11th Annual
MOBILE HEALTHCARE Summit

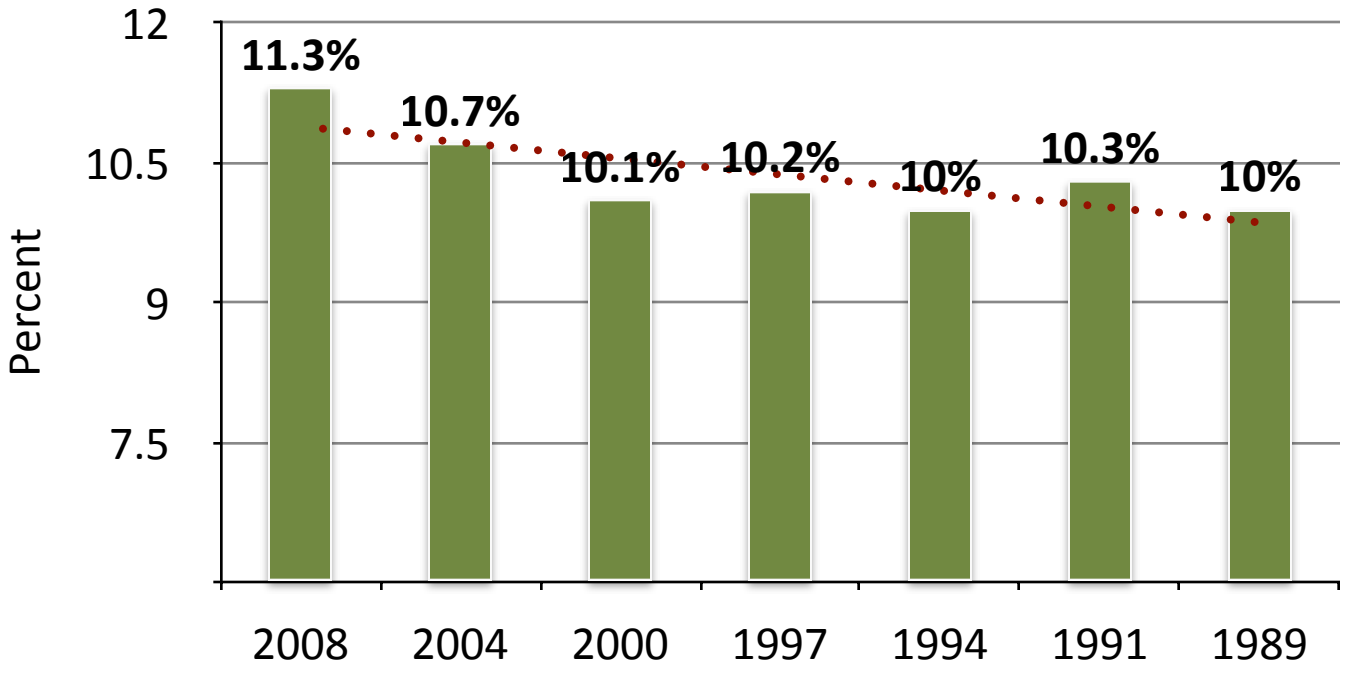
AudioSense: Measuring Hearing Aid Performance Using Smart Phones

Octav Chipara

University of Iowa

Hearing loss in US

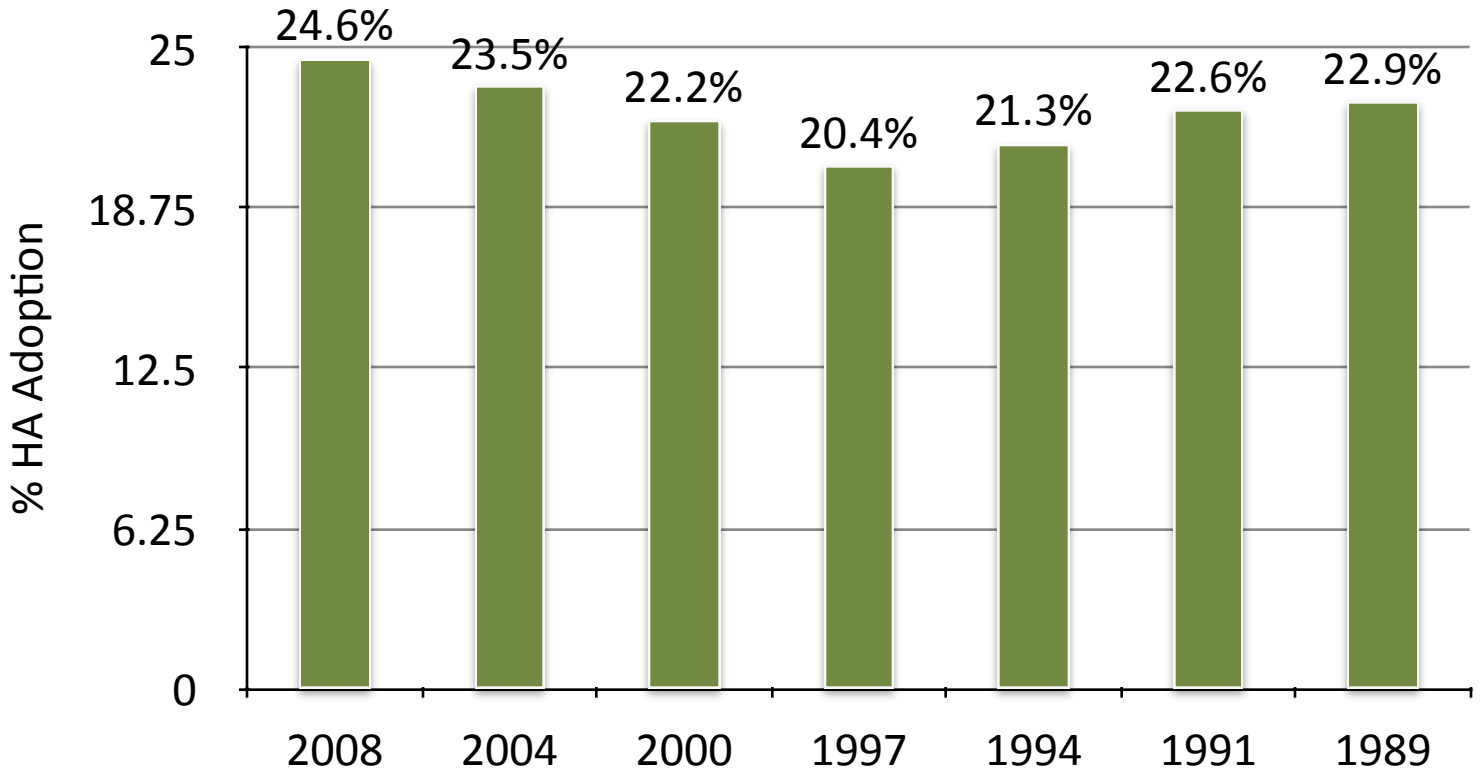
- 11.3% of US population has hearing loss
  - leads to communication difficulties, depression and dementia



K.S. Marketrak VIII: 25-year trends in the hearing health market, Hearing Review '09

Hearing loss in US

- Primary intervention is hearing aid amplification
  - dismal adoption rates (< 25%)



K.S. Marketrak VIII: 25-year trends in the hearing health market, Hearing Review '09

Hearing loss in US

- Primary intervention is hearing aid amplification
  - dismal adoption rates (< 25%)
  - only ≃ 50% of hearing aid users are satisfied with performance in noisy environments

Hearing loss in US

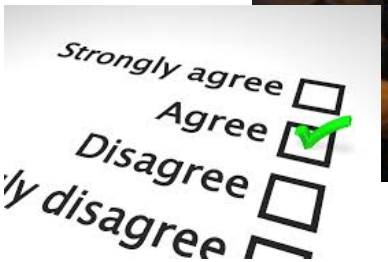
- Primary intervention is hearing aid amplification
  - dismal adoption rates (< 25%)
  - only ≃ 50% of hearing aid users are satisfied with performance in noisy environments

Are we doing the right thing to help people with hearing impairment?

Assessment approaches

- Laboratory-based measures
- Field-based measures

Laboratory

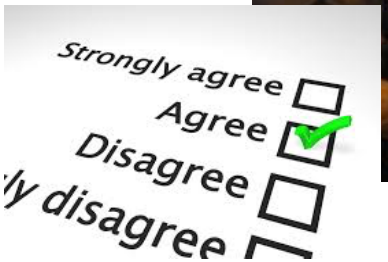


Assessment approaches

- Laboratory-based measures
- Field-based measures

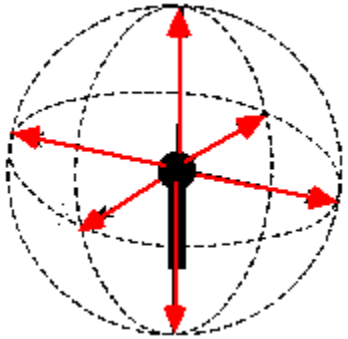
Laboratory

Real world

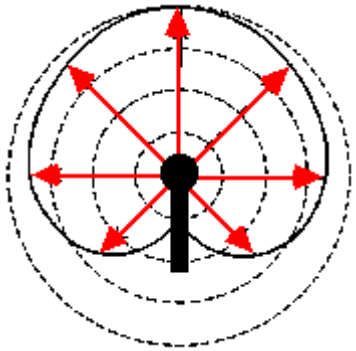


Hearing Aid Microphone Systems

- Omnidirectional system (OMNI)



- Directional system (DIR)



Laboratory data

- Laboratory data have consistently shown that DIR microphones provide substantial DIR benefit
  - 20 – 40%
  - 3-5 dB
- Real-world outcomes do not match laboratory predictions

Real-World Outcomes
DIR vs. OMNI

DIR is better

- Keidser et al., 2007
- Preves et al., 1999
- Ricketts et al., 2003

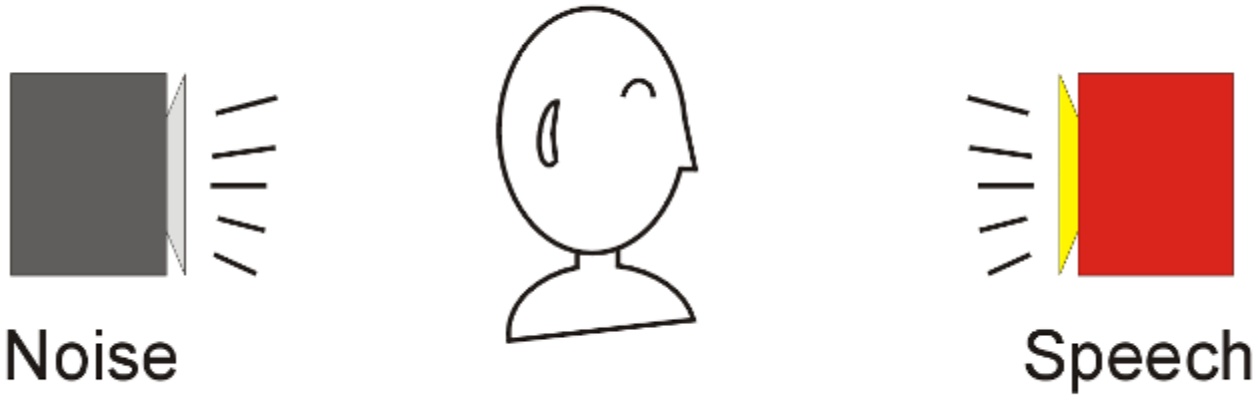
DIR is not better

- Cord et al., 2004
- Cord et al., 2002
- Gnewikow et al., 2009
- Humes et al., 2009
- Palmer et al., 2006
- Surr et al., 2002
- Walden et al., 2000
- Wu & Bentler, 2010
- Wu & Bentler, 2011

