or devices** such as desktops or mobile devices


tk
Exit



Prior work on visual aids for persons with hearing loss has **focused largely on non-speech sounds** (e.g., an alarm or doorbell)

These sounds are presented on **external displays** such as desktops or mobile devices

Moreover they **require sophisticated algorithms** to identify sounds, which is an open area of research

Most Relevant Work

Sound Compass - Kaneko et al., IEEE SMC '13

Most Relevant Work

Sound Compass - Kaneko et al., IEEE SMC '13

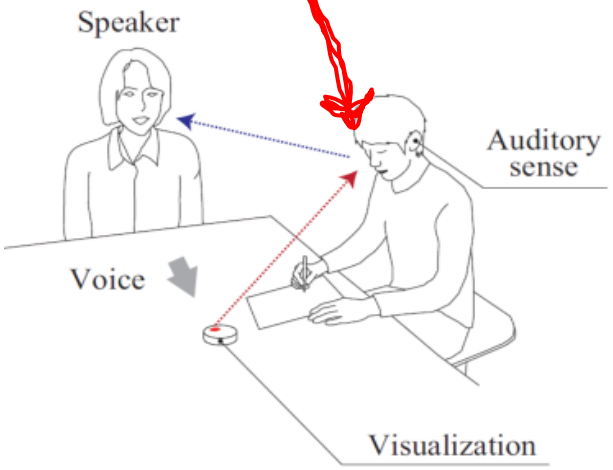
Device

Arm mounted

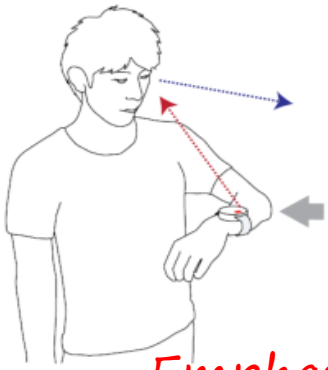
Most Relevant Work

Sound Compass - Kaneko et al., IEEE SMC '13

Turns gaze away from the conversation



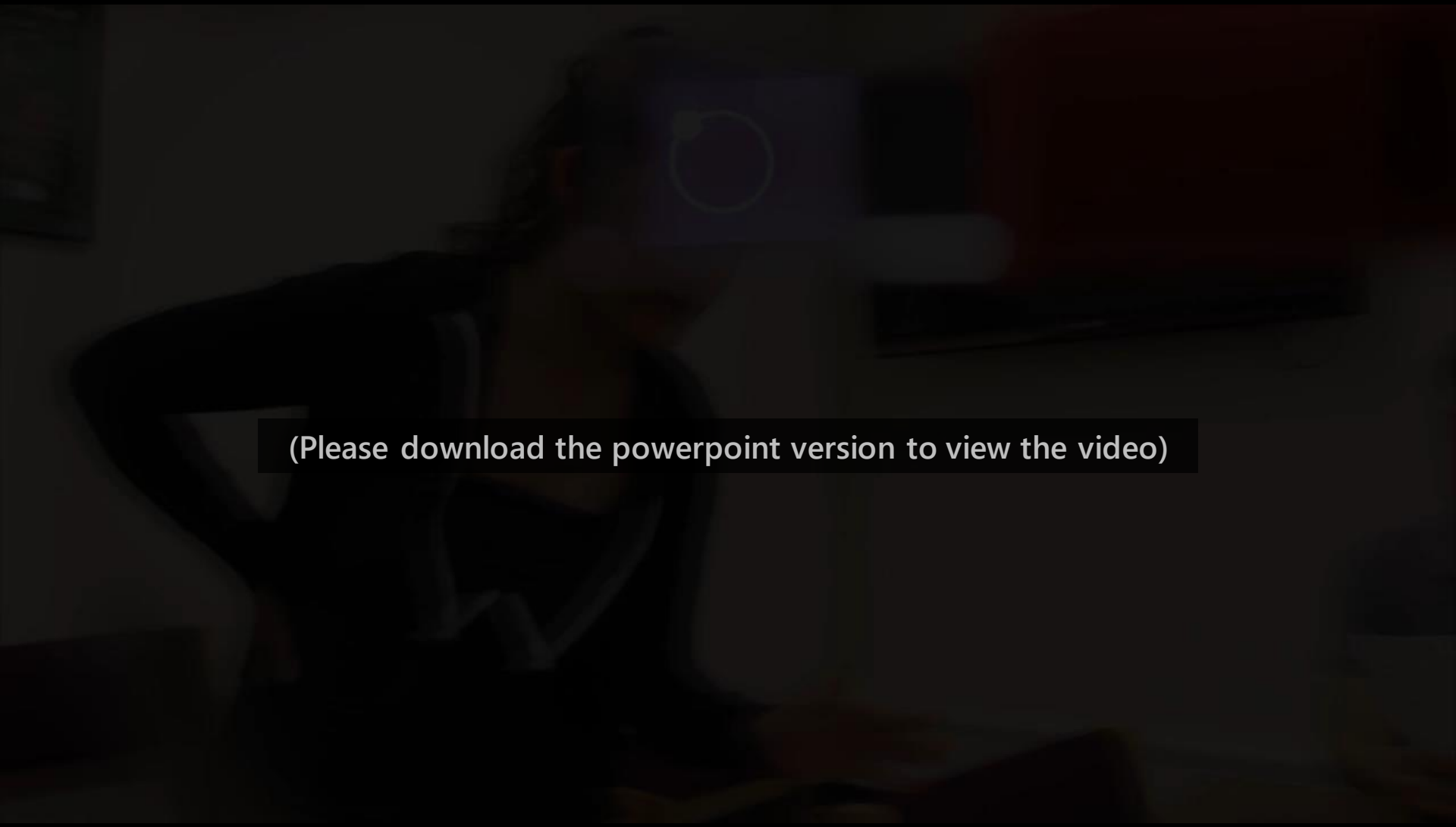
Device placed on a table



Arm-mounted use

Emphasis on sensing, not visual feedback

Our Approach:
Sound Visualization on HMD



Our Approach:
Sound Visualization on HMD

1 Increased Glanceability

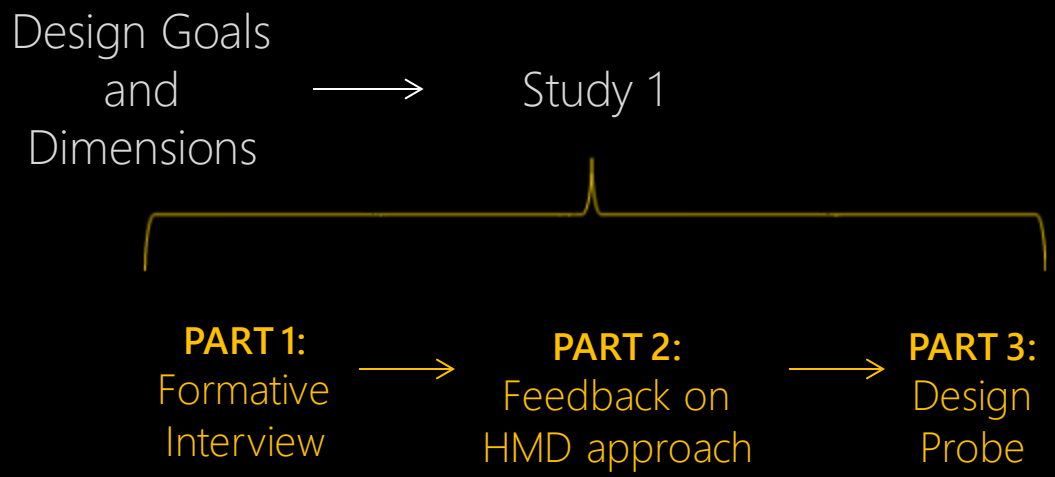
2 Privacy

3 Seamlessness

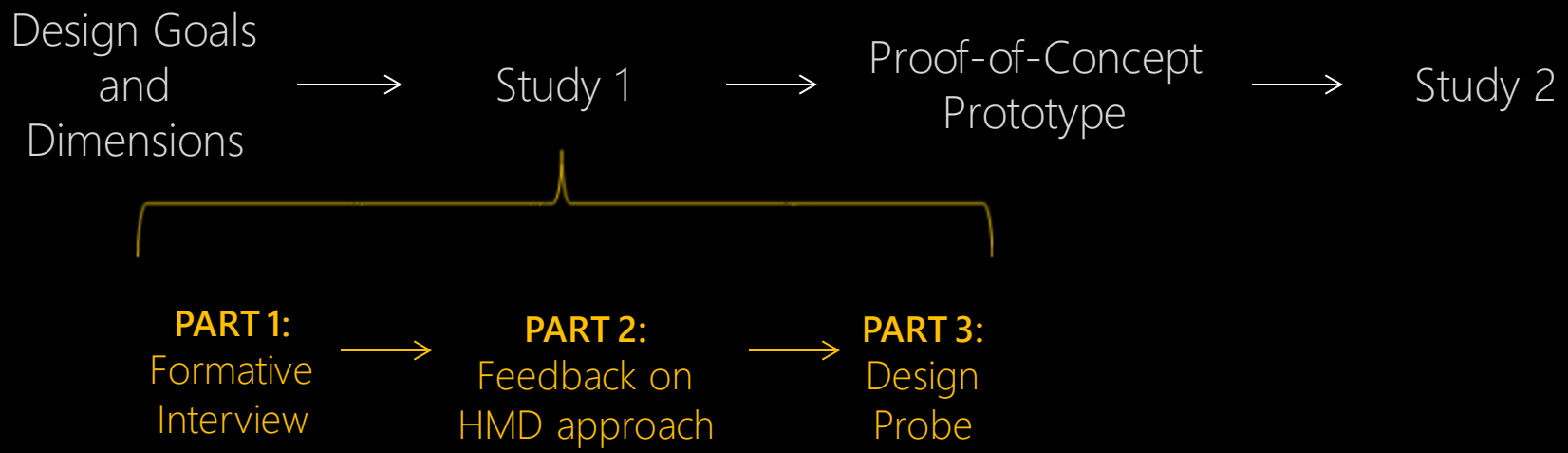
Outline

Design Goals
and
Dimensions

Outline


Design Goals and Dimensions
Study 1
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

Outline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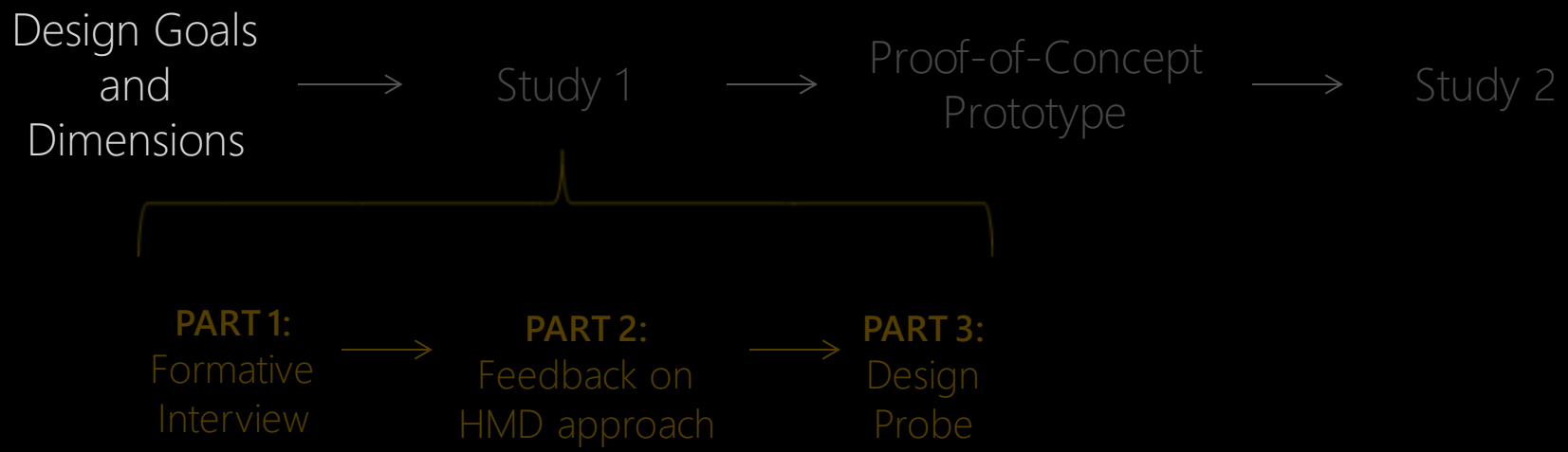
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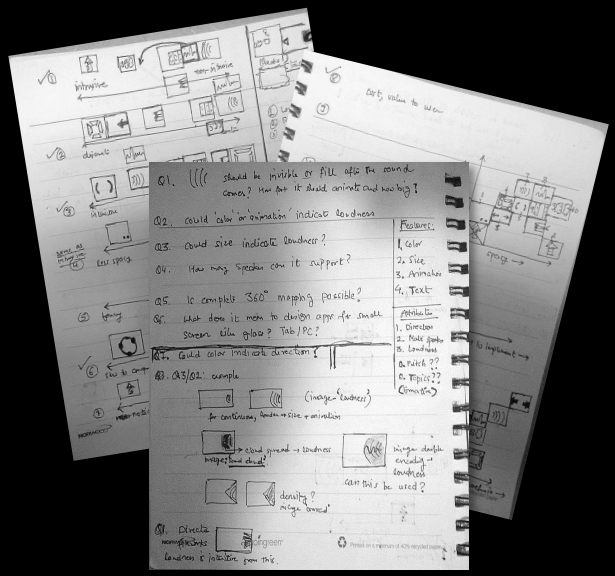
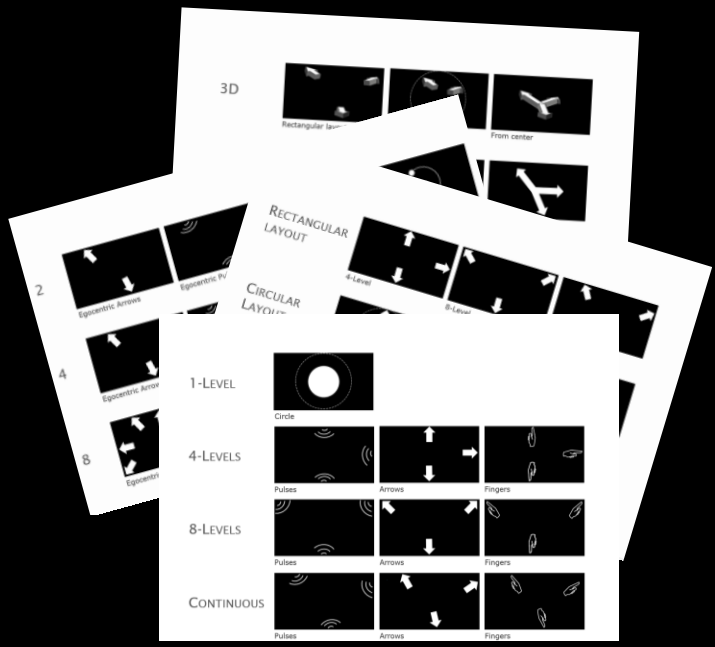
Iterative **Design Process**





Design Goals

Sketch

Design Dimensions

Q1. (((should be invisible or fill after the sound comes? How fast it should animate and how big?

Q2. could 'color' or 'animation' indicate loudness

Q3. could size indicate loudness?

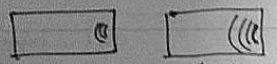
Q4. How many speaker can it support?

Q5. Is complete 360° mapping possible?

Q6. What does it mean to design apps for small screen like glass? Tab / PC?

Q7. could color indicate direction?

Q3/Q2: example



(image - 'loudness')

for continuous, louder → size + animation

image: 'loud cloud'

cloud spread → loudness

image double encoding → loudness

can this be used?

density? image 'crowd'

Q1. Directio

loudness is intuitive from this.

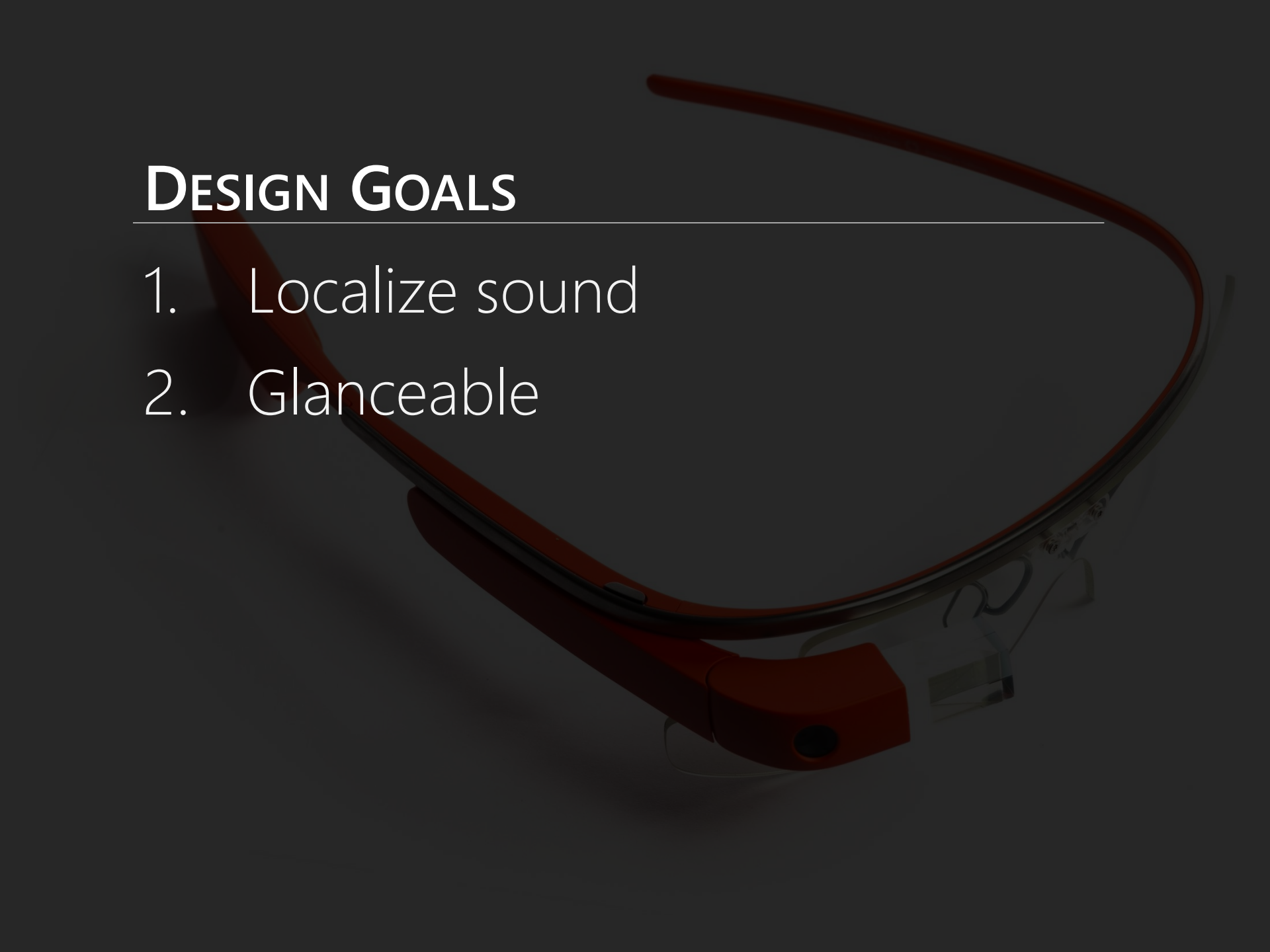
Features:
1. Color
2. Size
3. Animation
4. Text

Attributes
1. Direction
2. Multi speaker
3. Loudness
0. Pitch ??
0. Topics??
(Formative)

Printed on a minimum of 40% recycled paper

Design Goals

1. Localize sound
2. Glanceable



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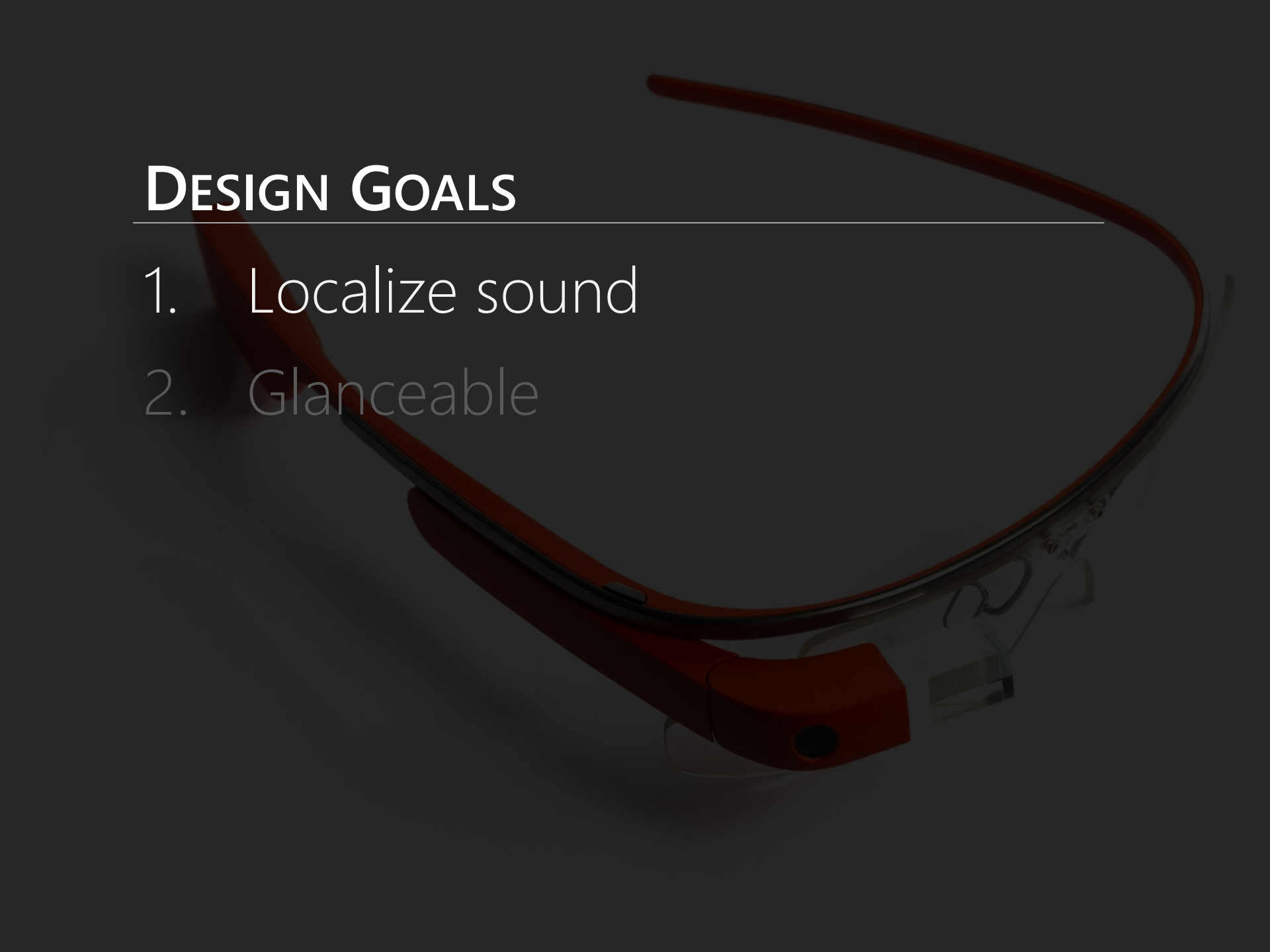
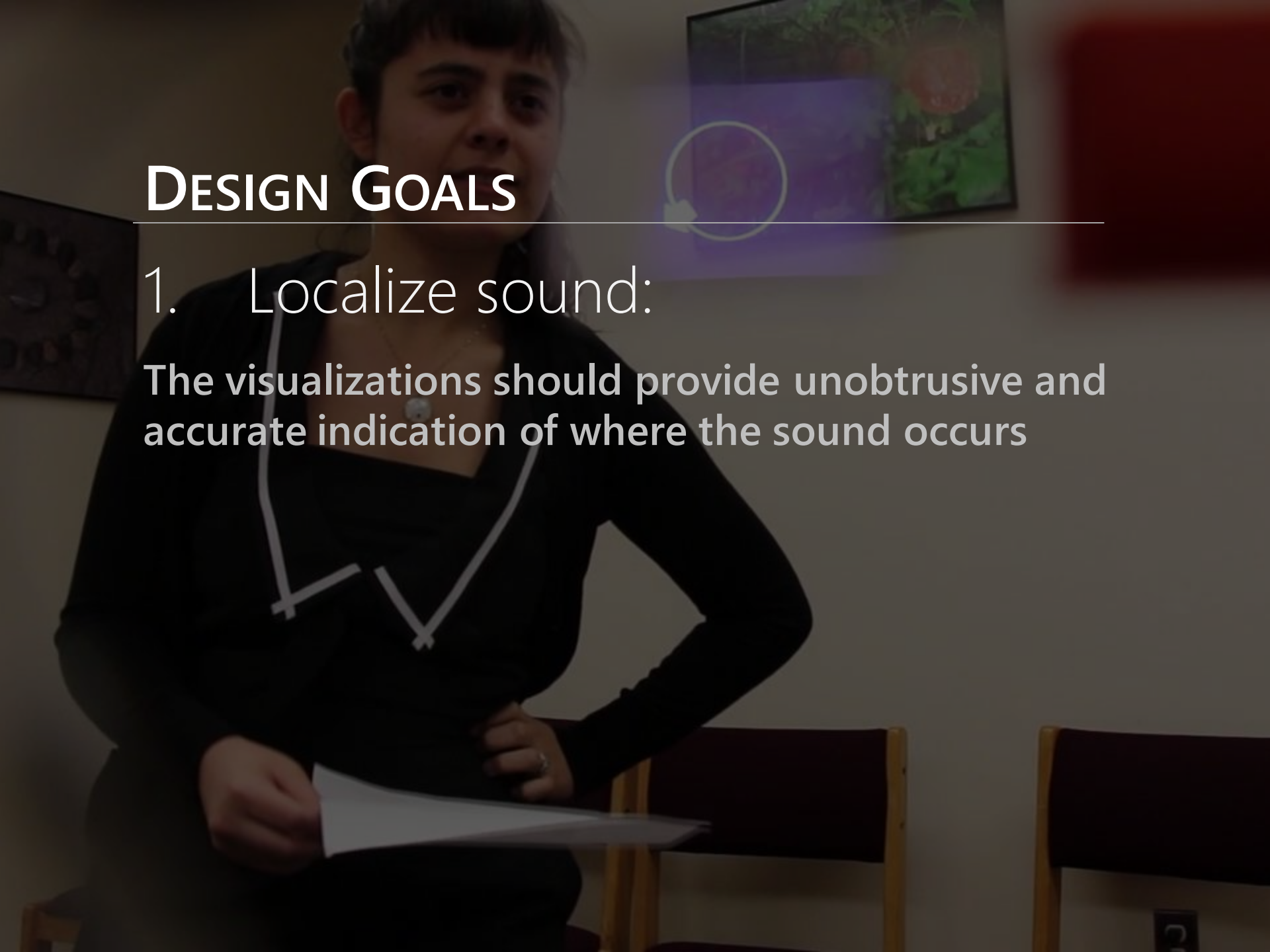




