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Waseda University

Institute of SCIENCE TOKYO

SnowEcho:
End-to-End Blind Skiing Assistance System Using Spatial Audio for Simulated Dynamic Slope

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What is Blind Skiing in the Real World?

People with visual impairments (PVI) ski with a sighted guide



They cannot ski **independently** [1]

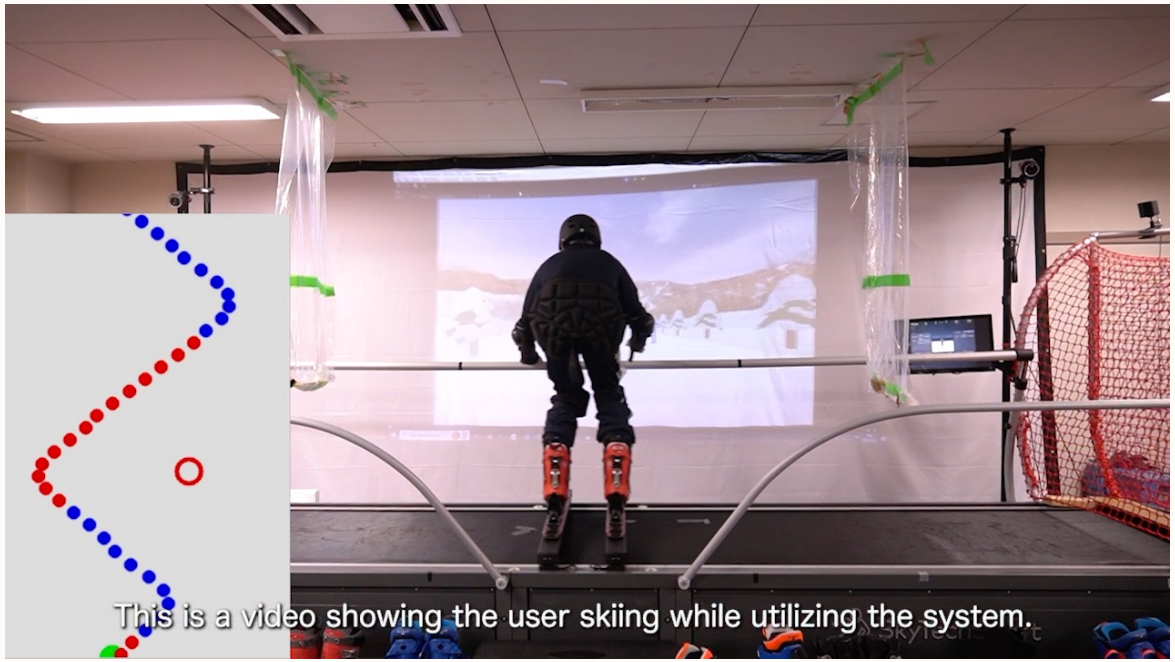
[1] Yusuke Miura, et al. Exploration of Sonification Feedback for People with Visual Impairment to Use Ski Simulator, AHs 2023
Image cited from the source on the right： Kanagawa BlindSkiClub https://kanagawa-blindski.com/


視覚障害
フライパスネーク
かながわ

Research Related to Blind Skiing: SlopeNav [2]

A system to enable independent skiing for PVI in a simulator environment

1. Detect obstacles
2. Plan a path in real time
3. Cue each turn with stereo audio



[2] Toshihiro Hirano, et al. SlopeNav: A Realtime Wearable Blind Ski Assistance System with Adaptive Path Planning for Simulated Environments, AHs 2025

Research Related to Blind Skiing: SlopeNav [2]

A system to enable **independent skiing** for PVI in a simulator

1. Detect obsta
2. Plan a path
3. Cue each tu

Realistic scenarios

Dynamic Obstacles

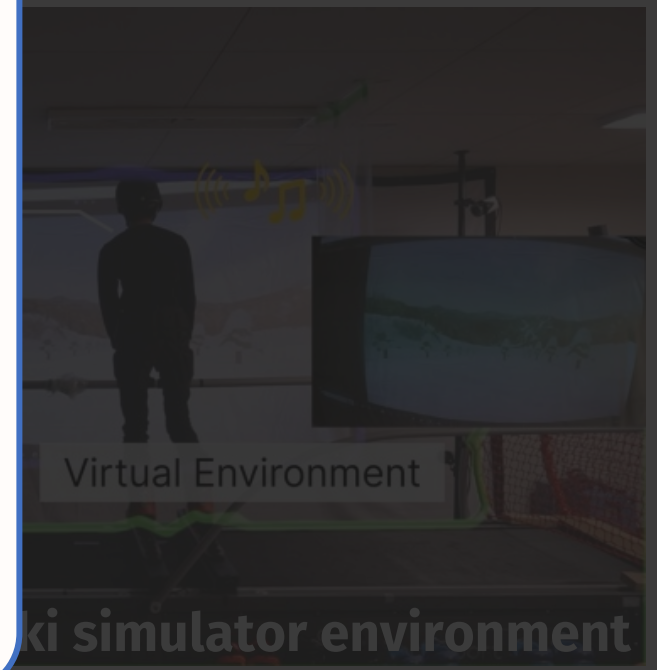


Skier



Snowboarder

SlopeNav handles static obstacles only

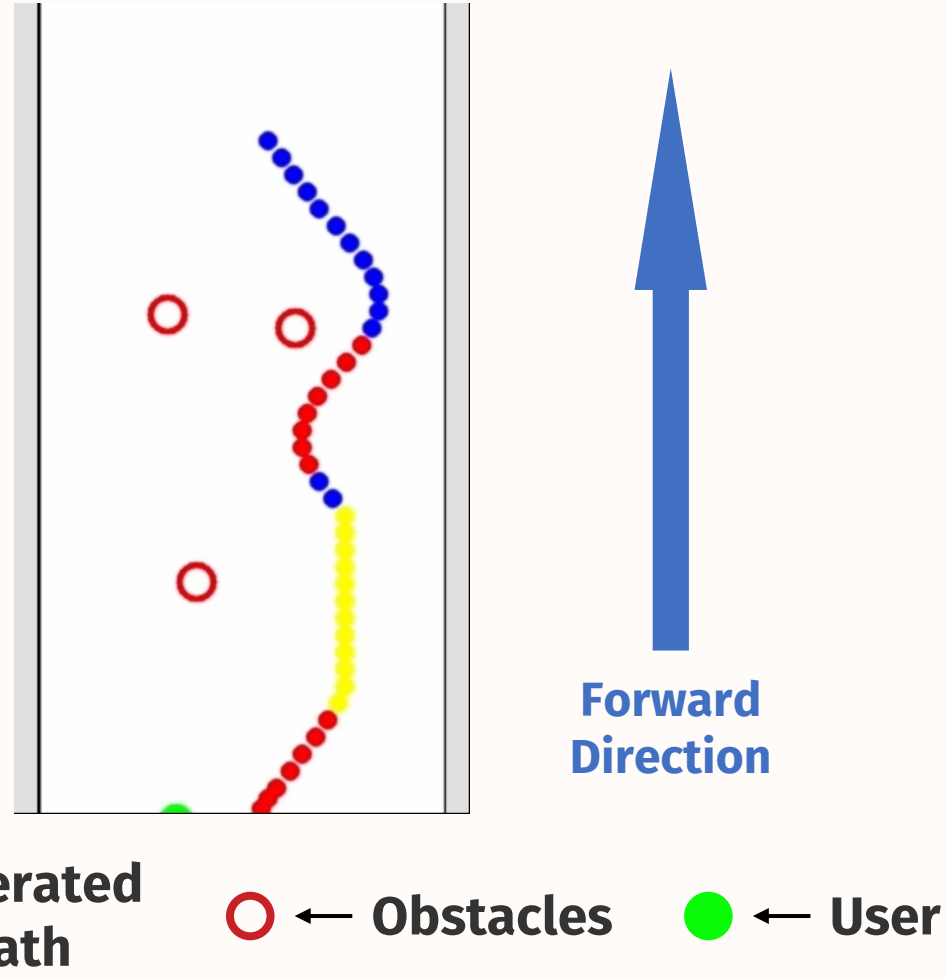


[2] Toshihiro Hirano, et al. SlopeNav: A Realtime Wearable Blind Ski Assistance System with Adaptive Path Planning for Simulated Environments, AHs 2025