Impact of visual queues

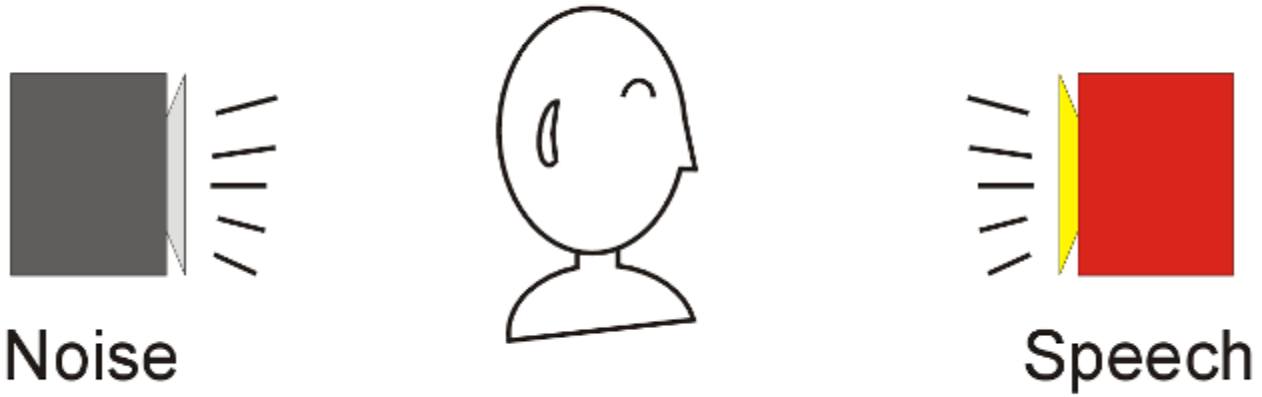
Impact of visual queues

Laboratory

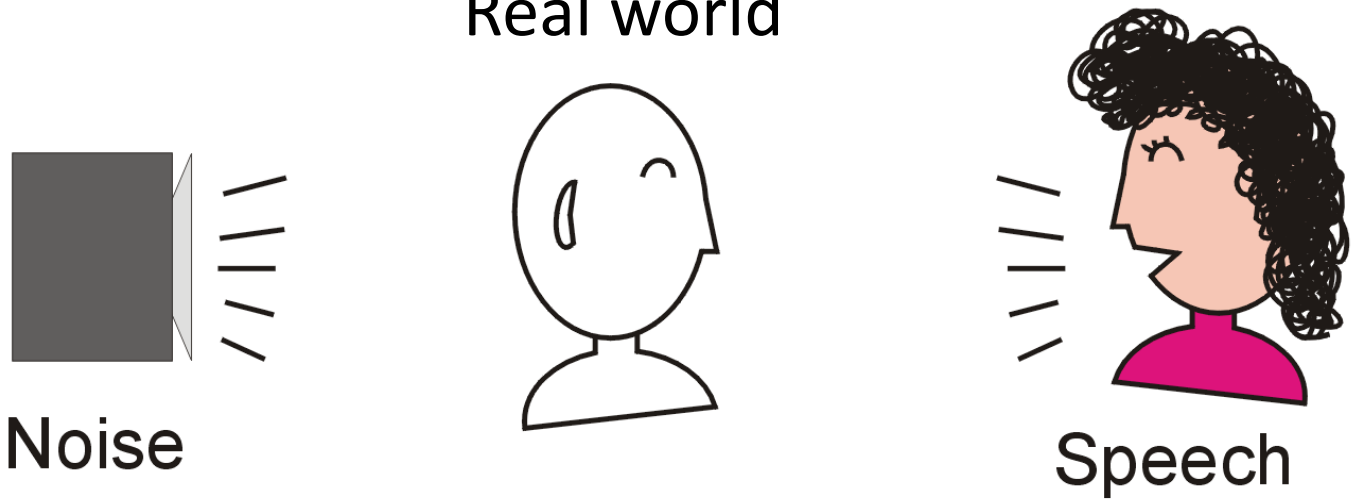


Impact of visual queues

Laboratory

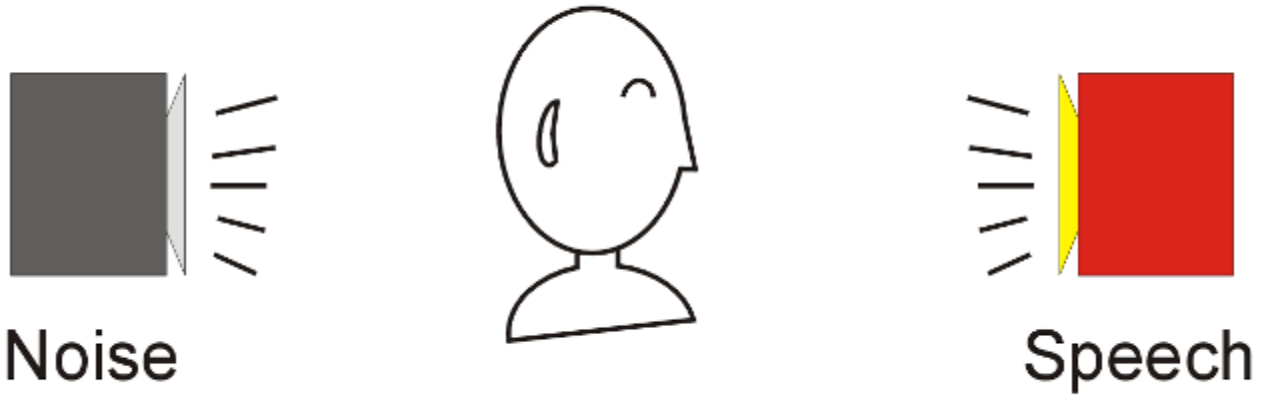


Real world

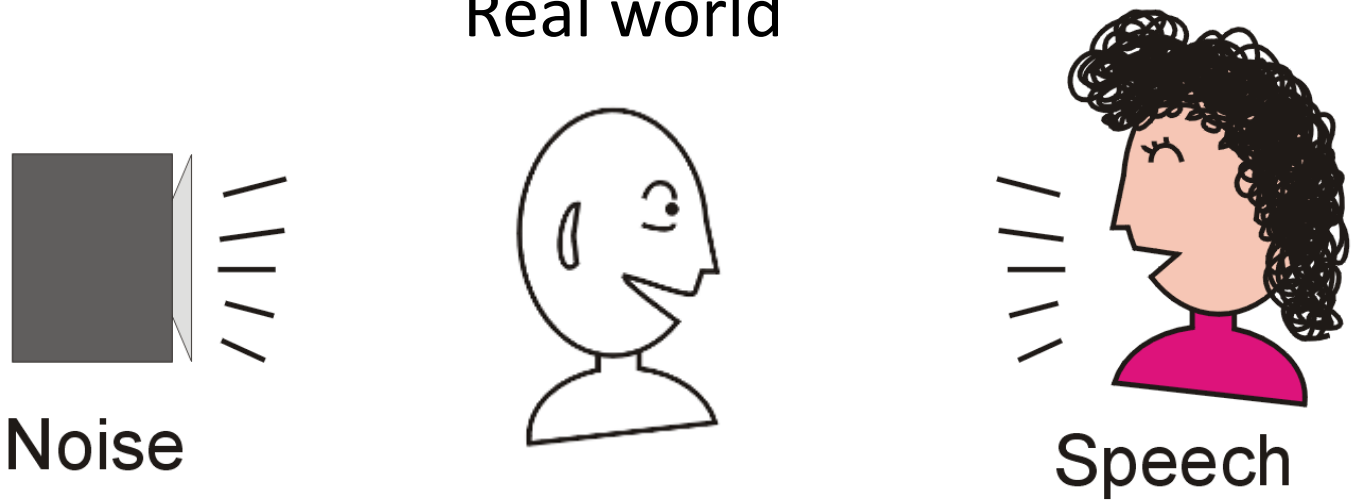


Impact of visual queues

Laboratory

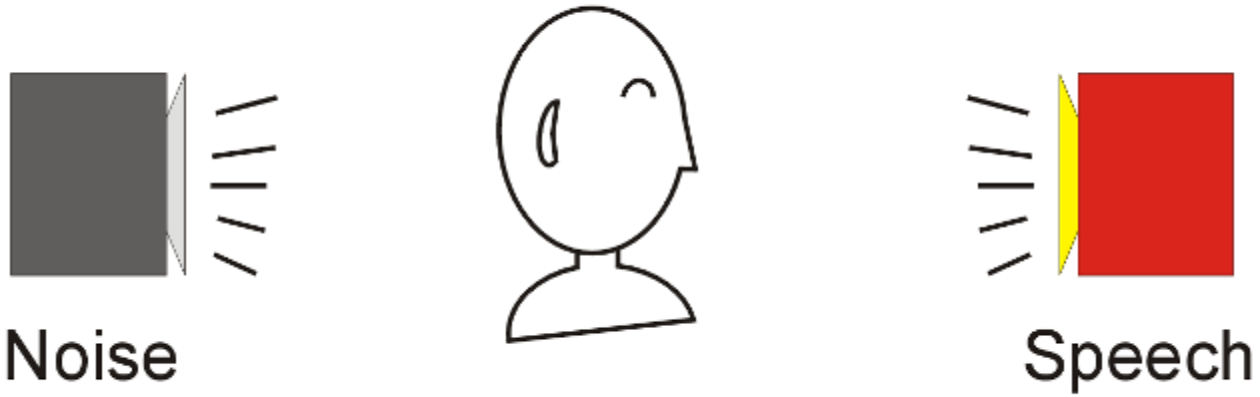


Real world

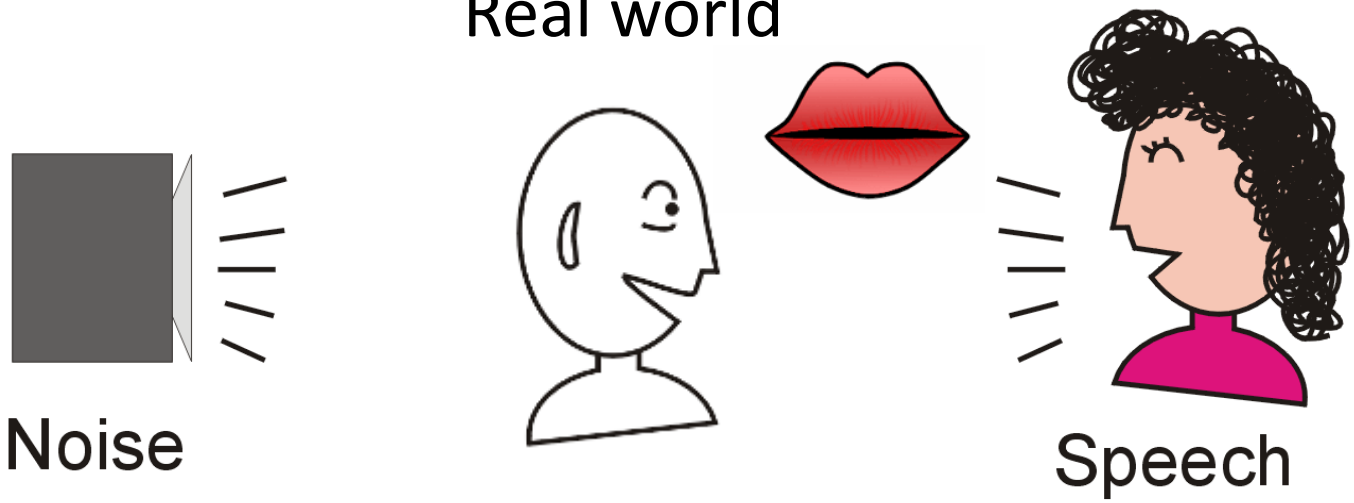


Impact of visual queues

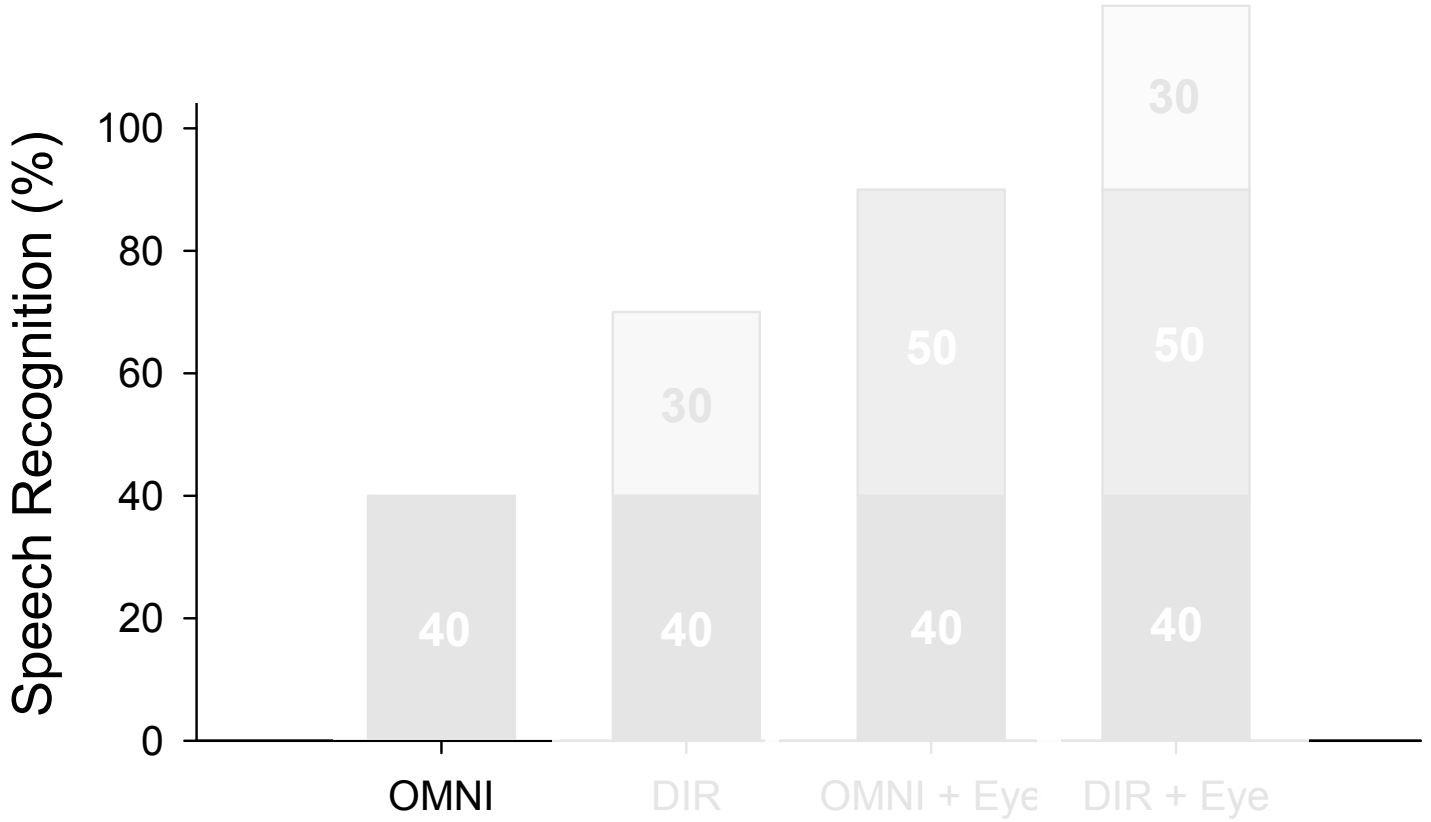
Laboratory



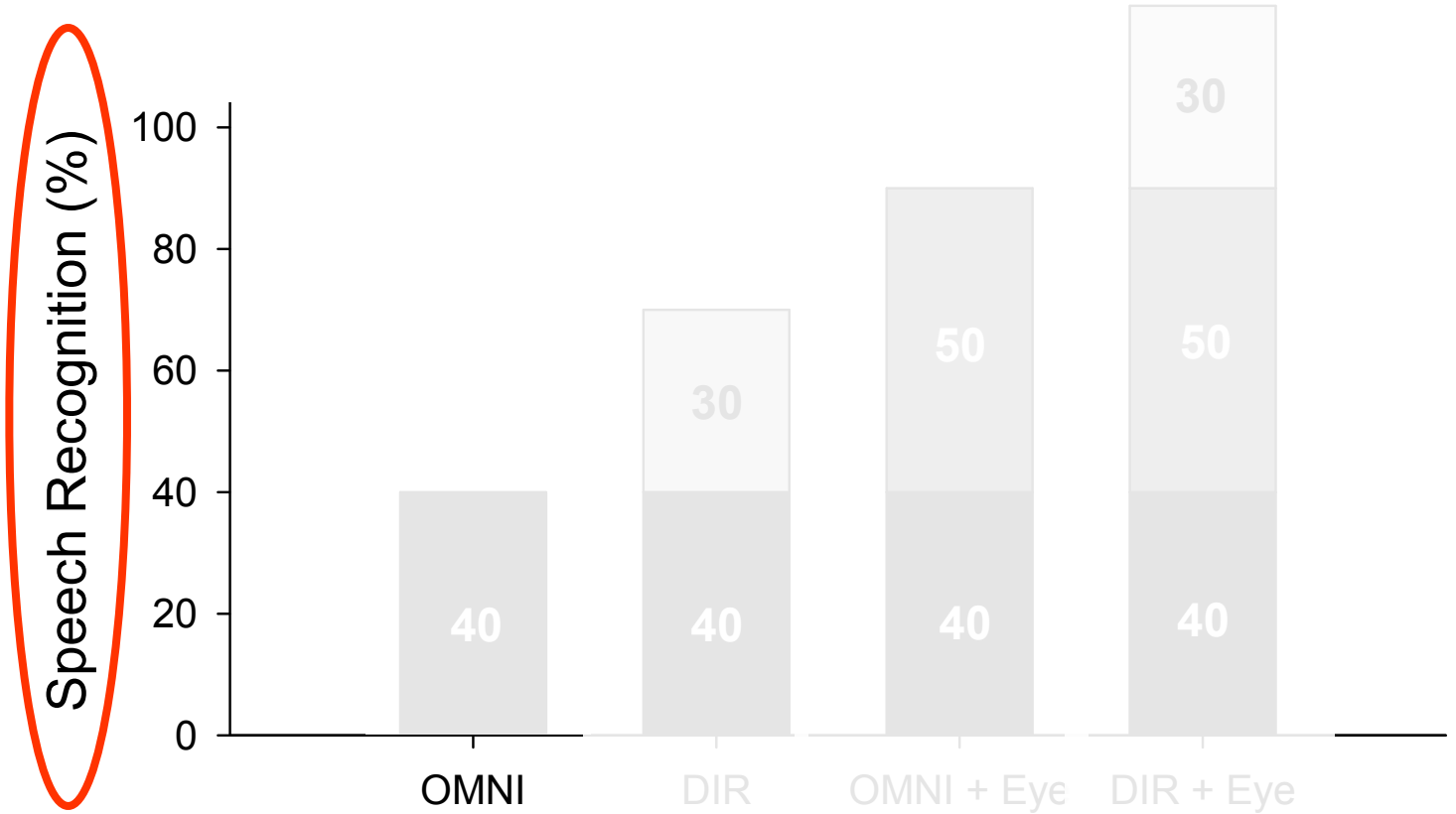
Real world



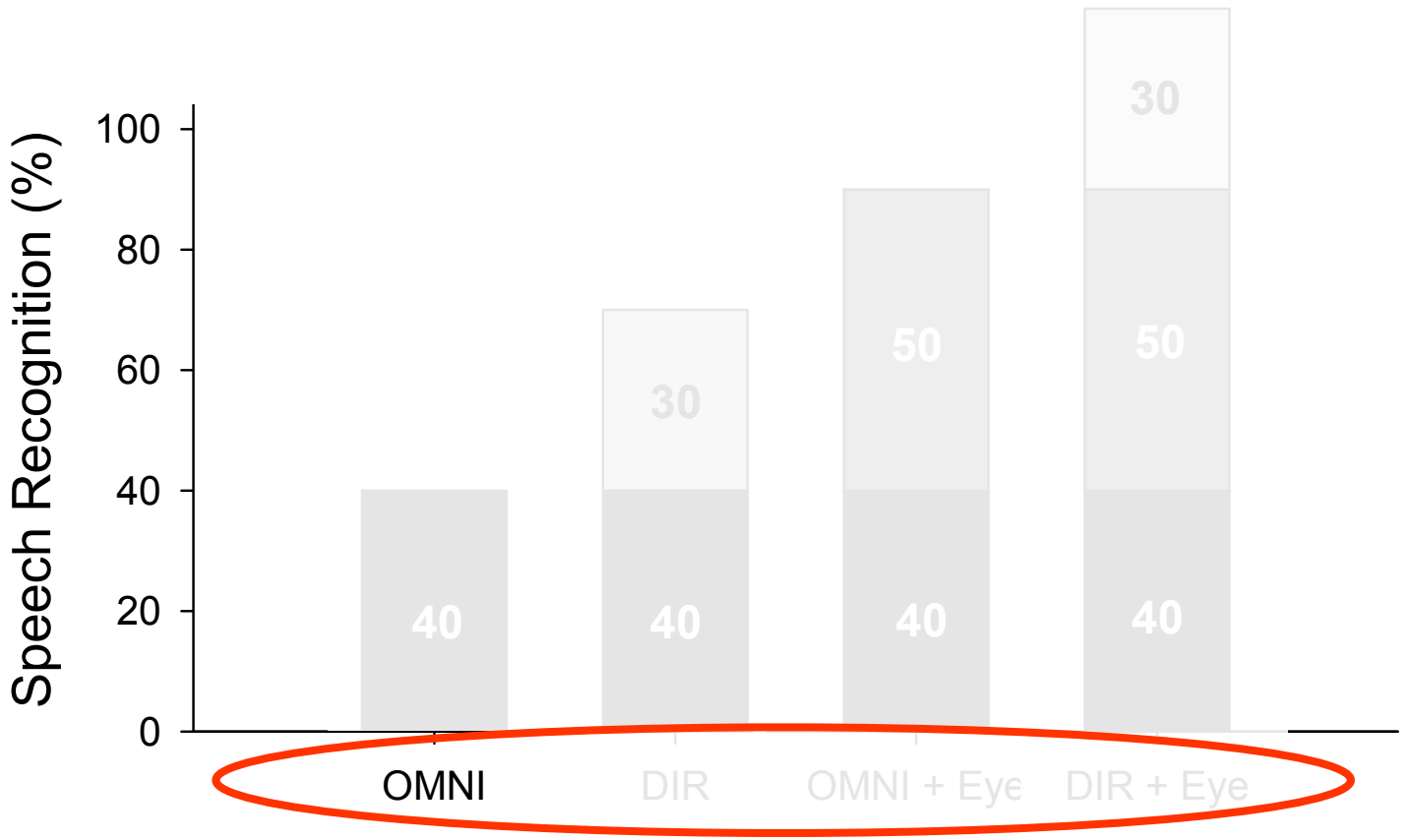
Visual Cues and DIR Benefit



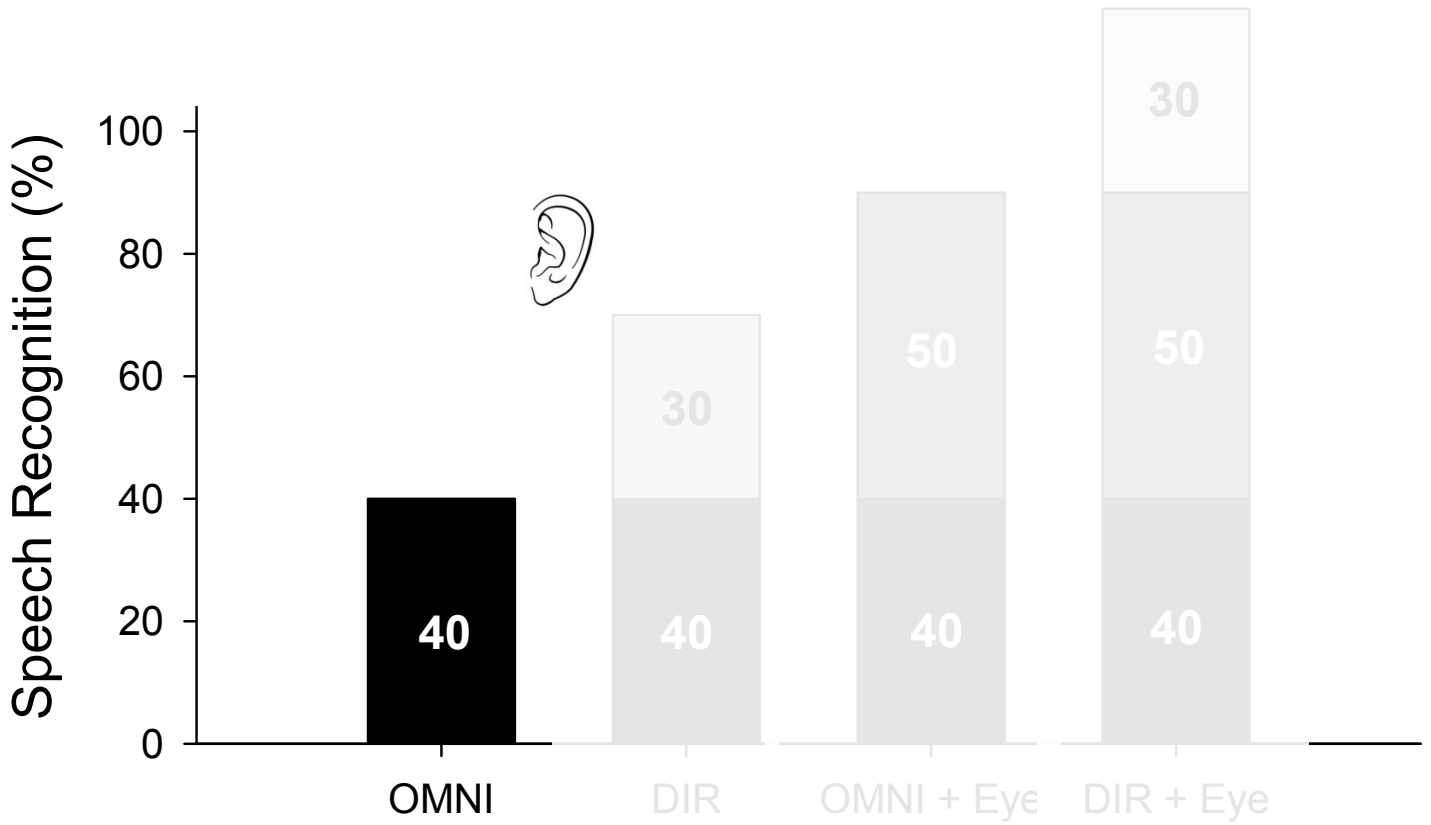
Visual Cues and DIR Benefit



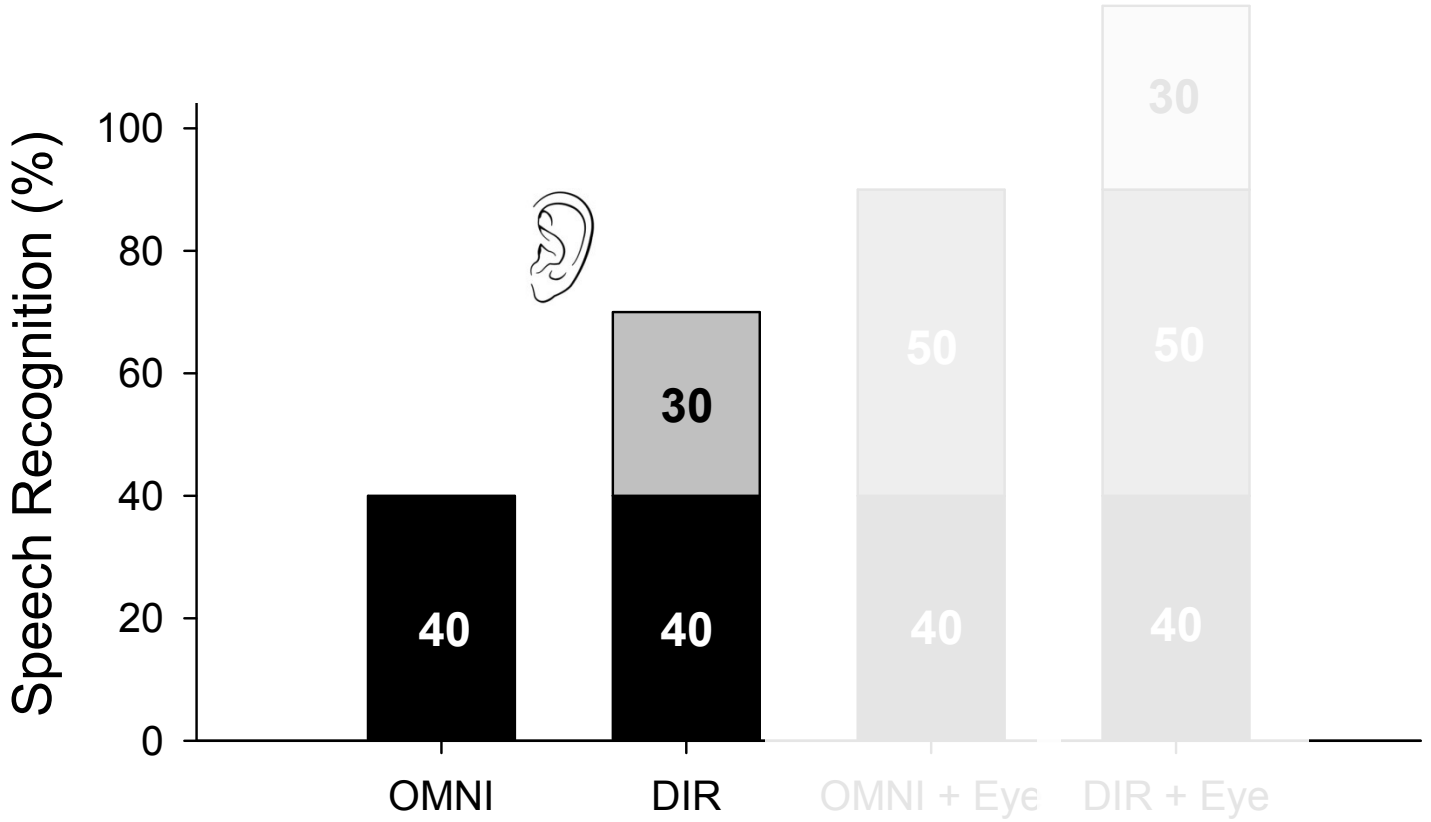
Visual Cues and DIR Benefit



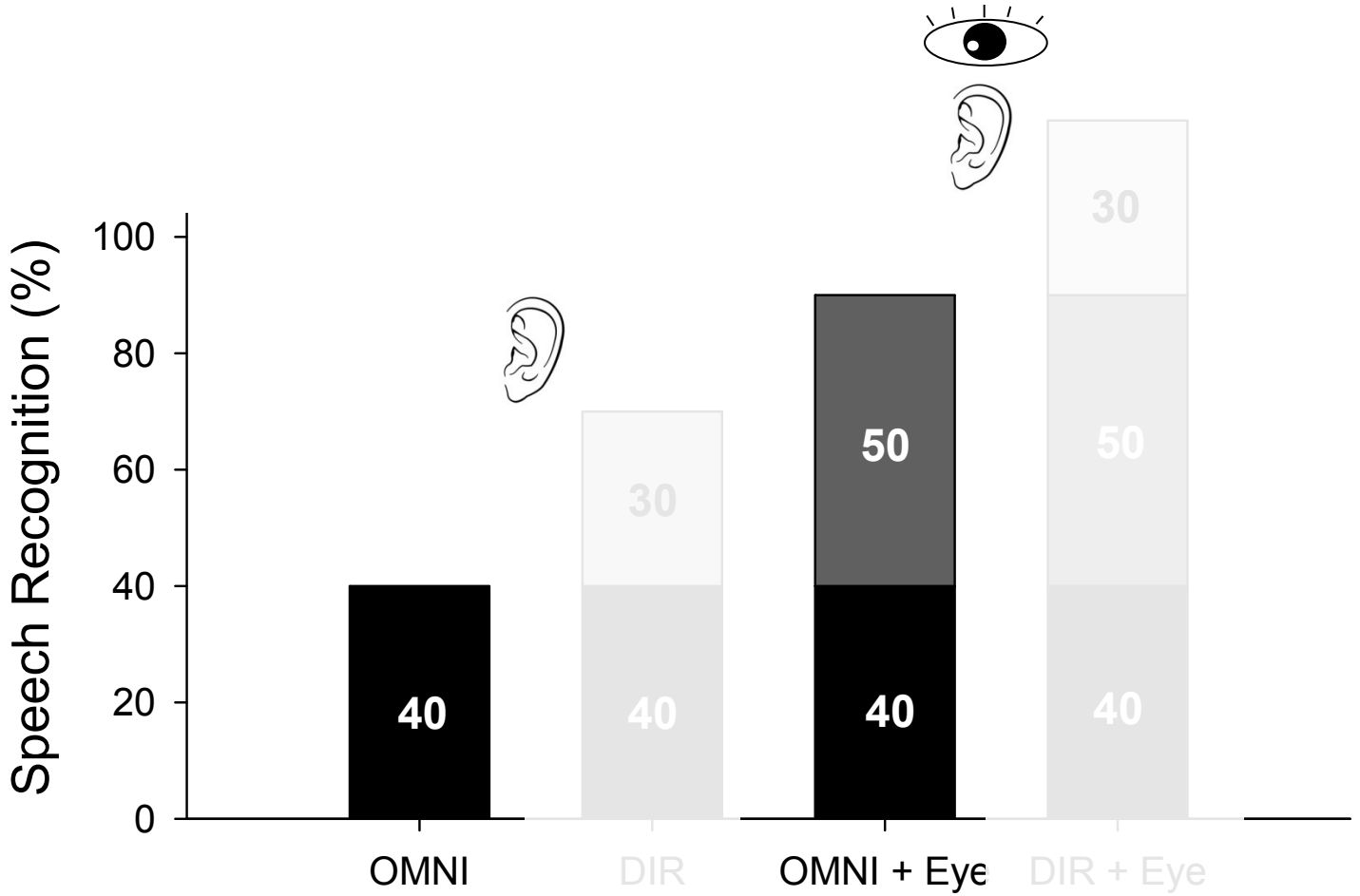
Visual Cues and DIR Benefit



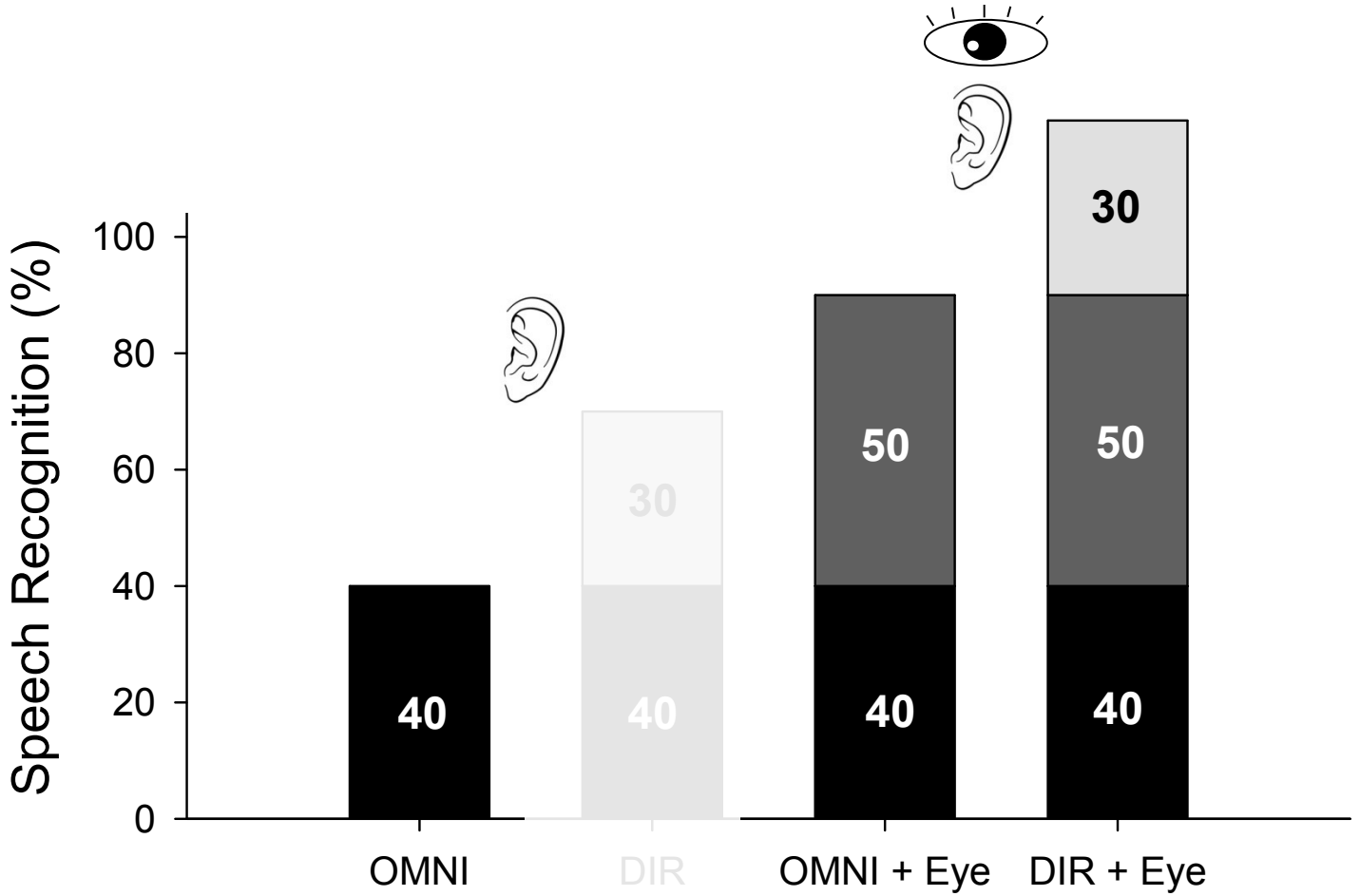
Visual Cues and DIR Benefit



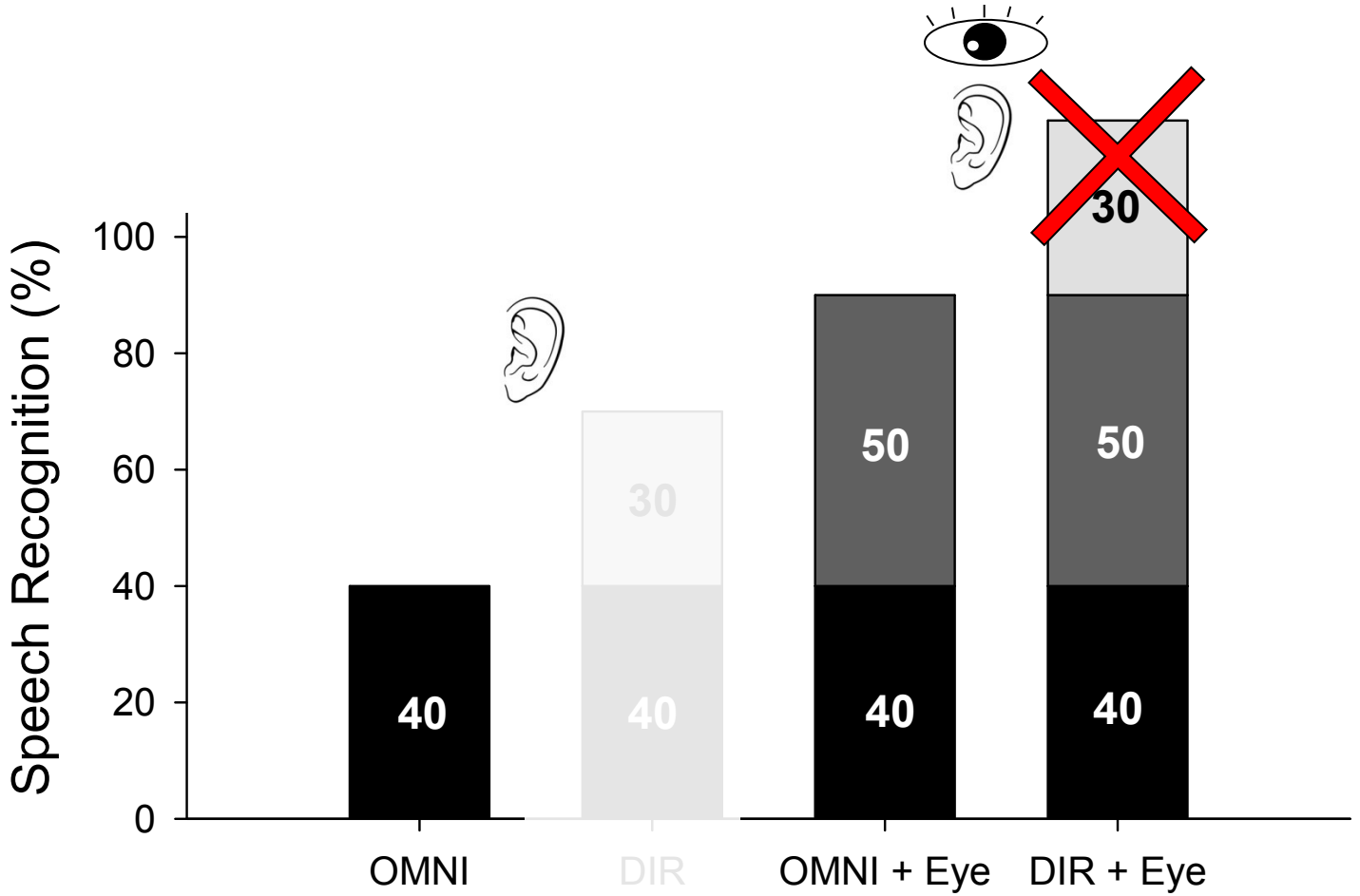
Visual Cues and DIR Benefit



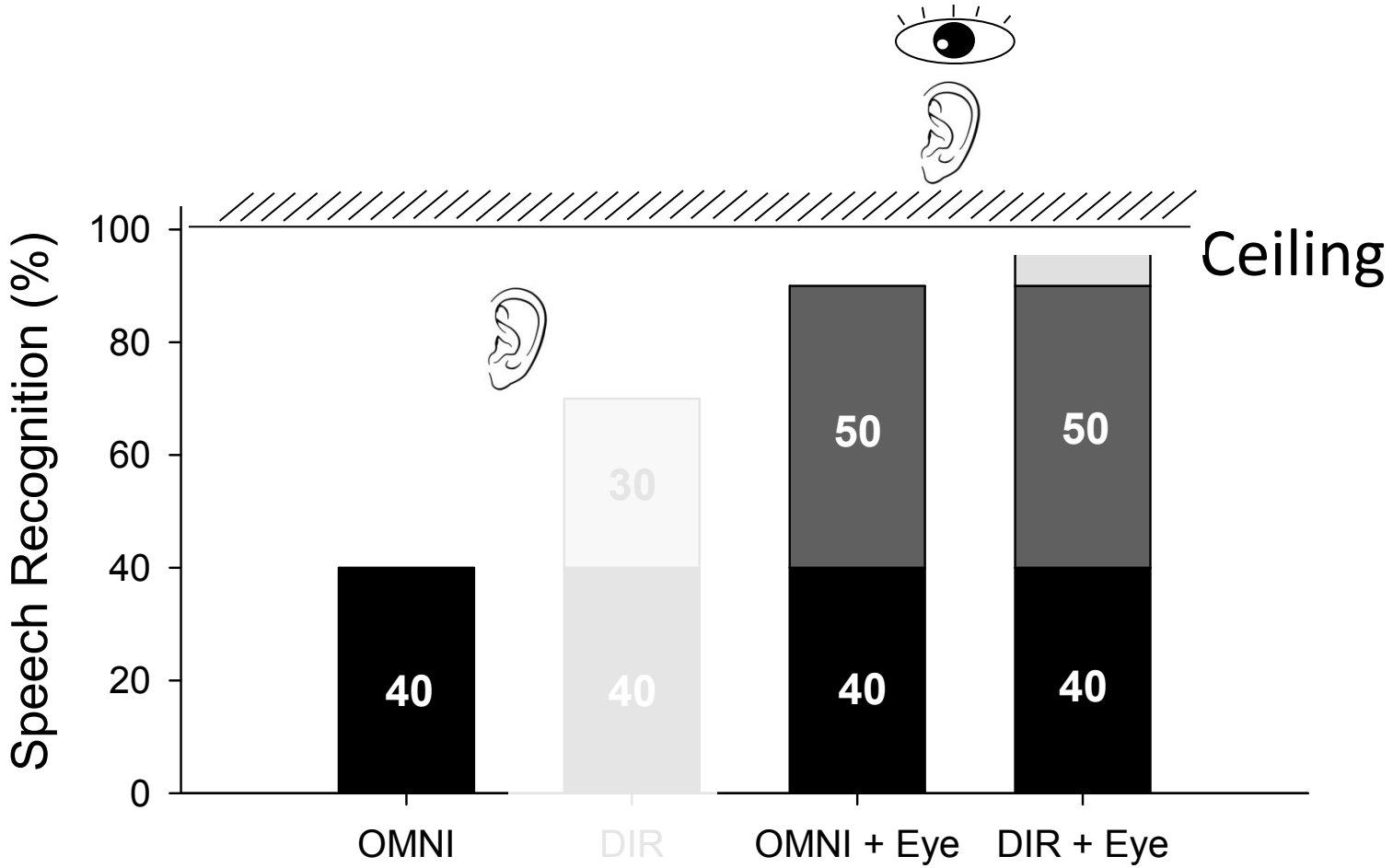
Visual Cues and DIR Benefit



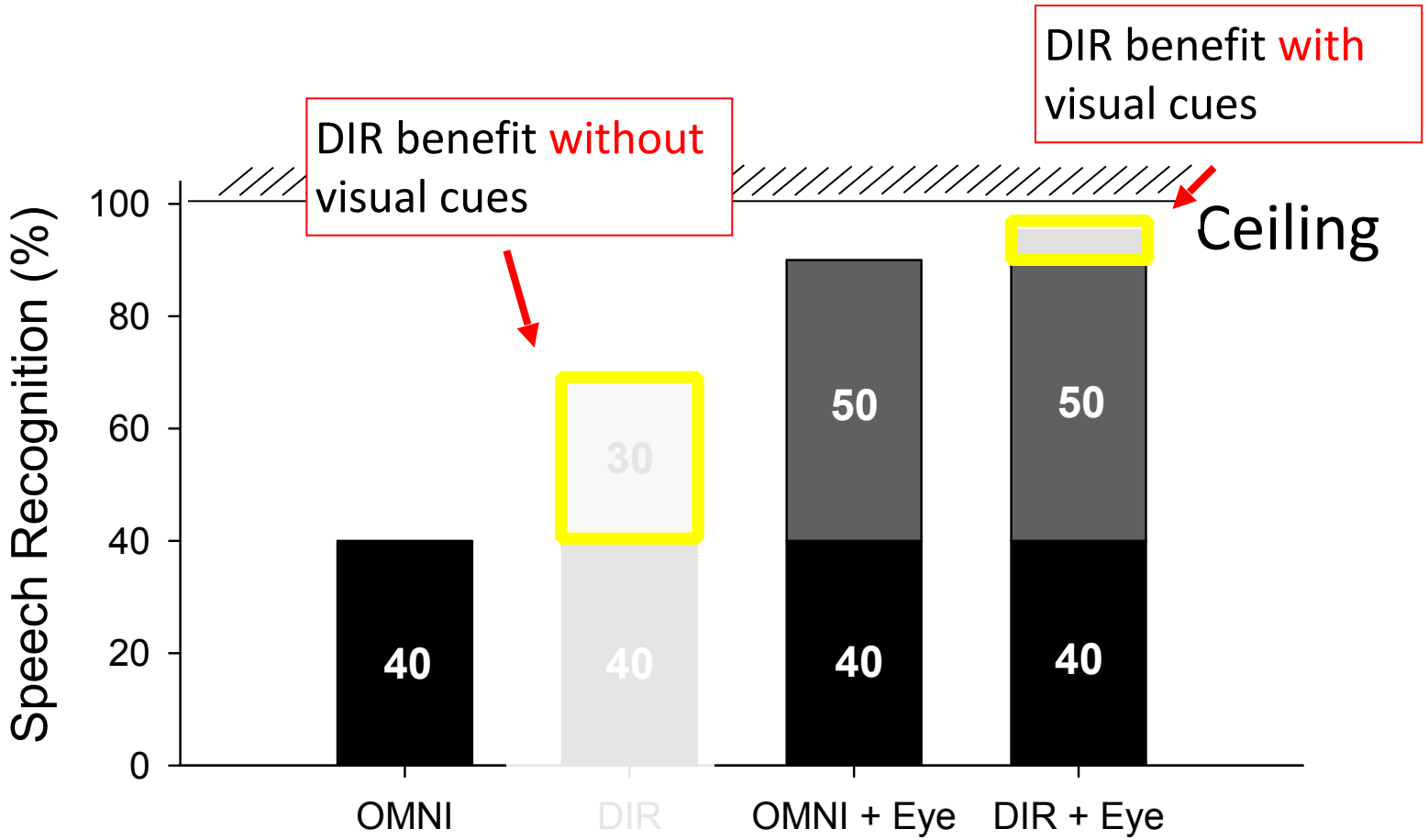
Visual Cues and DIR Benefit