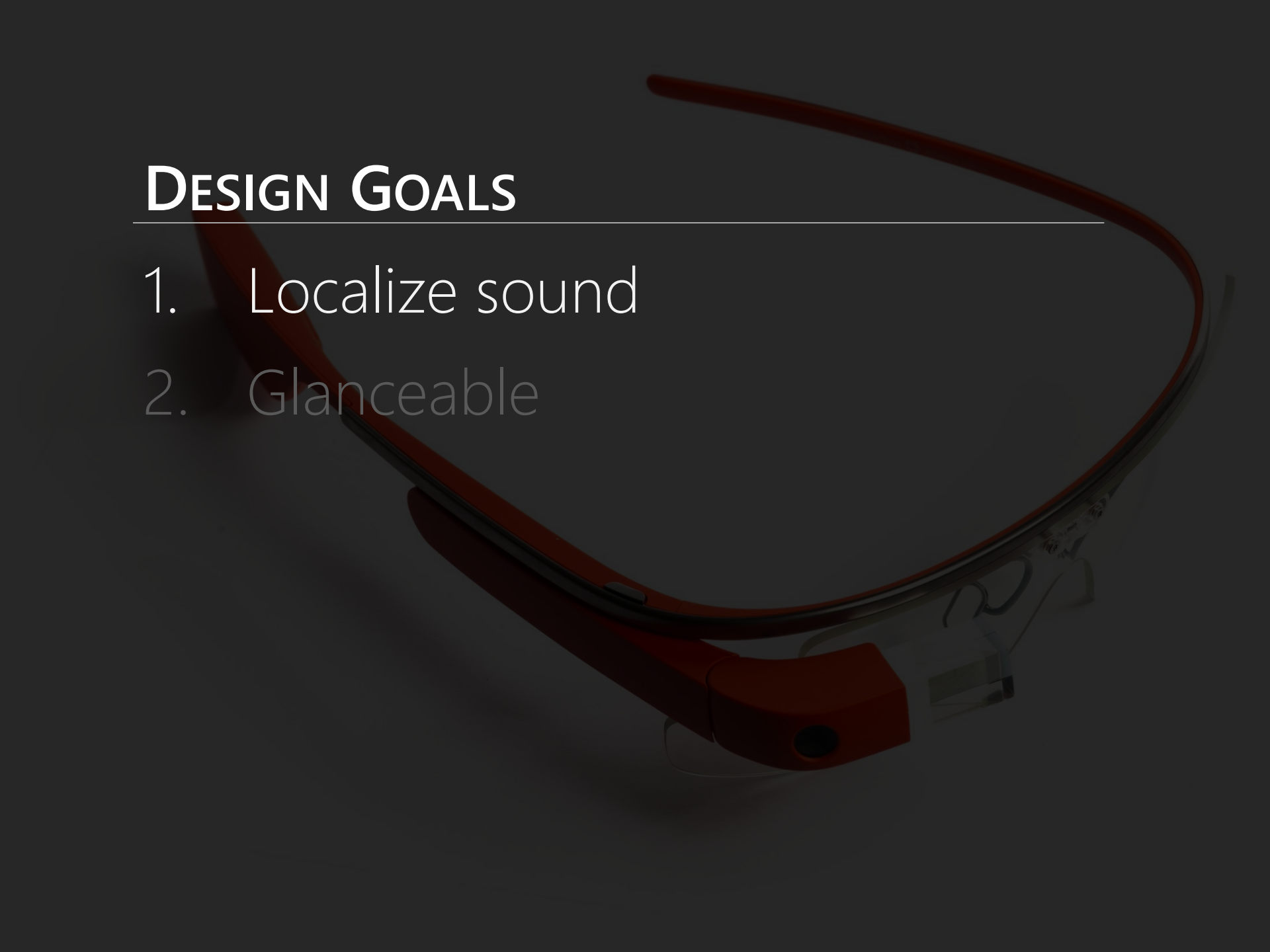
Design Goals

1. Localize sound:

The visualizations should provide unobtrusive and accurate indication of where the sound occurs

Design Goals

1. Localize sound
2. Glanceable



Design Goals

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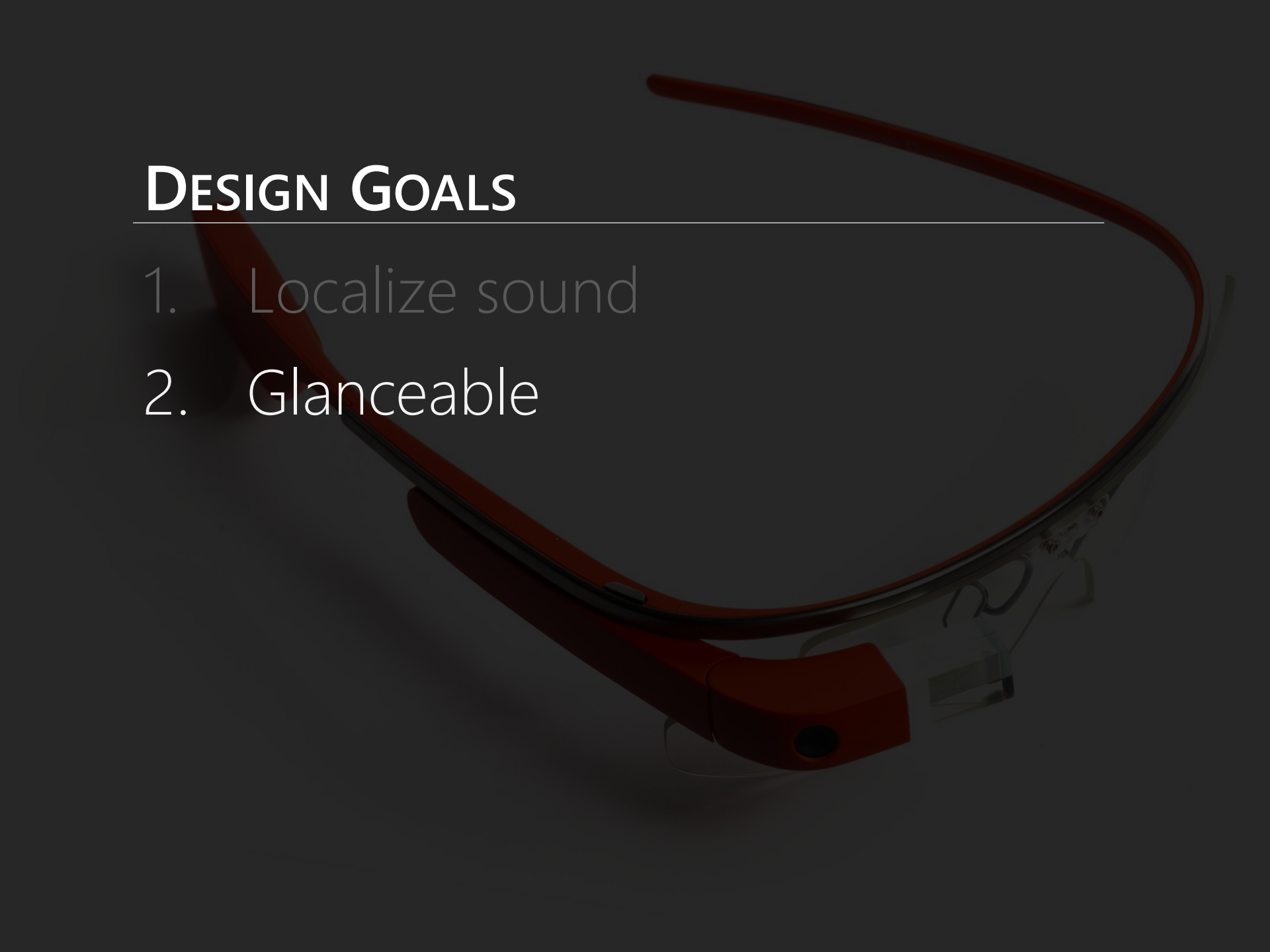
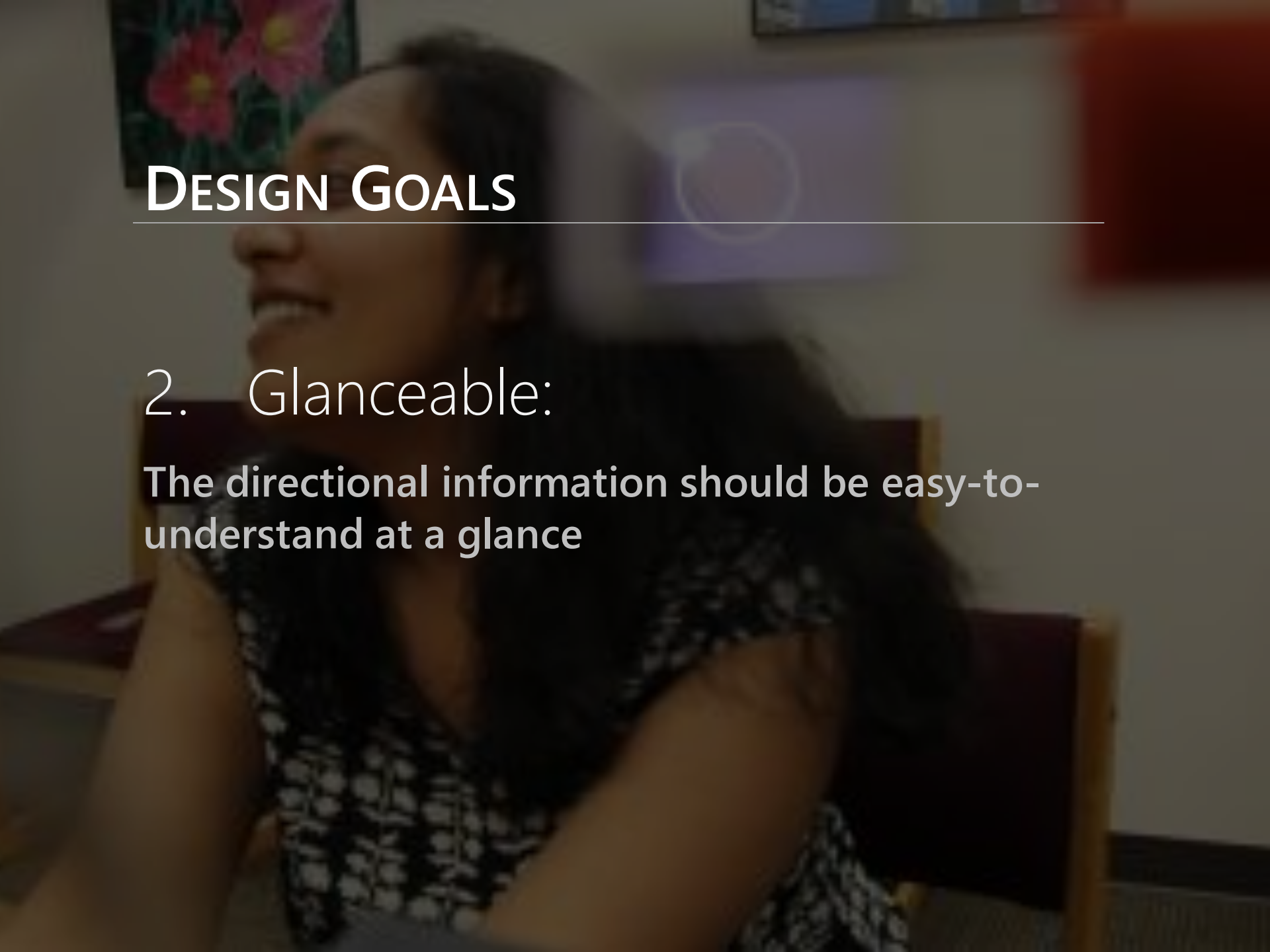
2. Glanceable

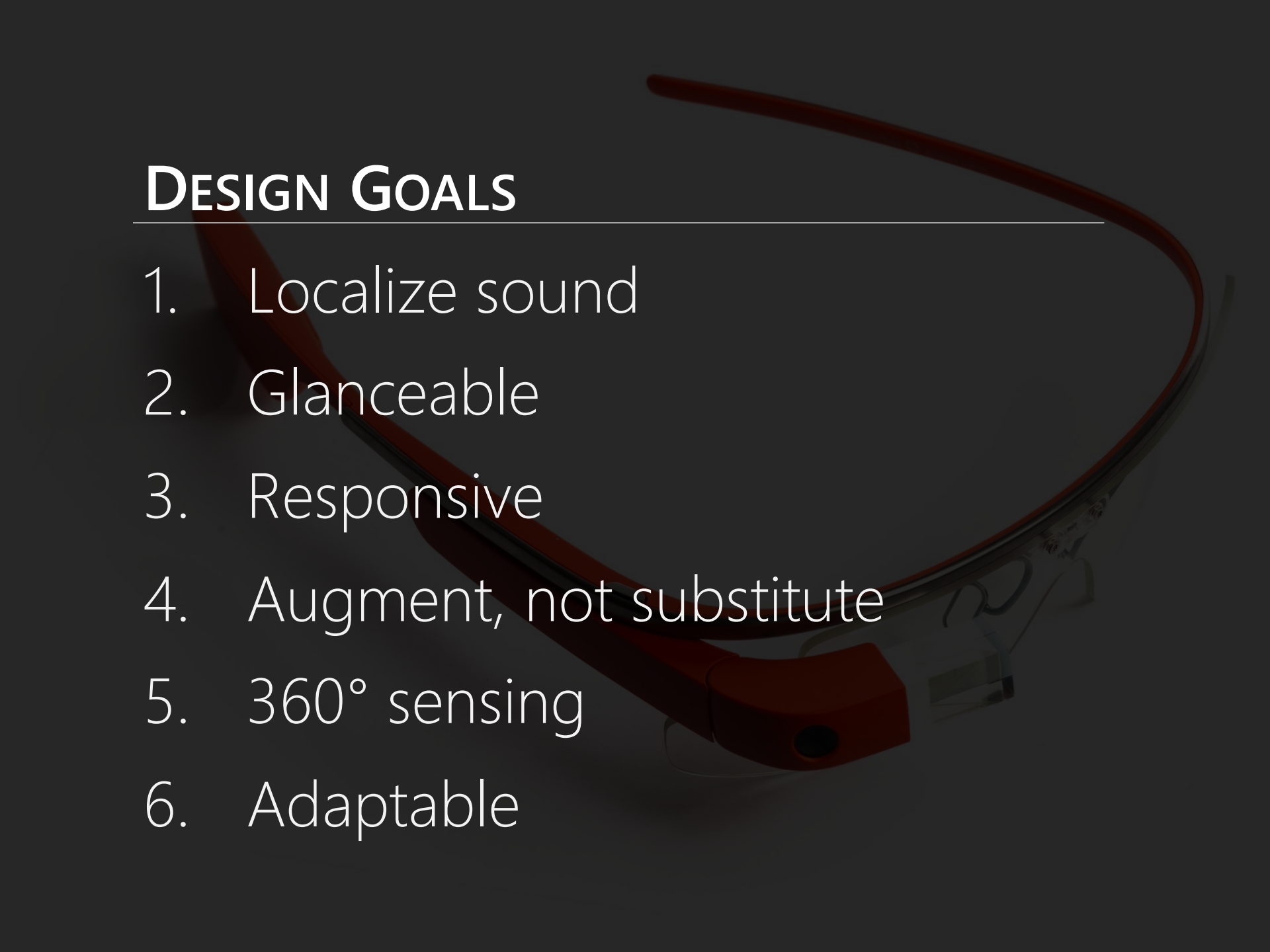




Design Goals

2. Glanceable:

The directional information should be easy-to-understand at a glance

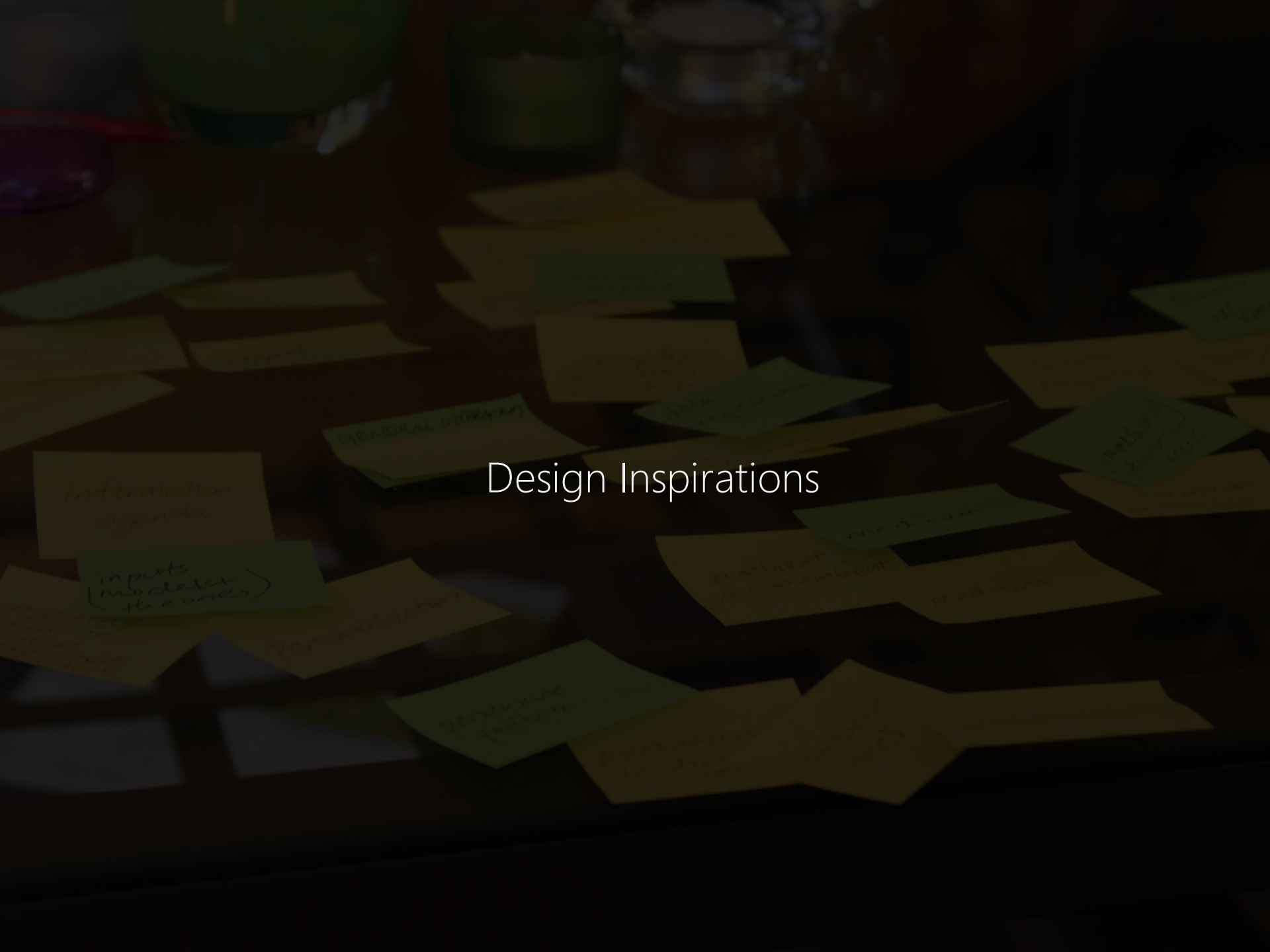


Design Goals

1. Localize sound
2. Glanceable
3. Responsive
4. Augment, not substitute
5. 360° sensing
6. Adaptable

Designing the Sound Visualizations

How does one go about the process of **designing interfaces** for **sound visualization** for **head-mounted display**?


Design Inspirations


information agenda
inputs (models+ theories)
personalization
persuasive robot
ambient vs non ambient
medium
medium


4# Far Cry


AMMO: 20/30
SCORE: 50
HP: 5
RELOAD


www.RampageCS.com


02:06
X4
001/003


WINNING
00:50
LEVEL 3


HULL INTEGRITY
24


6# HALO

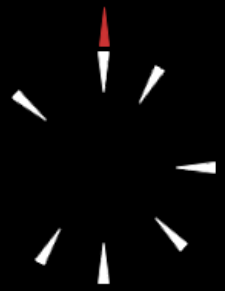
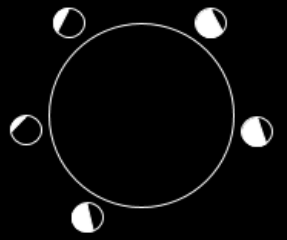
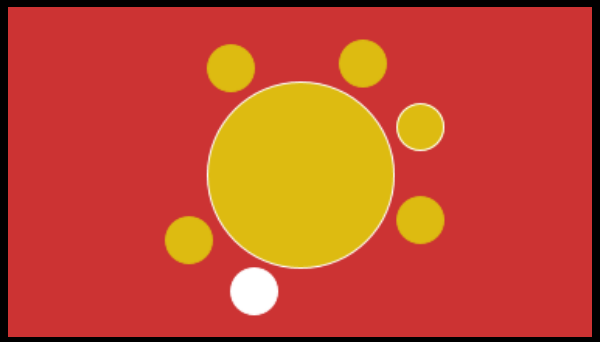
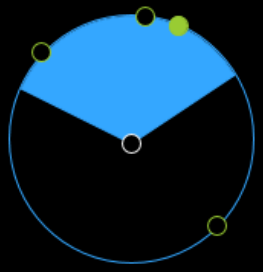

MILOS 2478

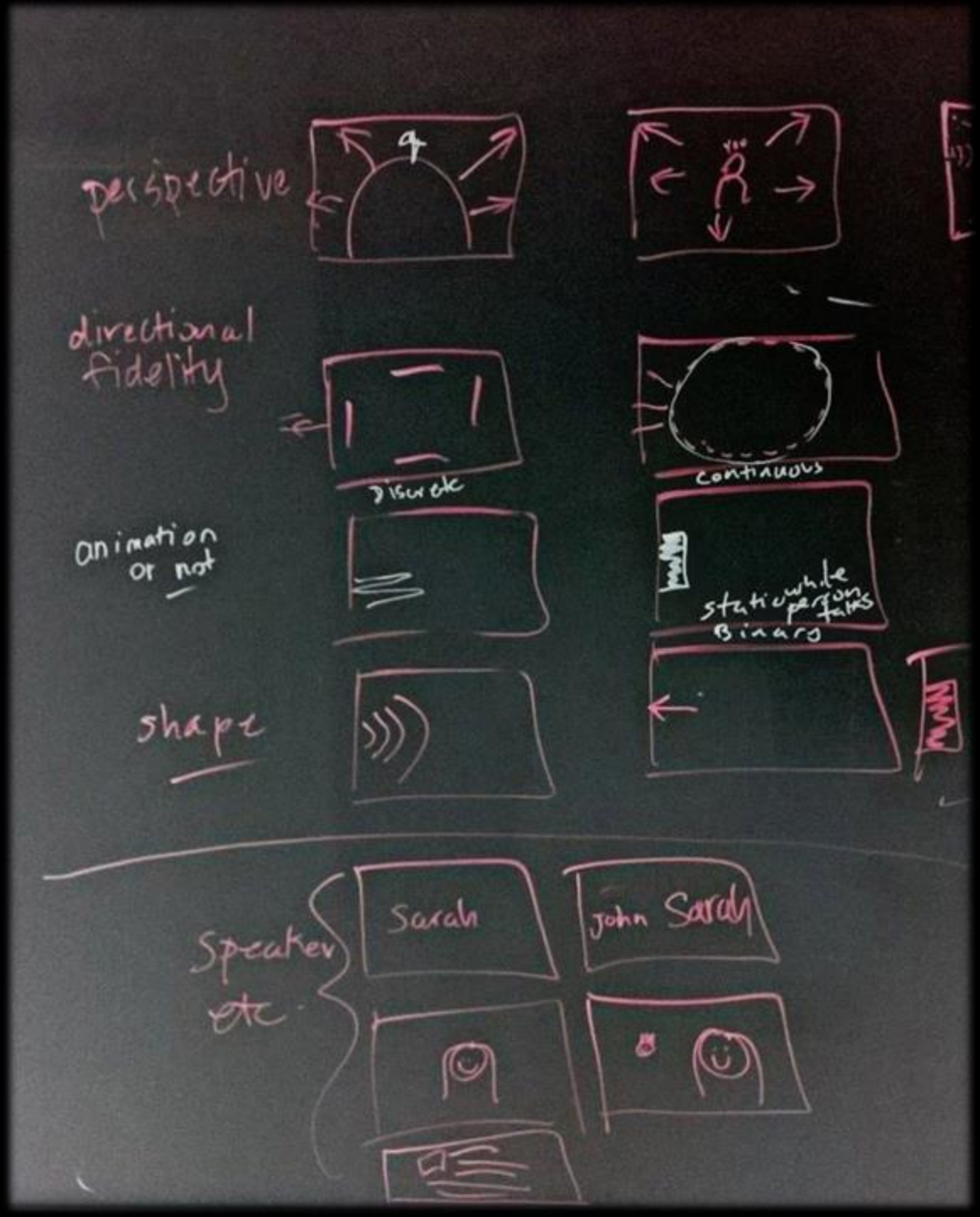

MILOS 2478


WINNING
00:50
LVL 5 / 21
LVL 13 / 21
LEVEL 3
DAMAGE +5.0%



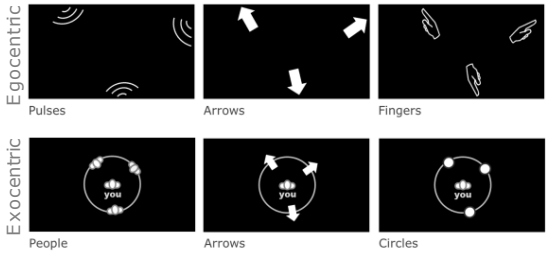


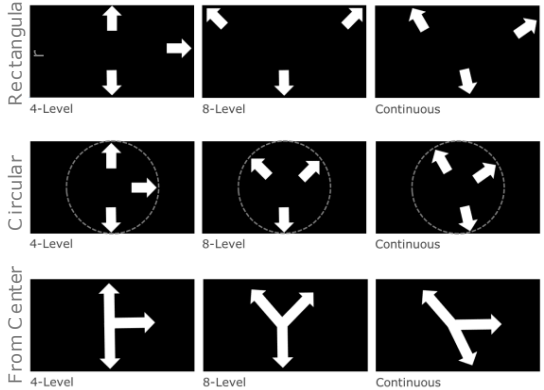


perspective
directional fidelity
discrete
continuous
animation or not
static while person talks
Binary
shape
Speaker etc.
Sarah
John Sarah