Difficulties in Responding to Dynamic Obstacles

Dynamic obstacles result in
frequent path update

May cause
confusion or **collision**



SnowEcho:

A skiing assistance system that conveys obstacle positions via spatial audio





Advantages of Obstacle Indication via Spatial Audio

1. The audio shifts **continuously** as the obstacle moves
2. Users can **intuitively** perceive hazards and respond proactively

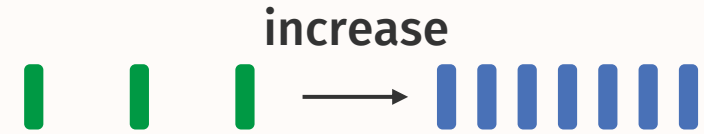


Object Audio: Cue from the Obstacle

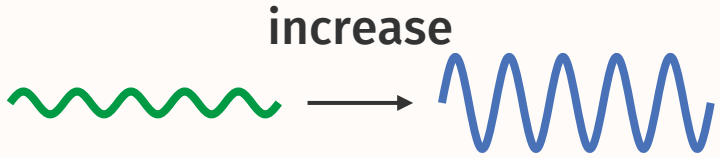
Change in several levels according to distance

As the distance decreases...

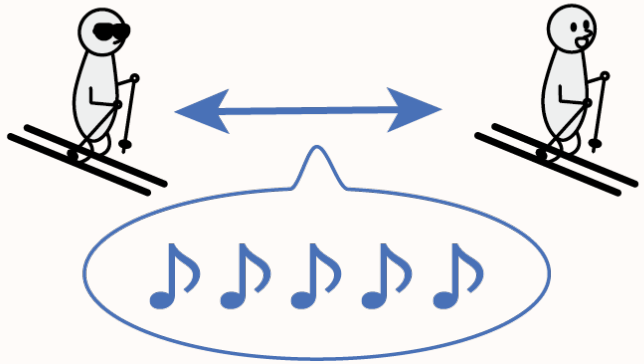
Frequency



Volume

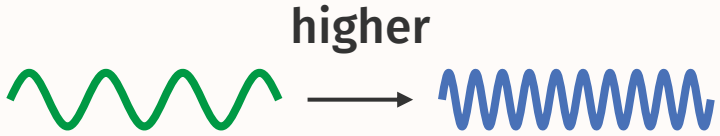






At the nearest level...

Pitch



Object Audio: Cue from the Obstacle

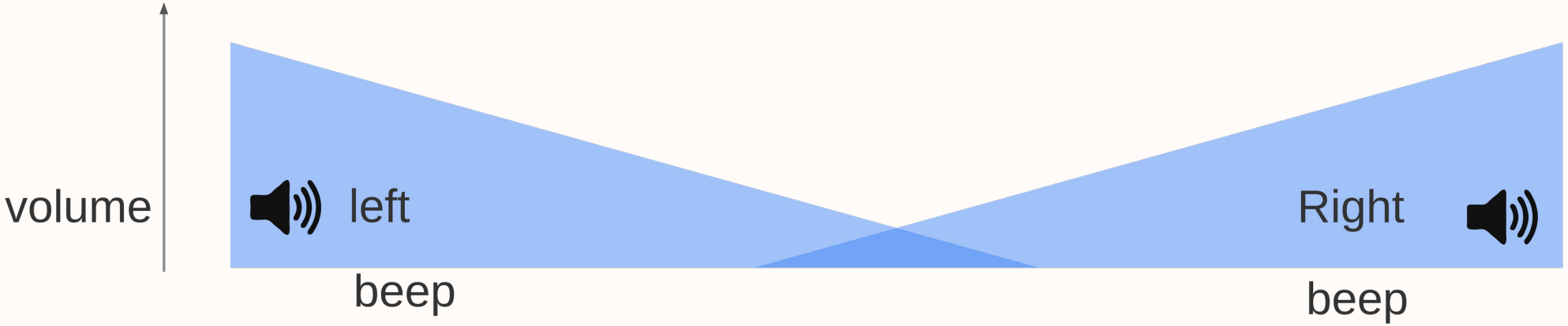


Side Audio: Cue from the Edge of the Course

As the user approaches the course edge…

Volume





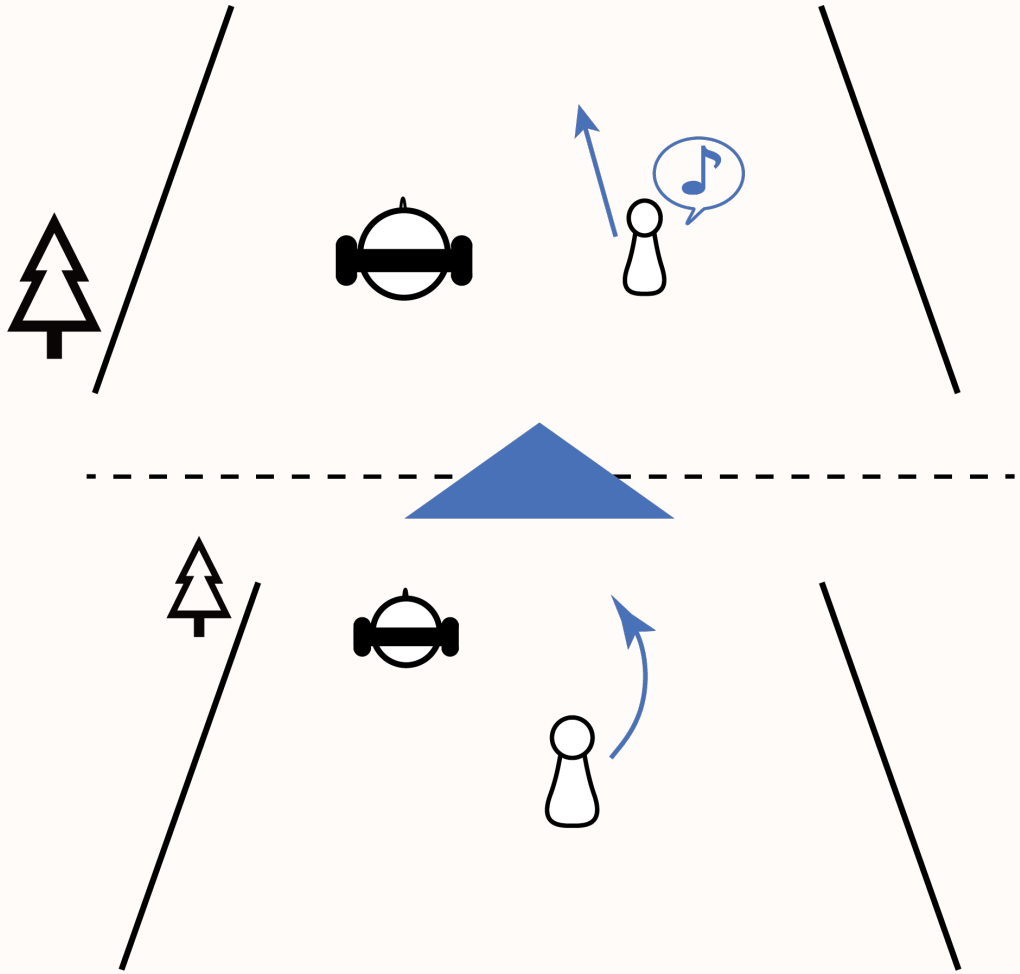
Side Audio: Cue from the Edge of the Course



Rear Passing Audio: Cue from the Overtaking Side

When a skier passes from behind...