Visual Cues and DIR Benefit



Visual Cues and DIR Benefit



Field outcome measures

- Surveys provide poor contextual information
- Subject to memory bias
- Attempts to overcome this limitations:
  - talking with the cashier in a crowded grocery store”

Attempts at capturing context

APHAB: Abbreviated Profile of Hearing Aid Benefit

Attempts at capturing context

“talking with the cashier in a crowded grocery store”

APHAB: Abbreviated Profile of Hearing Aid Benefit

Attempts at capturing context

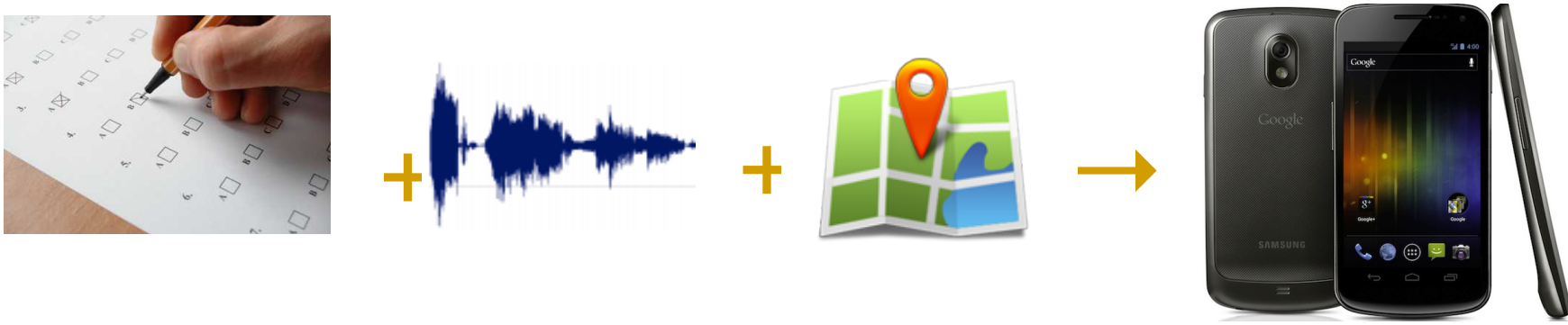
Cord et al., 2002, JAAA

Attempts at capturing context

"You are seated in the middle of a large, crowded, noisy cafeteria or dining hall having lunch and are conversing with the person seated directly across the table from you. There are the sounds of many people talking at tables all around you, trays, dishes, and cutlery clattering, etc."

Cord et al., 2002, JAAA

AudioSense



- Provides clinicians with subjective and objective measures of hearing aid outcomes and auditory contexts
  - subjective: Ecological Momentary Assessment (EMA)
  - objective: derived from audio and GPS