8 Design Dimensions

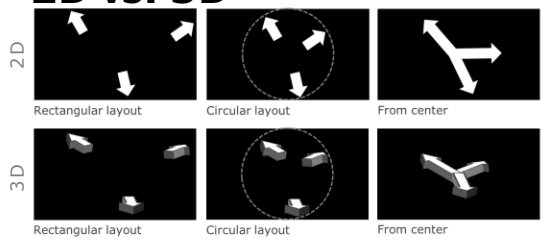
Wearer's Perspective



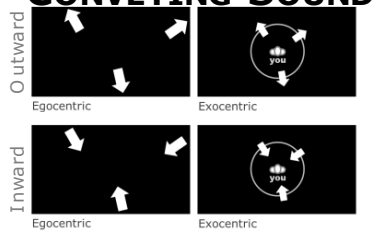
Screen Layout



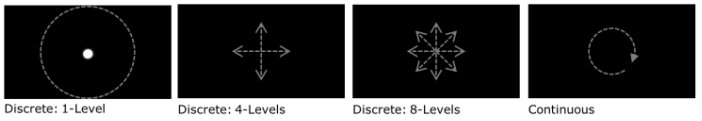
2D vs. 3D



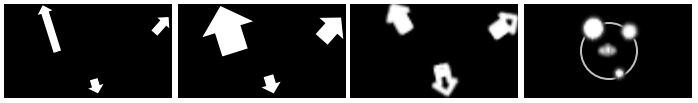
Conveying Sound Source



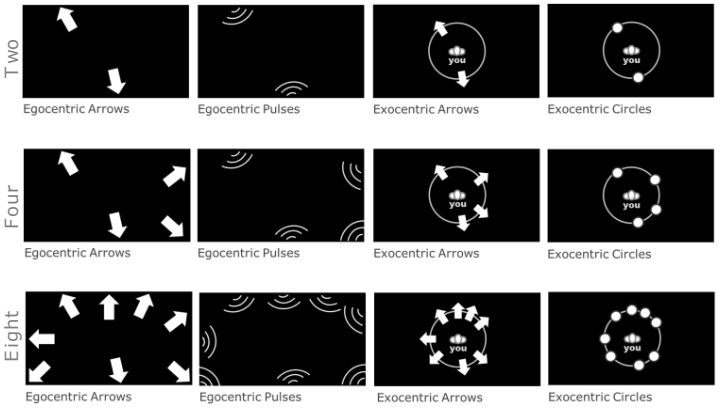
Directional Granularity



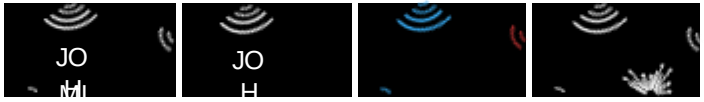
Loudness



Maximum Simultaneous Icons

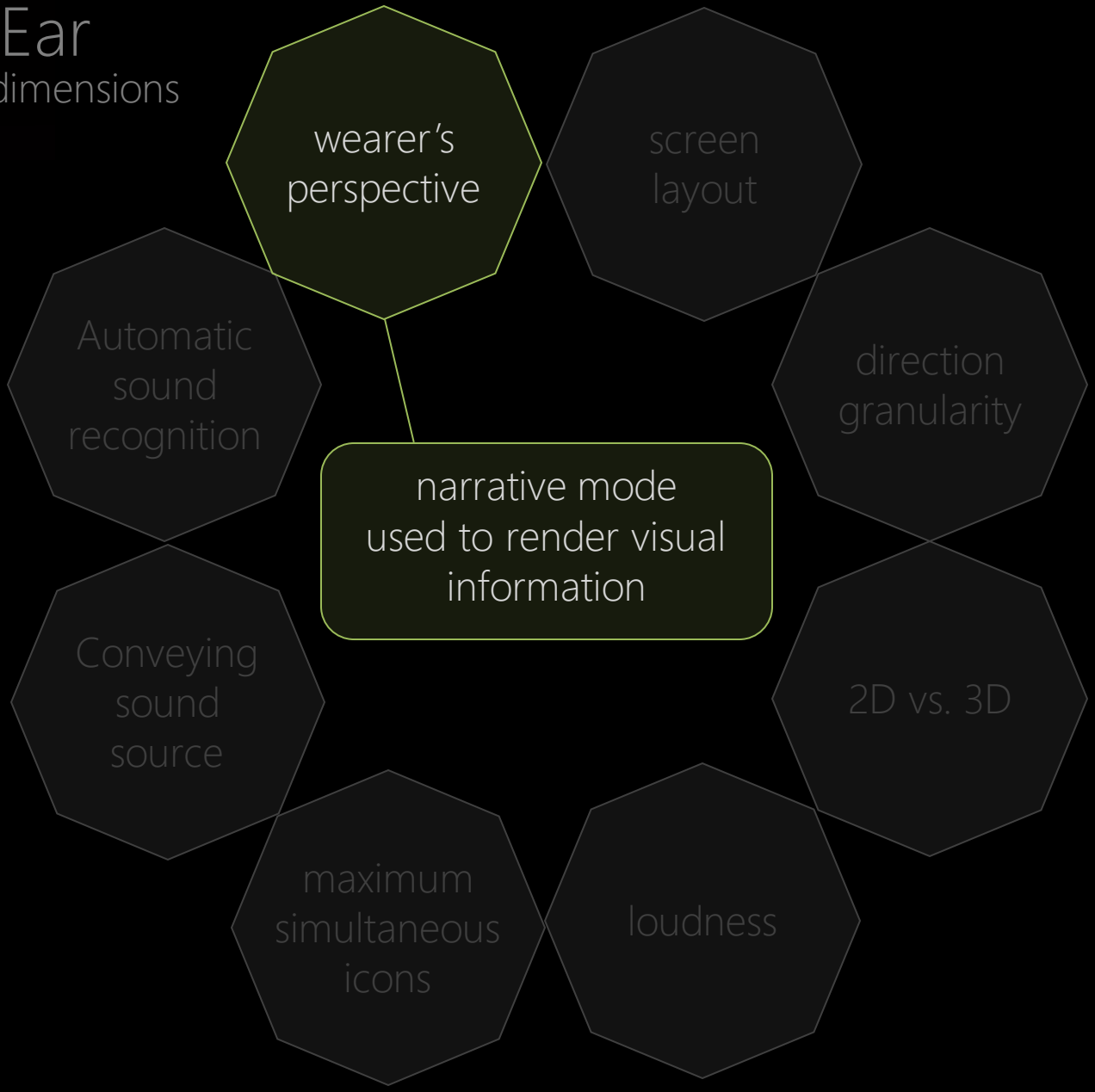


Automatic Sound Recognition

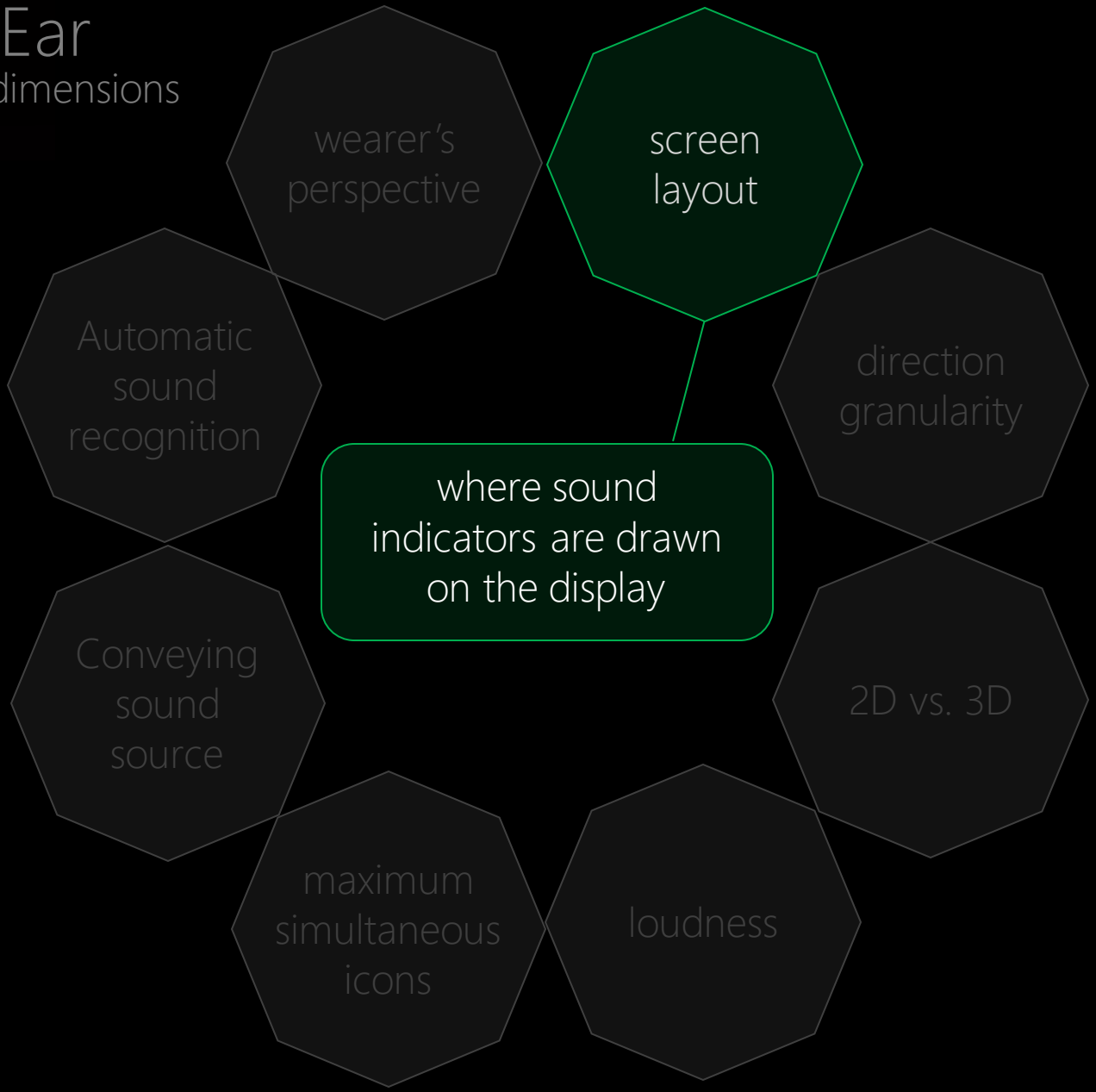



wearer's perspective
screen layout
direction granularity
2D vs. 3D
loudness
maximum simultaneous icons
Conveying sound source
Automatic sound recognition
the GLASS Ear
design dimensions

the GLOSS Ear
design dimensions



the GLOSS Ear
design dimensions



the GLOSS Ear
design dimensions

the GLOSS Ear
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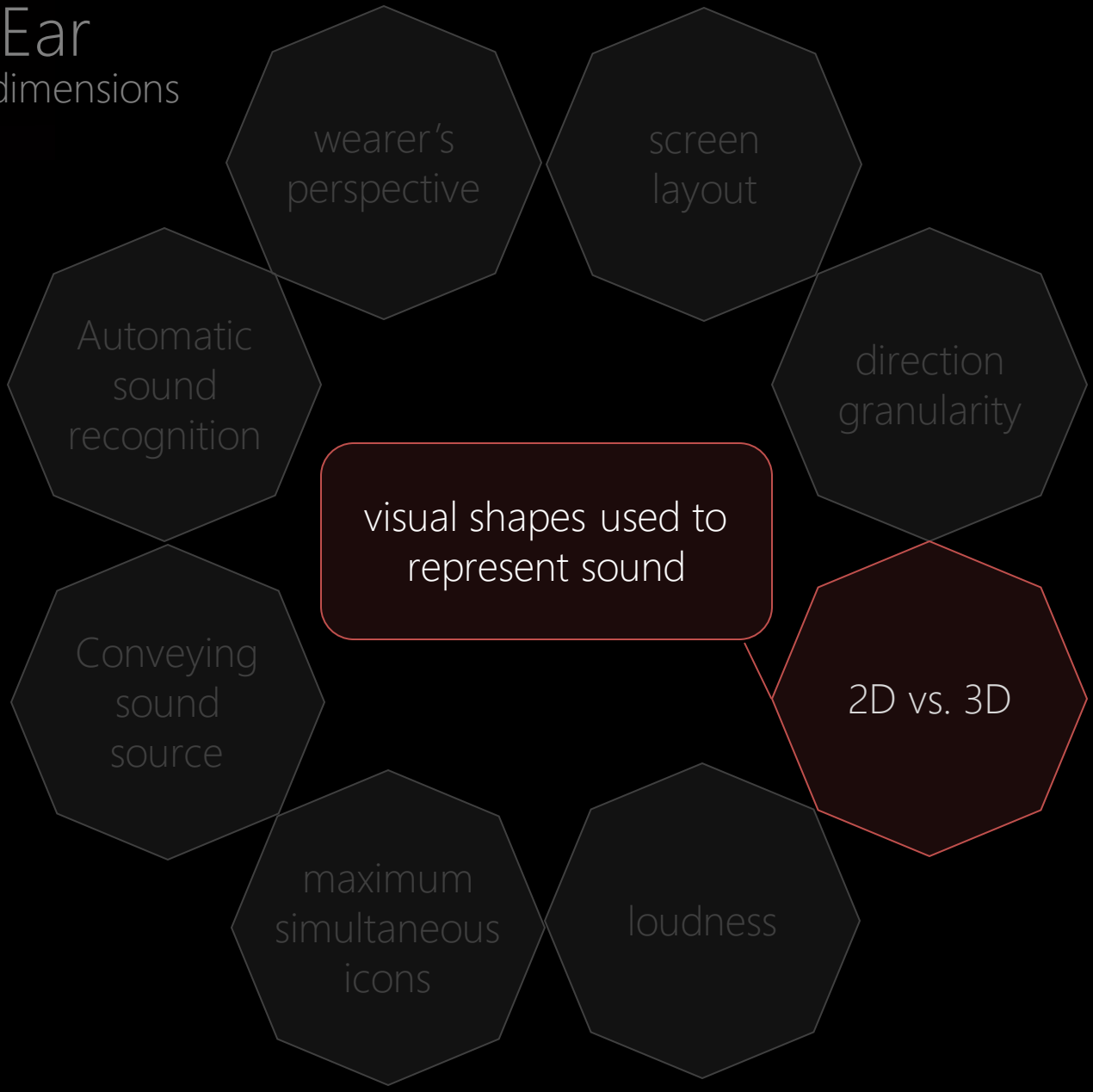
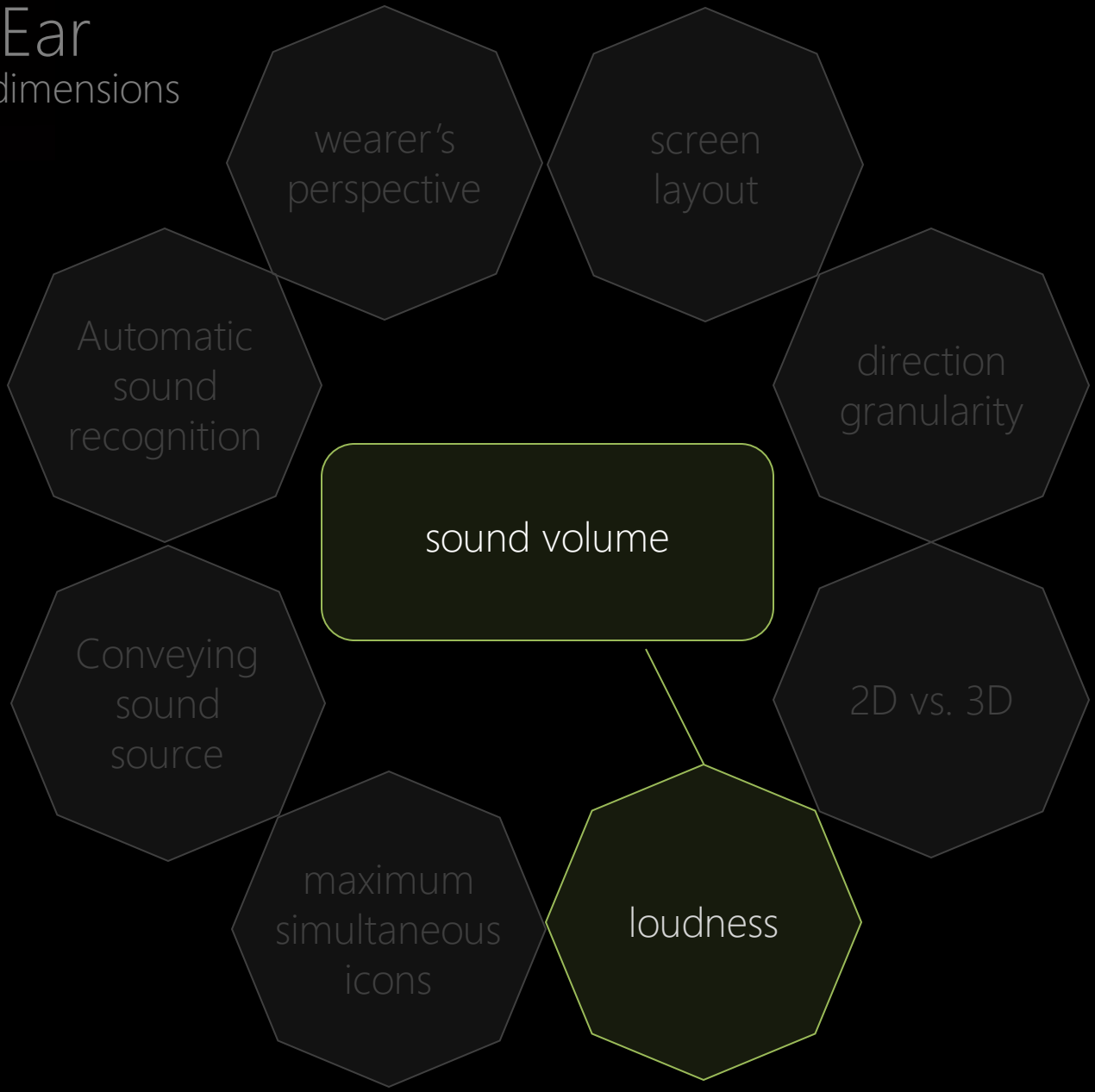
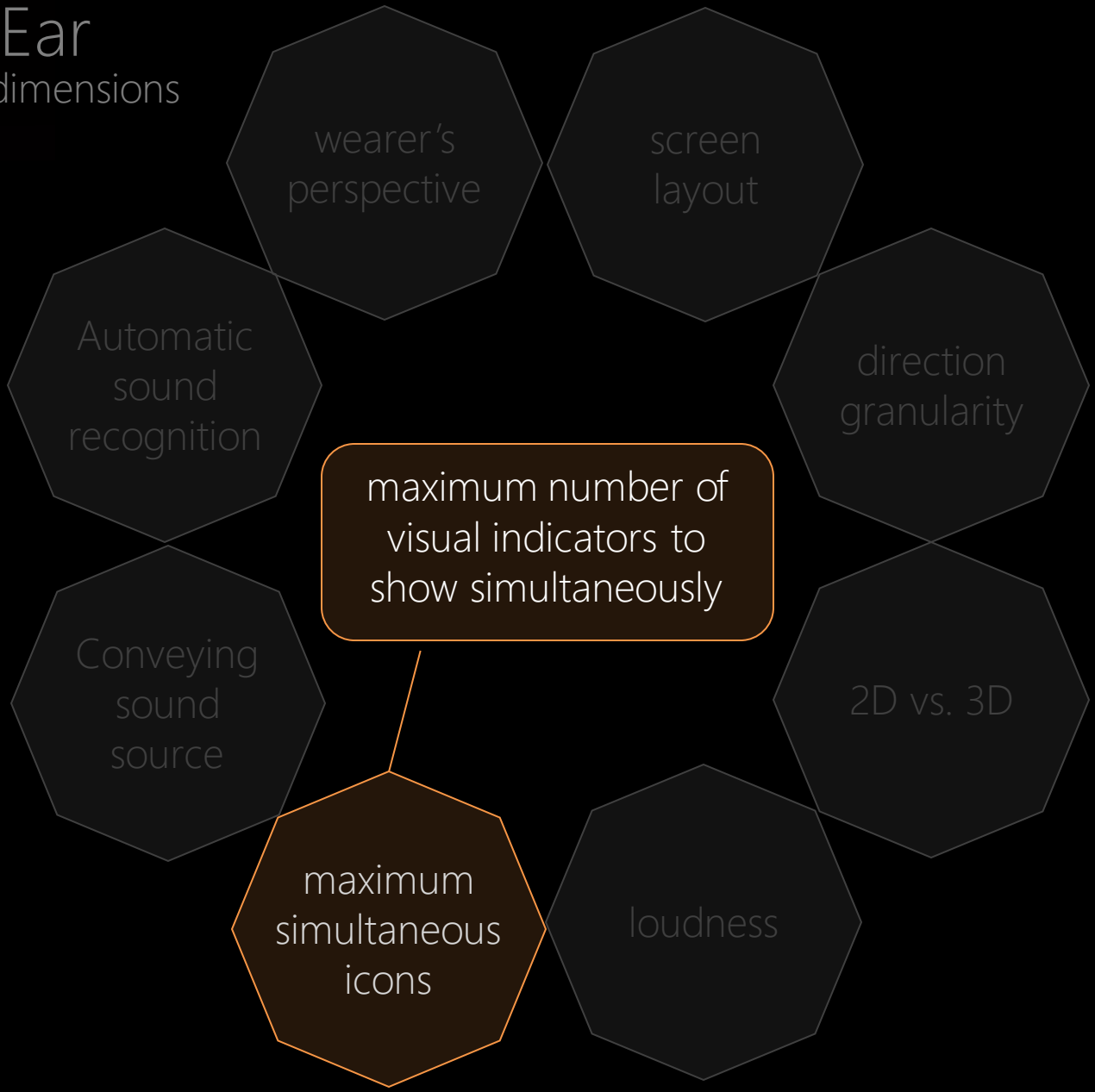