One short sound in that side



Rear Passing Audio: Cue from the Overtaking Side

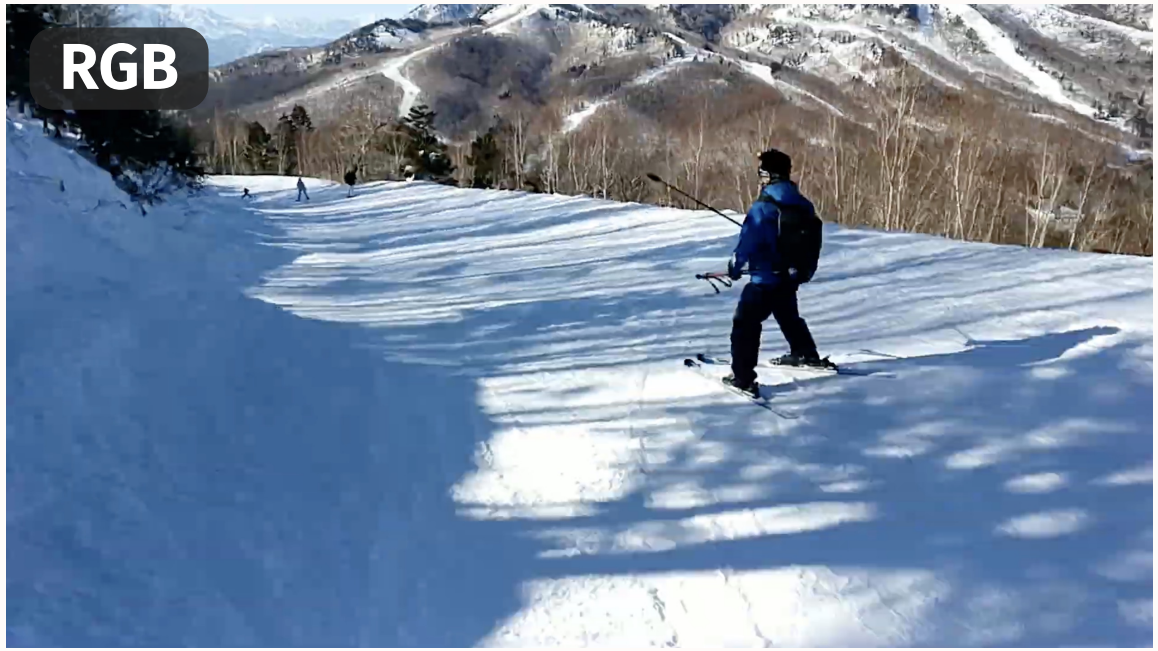


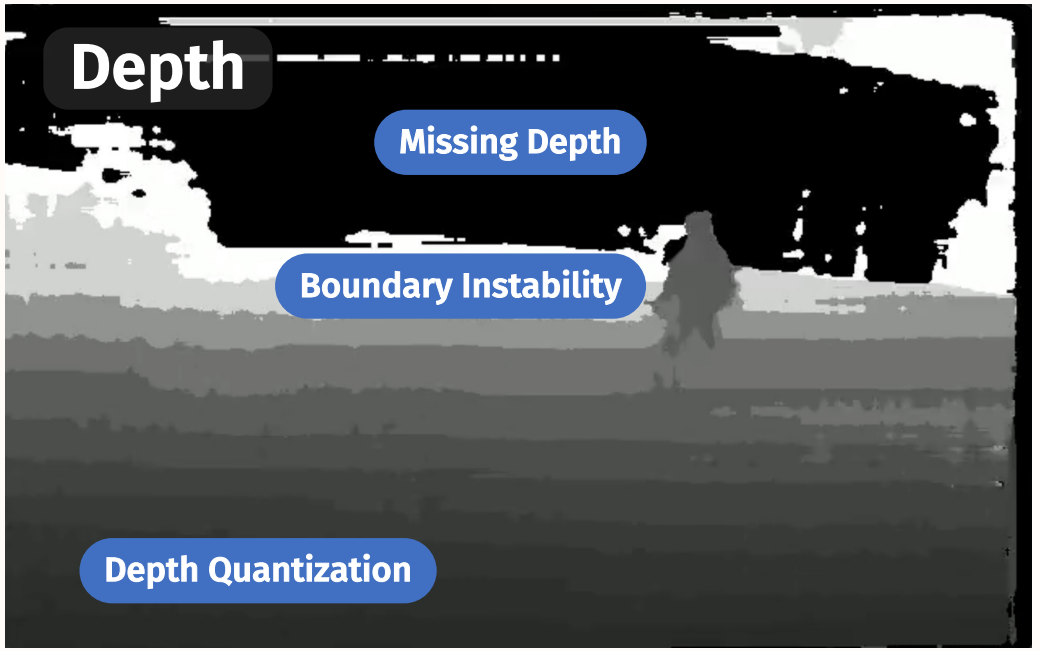
Real-Slope Data from a Head-Mounted Camera



Recorded at a real ski resort
with an OAK-D stereo camera on the head

Shiga Kogen, Nagano, Japan

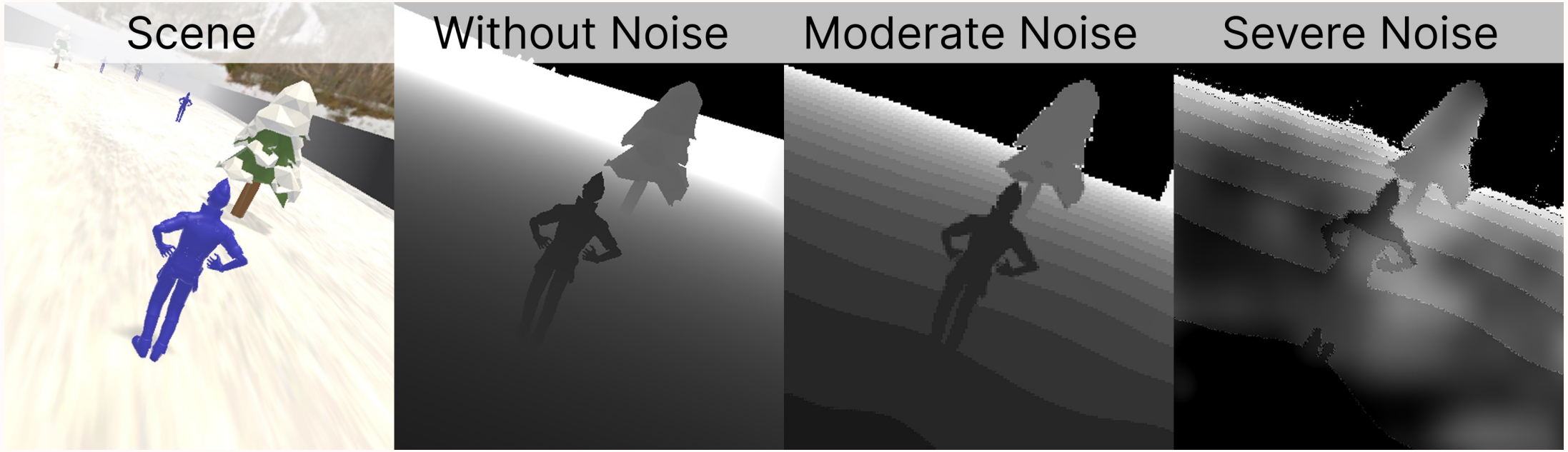




Depth Augmentation based on Real-Slope Noise

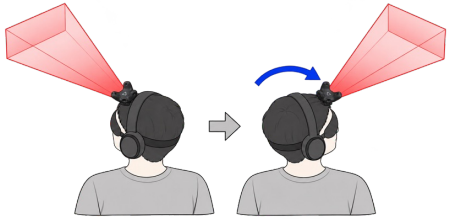
Types of Noise

- Distance-dependent Noise
- Depth Quantization
- Boundary Instability
- Missing Depth



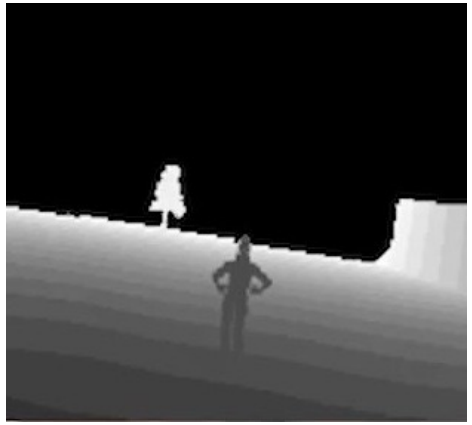
End-to-End Sensing Pipeline

1 Head Tracking



FOV 70°
like the OAK-D

2 Noisy Depth



Depth Augmentation
adds real-slope noise

3 YOLOv8n-seg



Finds obstacles
and course edges

4 Spatial Audio

Obstacles
Object Audio

Course edges
Side Audio

Overtaking skiers
Rear Passing Audio

Two User Studies

User Study 1

11 visually impaired skiers

RQ: Is spatial audio more effective than route guidance with dynamic obstacles?