  - data is collected in real-time and in-situ

S.S.Hasan, F. Lai, O. Chipara, Y-H. Wu
AudioSense : Enabling real-time evaluation of hearing-aid technology in-situ
CBMS 2013

Measuring the auditory context

social interaction

acoustic environment

activity

Measuring the auditory context

social interaction

Could you see the talker's face?

acoustic environment

activity

Measuring the auditory context

social interaction

Could you see the talker's face?

acoustic environment

activity

What were you listening to?

Measuring the auditory context

social interaction

Could you see the talker's face?

acoustic environment

Where were you?

ivity

What were you listening to?

Measuring the auditory cont

How noisy was it?

social interaction

Could you see the talker's face?

acou environment

Where were you?

ivity

What were you listening to?

Measuring the auditory cont

How noisy was it?

How important was it to hear well?

acou environment

social interaction

Could you see the talker's face?

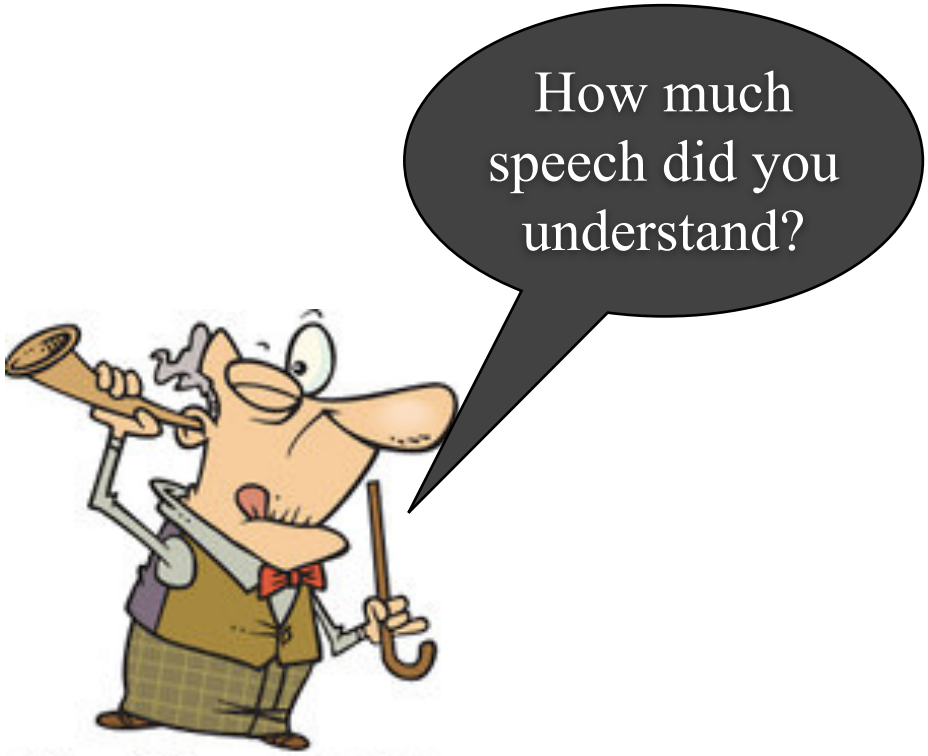
Where were you?

ivity

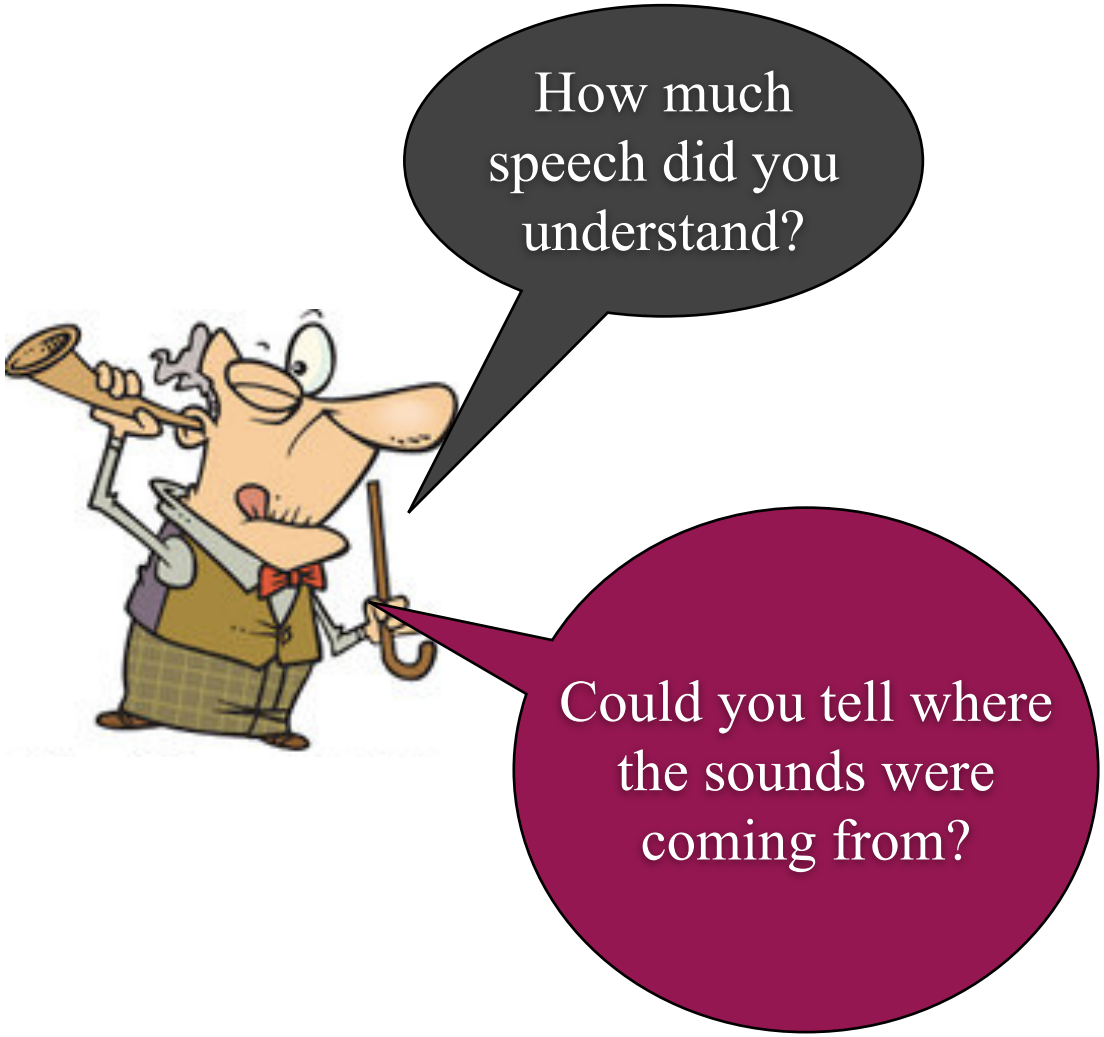
What were you listening to?