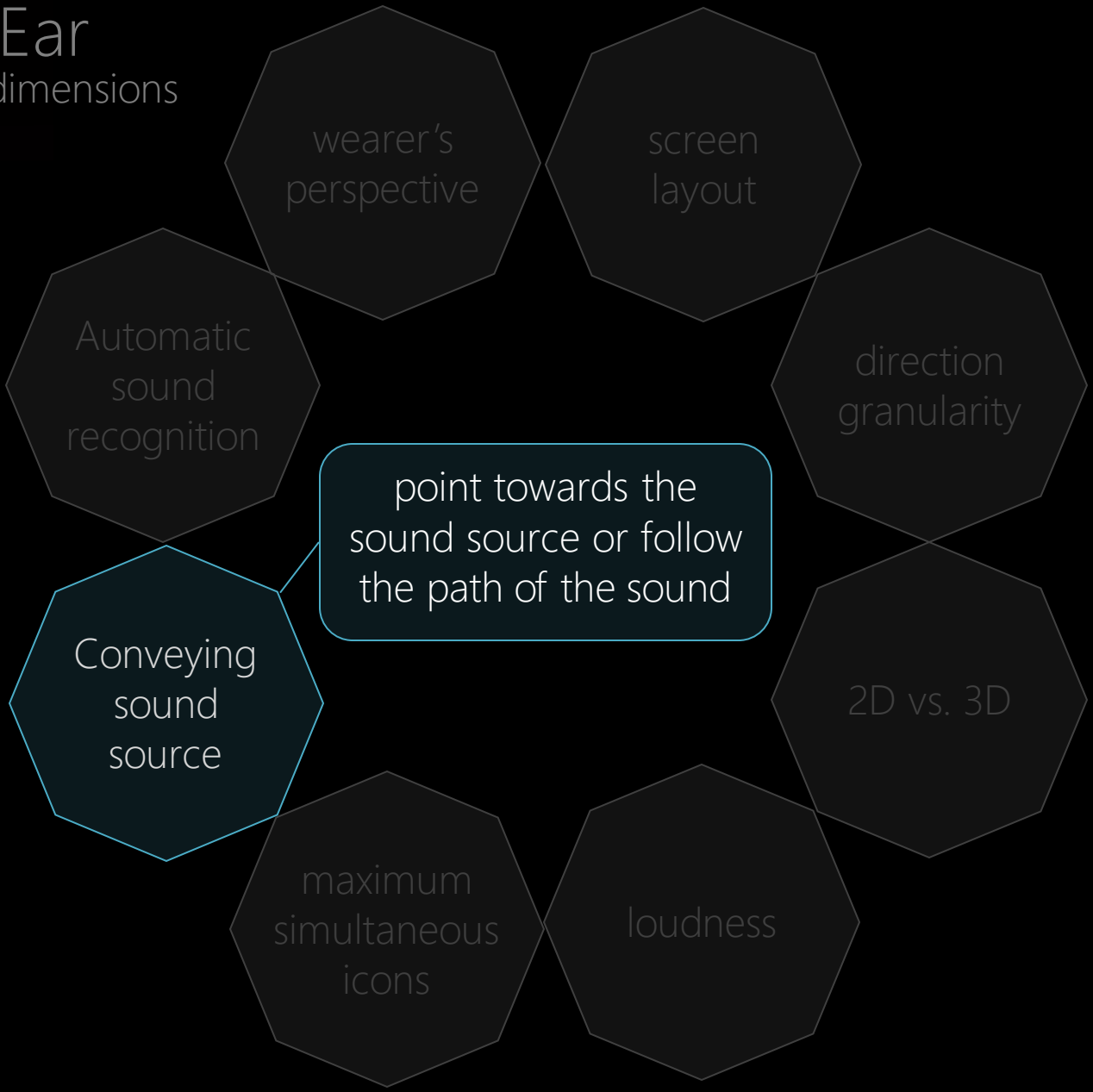
the GLASS Ear
design dimensions



the GLOSS Ear
design dimensions

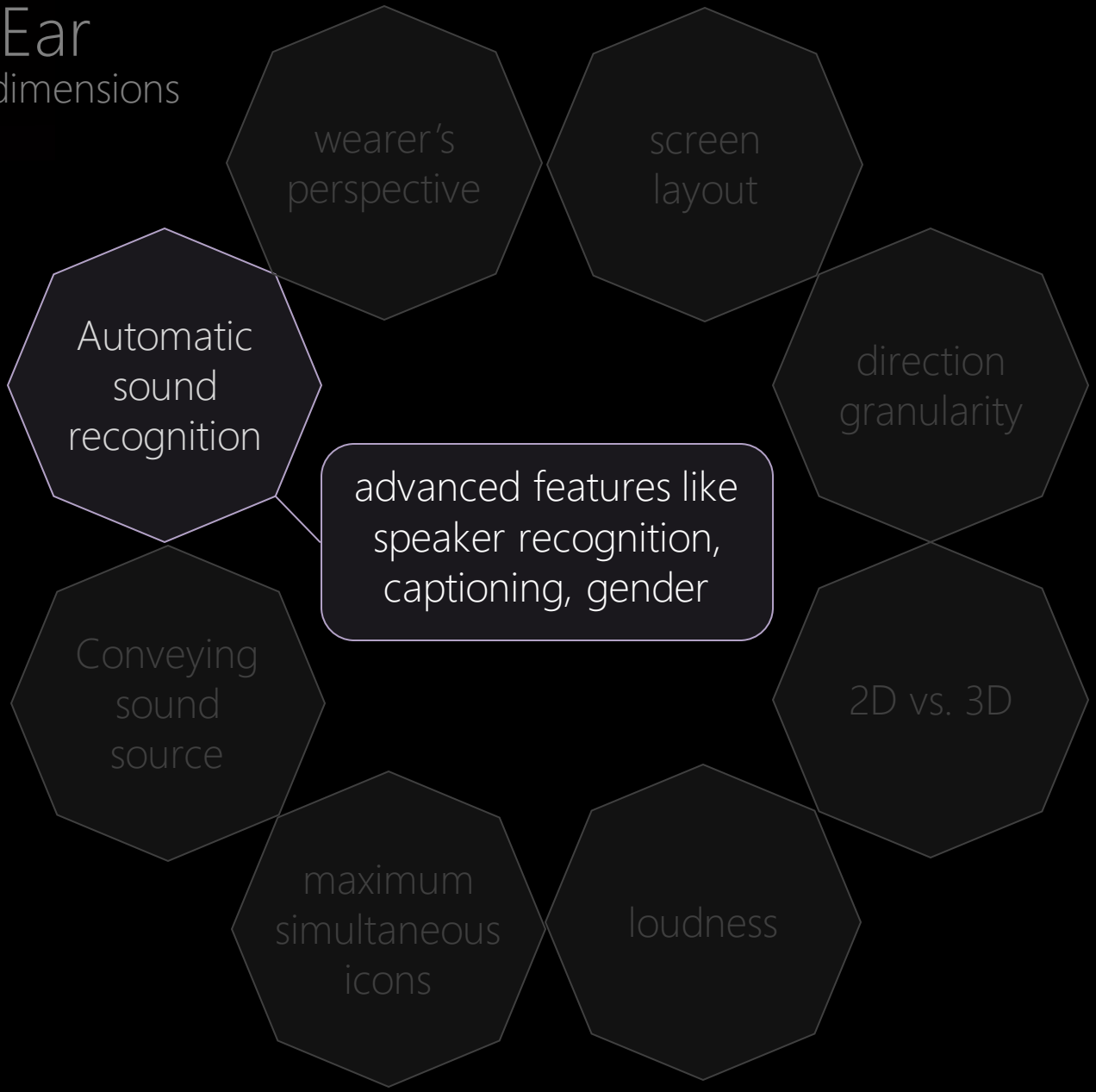


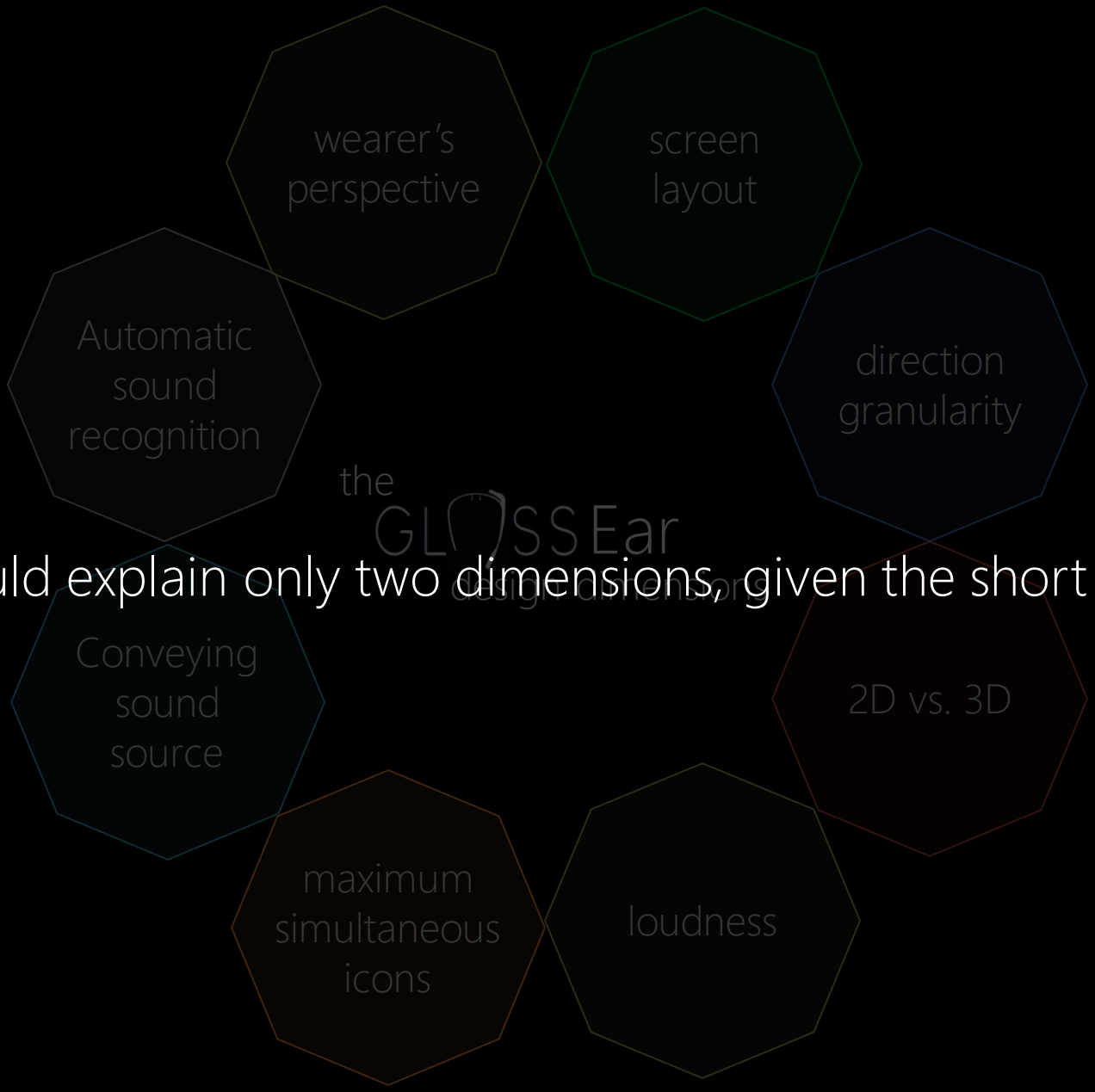
the GLOSS Ear
design dimensions



the GLOSS Ear

design dimensions





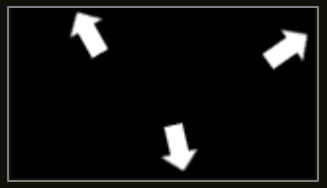
I would explain only two dimensions, given the short time


wearer's perspective
screen layout
direction granularity
2D vs. 3D
loudness
maximum simultaneous icons
Conveying sound source
Automatic sound recognition
the GLOSS Ear
design dimensions

wearer's perspective

EGOCENTRIC

Pulses

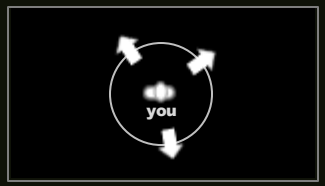


Arrows

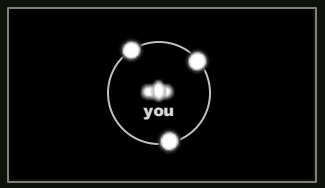
Fingers

EXOCENTRIC

People



Arrows

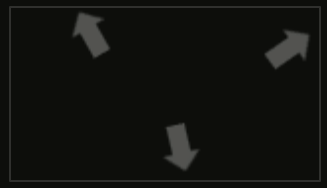


Circles

wearer's perspective

EGOCENTRIC

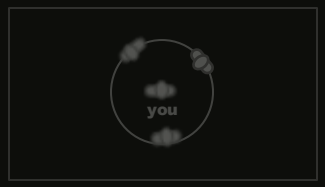
Pulses



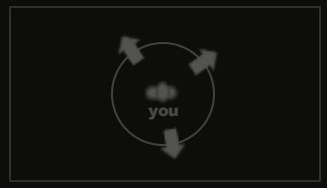
Arrows

Fingers

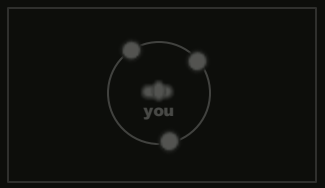
EXOCENTRIC



People



Arrows

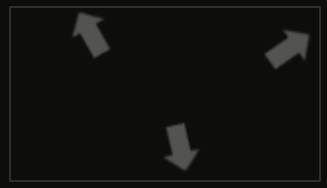


Circles

wearer's perspective

EGOCENTRIC

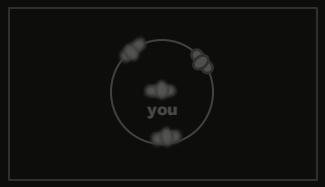
Pulses



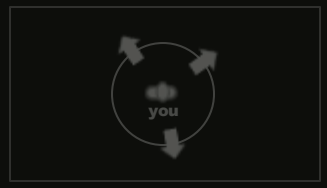
Arrows

Fingers

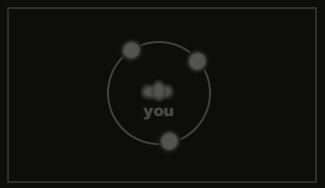
EXOCENTRIC



People



Arrows

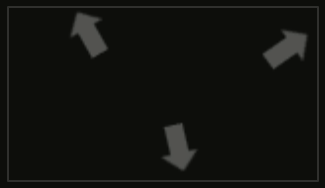


Circles

wearer's perspective

EGOCENTRIC

Pulses

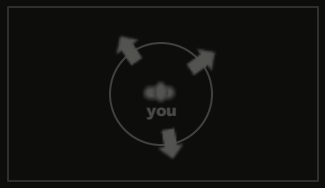


Arrows

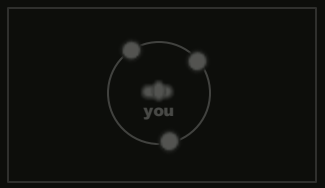
Fingers

EXOCENTRIC

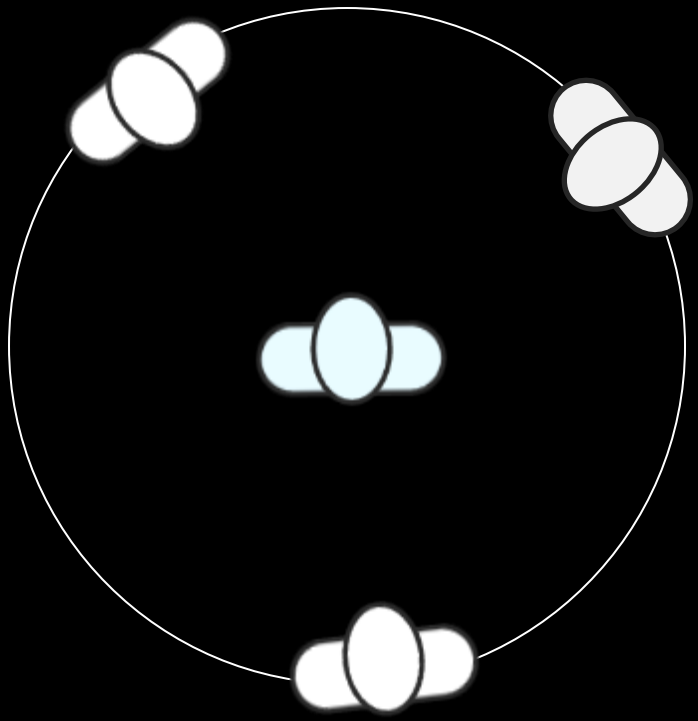
People



Arrows



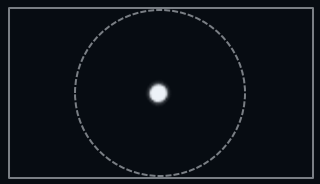
Circles



wearer's perspective

wearer's perspective

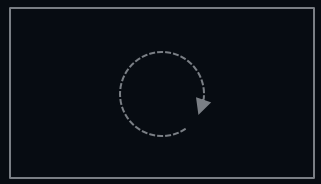
direction granularity



Discrete: 1-Level

Discrete: 4-Levels

Discrete: 8-Levels



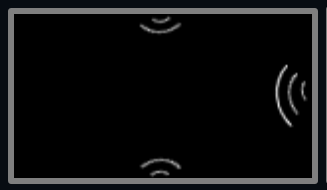
Continuous

direction granularity

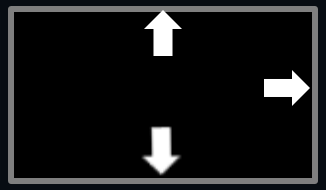
1-Level

Circle

4-Levels



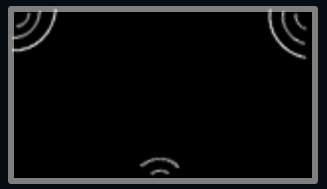
Pulses



Arrows

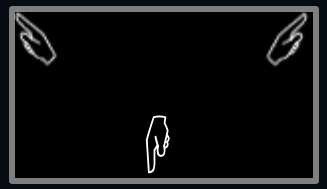
Fingers

8-Levels



Pulses

Arrows



Fingers

Continuous

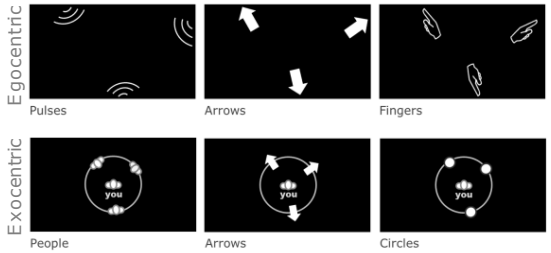
Pulses

Arrows

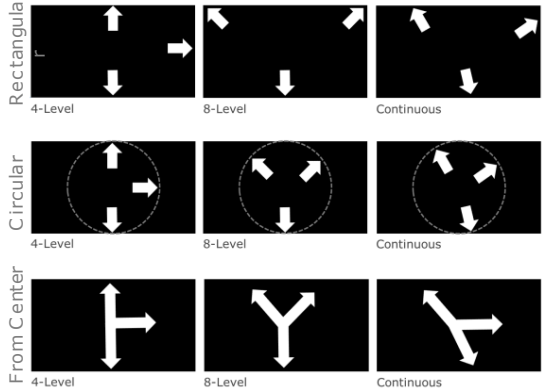
Fingers

Design Dimensions

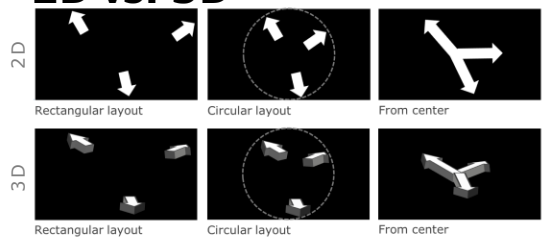
Wearer's Perspective



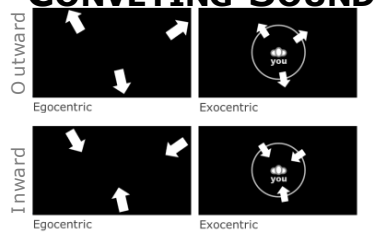
Screen Layout



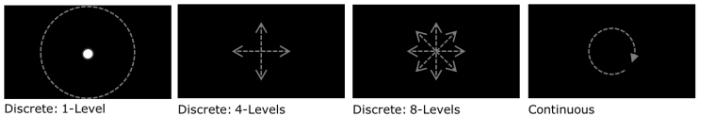
2D vs. 3D



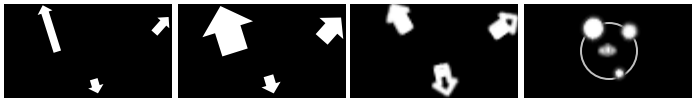
Conveying Sound Source



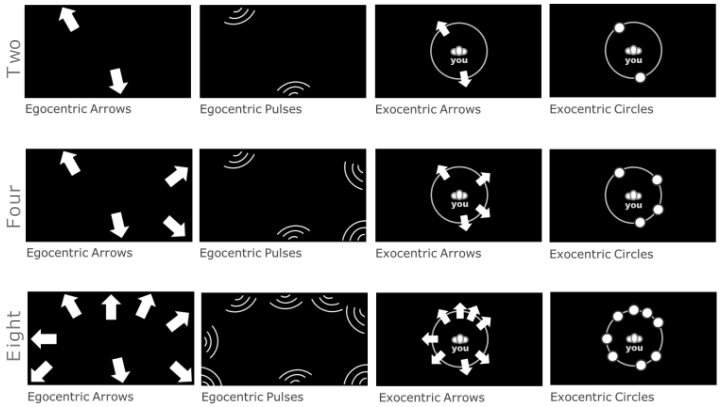
Directional Granularity



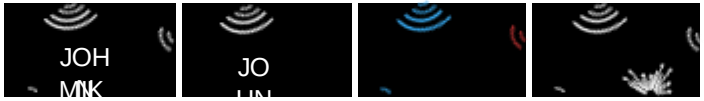
Loudness



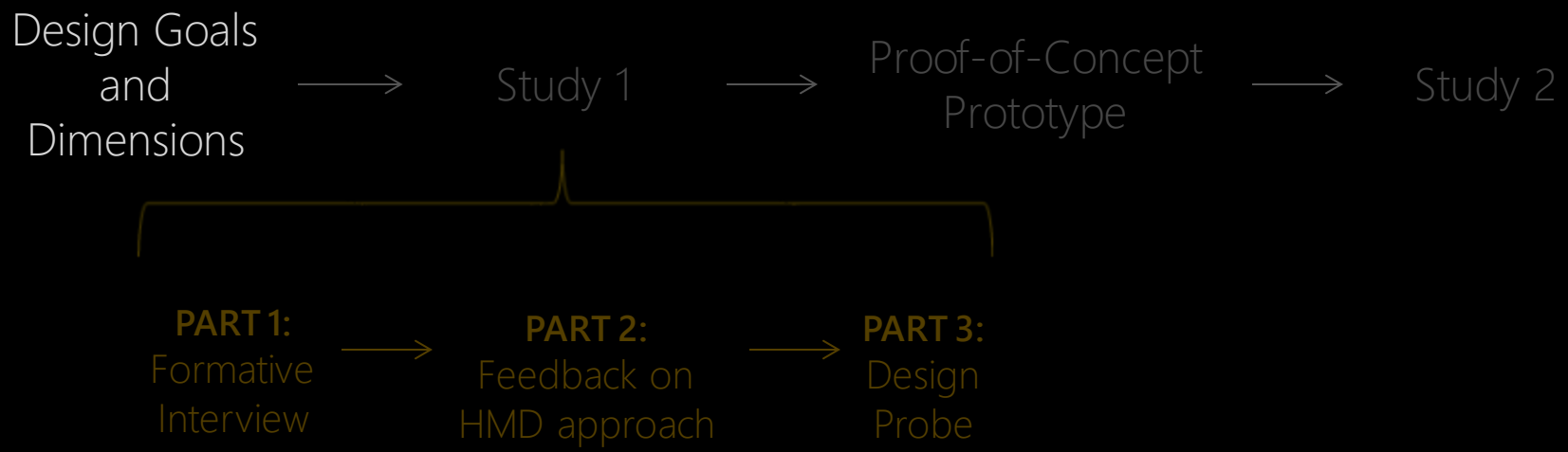
Maximum Simultaneous Icons



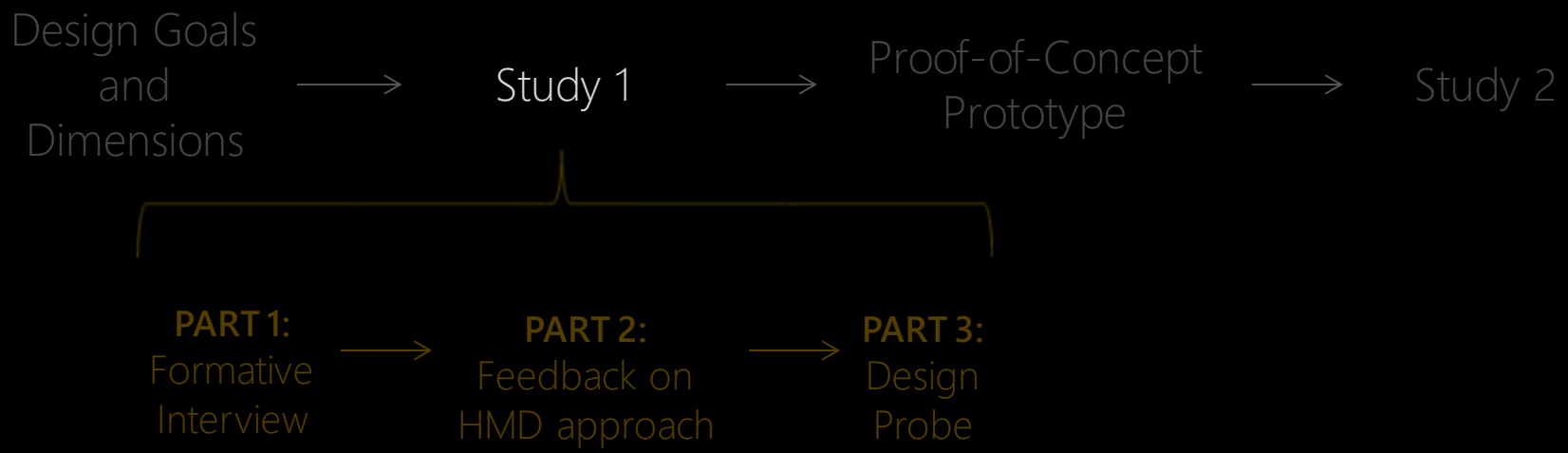
Automatic Sound Recognition



Outline


Design Goals and Dimensions
Study 1
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

Outline


Design Goals and Dimensions
Study 1
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
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PART 3: Design Probe

Study 1

Recruitment

- Online postings and social media
- Received ~300 responses, recruited 24

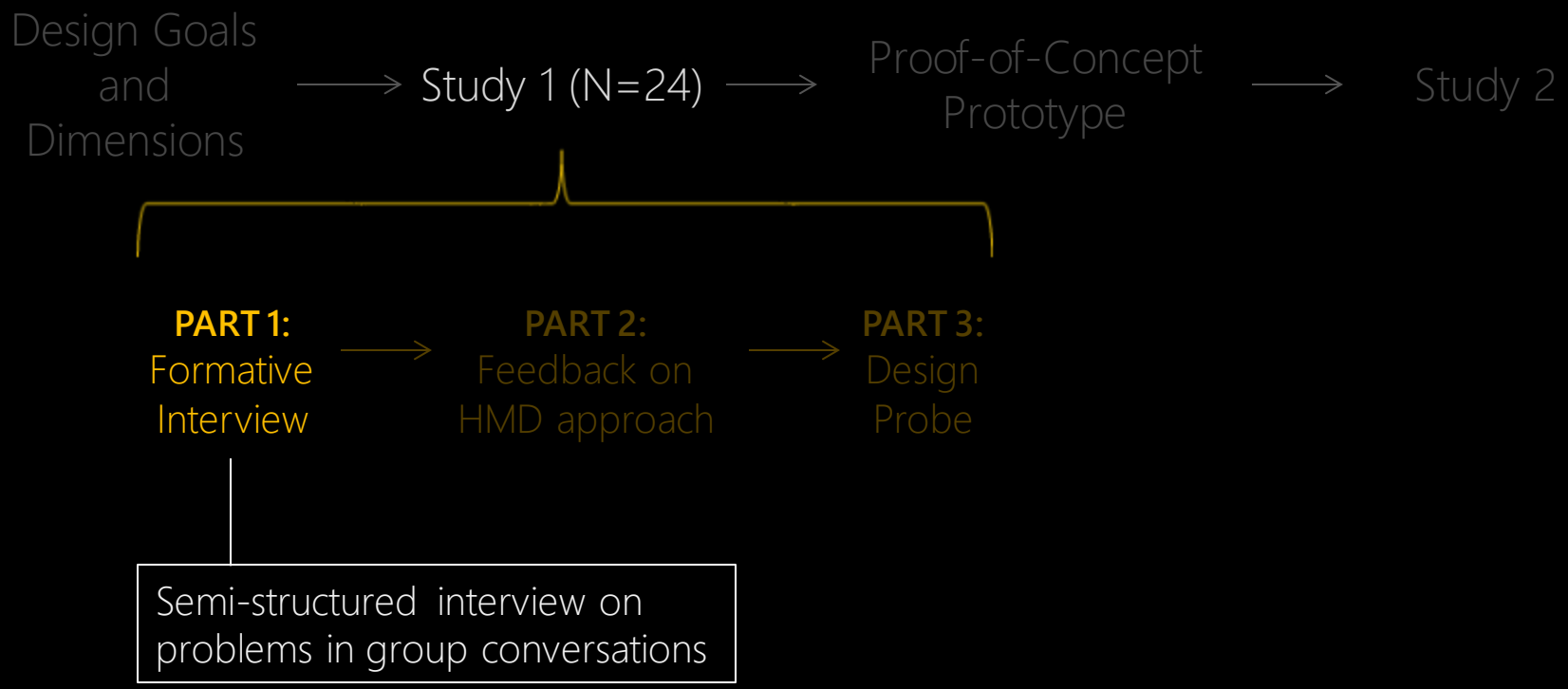
Study Method

- Semi-structured interview, feedback on HMD approach and design probe
- Average 67 minutes
- Participated communicated verbally (N=9) or by typing (N=15), according to preference

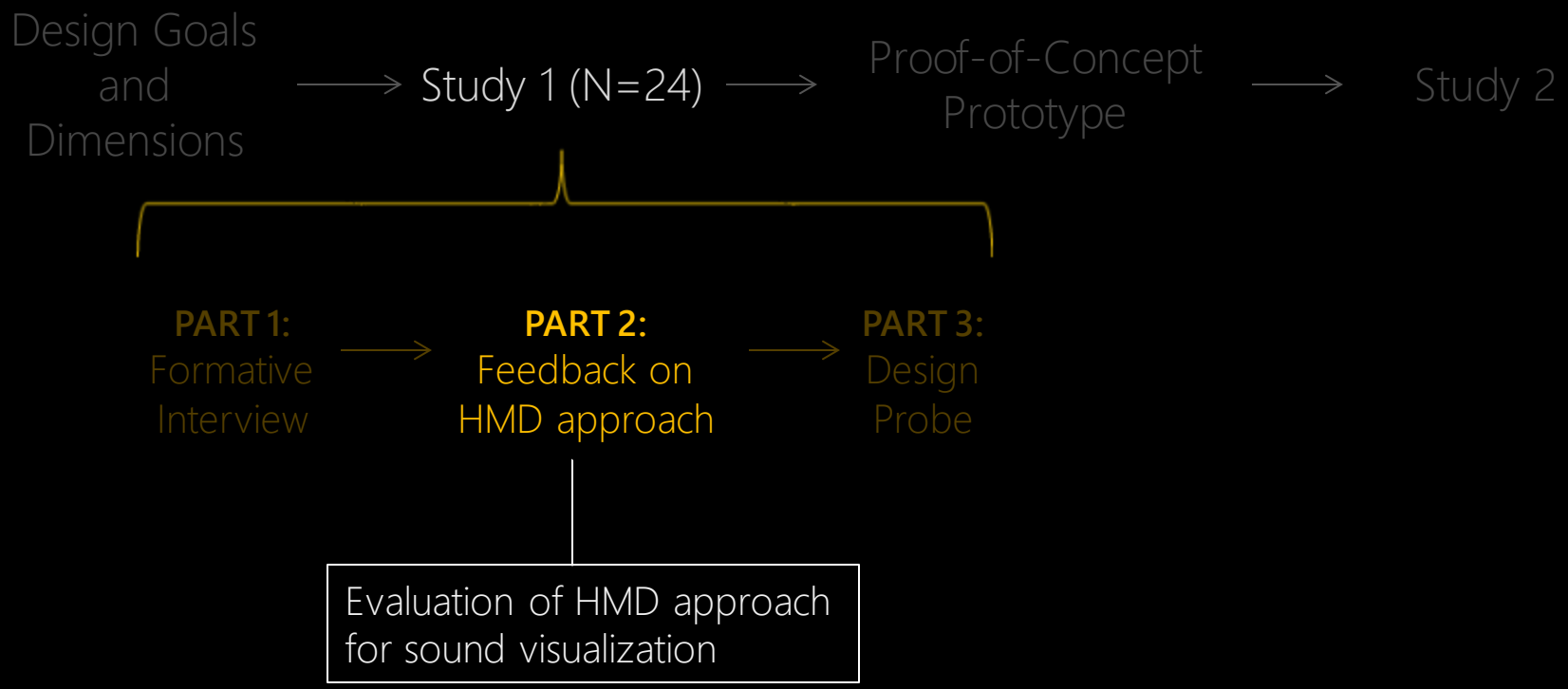
Participants

- 12 female/12 male
- 20 with profound, the remaining 4 had at least moderate hearing loss
- 19 employed lip-reading during conversations