User Study 2

5 skiers from Study 1

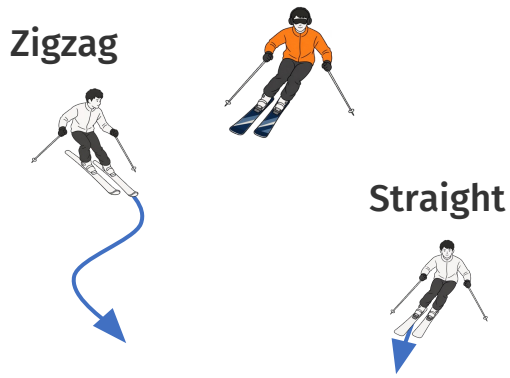
RQ: How much sensing noise can blind skiers tolerate in SnowEcho?

User Study 1: Effectiveness of Our Feedback

C_{Sparse}



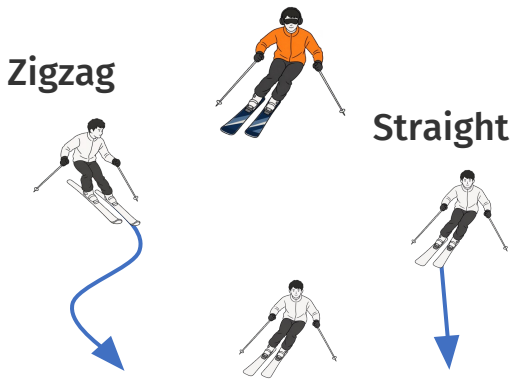
interval : 15 m
10 Dynamic Obstacles



C_{Dense}



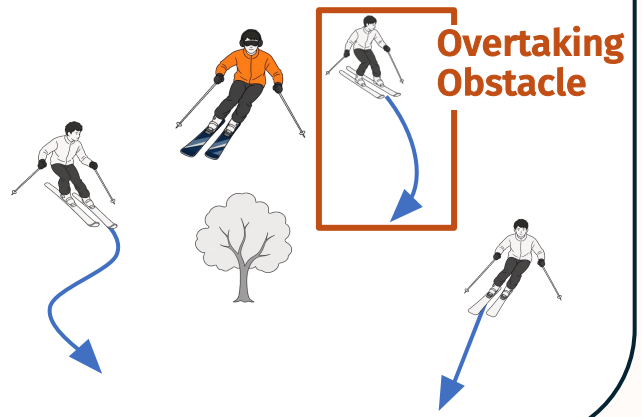
interval : 8 m
20 Dynamic Obstacles



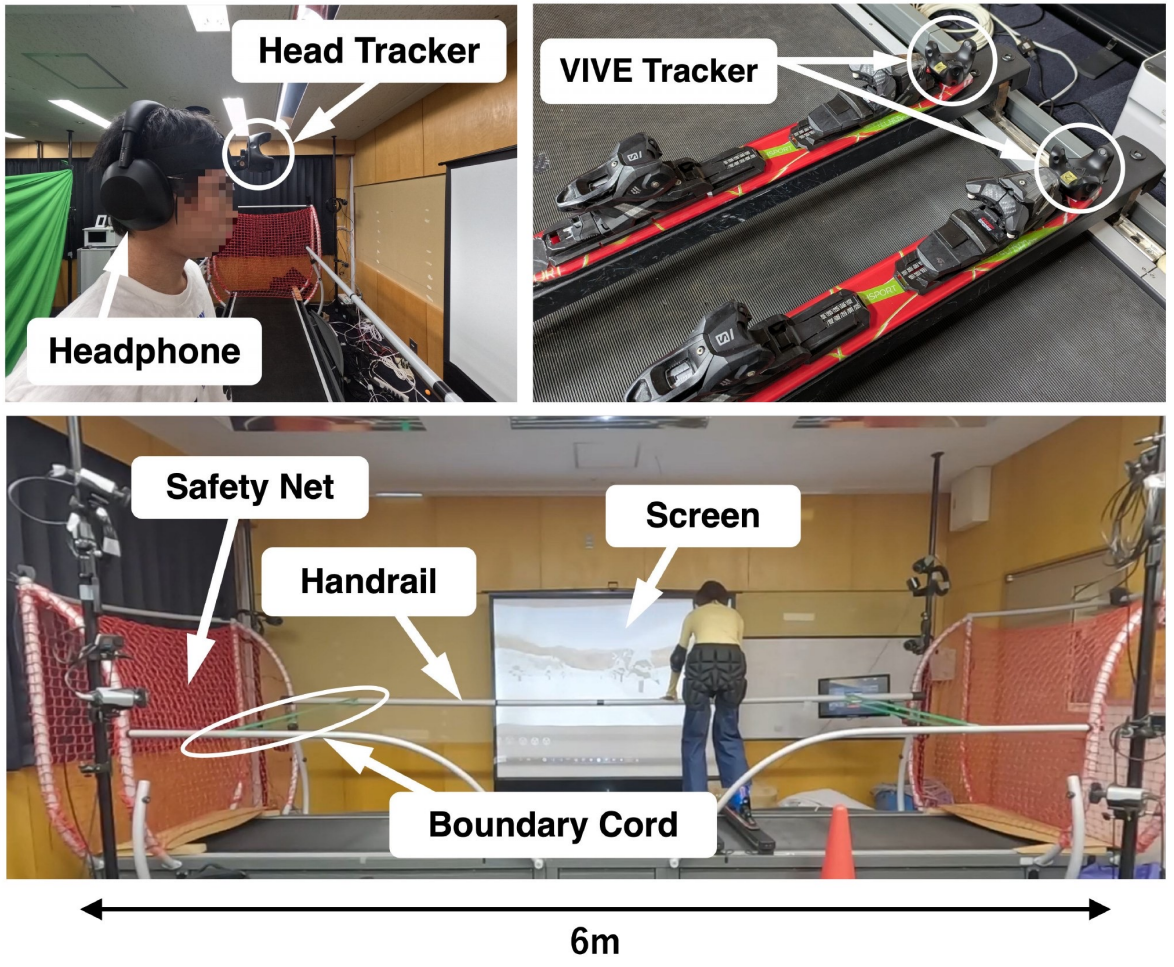
C_{Real}



interval : 10 m
20 Dynamic & Static Obstacles



Procedure



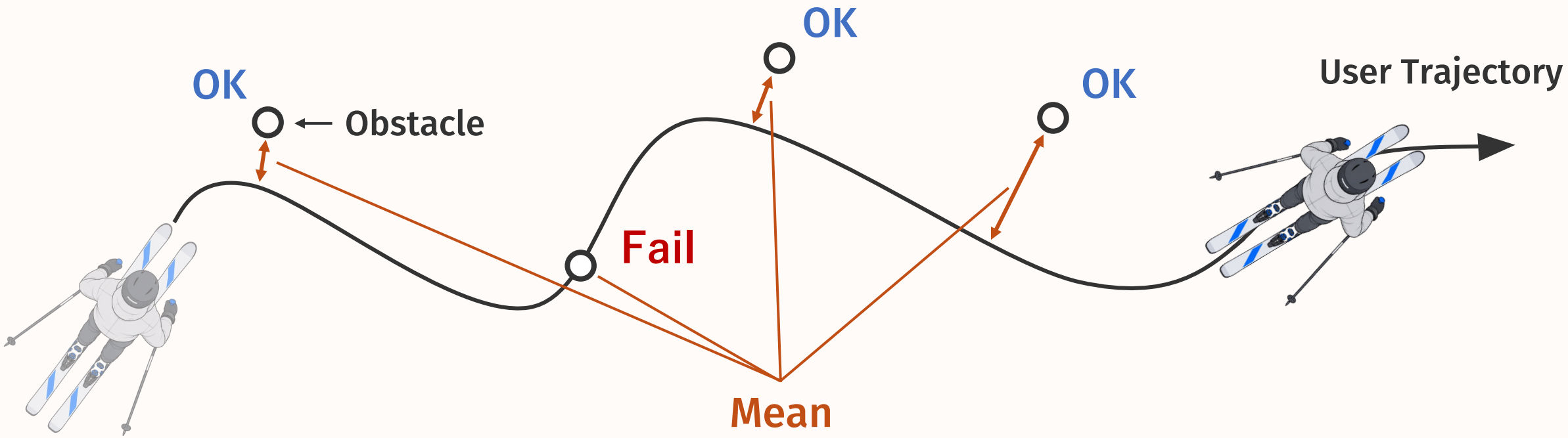
1. **Pre-study interview on skiing experience**
2. **Practice on the simulator and each course**
3. **One run on each course, in random order**
   Only **foot positions** are recorded,
   from the VIVE trackers on the ski tips
4. **Questionnaires (NASA-TLX, SUS, and ratings)**
5. **Steps 2 to 4 again with the other system**
   Counterbalanced, 5 SnowEcho first and 6 SlopeNav first
6. **Final questionnaire and interview**