Measuring the outcomes

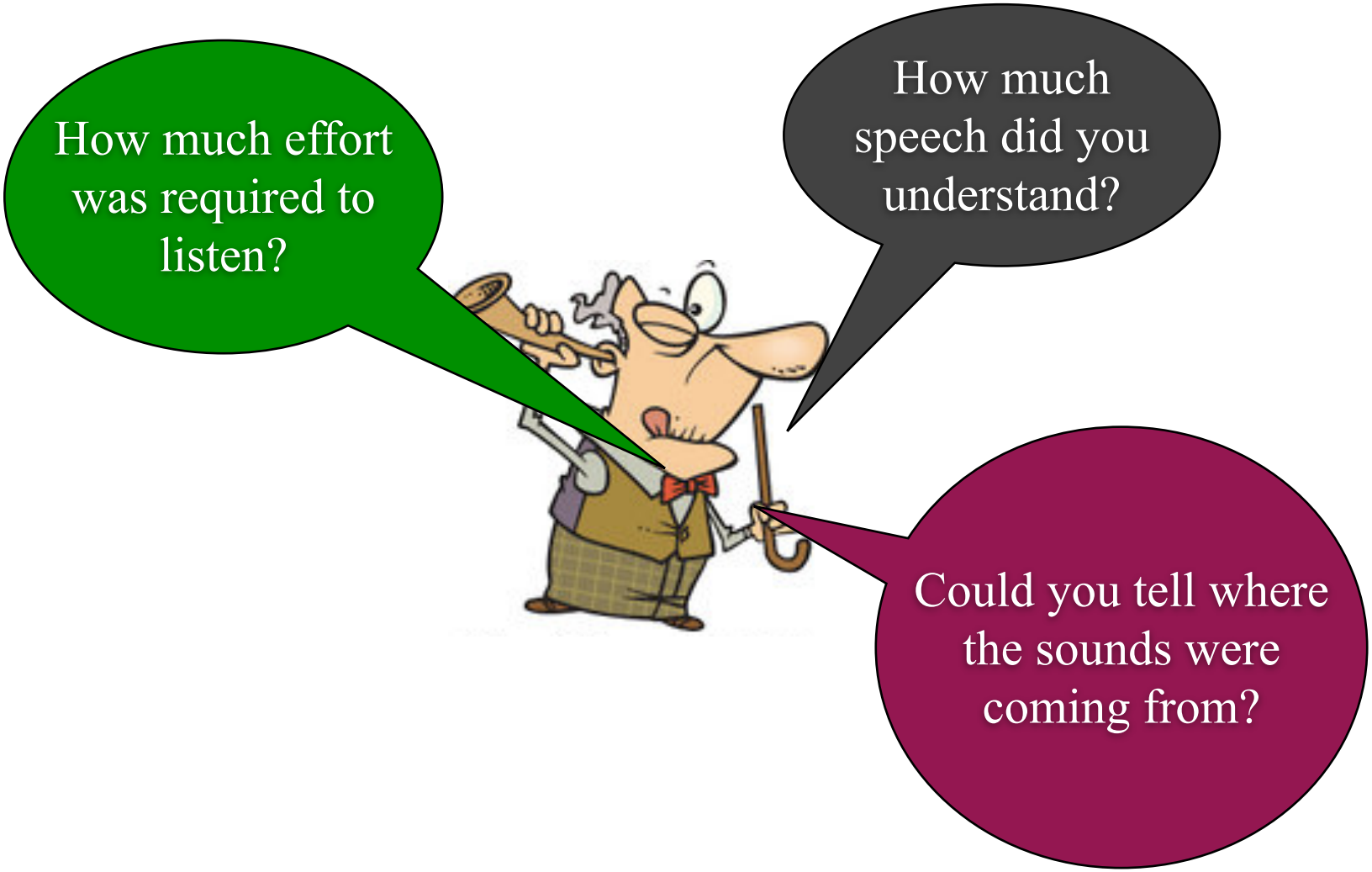
Measuring the outcomes



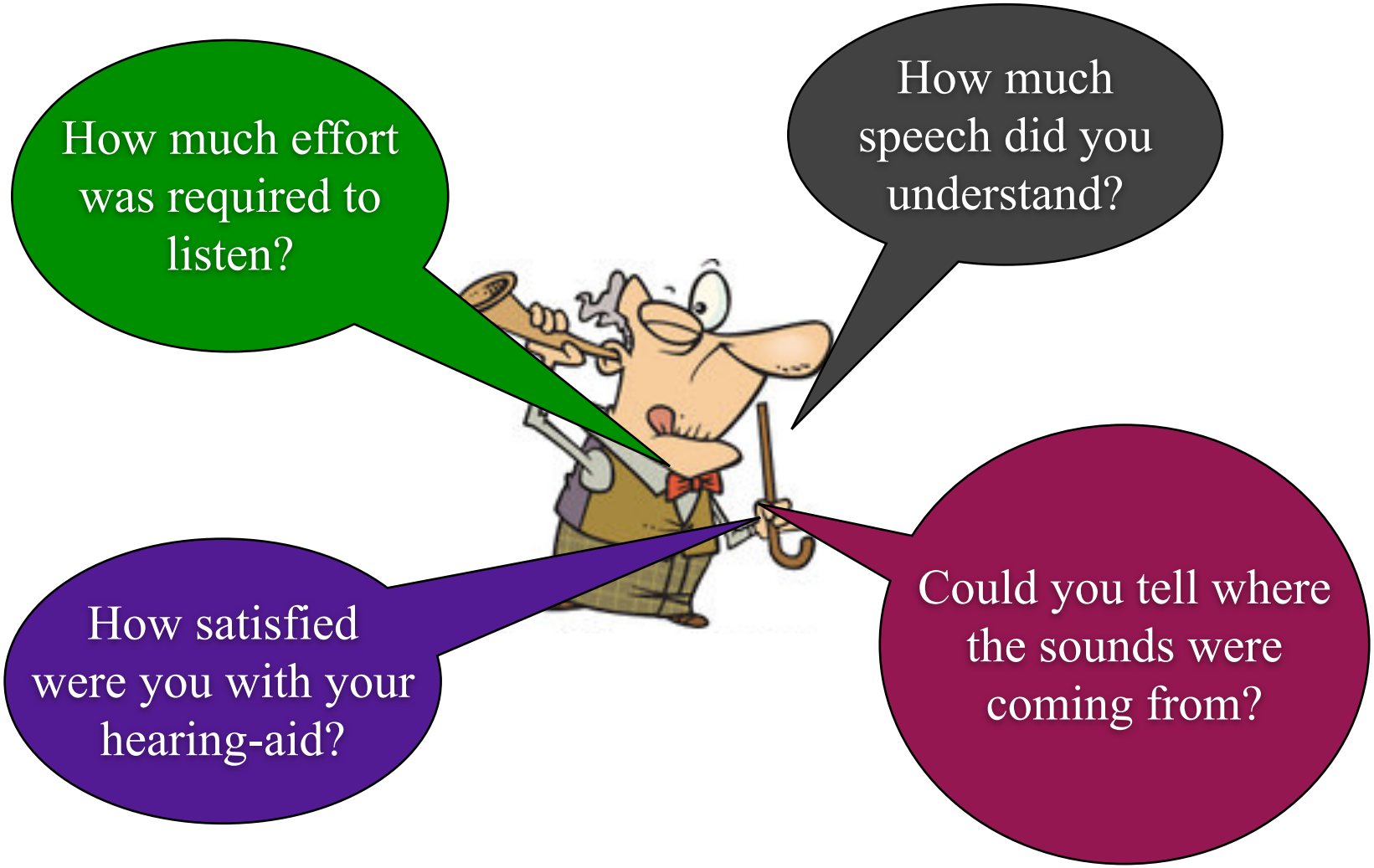
Measuring the outcomes



Measuring the outcomes



Measuring the outcomes



Architecture of AudioSense

Android Phones

Web Server

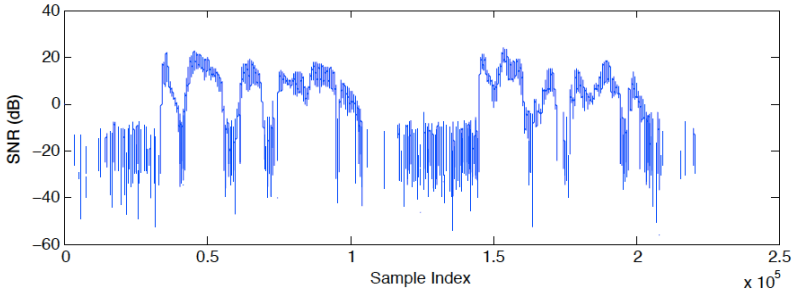
django

Web Interface

Condition	Last user survey	Last timer survey	Last log time	User count	Timer count	Compliance
55	June 12, 2013, 10:54 a.m.	June 11, 2013, 8:09 p.m.	June 12, 2013, 11:19 a.m.	7	7 / 63 (3 snooze)	11.67
33	June 12, 2013, 11:29 a.m.	June 12, 2013, 1:10 p.m.	June 12, 2013, 1:10 p.m.	1	2 / 5 (0 snooze)	40.00

MATLAB

Extensible Analysis Environment



Architecture of AudioSense

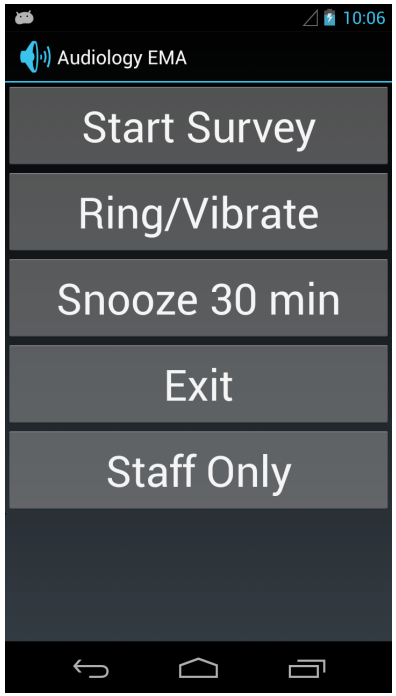
Android Phones

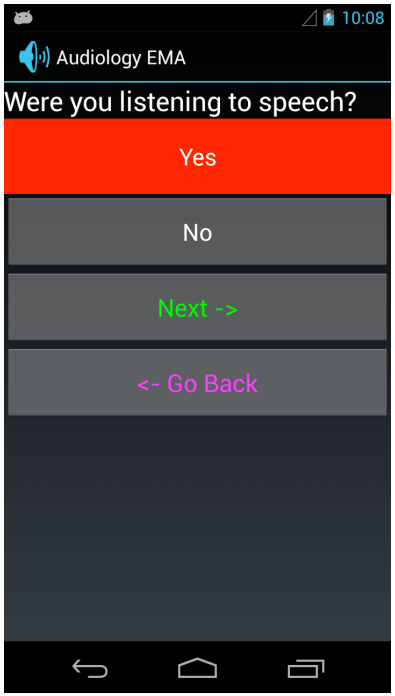
- EMA
- Extensible user interface and effective alarms
- Energy efficient data collection, high reliability

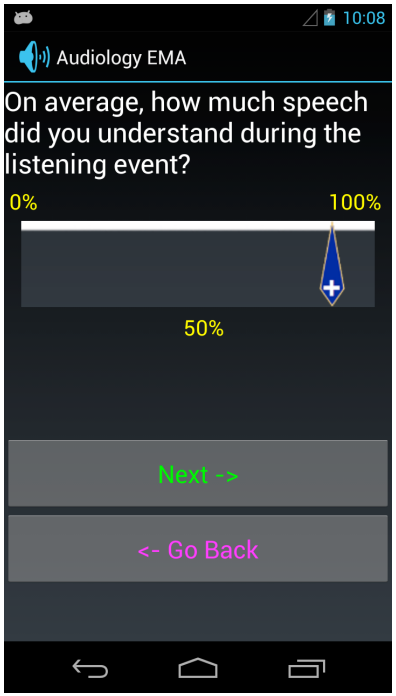
Web Server

- Real-time compliance information
- Extensible data analysis environment
- Scales to support multiple concurrent users

User Interface Design







- Iterative design based on patient feedback
  - patients of hearing loss tend to be older, may have impaired vision ⇒ larger fonts, bigger buttons, contrasting colors

Alarms

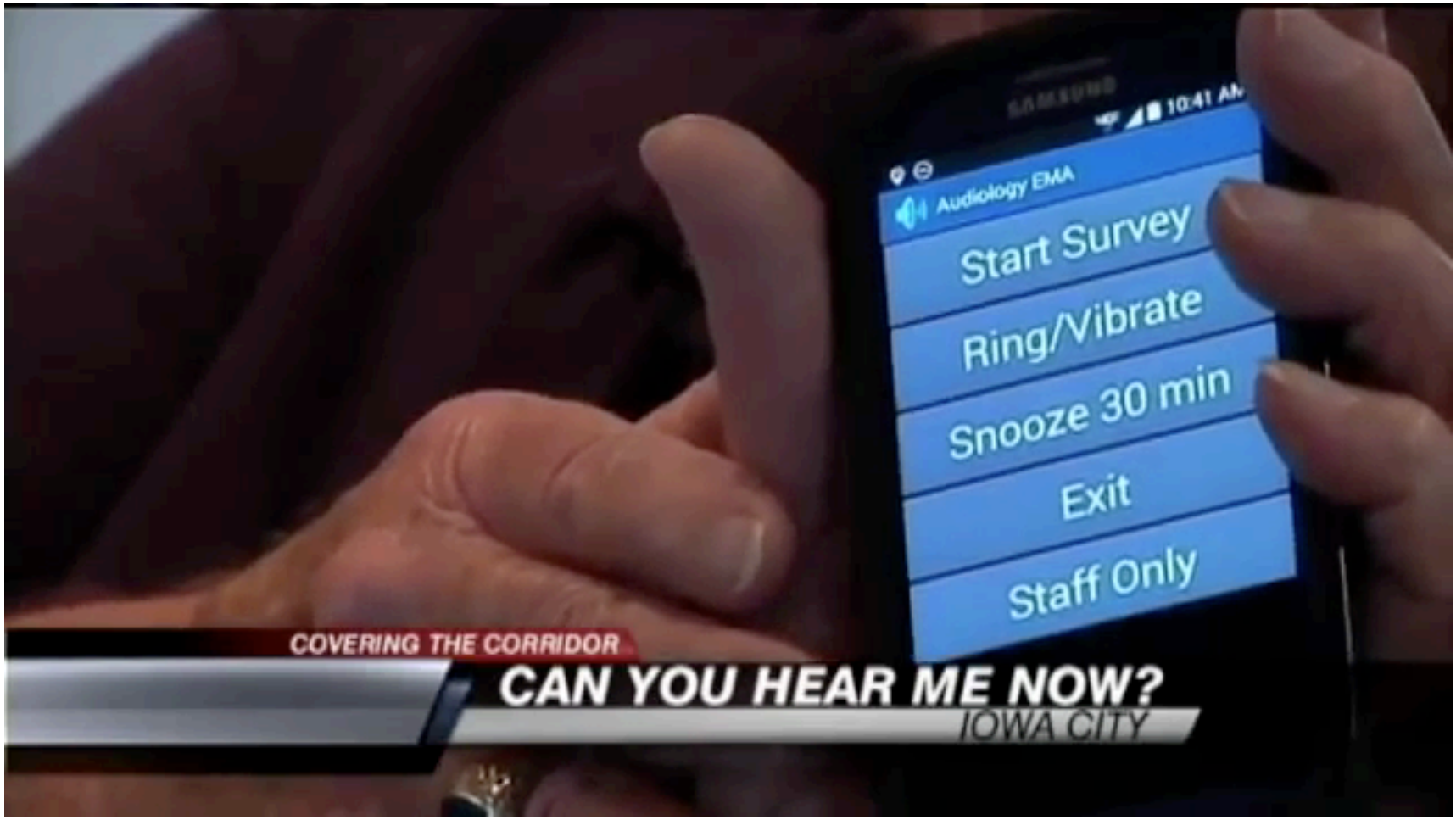
- Design refined over several iterations based on patient feedback
- Challenge: find sweet-spot between invasiveness and compliance
  - loud ringtones, screen and camera flash blinking
  - subjects can switch to vibration mode