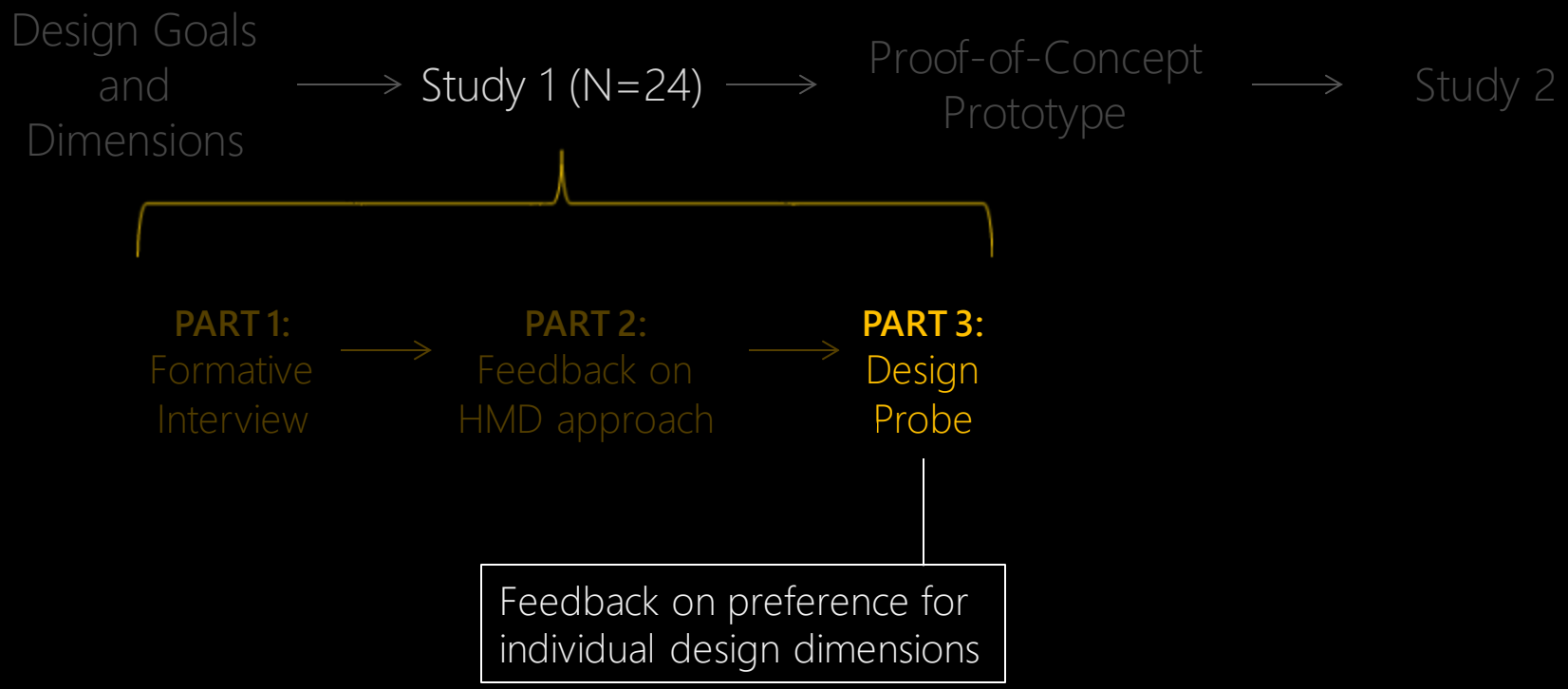
Outline


Design Goals and Dimensions
Study 1 (N=24)
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe
Semi-structured interview on problems in group conversations

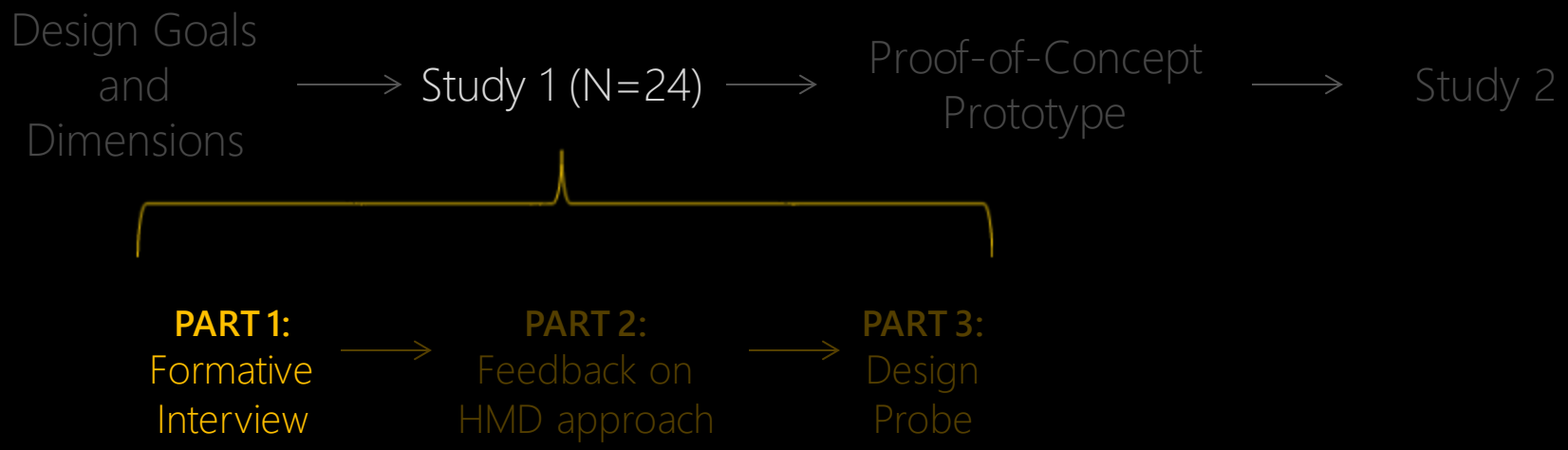
Outline


Design Goals and Dimensions
Study 1 (N=24)
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe
Evaluation of HMD approach for sound visualization

Outline


Design Goals and Dimensions
Study 1 (N=24)
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe
Feedback on preference for individual design dimensions

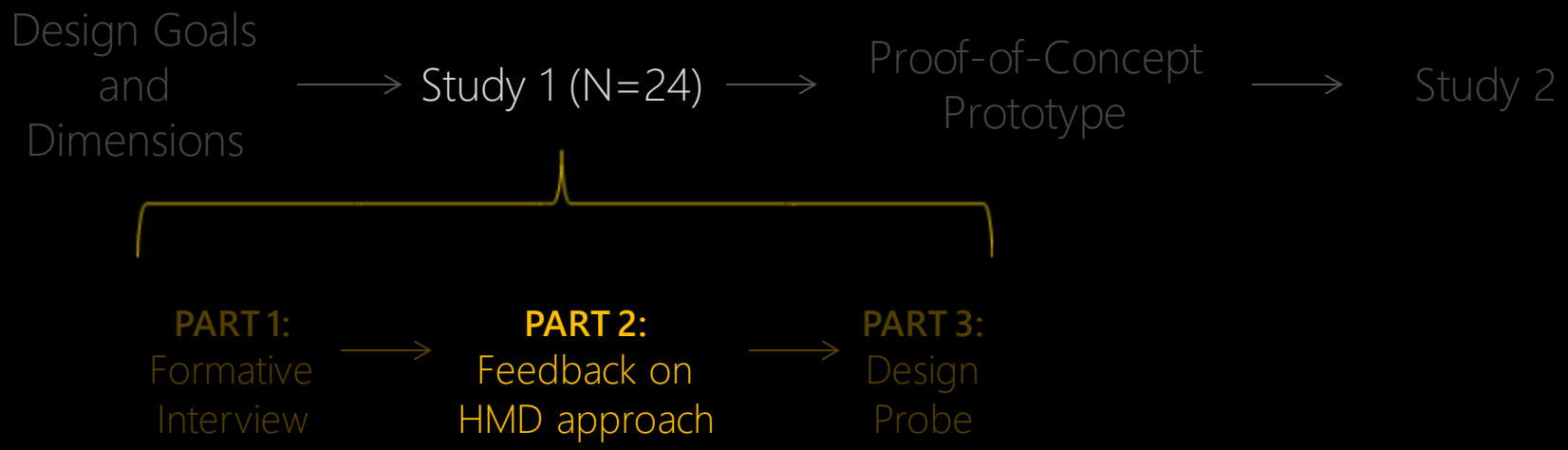
Outline


Design Goals and Dimensions
Study 1 (N=24)
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

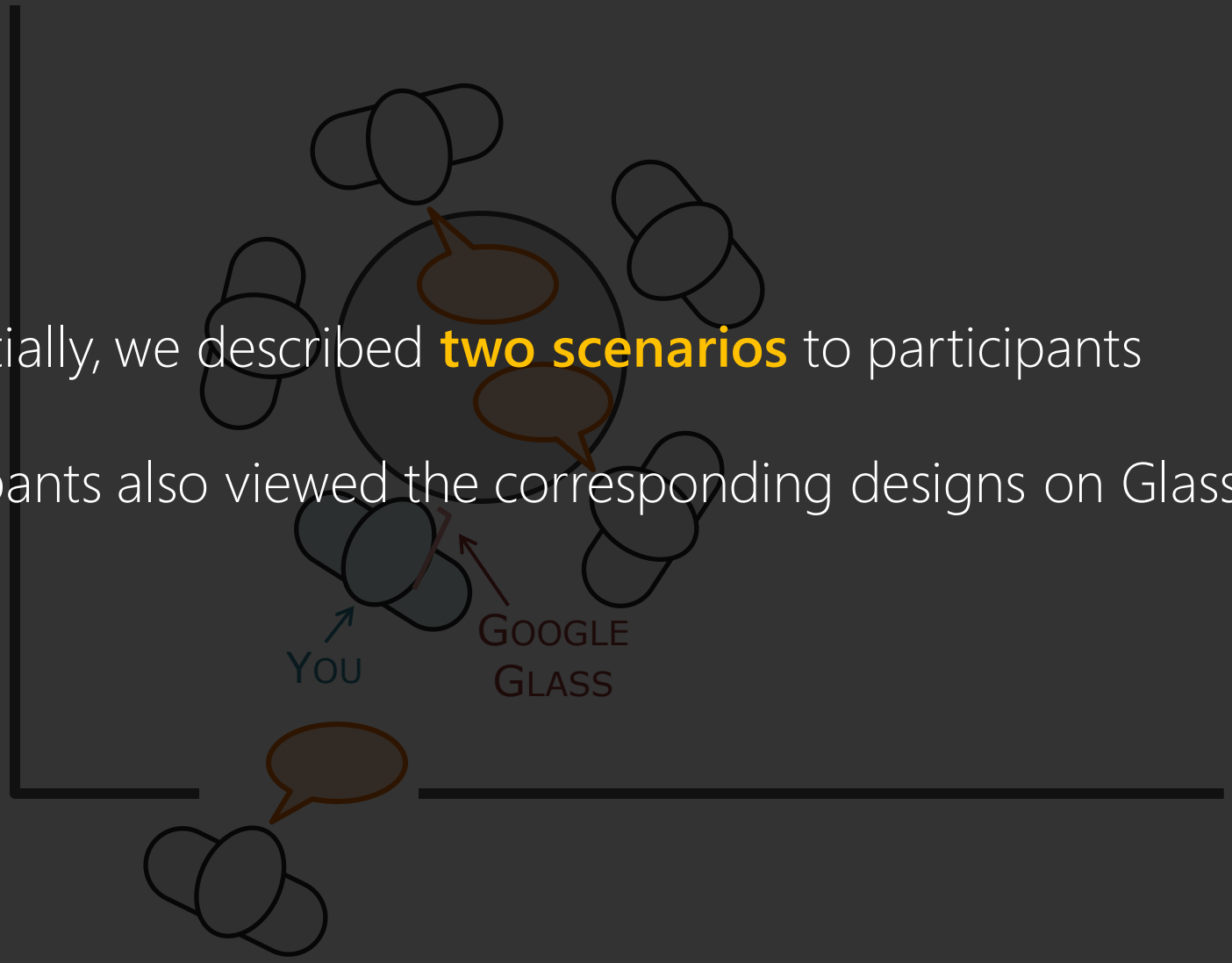
Study 1 Part 1: Formative Interview

- **Problems encountered** in group conversations
- How the participant **accommodated** those problems
- Prior experience with **computing or mobile devices** to support group conversation
- **Ideas for future** technology

Outline


Design Goals and Dimensions
Study 1 (N=24)
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

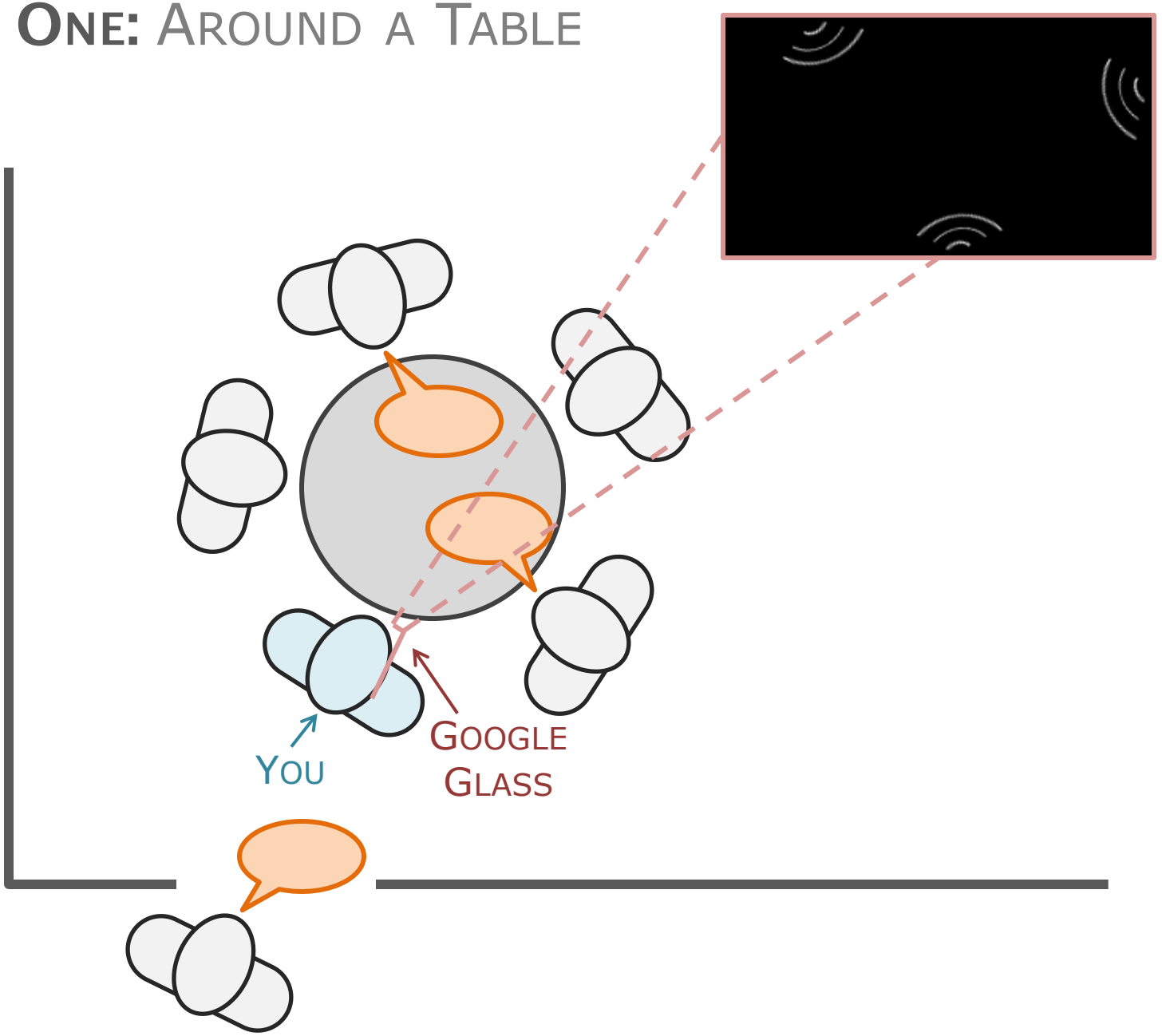
Scenario One: Around a Table



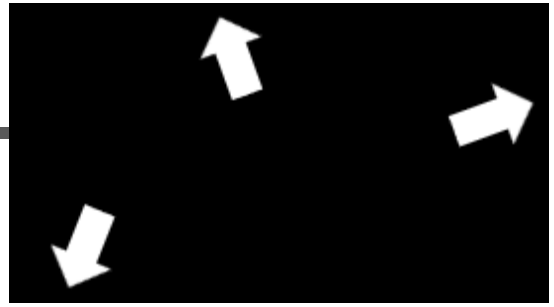
Initially, we described **two scenarios** to participants