About 2.5 hours per participant

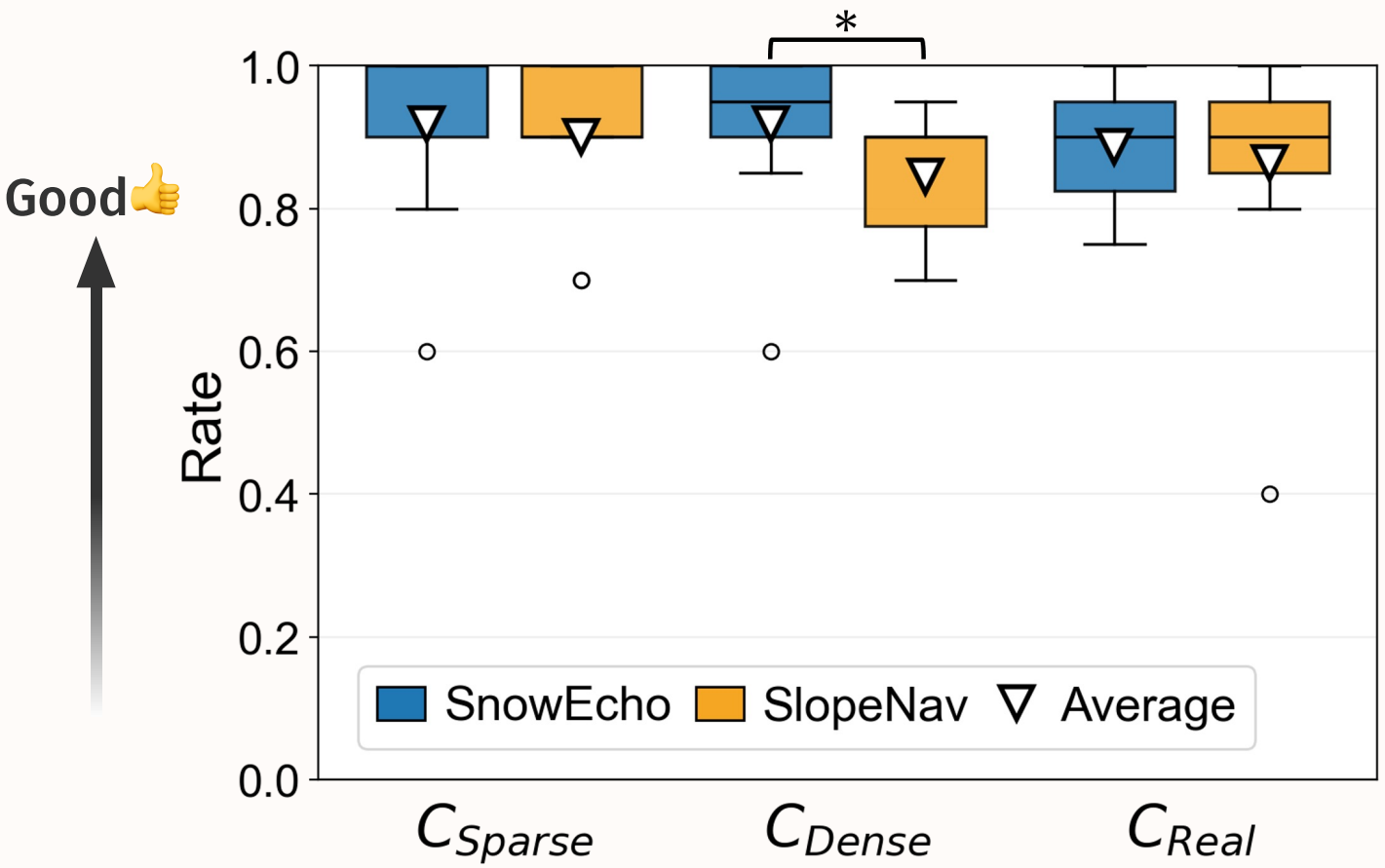
Evaluation Metrics

We evaluate user performance with

1. Obstacle Avoidance Rate
2. Average Minimum Distance to Obstacle



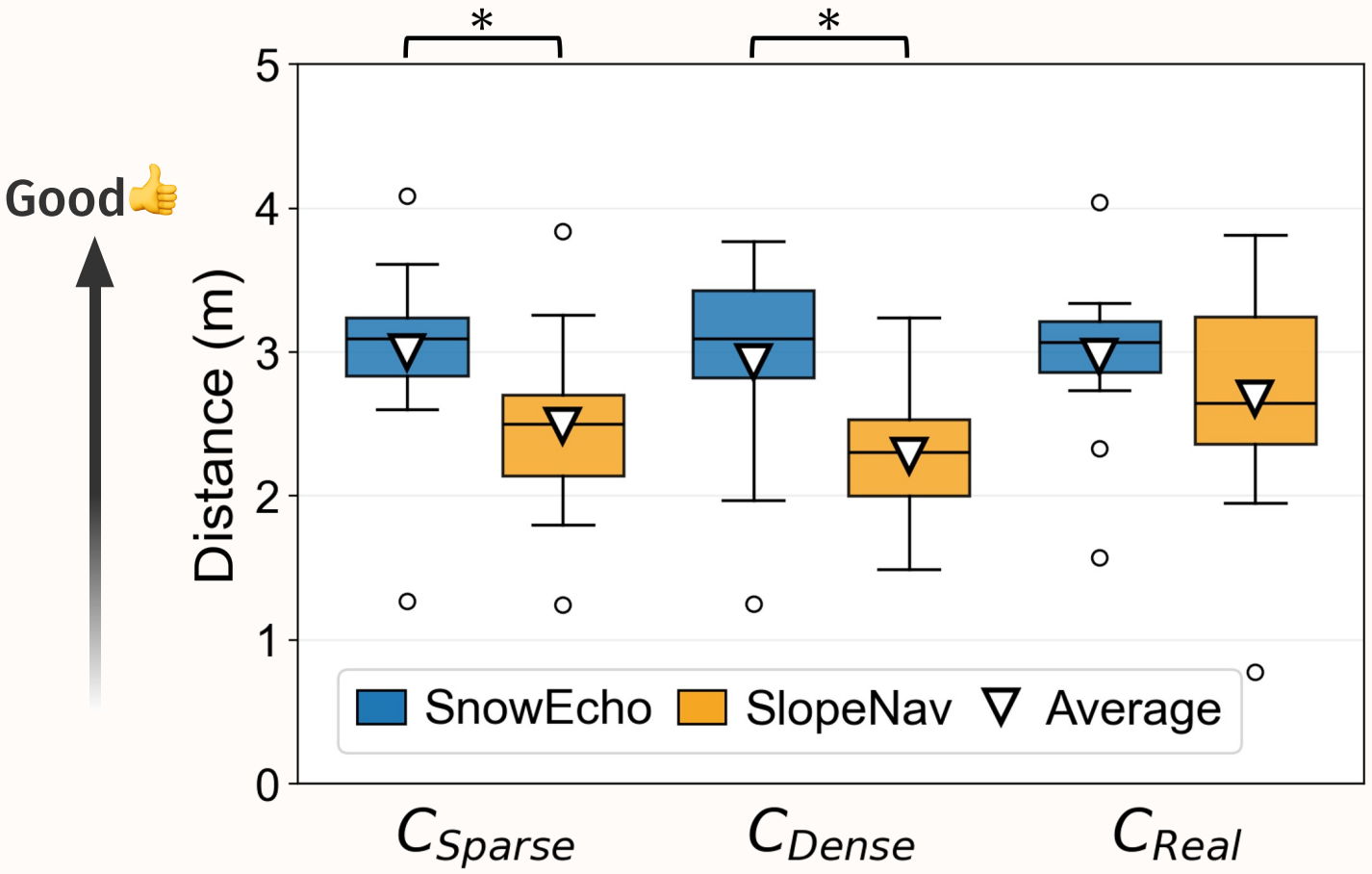
Result 1: Obstacle Avoidance Rate



Users could avoid approximately 90 percent of obstacles on average

In C_{Dense}, SnowEcho is significantly superior

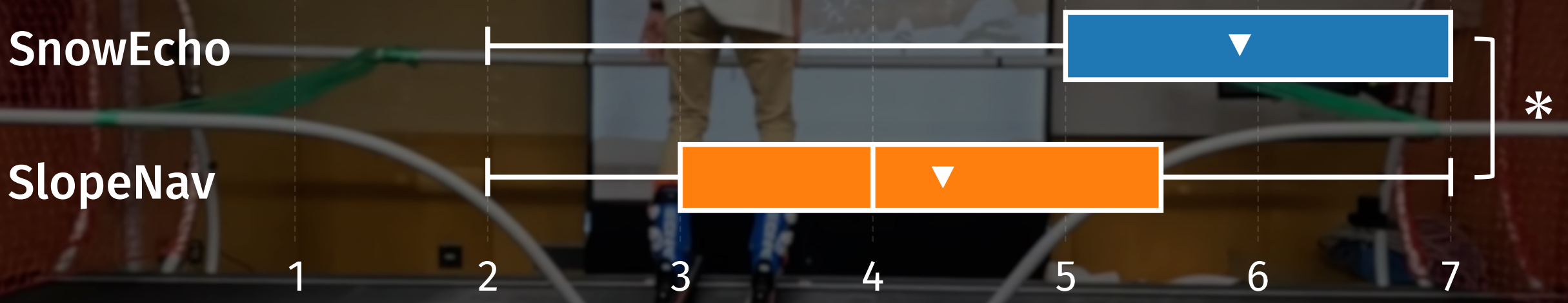
Result 2: Average Minimum Distance to Obstacle



SnowEcho significantly outperformed SlopeNav in C_{Sparse} and C_{Dense}

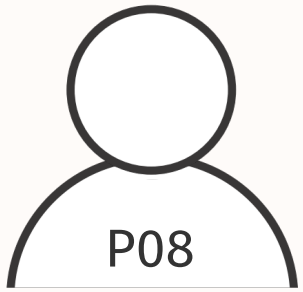
Subjective Evaluation using a Likert Scale

Q. I was able to ski with a sense of agency.

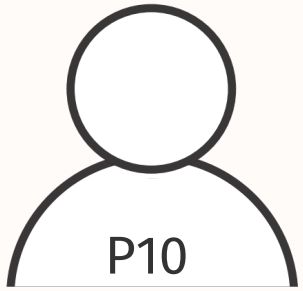


The sense of agency while skiing improved significantly.