Alarms

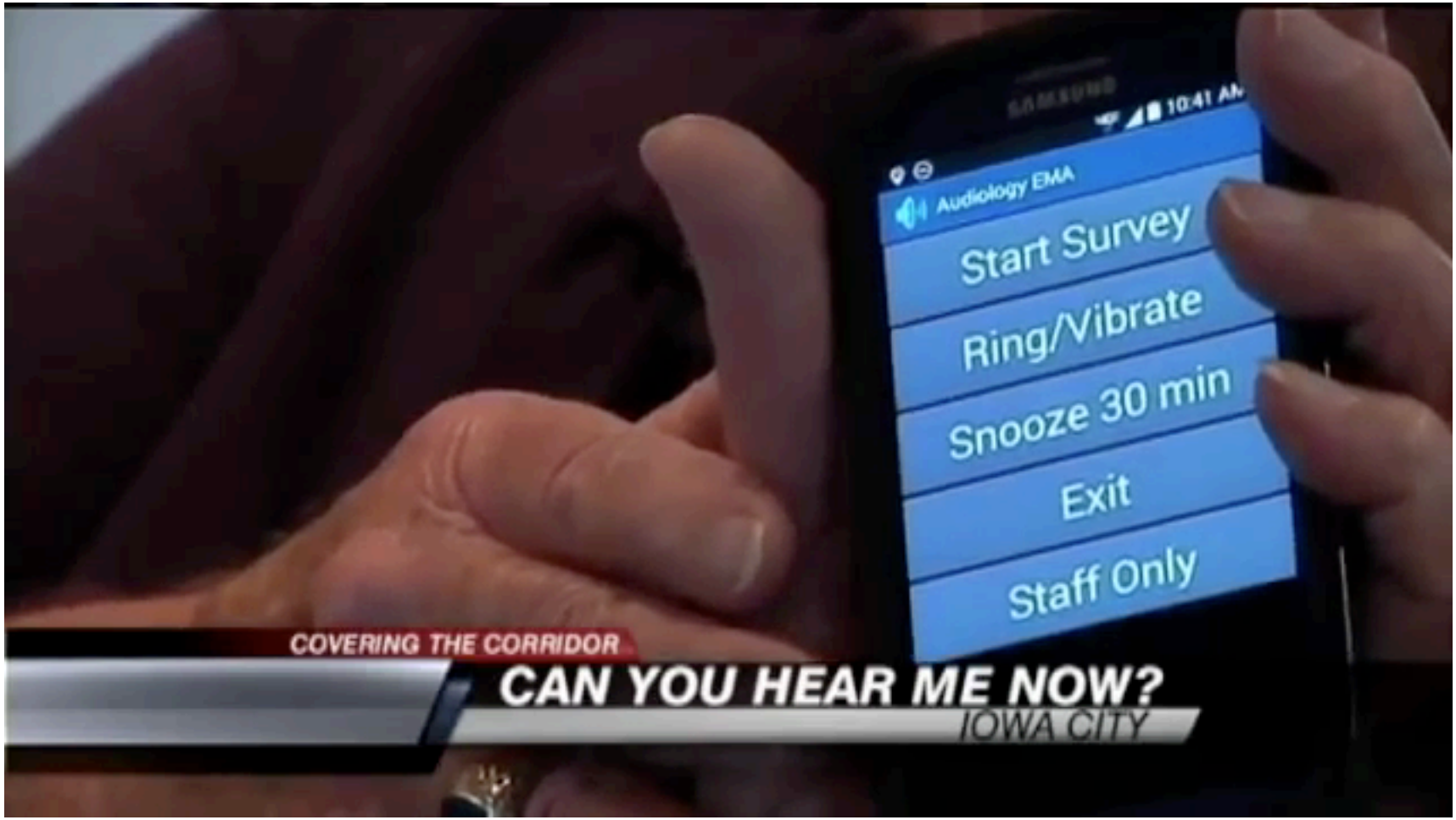
- Design refined over several iterations based on patient feedback
- Challenge: find sweet-spot between invasiveness and compliance
  - loud ringtones, screen and camera flash blinking
  - subjects can switch to vibration mode

Alarms not noticed by the subjects

Our subjects



Our subjects



Field Study

- 19 older adults
  - mild-to-moderate hearing loss
  - age range: 65 - 87
- 2 hearing aids
  - Phonak Bolero Q50 : low cost, low-end adaptive directional microphone (DM) and digital noise reduction (DNR)
  - Phonak Bolero Q90 : premium level, advanced DM and DNR
- 6 sessions
  - one unaided, one application practice

S. S. Hasan, O. Chipara, Y.-H. Wu, and Nazan Aksan
Evaluating Auditory Contexts and Their Impacts on Hearing Aid Outcomes with Mobile Phones
PervasiveHealth 2014

Remainder of the talk

What are the typical auditory contexts?

Are the hearing aid outcomes correlated?

Can the hearing aid outcomes be predicted?

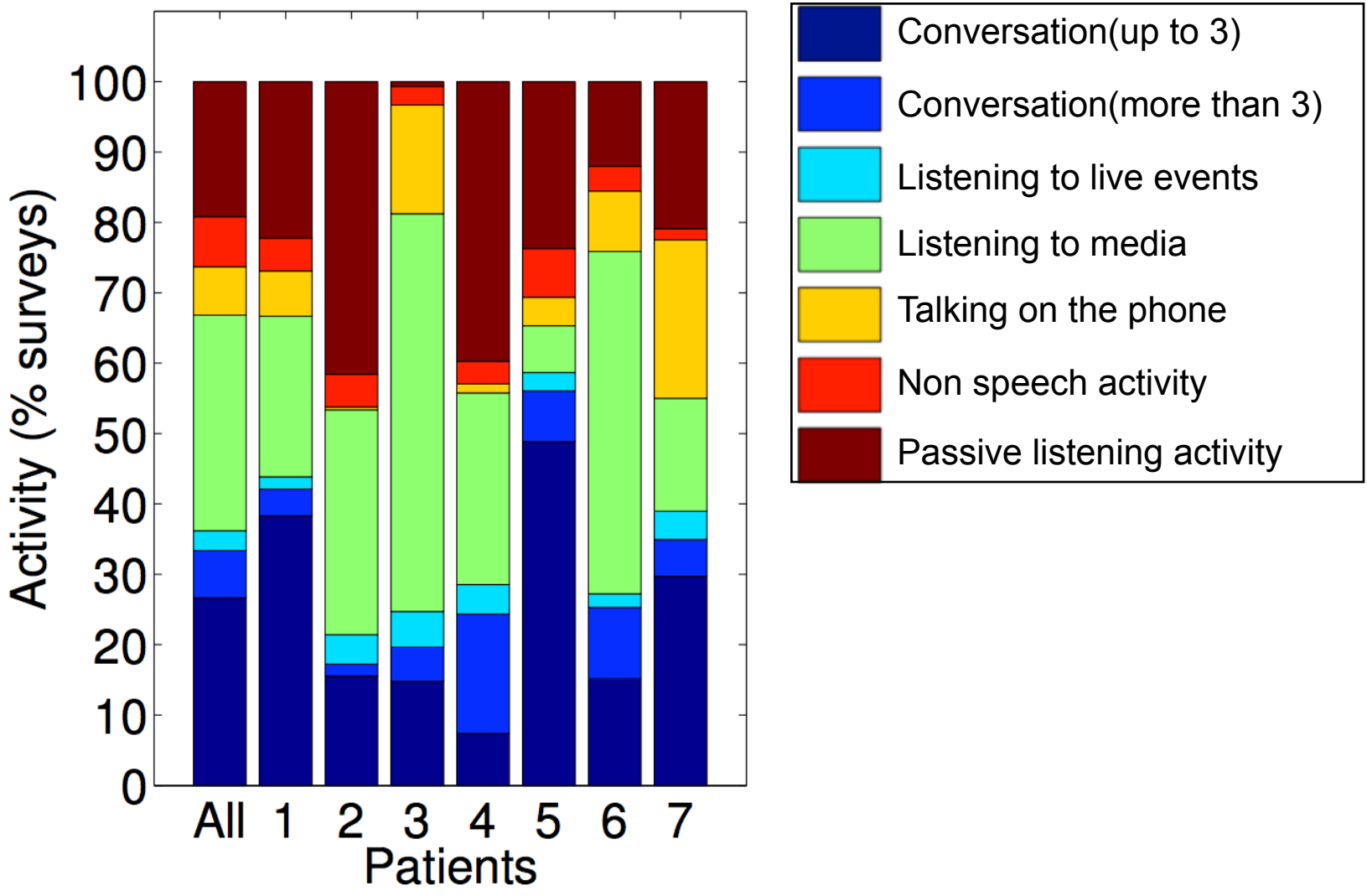
Remainder of the talk

What are the typical auditory contexts?

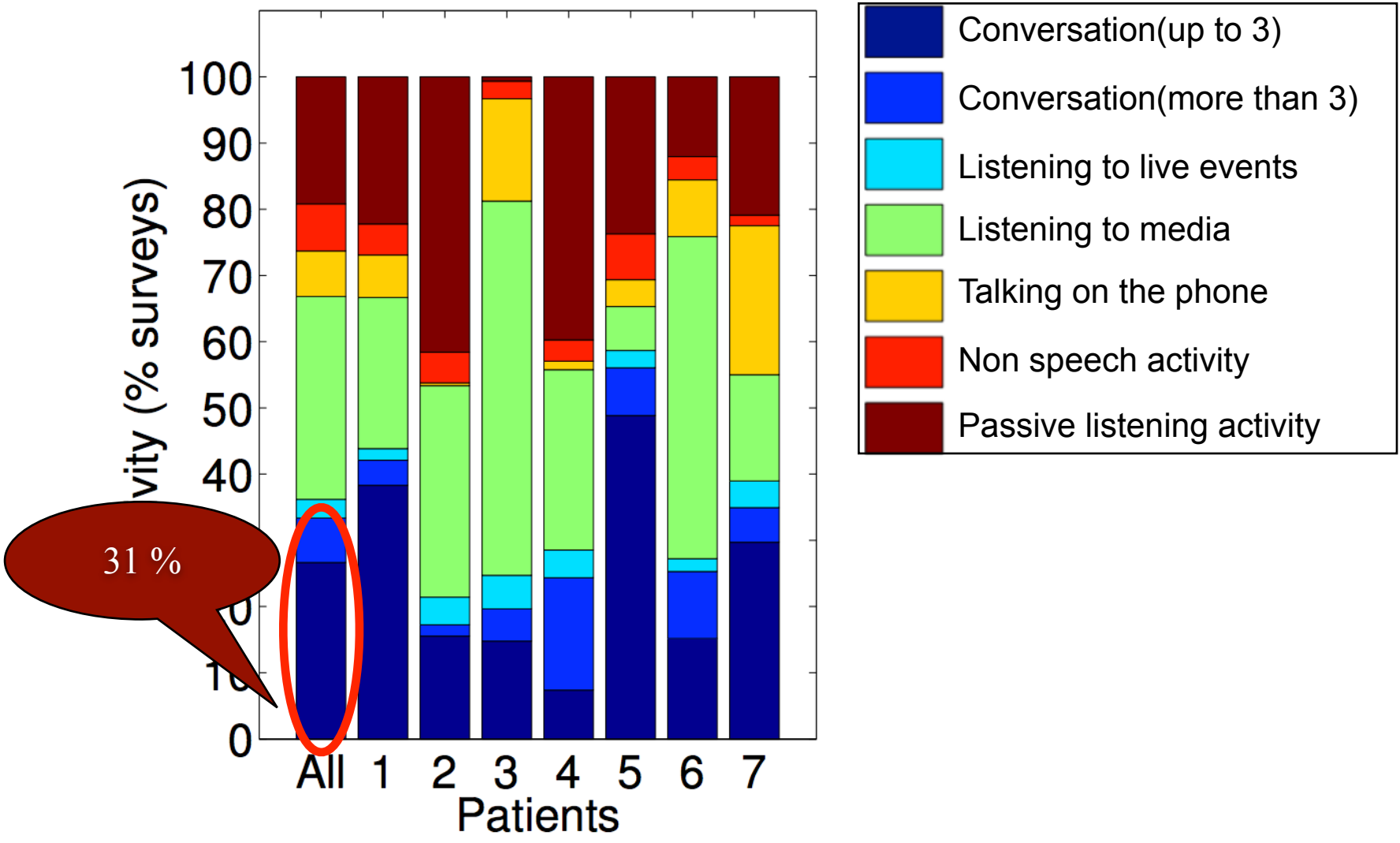
Are the hearing aid outcomes correlated?

Can the hearing aid outcomes be predicted?