Participants also viewed the corresponding designs on Glass

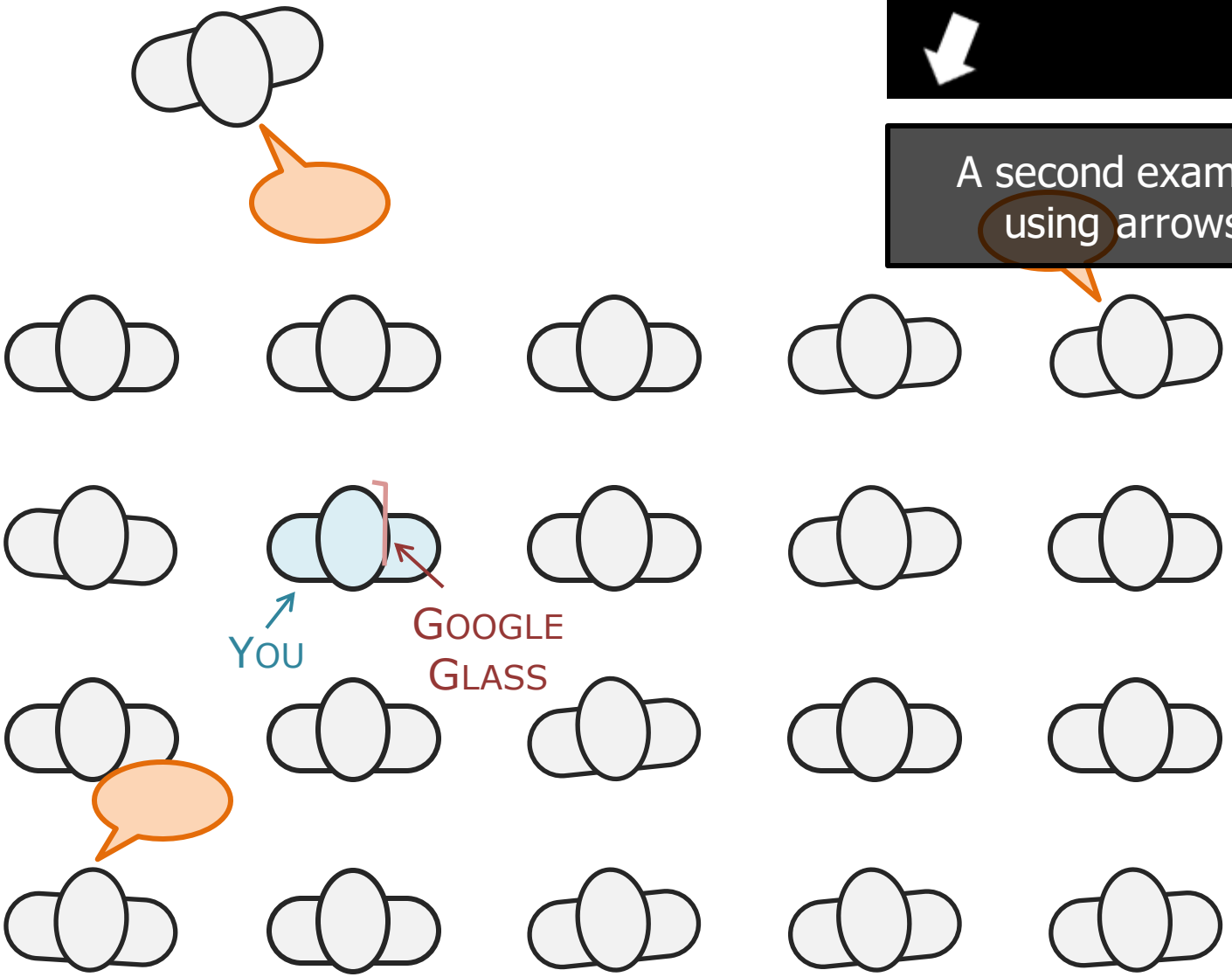
Scenario One: Around a Table

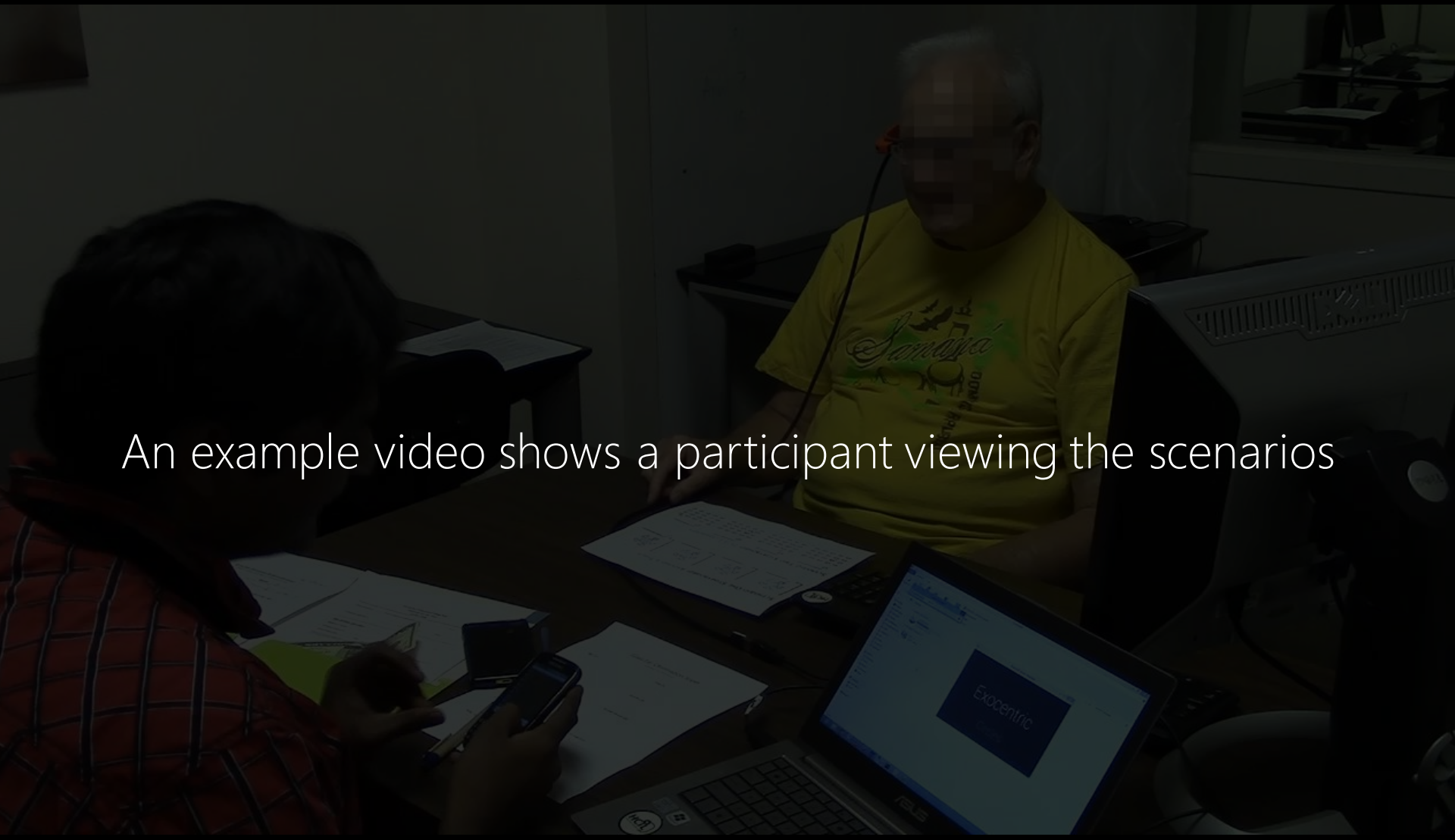


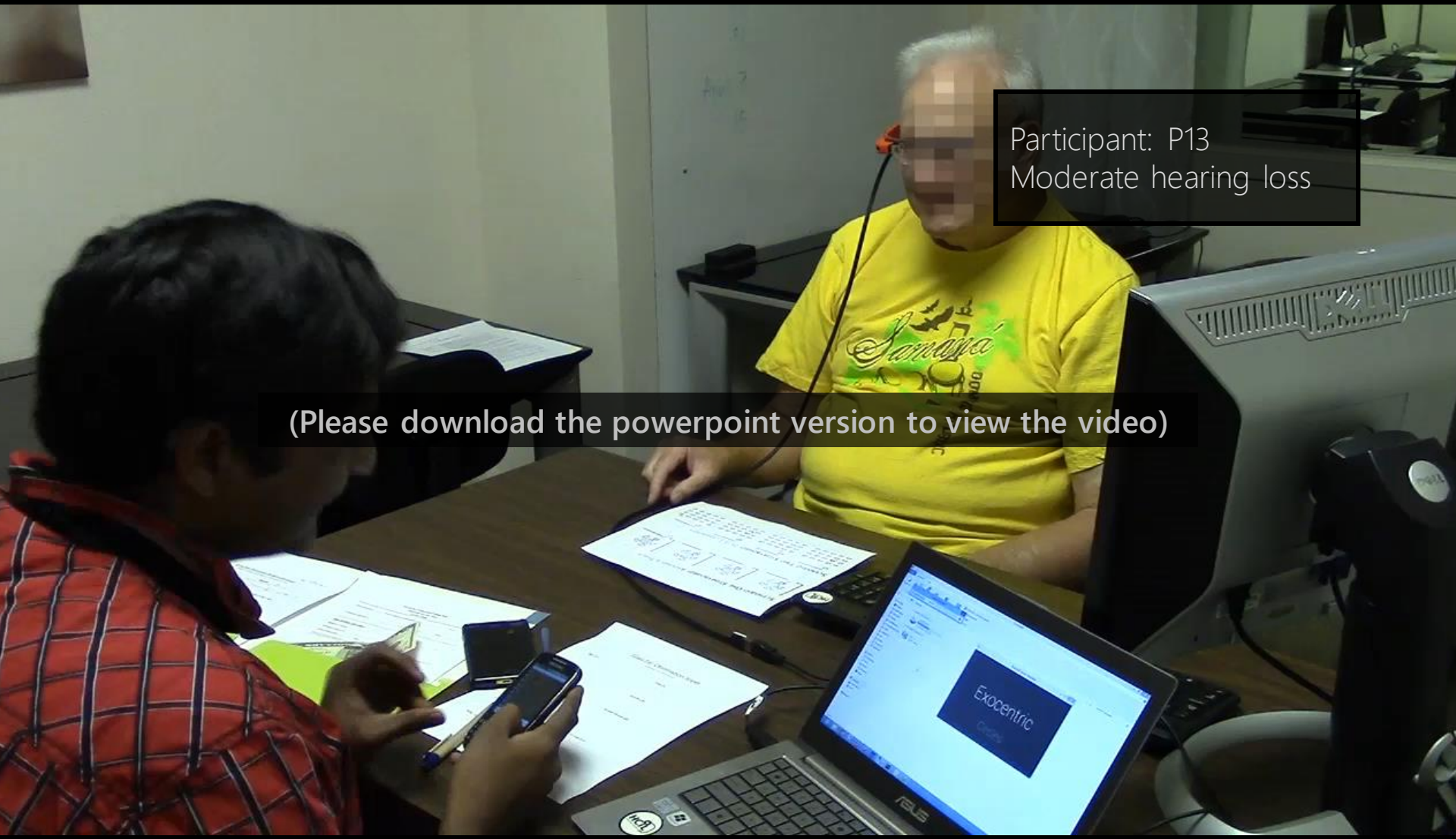
Scenario Two: In A Classroom



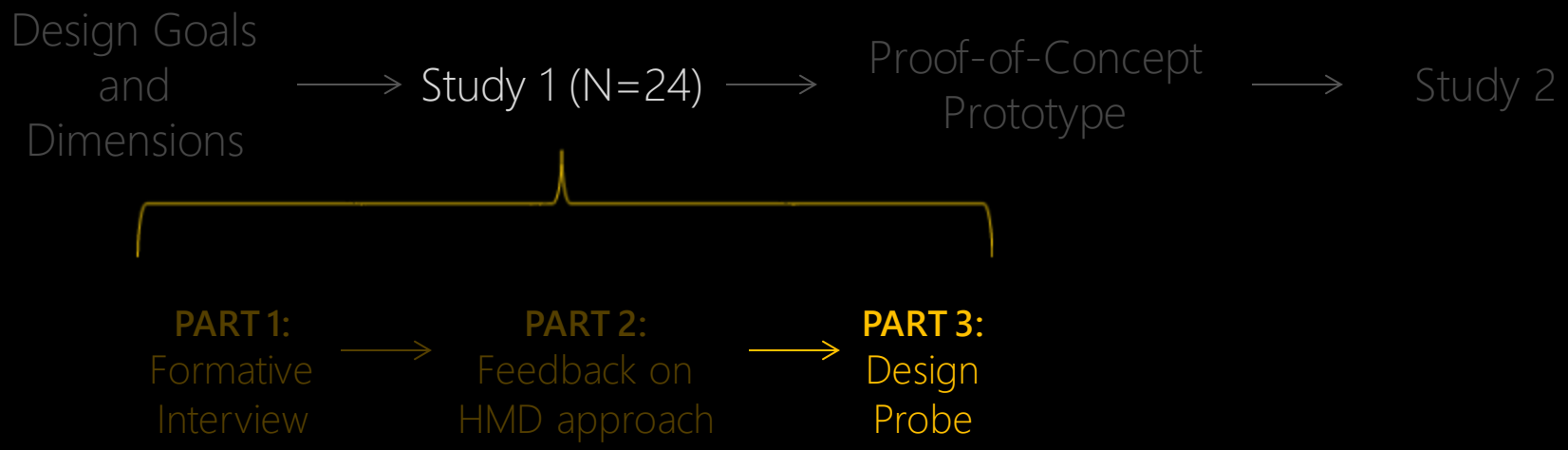
A second example using arrows




An example video shows a participant viewing the scenarios

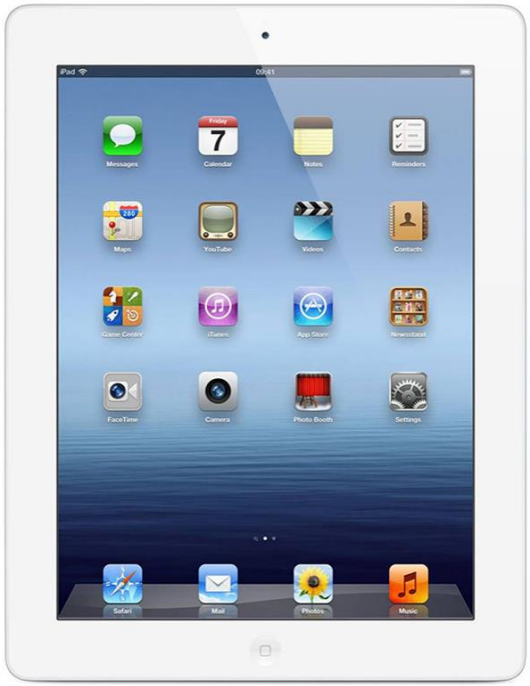

Participant: P13
Moderate hearing loss
(Please download the powerpoint version to view the video)
Exocentric

Outline


Design Goals and Dimensions
Study 1 (N=24)
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

Design **Probe**

Design **Probe**

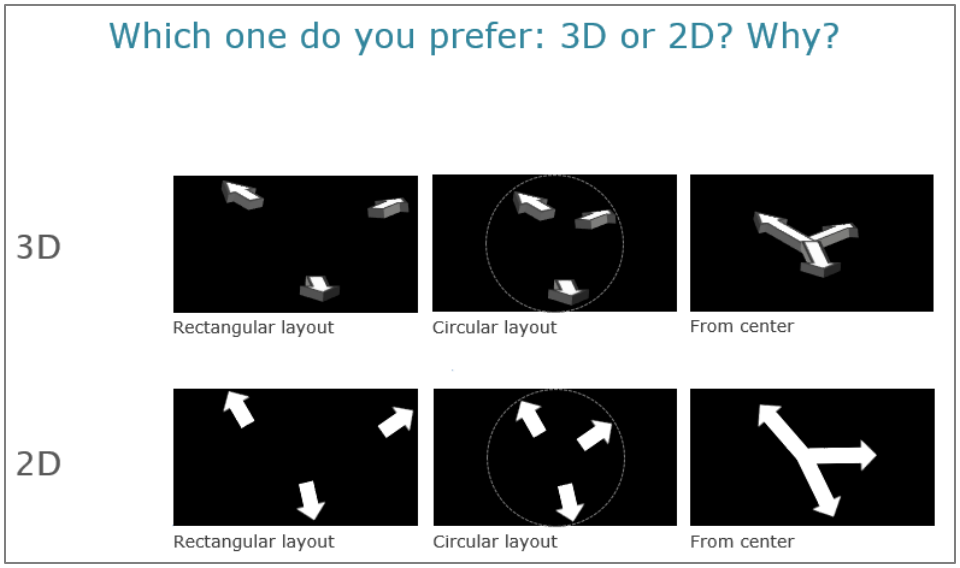


iPad

Glass

Two Visual Mediums

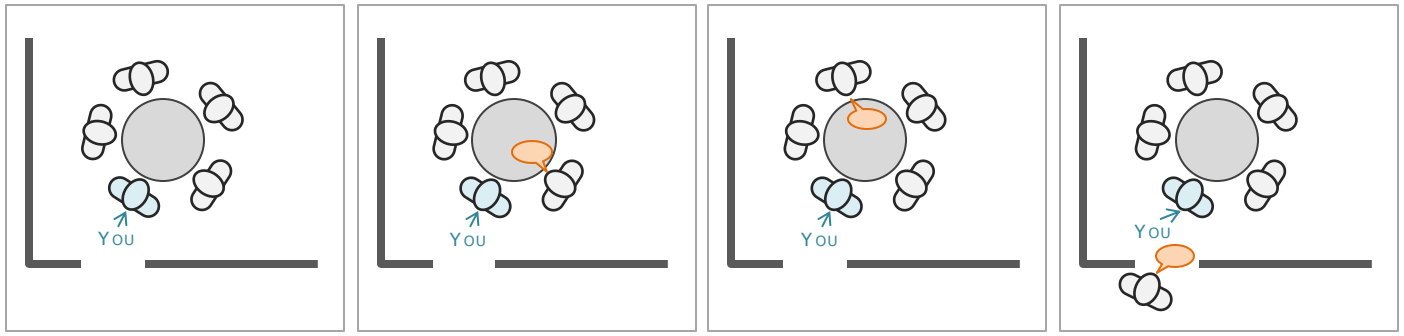
Design **Probe**



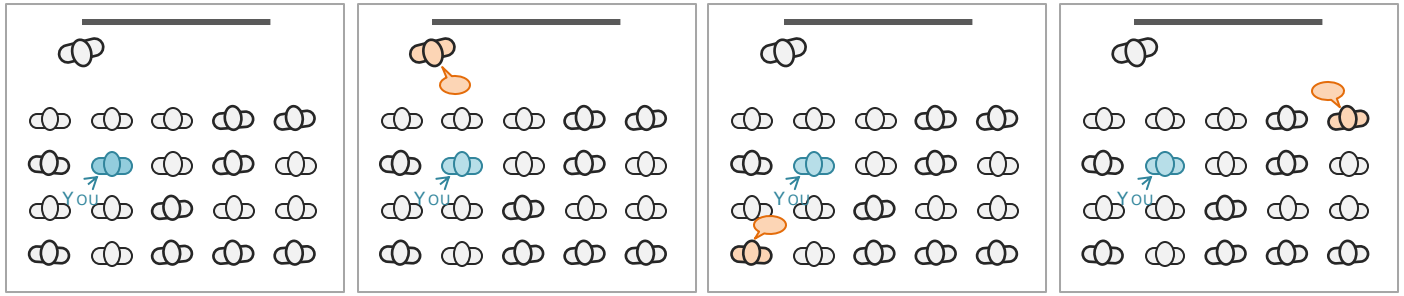
iPad

Glass

Design **Probe**



Scenario 1: Around a Table



Scenario 2: In a Classroom

We **evaluated** the **design dimensions** by showing examples

We asked for **open ended feedback** and
specific preference with **rationale**

Two example videos demonstrate this


2D vs. 3D
Participant: P8
Profound hearing loss
(Please download the powerpoint version to view the video)
2D
Sequence shown on Google Glass

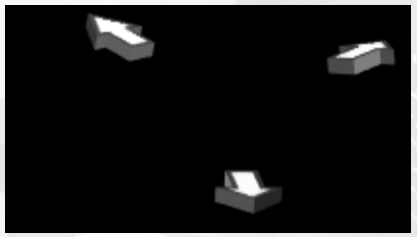
Sequence shown on iPAD

Which one do you prefer: 3D or 2D? Why?

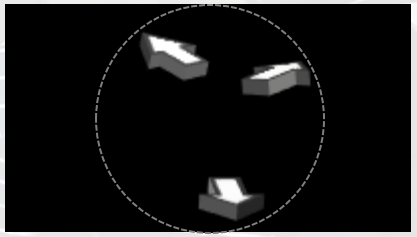
2D vs. 3D

Participant: P8
Profound hearing loss

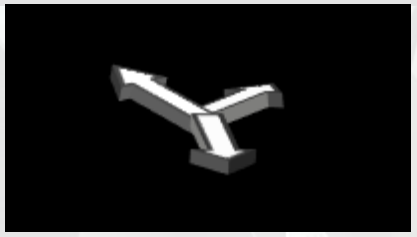
3D



Rectangular layout

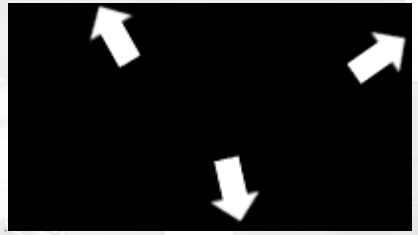


Circular layout

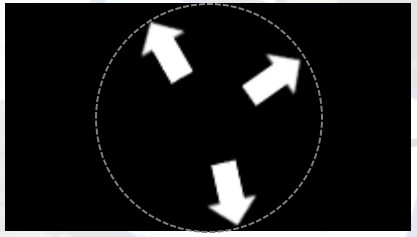


From center

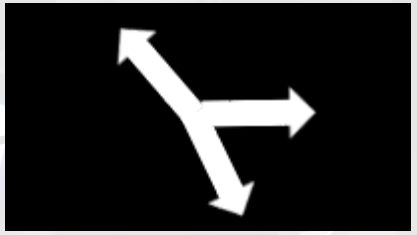
2D



Rectangular layout

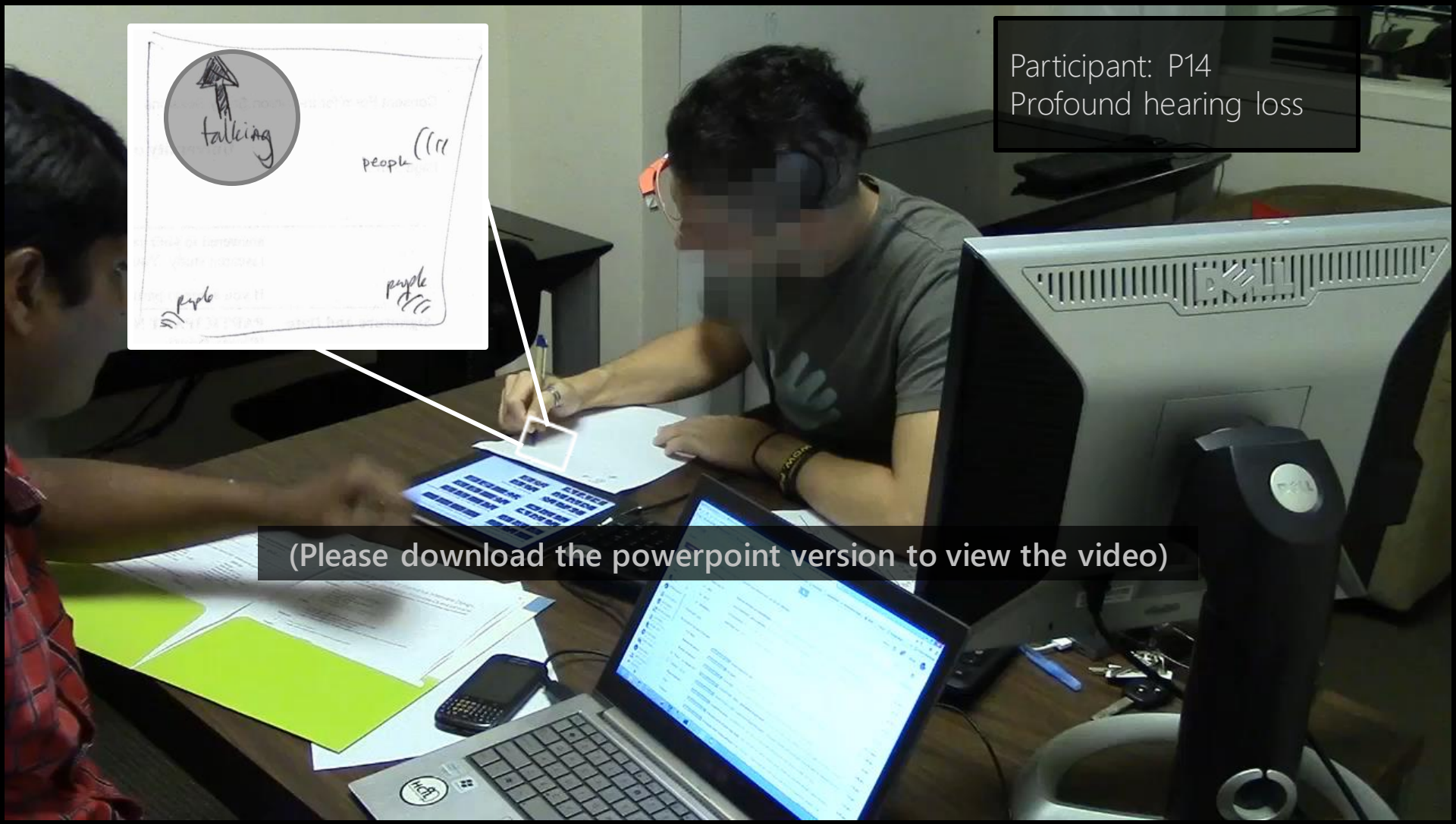


Circular layout



From center

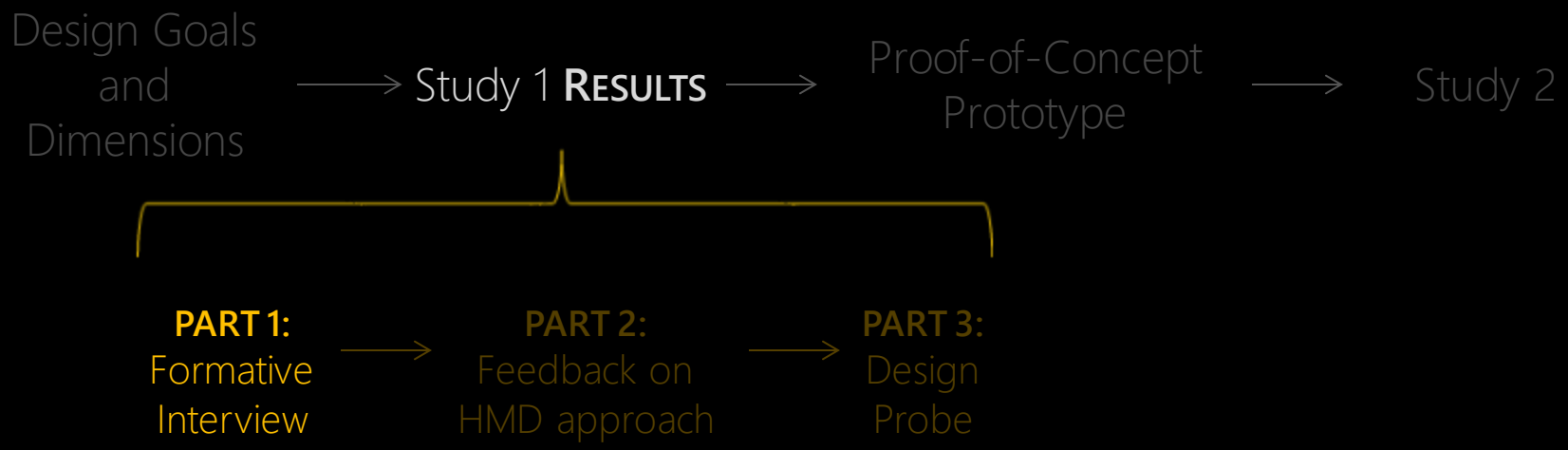
When asked to sketch their own designs…



Results

Study 1: Evaluating Design Dimensions

Outline


Design Goals and Dimensions
Study 1 RESULTS
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

Two researchers iteratively coded the formative interview


All 24 participants agreed that communicating in a group with hearing persons can be challenging

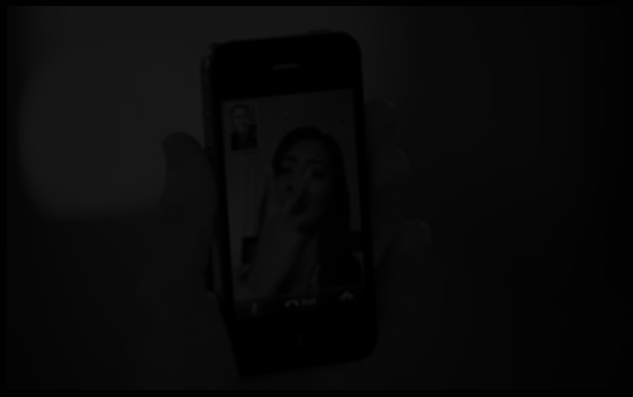

“If one person finishes talking, I do not know who to look at next—that is my problem because hearing people can hear who the next person is, and what they are saying.”
-P20, profound hearing loss

Adaptive Strategies for Group Communication

Traditional techniques
Interpreters/Captioners

Participants mentioned various strategies for group communication

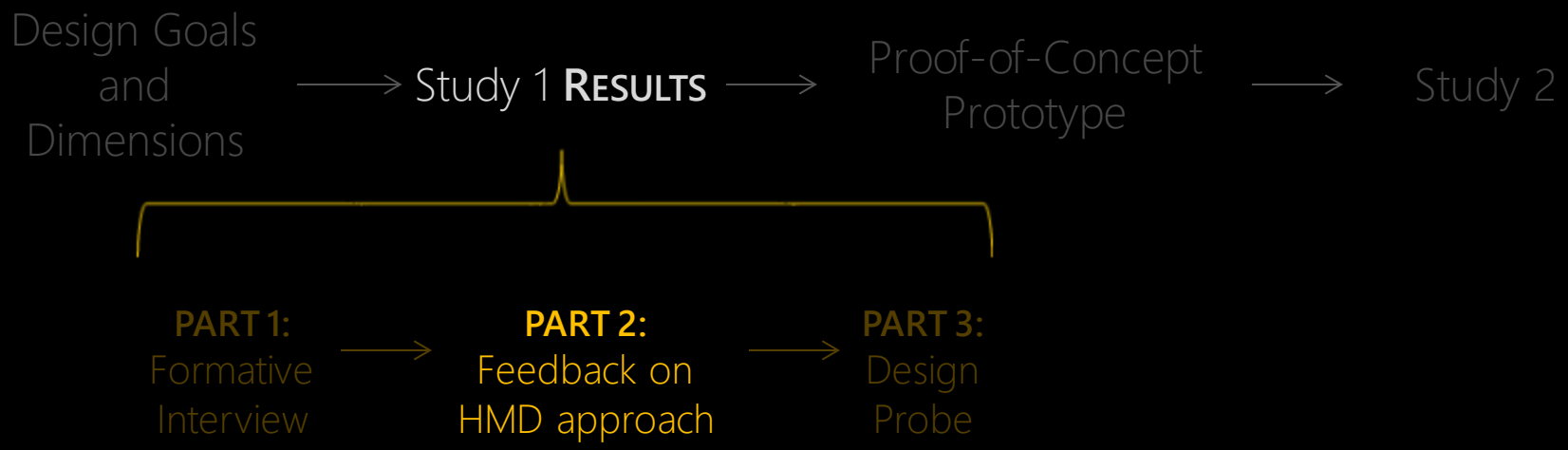
Low-fidelity adaptation
Pen/Paper
(7 Participants)



Use of technology
iPhone/Computer
(16 Participants)


7 participants mentioned maladaptive strategies,
i.e. distract or prevent communication

Outline


Design Goals and Dimensions
Study 1 RESULTS
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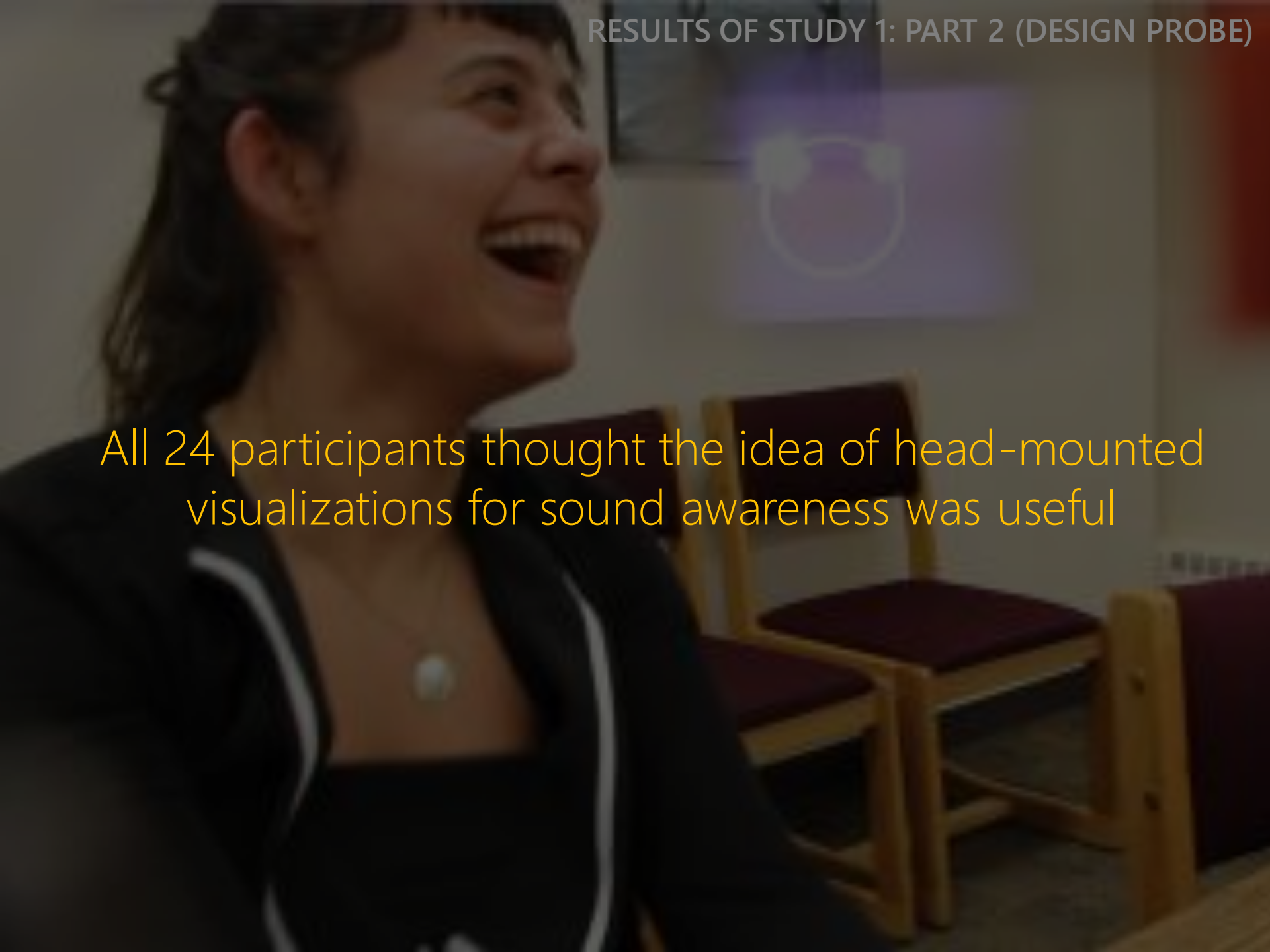
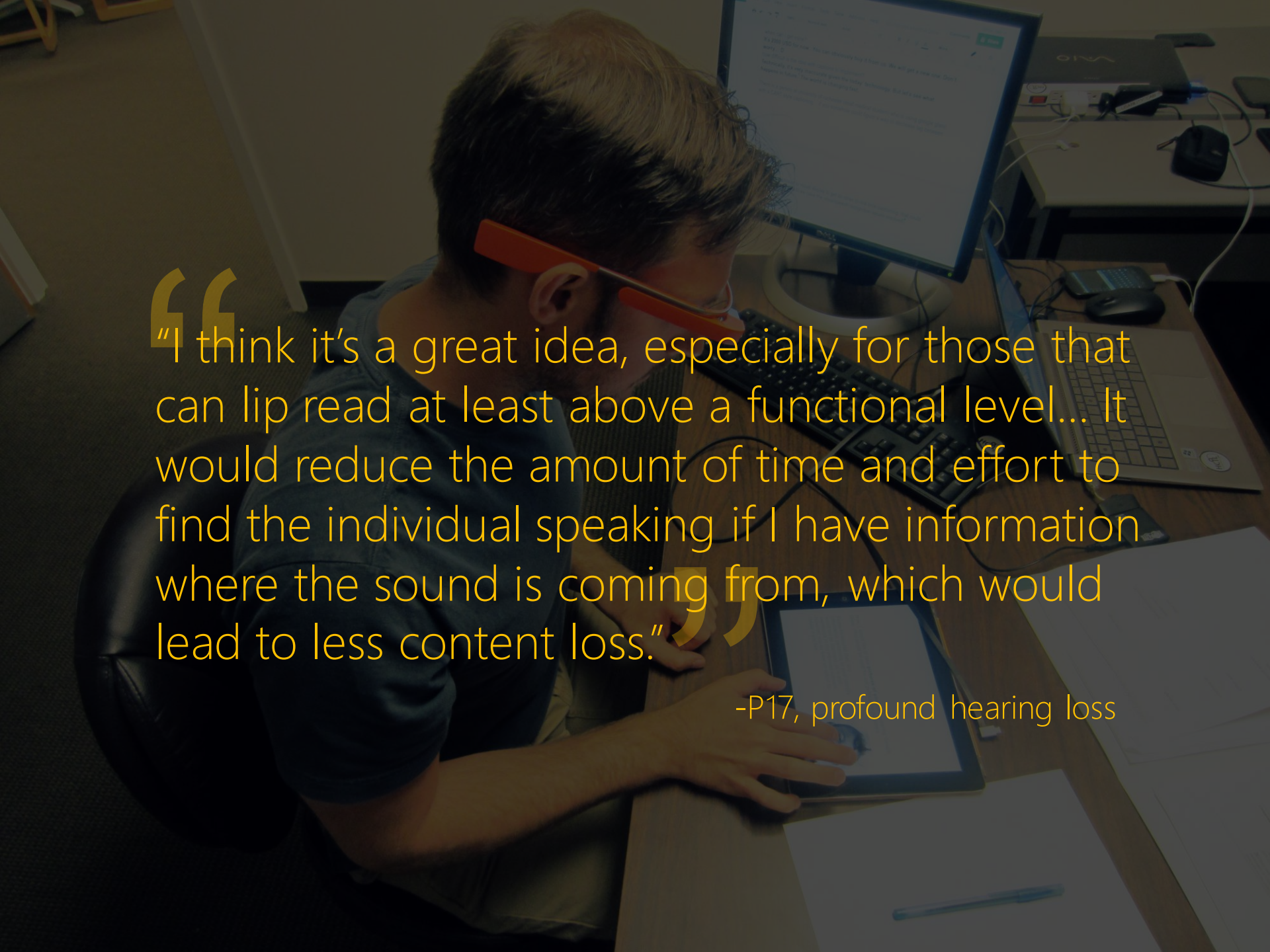
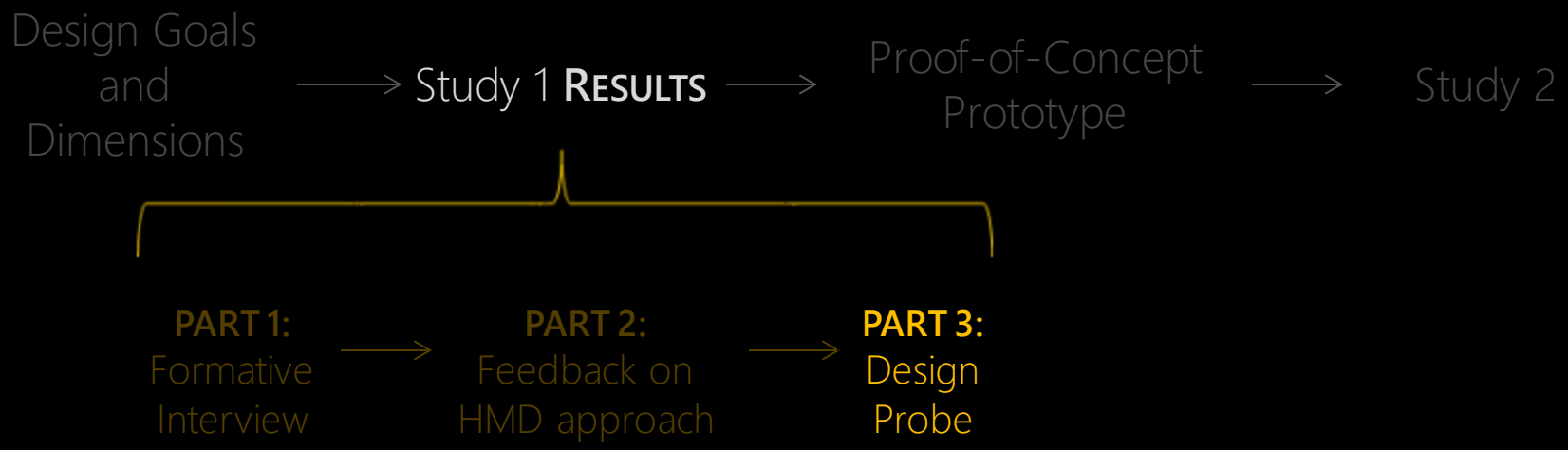