Comment about the Design of the System



*At the moment the sound starts, it is difficult to judge whether the obstacle is on the left or right, but as it **gets closer**, the direction **becomes clearer**.*



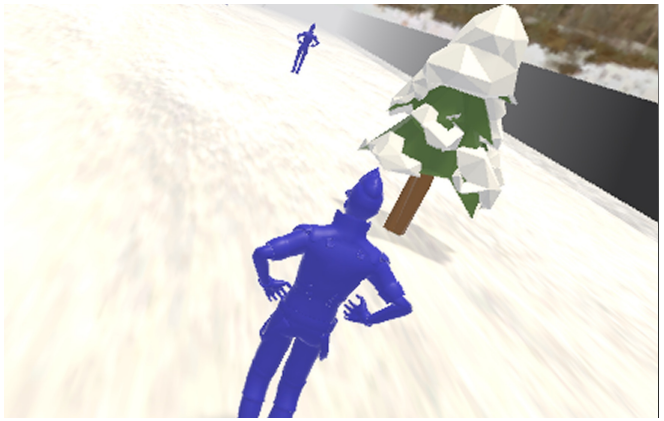
*(As for Rear Passing Audio,) I assume **people behind me will avoid me**, so I think it's **fine without it**.*

8 of 11 participants said Rear Passing Audio was not needed

User Study 2: Tolerance to Sensing Noise

Three Sensing Conditions

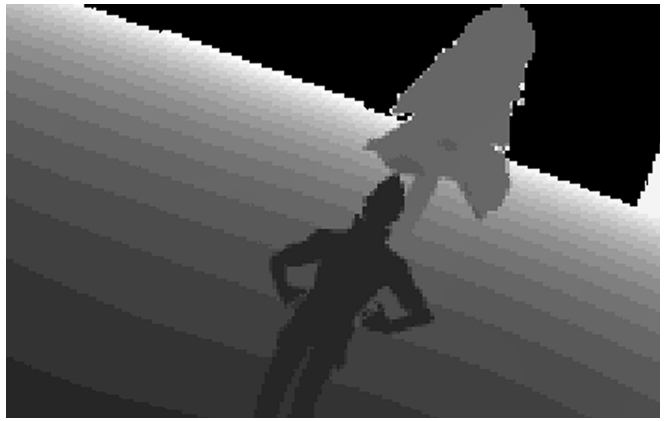
1 Oracle Value



- Positions read directly from the simulator
- No sensing errors

Mean distance error **0 m**

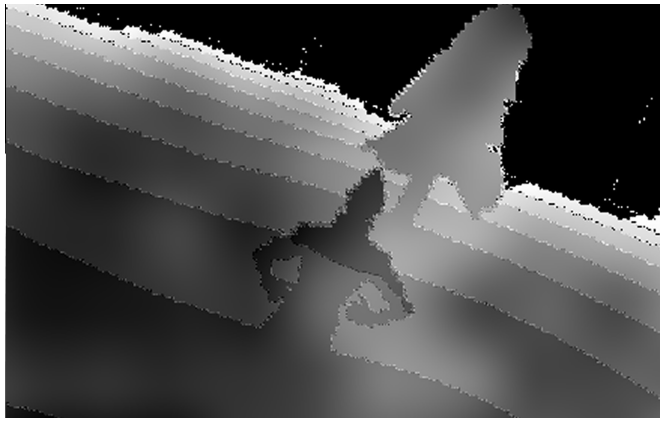
2 Moderate Noise



- Depth rounded to 0.5 m steps
- Noise up to 0.3 m at 10 m
- Slightly unstable edges