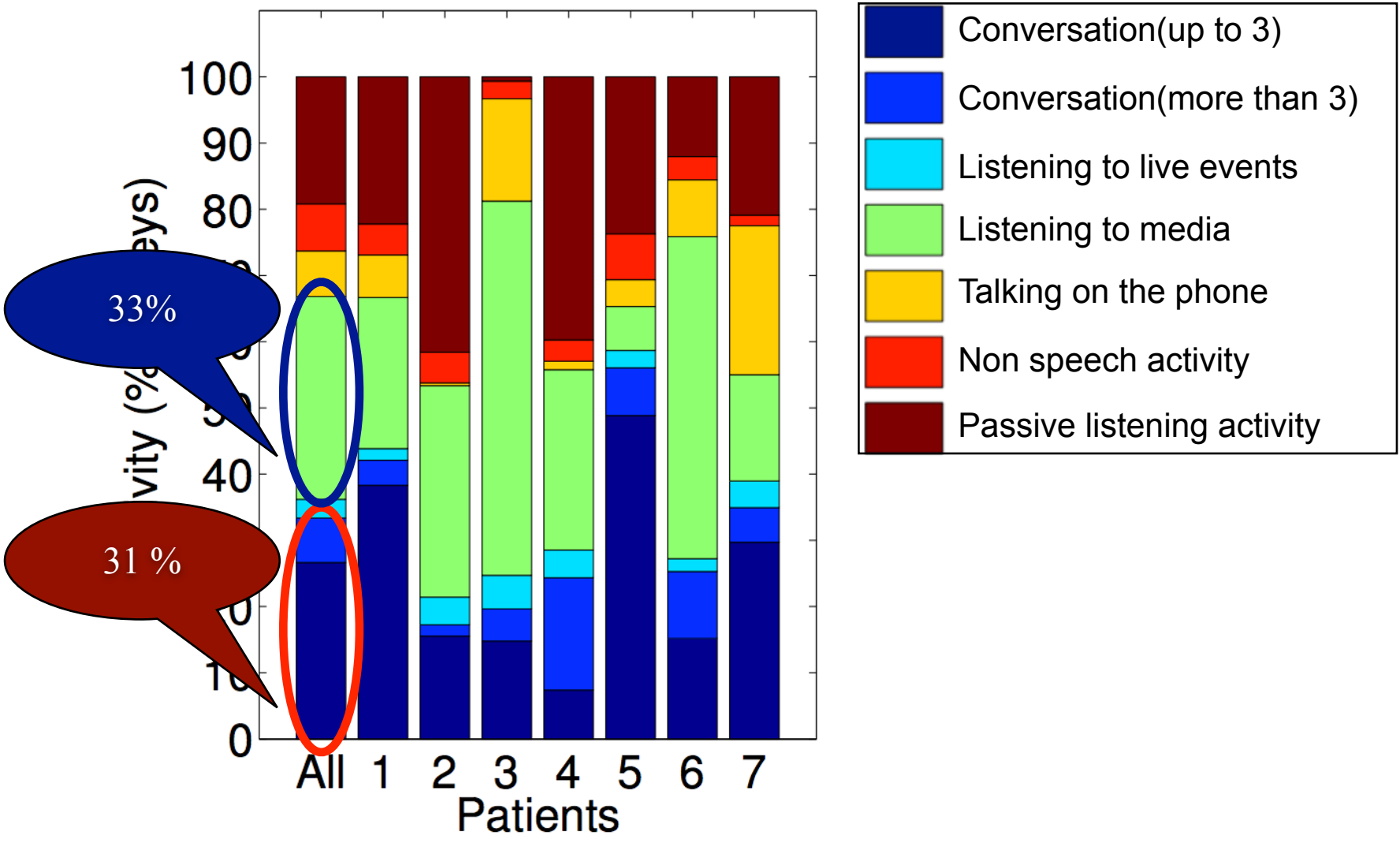
Activity context distribution



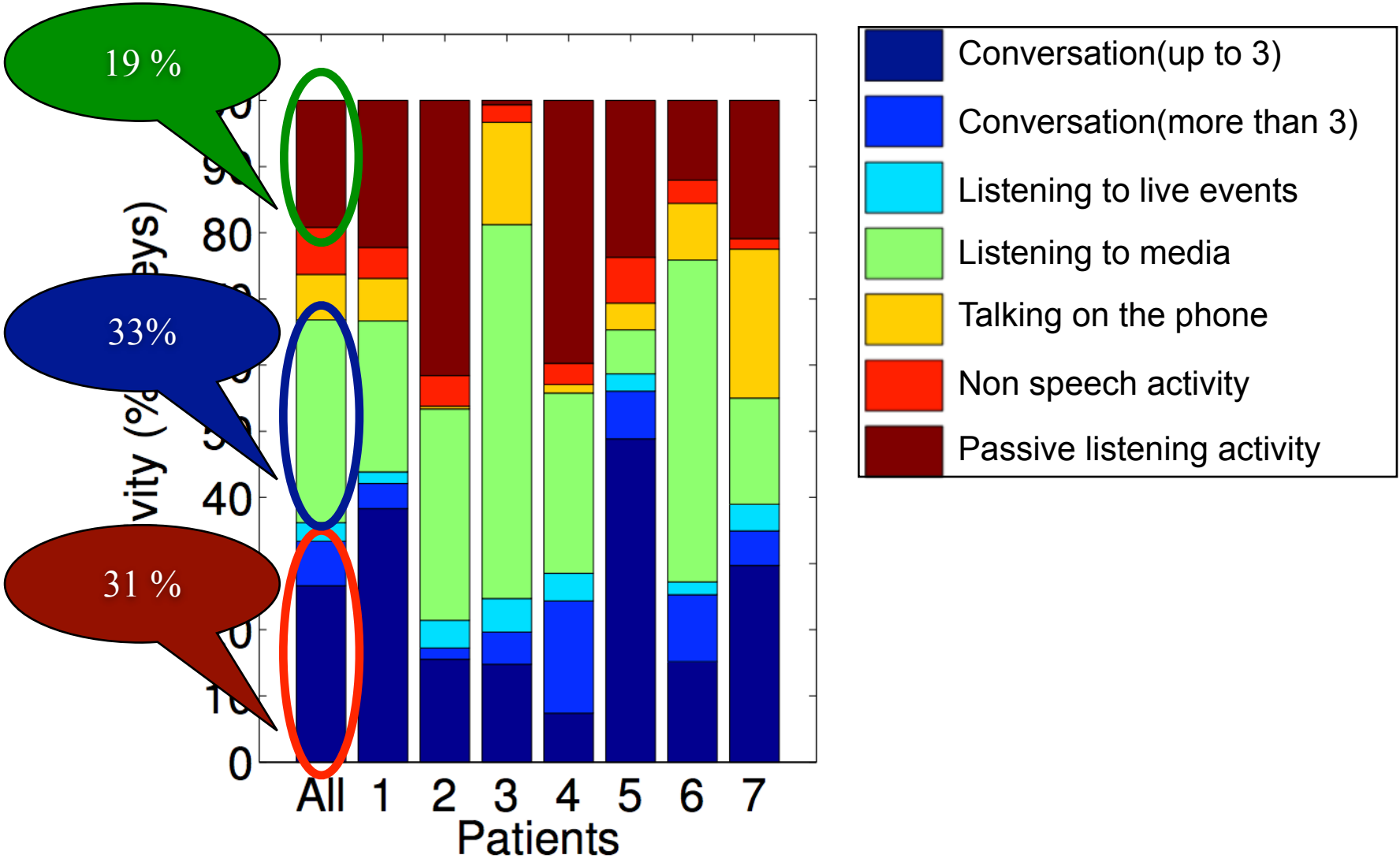
Activity context distribution



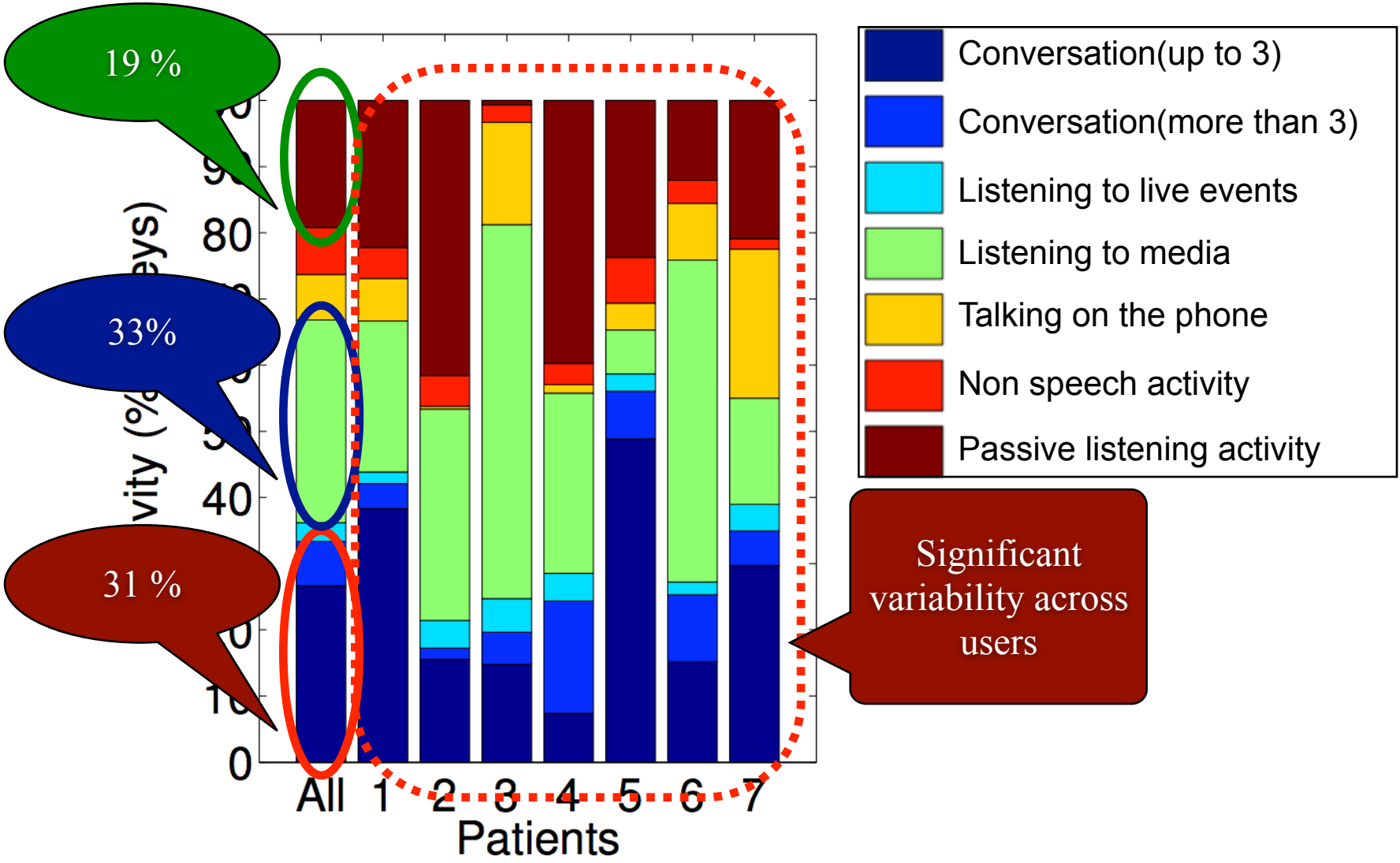
Activity context distribution



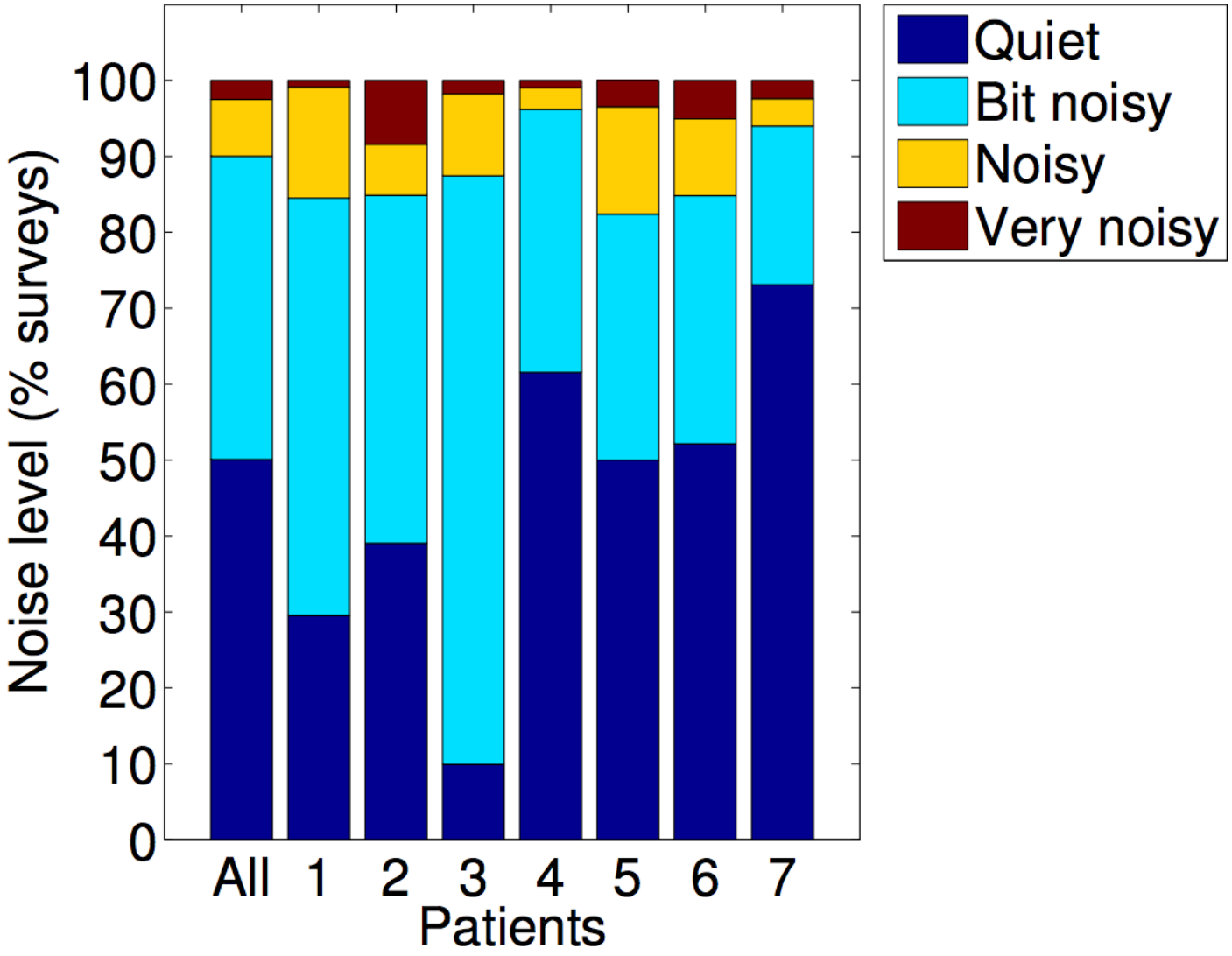
Activity context distribution



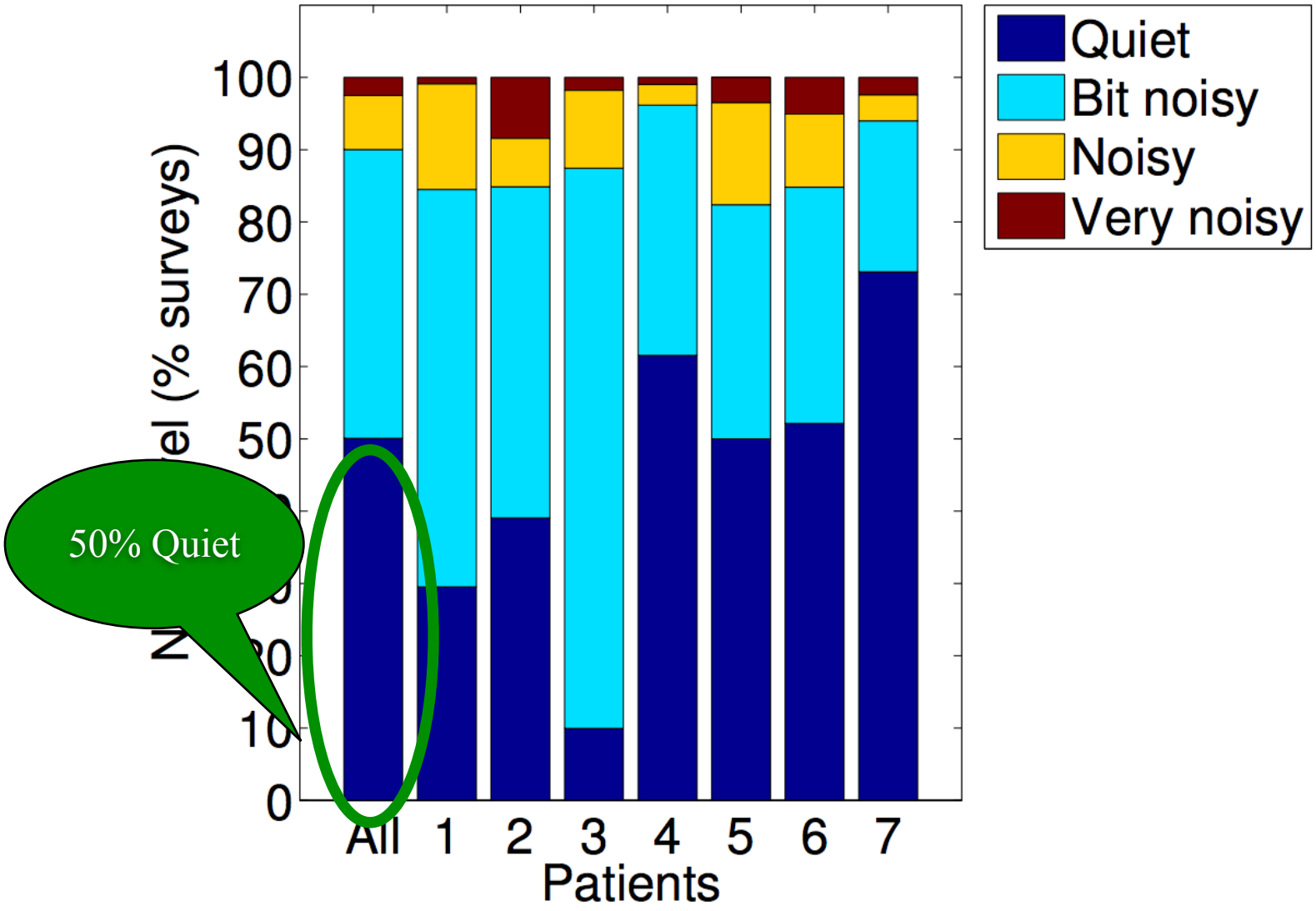
Activity context distribution



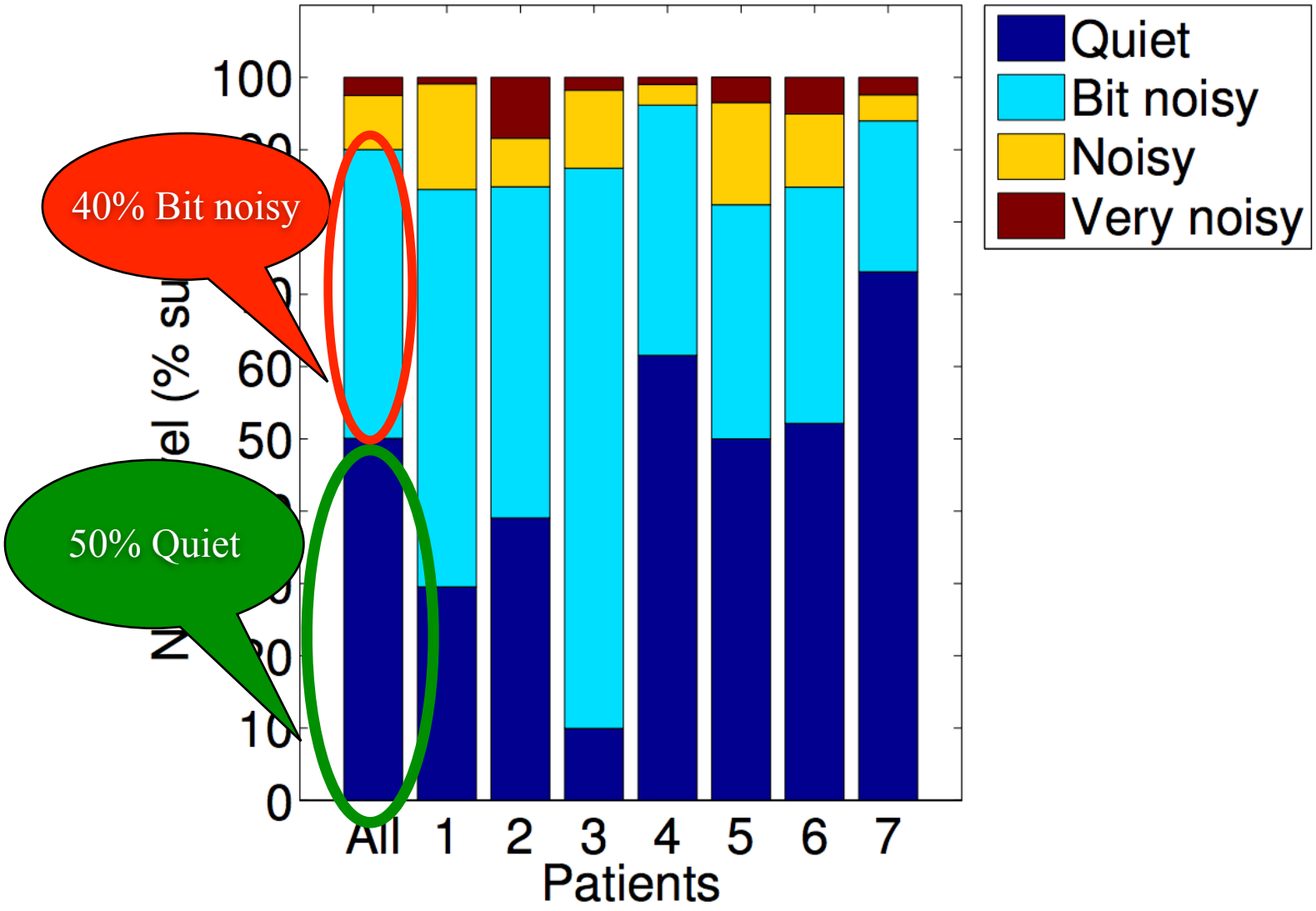