All 24 participants thought the idea of head-mounted visualizations for sound awareness was useful


“I think it’s a great idea, especially for those that can lip read at least above a functional level… It would reduce the amount of time and effort to find the individual speaking if I have information where the sound is coming from, which would lead to less content loss.”
-P17, profound hearing loss

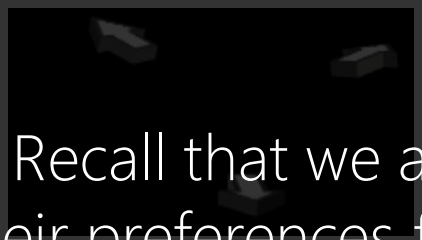
Outline


Design Goals and Dimensions
Study 1 RESULTS
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

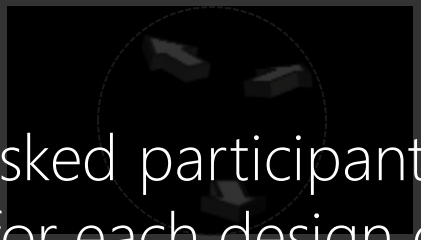
Preferences for Design Dimensions

Which one do you prefer: 3D or 2D? Why?

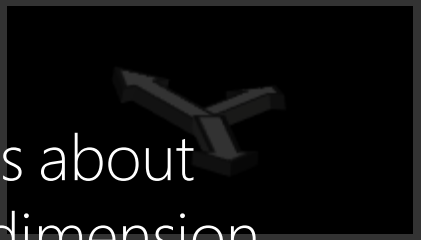
3D



Rectangular layout



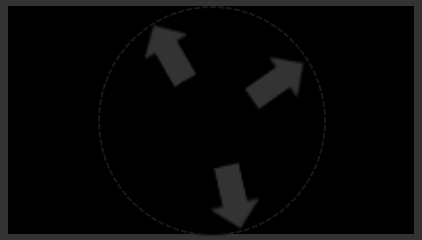
Circular layout



From center

2D

Rectangular layout



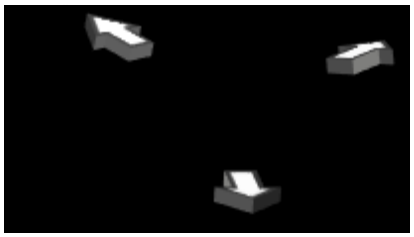
Circular layout

From center

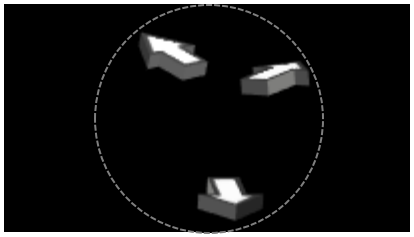
Recall that we asked participants about their preferences for each design dimension

Which one do you prefer: 3D or 2D? Why?

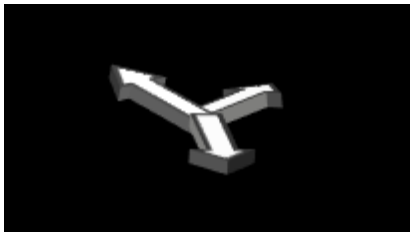
3D



Rectangular layout

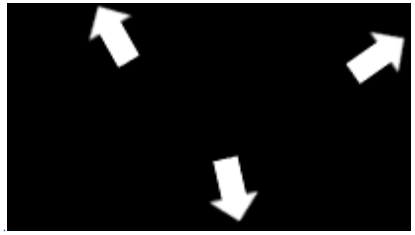


Circular layout

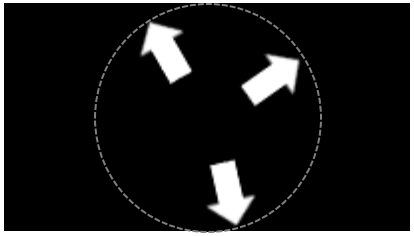


From center

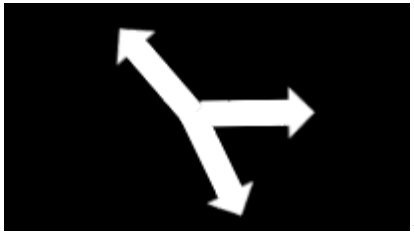
2D



Rectangular layout



Circular layout



From center

Preferences For Some Design Dimensions

Chi-Square Test on Distribution of Preference

One vote for "Yes"

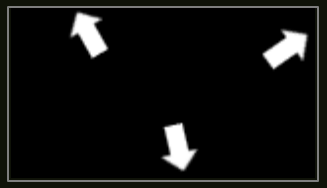
Zero vote for "No"

0.5 vote each for "Maybe", "I like both"

wearer's perspective

EGOCENTRIC (11 VOTES)

Pulses

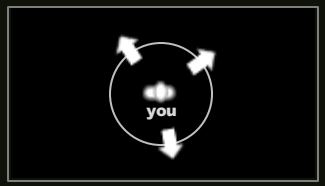


Arrows

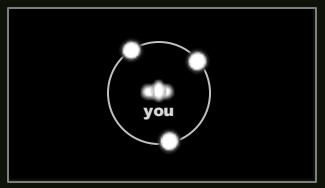
Fingers

EXOCENTRIC (13 VOTES)

People



Arrows



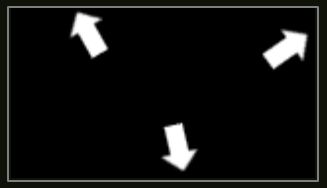
Circles

$\chi^2_{(1,N=24)} = 0.04$, p = ns

wearer's perspective

EGOCENTRIC (11 VOTES)

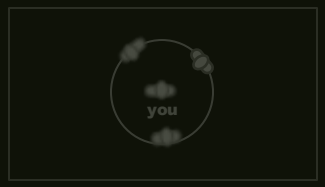
Pulses



Arrows

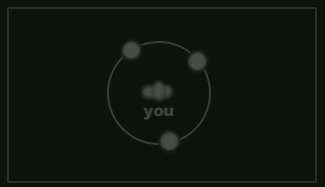
Fingers

EXOCENTRIC (13 VOTES)



People

Arrows



Circles

$\chi^2_{(1,N=24)} = 0.04$, p = ns

Egocentric Perspective (11 Votes)

Easier to interpret

(4 Participants)

Less cluttered

(3 Participants)

wearer's perspective

EGOCENTRIC (11 VOTES)

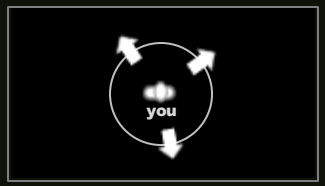
Pulses

Arrows

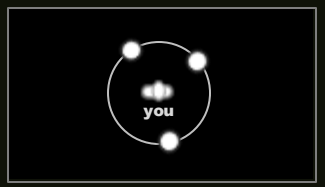
Fingers

EXOCENTRIC (13 VOTES)

People



Arrows



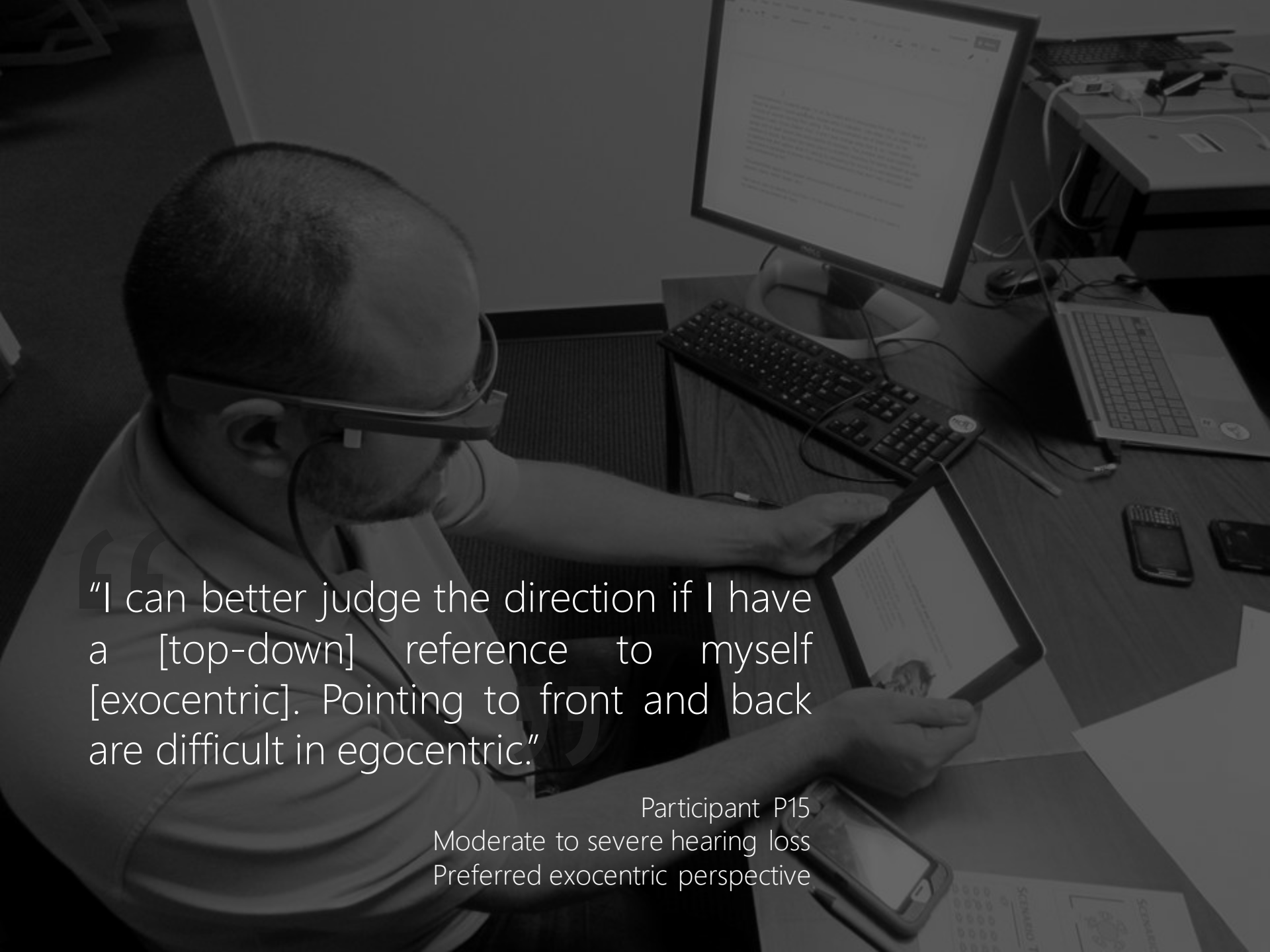
Circles

$\chi^2_{(1,N=24)} = 0.04$, p = ns

Exocentric Perspective (13 Votes)

Shows the location of the wearer

(12 Participants)



"I can better judge the direction if I have a [top-down] reference to myself [exocentric]. Pointing to front and back are difficult in egocentric."

Participant P15
Moderate to severe hearing loss
Preferred exocentric perspective

Both egocentric and exocentric were well received, so **either could be used**

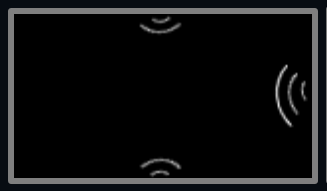
direction granularity

$X^2_{(3,N=24)} = 17.75, p < .001$

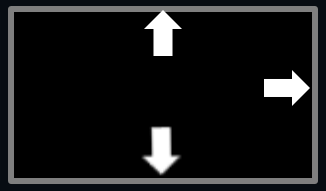
1-Level
(1 Vote)

Circle

4-Levels
(3 Votes)



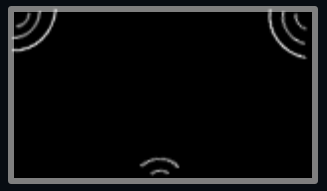
Pulses



Arrows

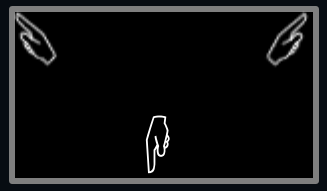
Fingers

8-Levels
(5.5 Votes)



Pulses

Arrows



Fingers

Continuous
(14.5 Votes)

Pulses

Arrows

Fingers

direction granularity

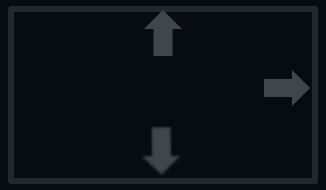
$X^2_{(3,N=24)} = 17.75, p < .001$

1-Level
(1 Vote)

Circle

4-Levels
(3 Votes)

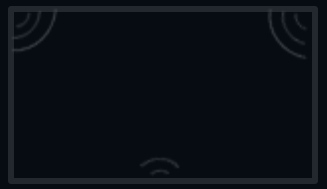
Pulses



Arrows

Fingers

8-Levels
(5.5 Votes)



Pulses

Arrows

Fingers

Continuous
(14.5 Votes)

Pulses

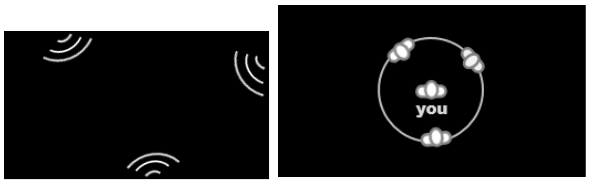
Arrows

Fingers

Precision is valued,
use **high** directional **granularity**

Preferences For Some Design Dimensions

Wearer's Perspective



Egocentric
11 votes

Exocentric
13 votes

Directional Granularity

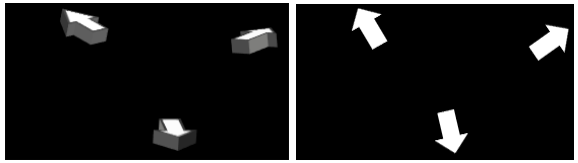
Continuous
14.5 votes

8-Level
5.5 votes

4-Level
3 votes

1-Level
1 vote

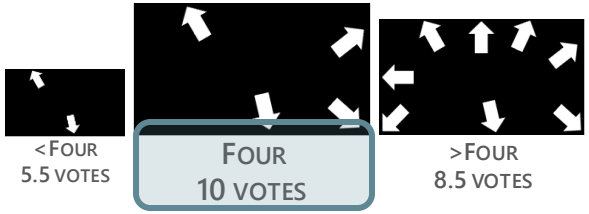
2D vs. 3D



3D
12 votes

2D
12 votes

Maximum Simultaneous Icons

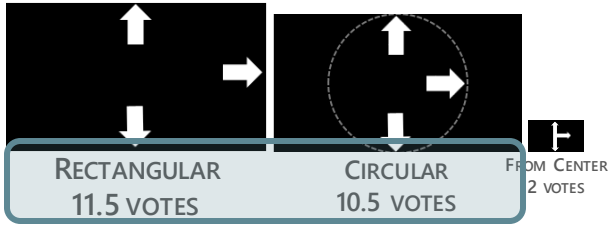


<Four
5.5 votes

Four
10 votes

>Four
8.5 votes

Screen Layout

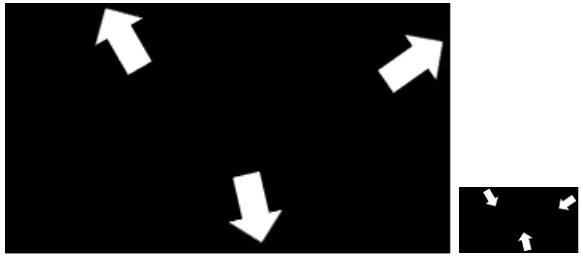


Rectangular
11.5 votes

Circular
10.5 votes

From Center
2 votes

Conveying Sound Source

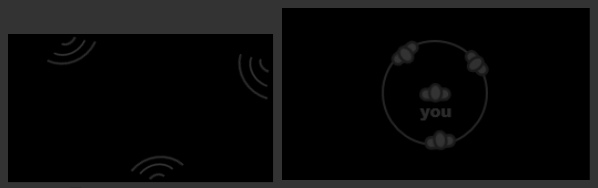


Outward
19 votes

Inward
5 votes

Preferences For Some Design Dimensions

Wearer's Perspective



Egocentric
11 votes

Exocentric
13 votes

Directional Granularity

Continuous
14.5 votes

8-Level
5.5 votes

4-Level
3 votes

1-Level
1 vote

2D vs. 3D

3D
12 votes

2D
12 votes

Maximum Simultaneous Icons

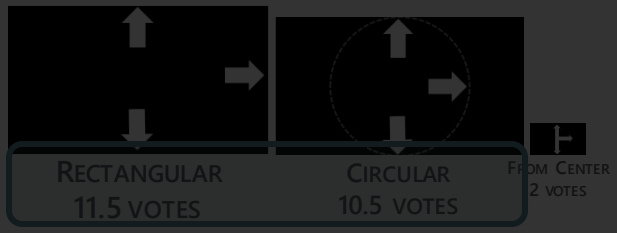
<Four
5.5 votes

Four
10 votes

>Four
8.5 votes

Please refer to the paper for more design results

Screen Layout



Rectangular
11.5 votes

Circular
10.5 votes

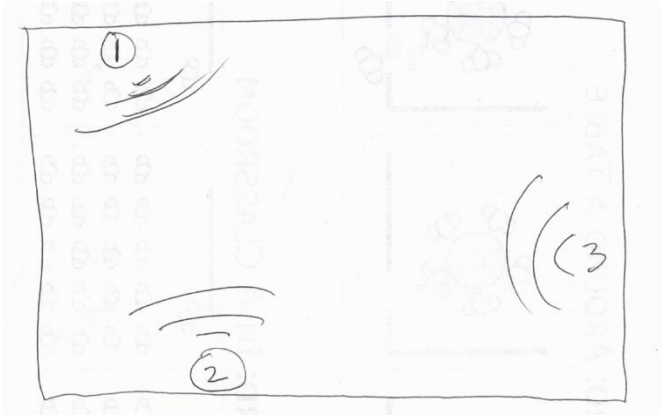
From Center
2 votes

Conveying Sound Source

Outward
19 votes

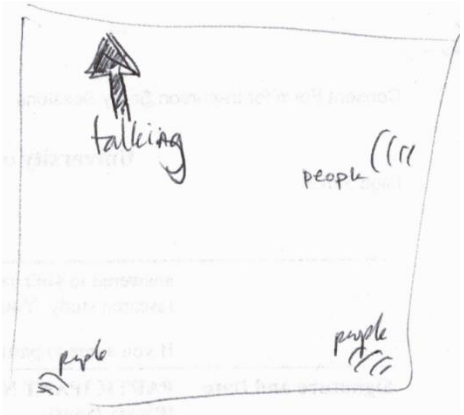
Inward
5 votes

Designs Sketched By Participants

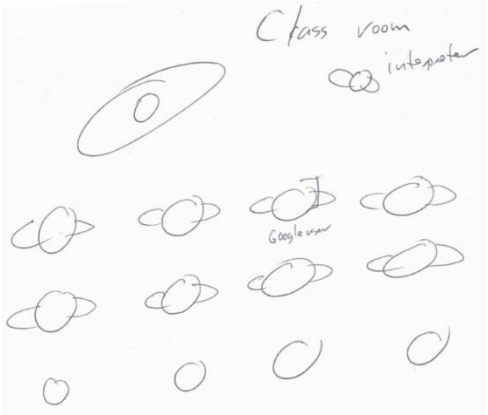


P19: Extended Egocentric Pulses
To show recent speaking order

P14: Different Exocentric Design
Visualize all potential speakers

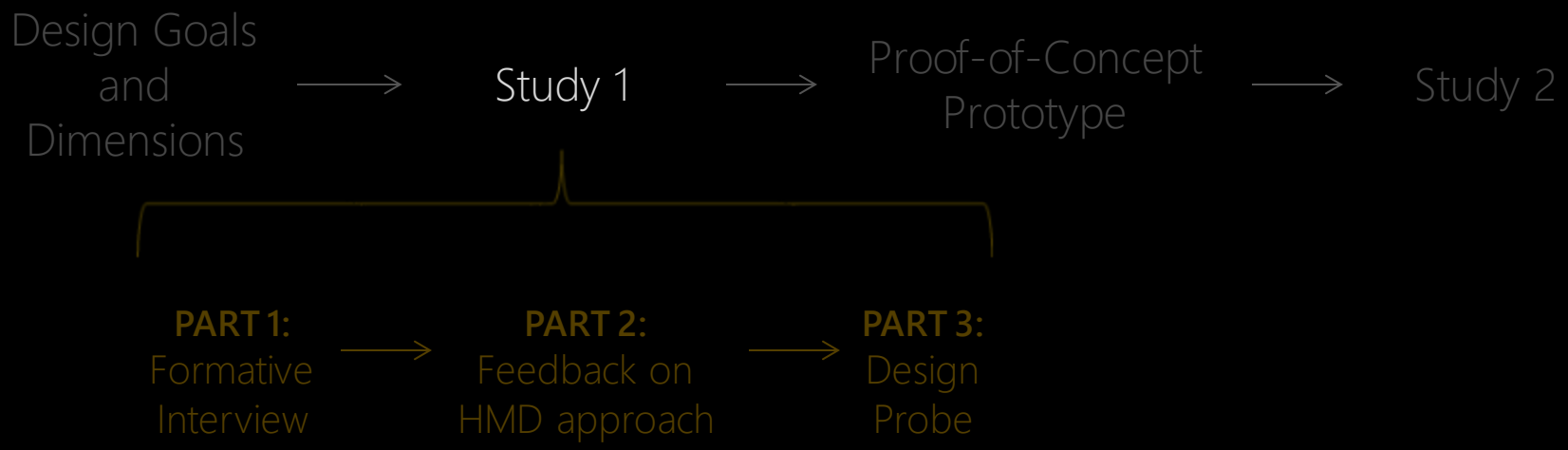


P14: Extended Egocentric Design
Pulses represent recent speakers, 3D arrow shows current speaker