Mean distance error **0.61 m**

3 Severe Noise

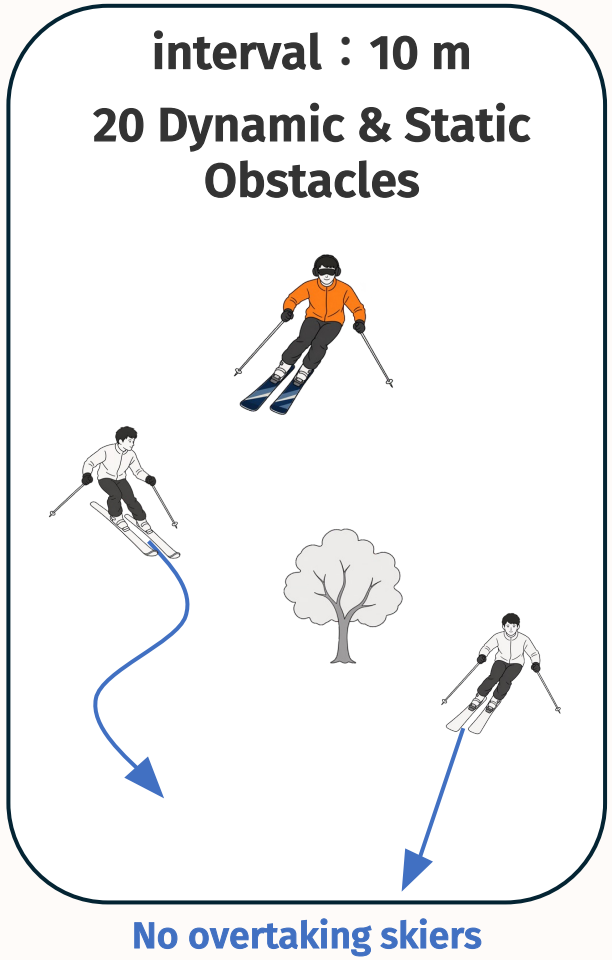


- Depth rounded to 1 m steps
- Noise up to 4 m at 10 m
- Strongly unstable edges

Mean distance error **1.21 m**

Procedure

C_{Real}

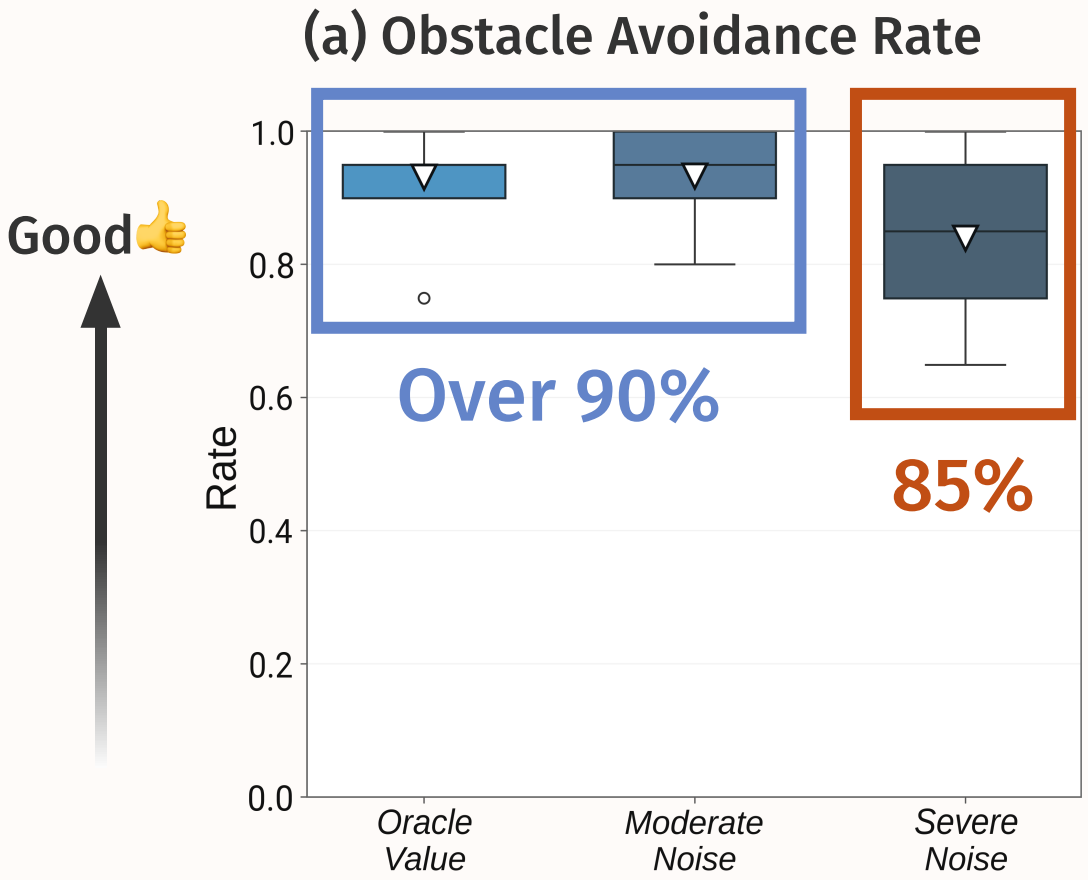


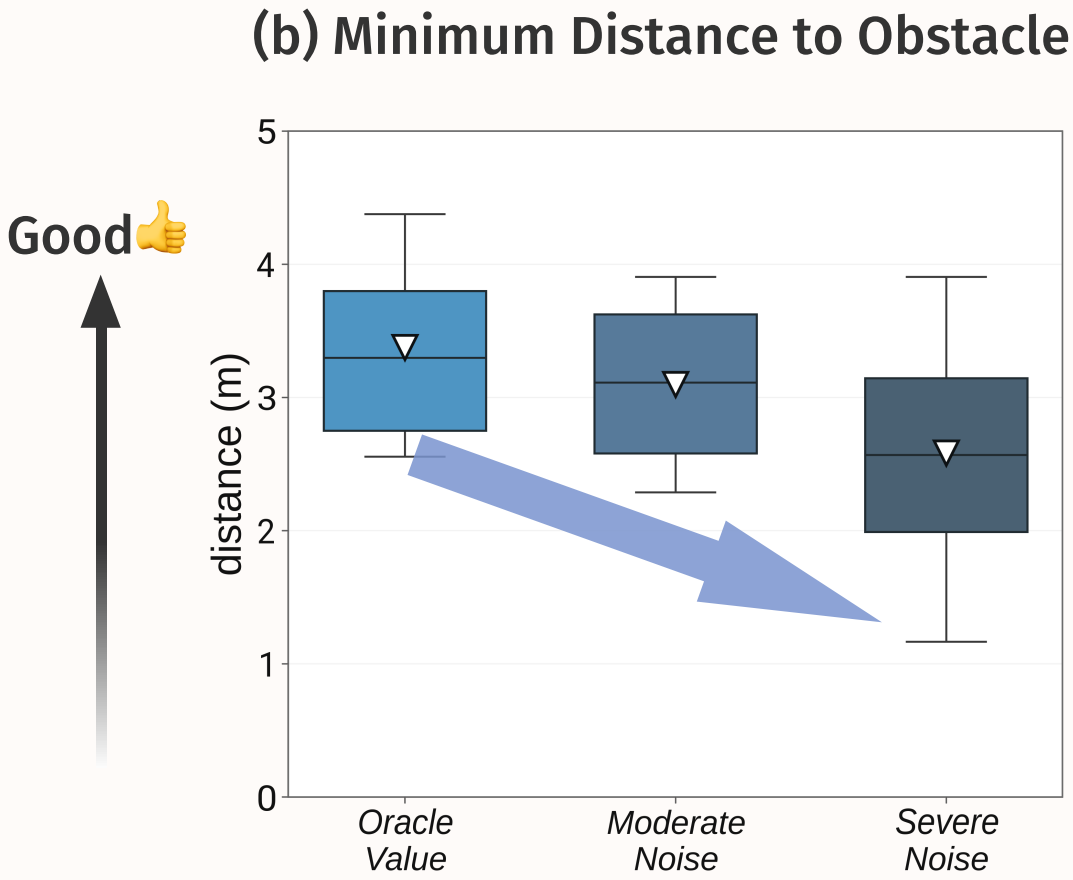
5 participants from Study 1

1. **Brief refresher** on the simulator and the sounds
2. Practice, including a short run with the **sensing pipeline**
3. **Three runs in each condition**, in counterbalanced order
4. Questionnaire after each condition, then a final interview

About 2 hours per participant

Robust to *Moderate Noise*, Not to *Severe Noise*





Limitation

1. Fixed skiing speed

   Skiers could not slow down or stop, so every avoidance was **a left or right turn**

2. Flickering cues

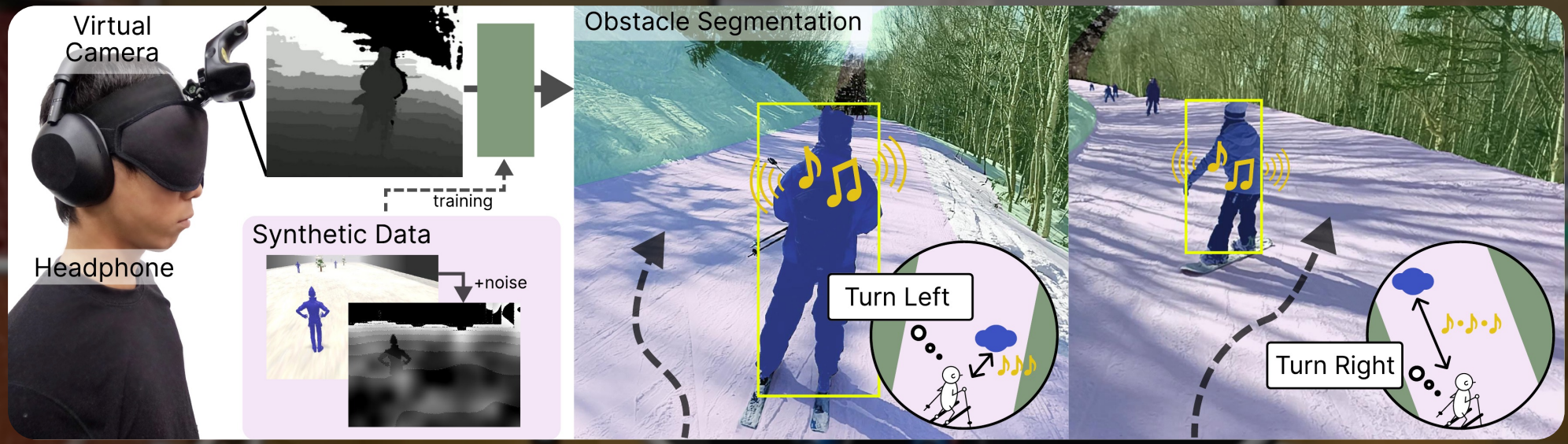
   Cues are **updated every frame**, so detection noise makes them jump

3. Simulator-only evaluation

   Safety and usability on real slopes are still untested

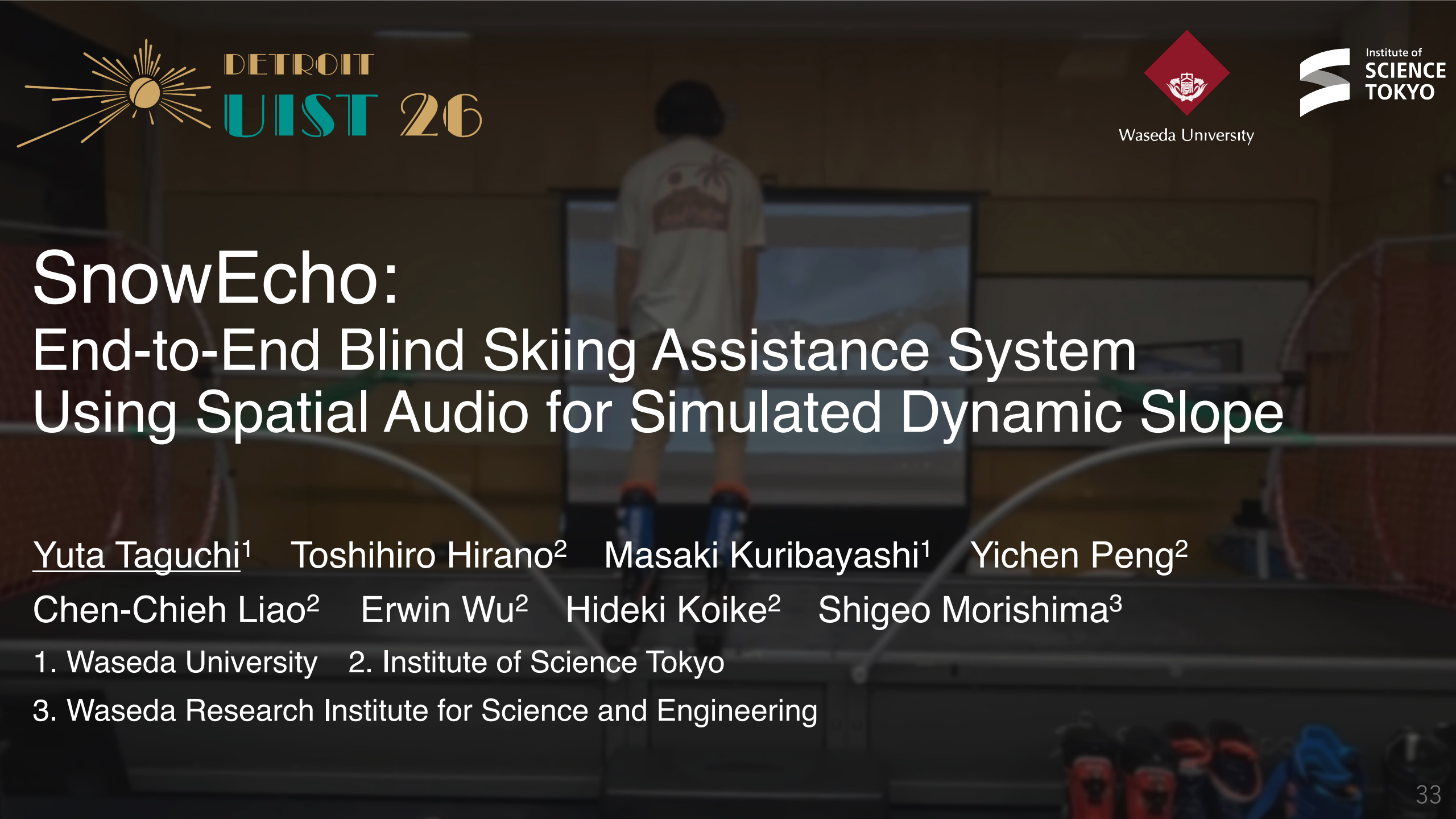
Summary

SnowEcho conveys obstacle positions with spatial audio, so skiers with visual impairments can **choose their own path**



Paper

- About **90%** of obstacles were avoided, significantly more than with SlopeNav in environments with a high density of dynamic obstacles.
- **Sense of agency** improved significantly compared with SlopeNav.
- Performance **remained high under *Moderate Noise*** but declined under *Severe Noise*.



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