P7: Different Exocentric Design
Room layout and people locations

Outline


Design Goals and Dimensions
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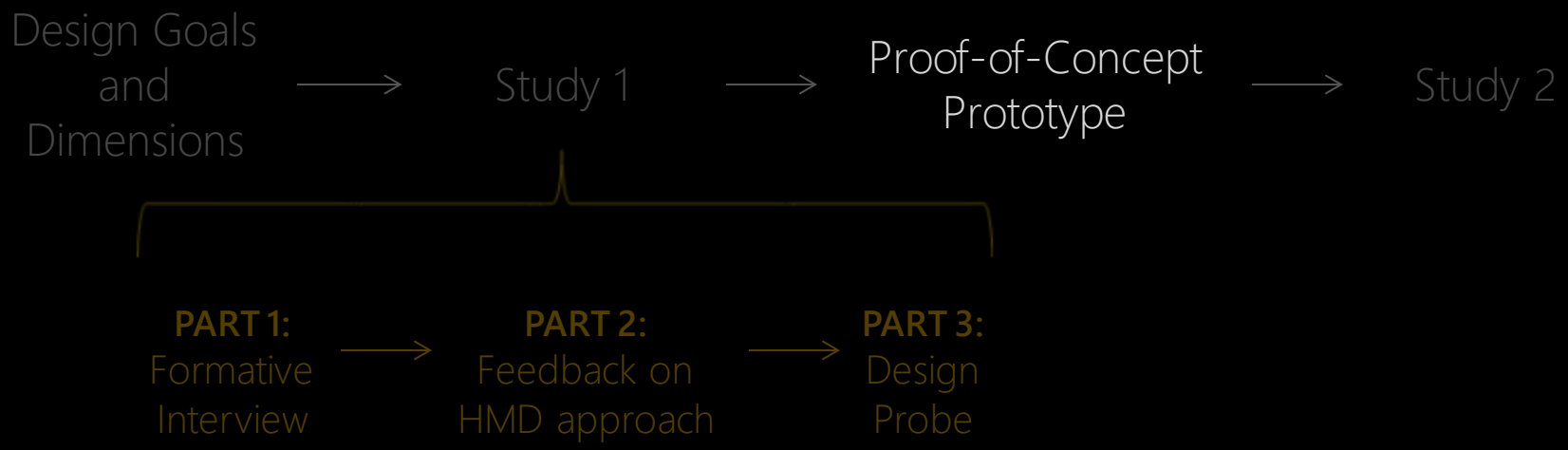
Outline


Design Goals and Dimensions
Study 1
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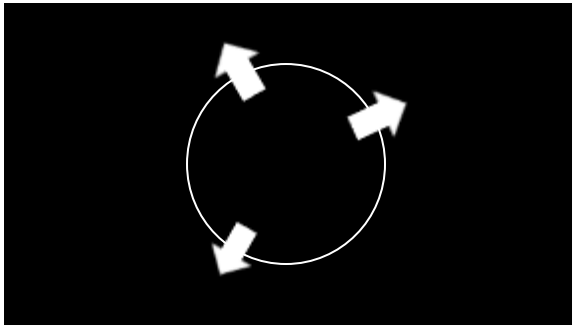
PART 3: Design Probe


Microphone array
Laptop for interfacing
Visualization that is shown on Google Glass

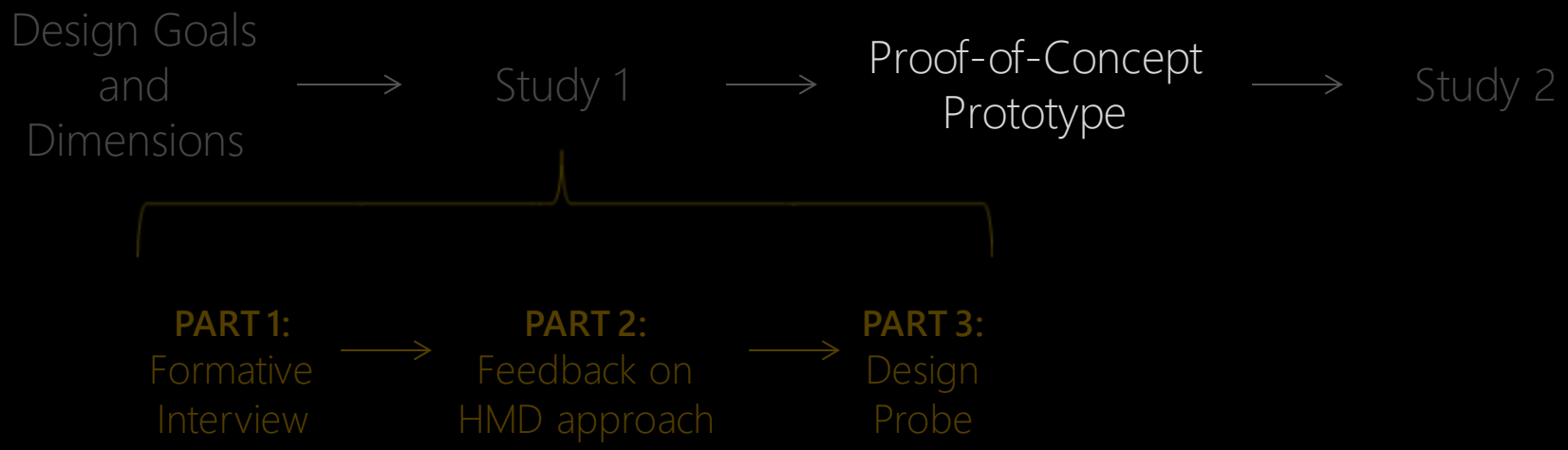
We implemented live versions of two popular designs:

Egocentric Pulses



Exocentric Arrows

Outline


Design Goals and Dimensions
Study 1
Proof-of-Concept Prototype
Study 2
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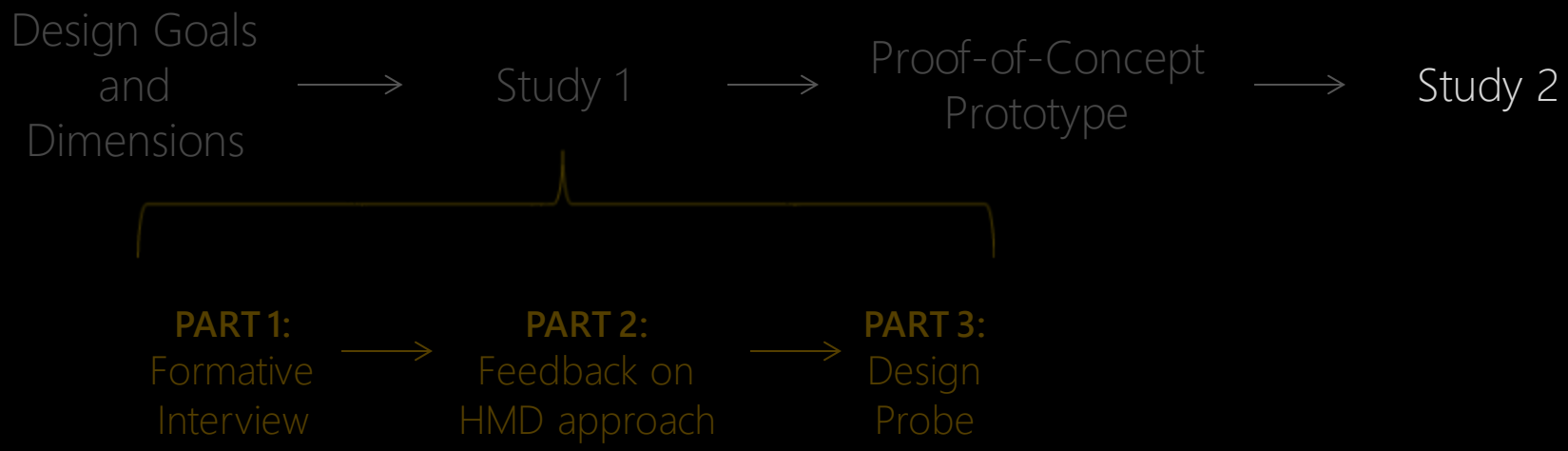
PART 2: Feedback on HMD approach
PART 3: Design Probe

Outline


Design Goals and Dimensions
Study 1
Proof-of-Concept Prototype
Study 2
PART 1: Formative Interview
PART 2: Feedback on HMD approach
PART 3: Design Probe

We implemented live versions of two popular designs:

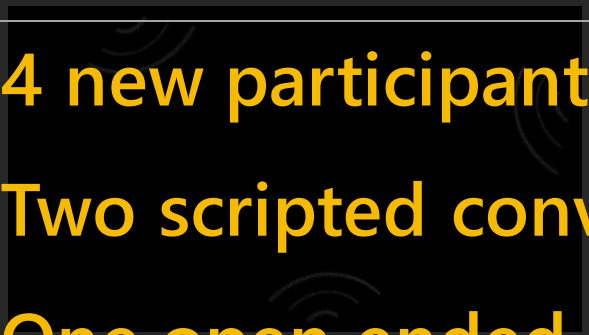
Study 2

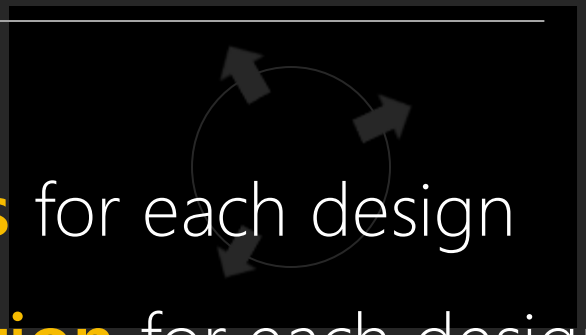
4 new participants

Two scripted conversations for each design

One open ended conversation for each design

Qualitative interview after each design





Scripted Conversation

Script: Ghostbusters

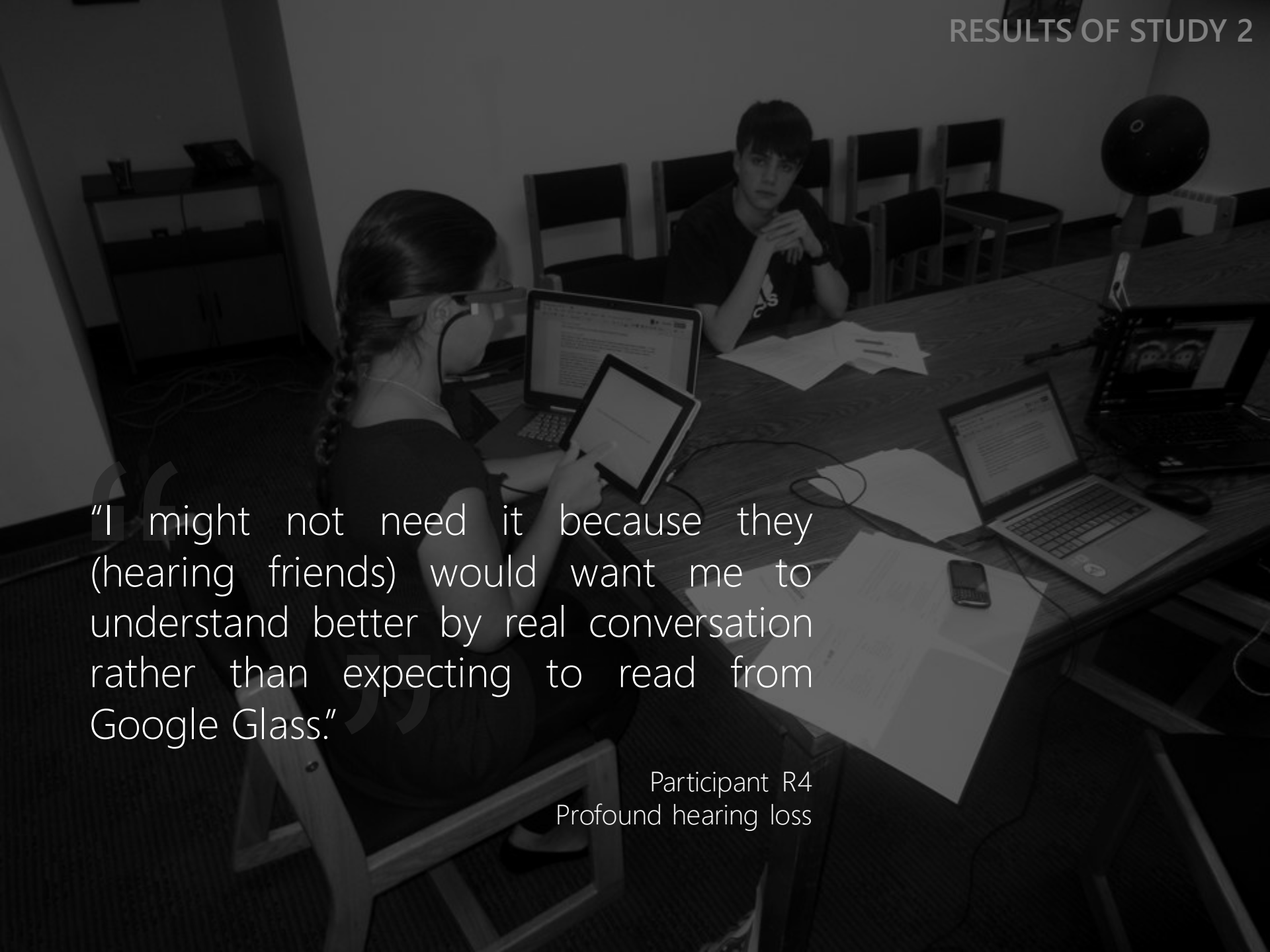
(Please download the powerpoint version to view the video)

Preliminary Feedback

Study 2: Evaluating Proof-of-Concept Prototype

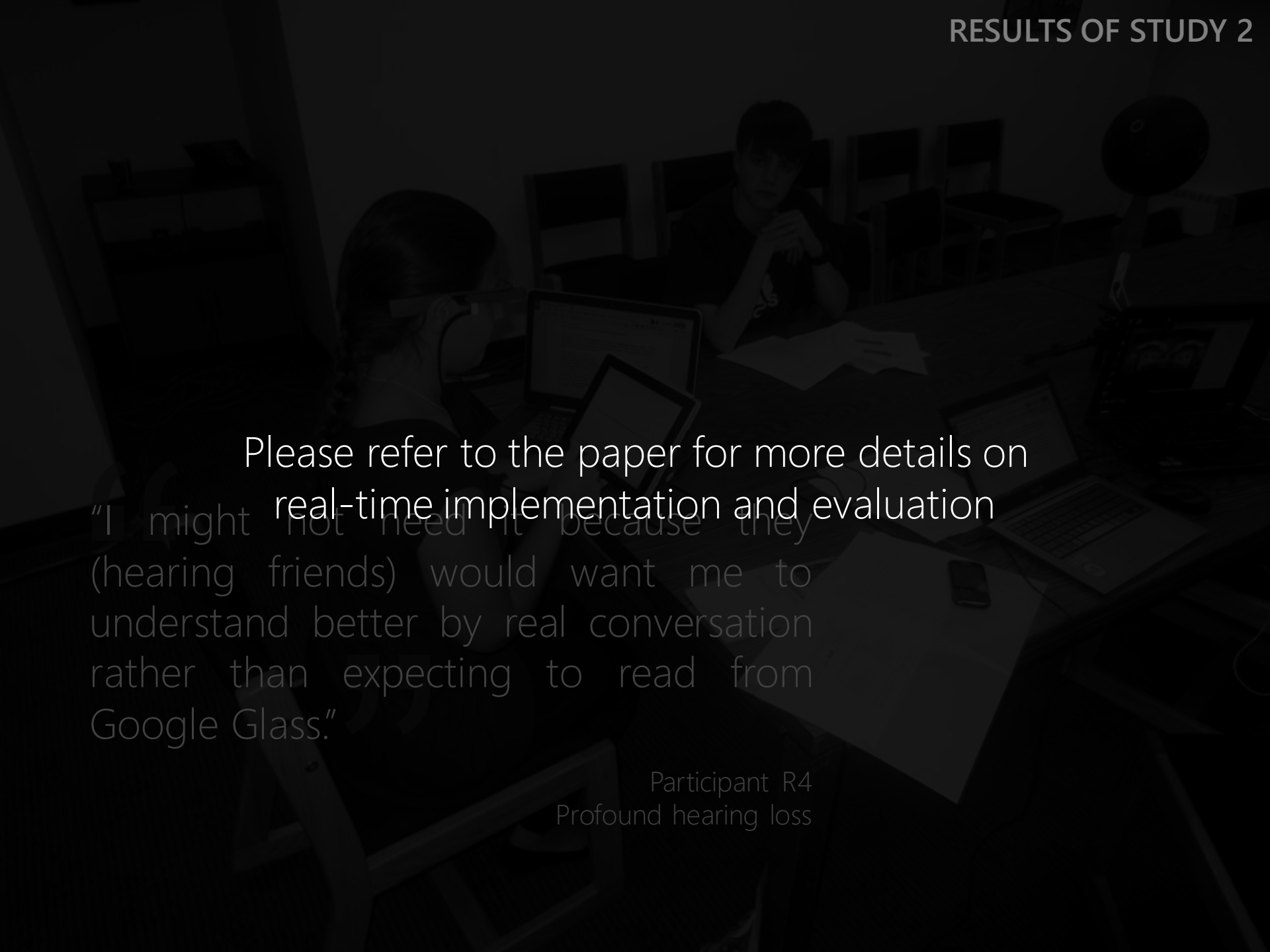
"This approach would be helpful because my sound processor is not able to point where the sound was from"

-R2, severe hearing loss



"I might not need it because they (hearing friends) would want me to understand better by real conversation rather than expecting to read from Google Glass."

Participant R4
Profound hearing loss



Please refer to the paper for more details on real-time implementation and evaluation

"I might not need it because they (hearing friends) would want me to understand better by real conversation rather than expecting to read from Google Glass."

Participant R4
Profound hearing loss

Closing Thought For Study 2

Participant's Overall Experience With Prototype

Primary Contributions

1. **First work** to design and evaluate sound visualizations on HMDs for the deaf and hard of hearing

2. Explored a broad range of **novel designs**

3. Implemented a preliminary **working prototype**

Reflections

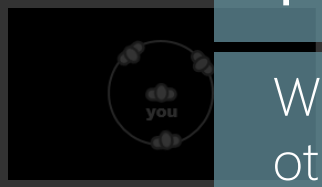
Preferences For Some Design Dimensions

Need for Customizability

While strong preference existed for certain features, others were mixed

Wearer's Perspective

Egocentric
11 votes



Exocentric
13 votes

Continuous

Continuous
14.5 votes

8-Level

8-Level
5.5 votes

4-Level

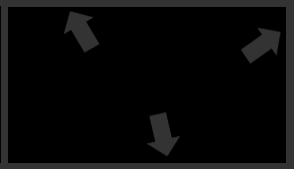
4-Level
3 votes

1-Level

1-Level
1 vote

2D vs. 3D

3D
12 votes



2D
12 votes

Maximum Simultaneous Icons

<Four
5.5 votes

Four
10 votes

>Four
8.5 votes

Screen Layout

Rectangular
11.5 votes

Circular
10.5 votes

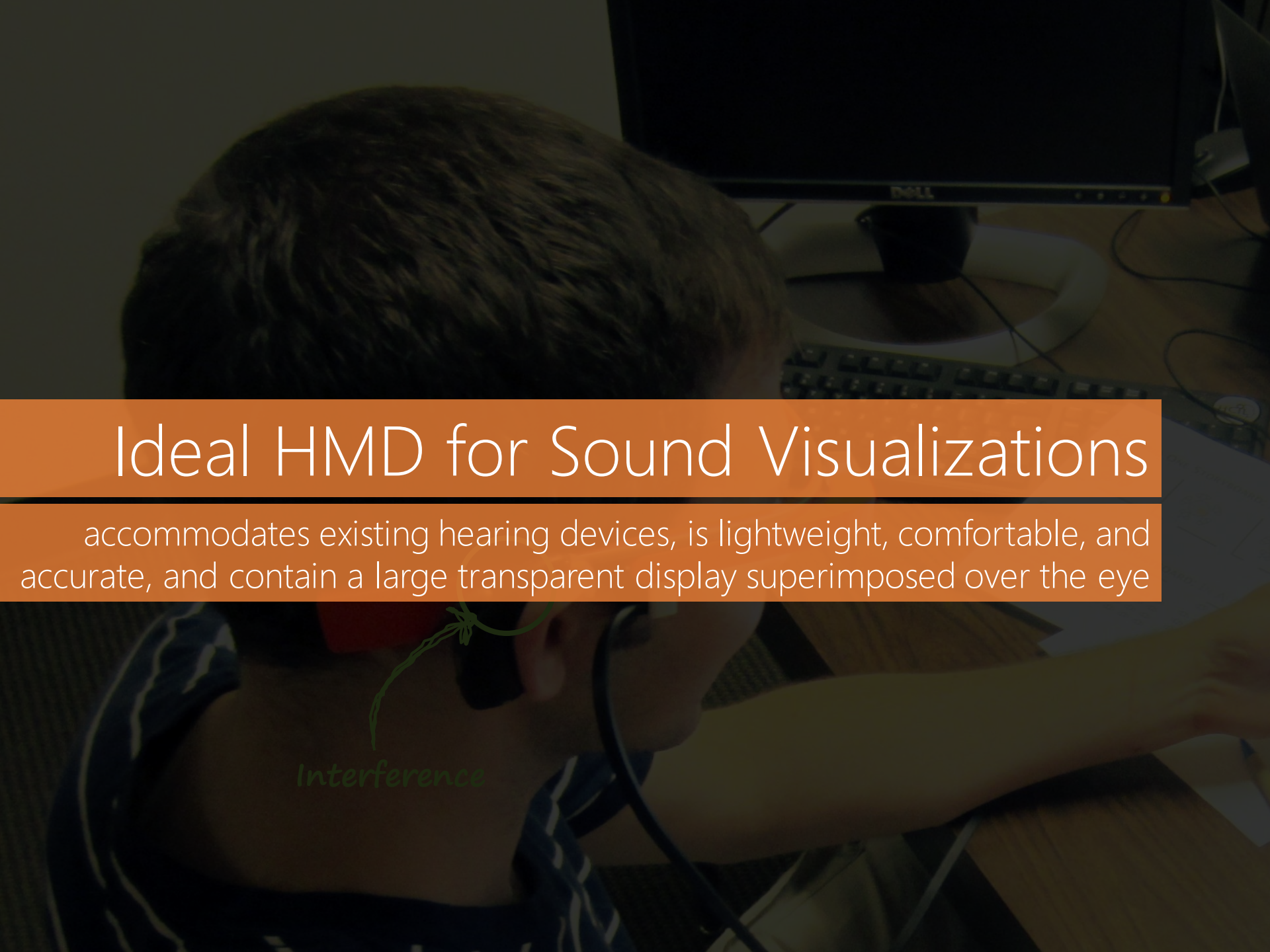
From Center
2 votes

Conveying Sound Source

Outward
19 votes

Inward
5 votes


Interference

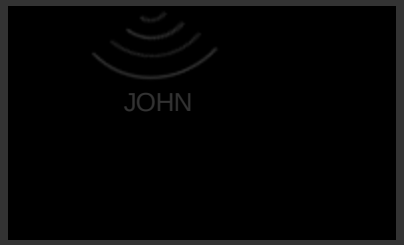


Ideal HMD for Sound Visualizations

accommodates existing hearing devices, is lightweight, comfortable, and accurate, and contain a large transparent display superimposed over the eye

More Sophisticated Sound Processing

Example: Speaker Identity



Example: Captions


Example: Gender


Example: Speech vs. Non-Speech Sounds

More Sophisticated Sound Processing

Automatic sound recognition, real-time captioning, gender identification

HMDs as **glanceable displays**
offer an interesting opportunity

to

transform the **auditory sense**
to the **visual sense**

leading to

new solutions for accessibility

Head-Mounted Display Visualizations to Support Sound Awareness for the Deaf and Hard of Hearing

Dhruv Jain[1,2,5], Leah Findlater[1,5], Jamie Gilkeson[4], Benjamin Holland[4], Ramani Duraiswami[5], Dmitry Zotkin[5], Christian Vogler[3], Jon Froehlich[1,5]

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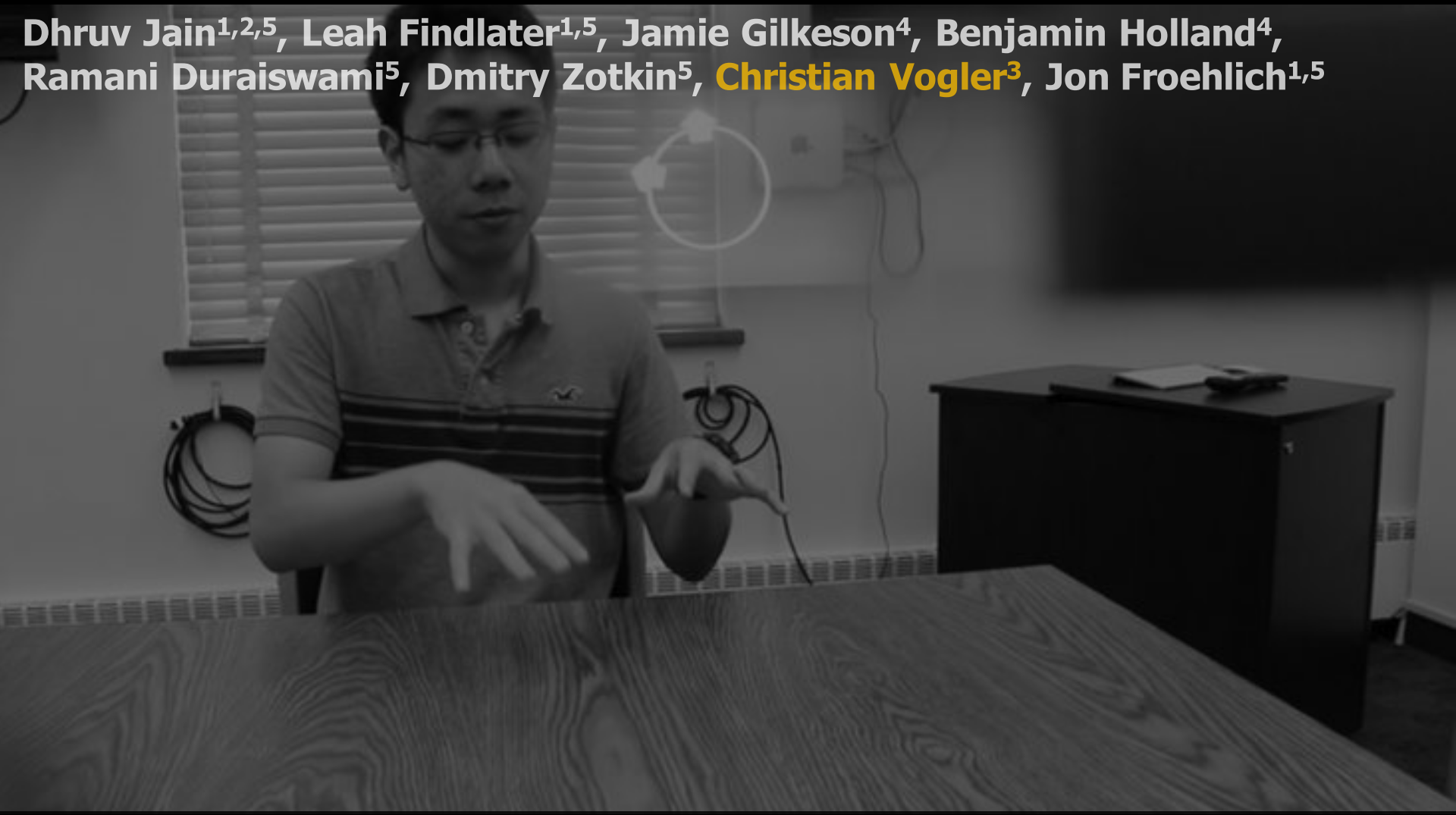

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