Noise level distribution



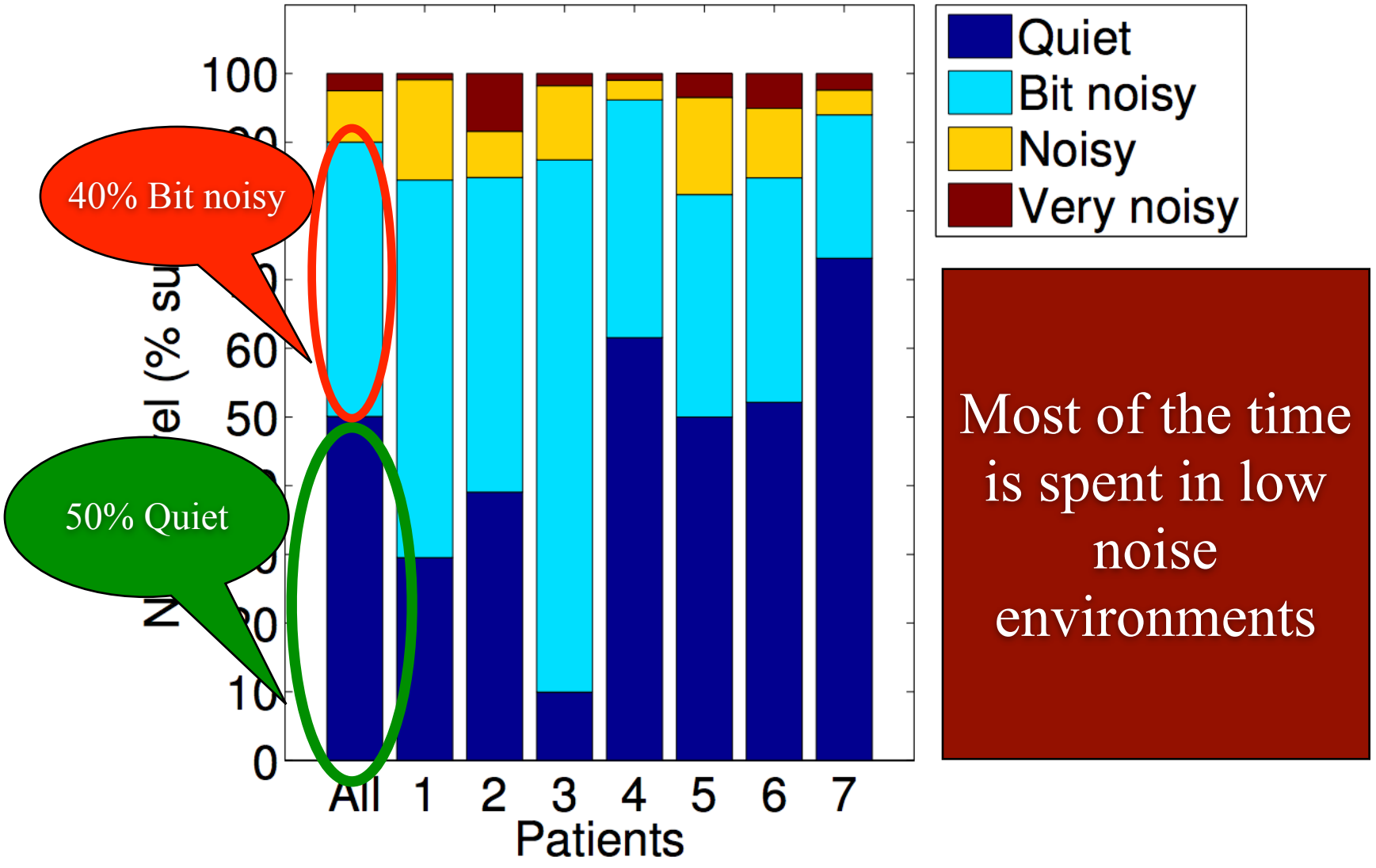
Noise level distribution



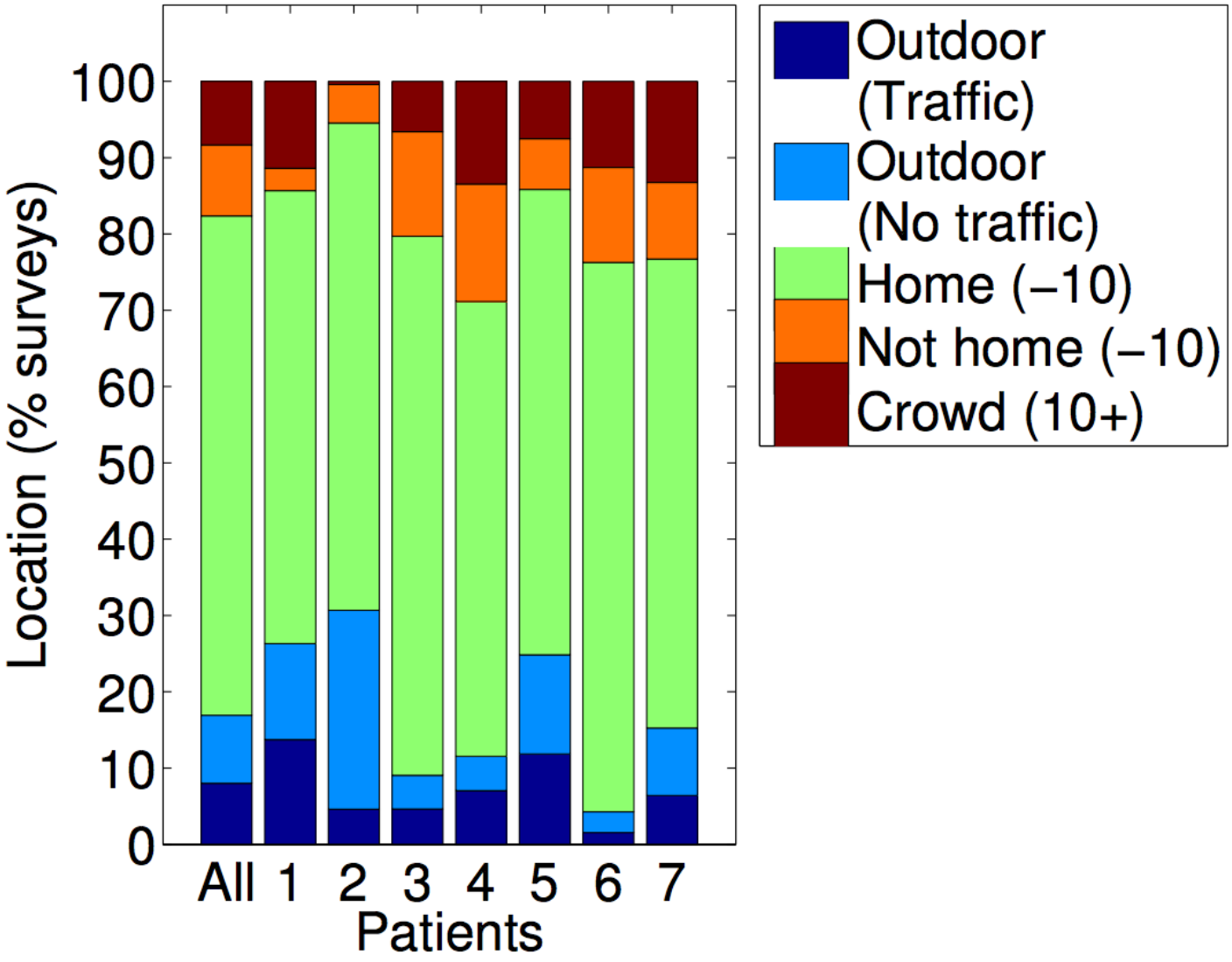
Noise level distribution



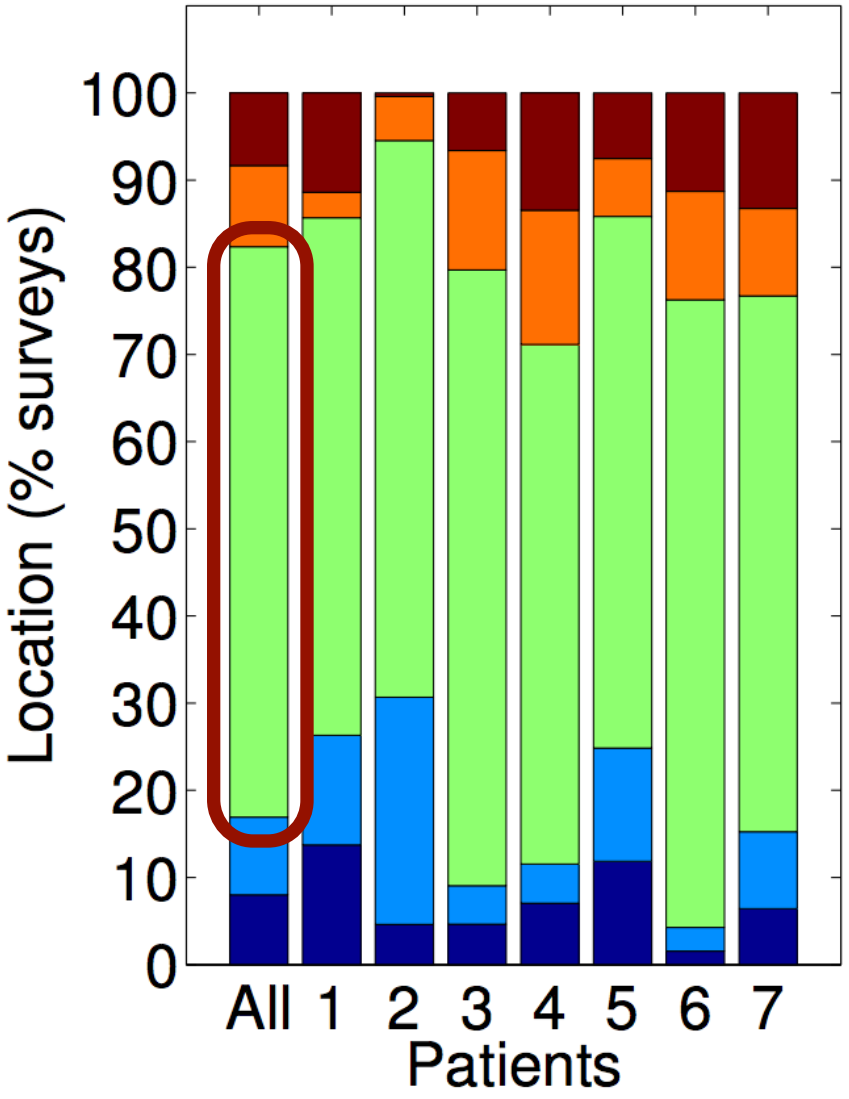
Noise level distribution

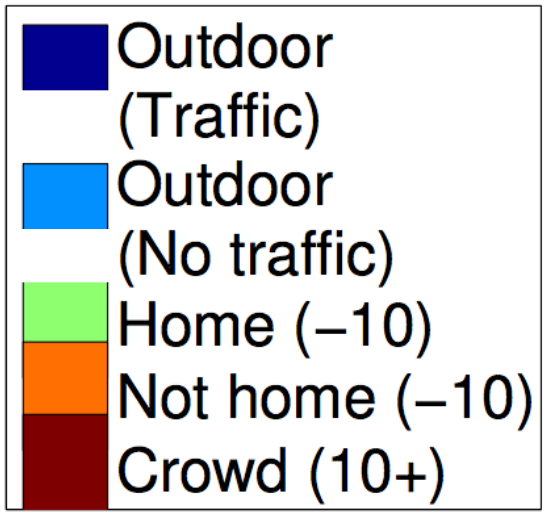


Location context distribution



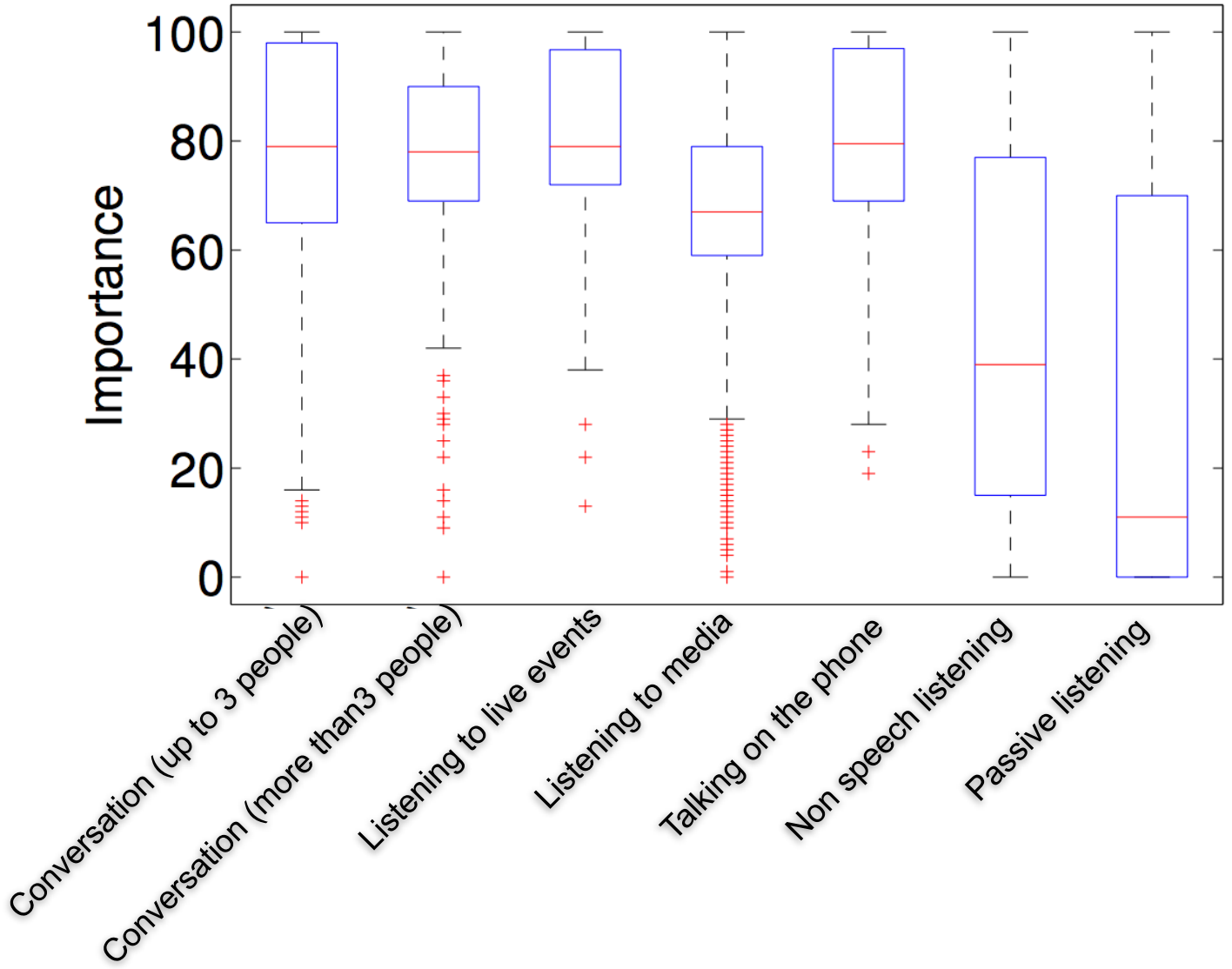
Location context distribution





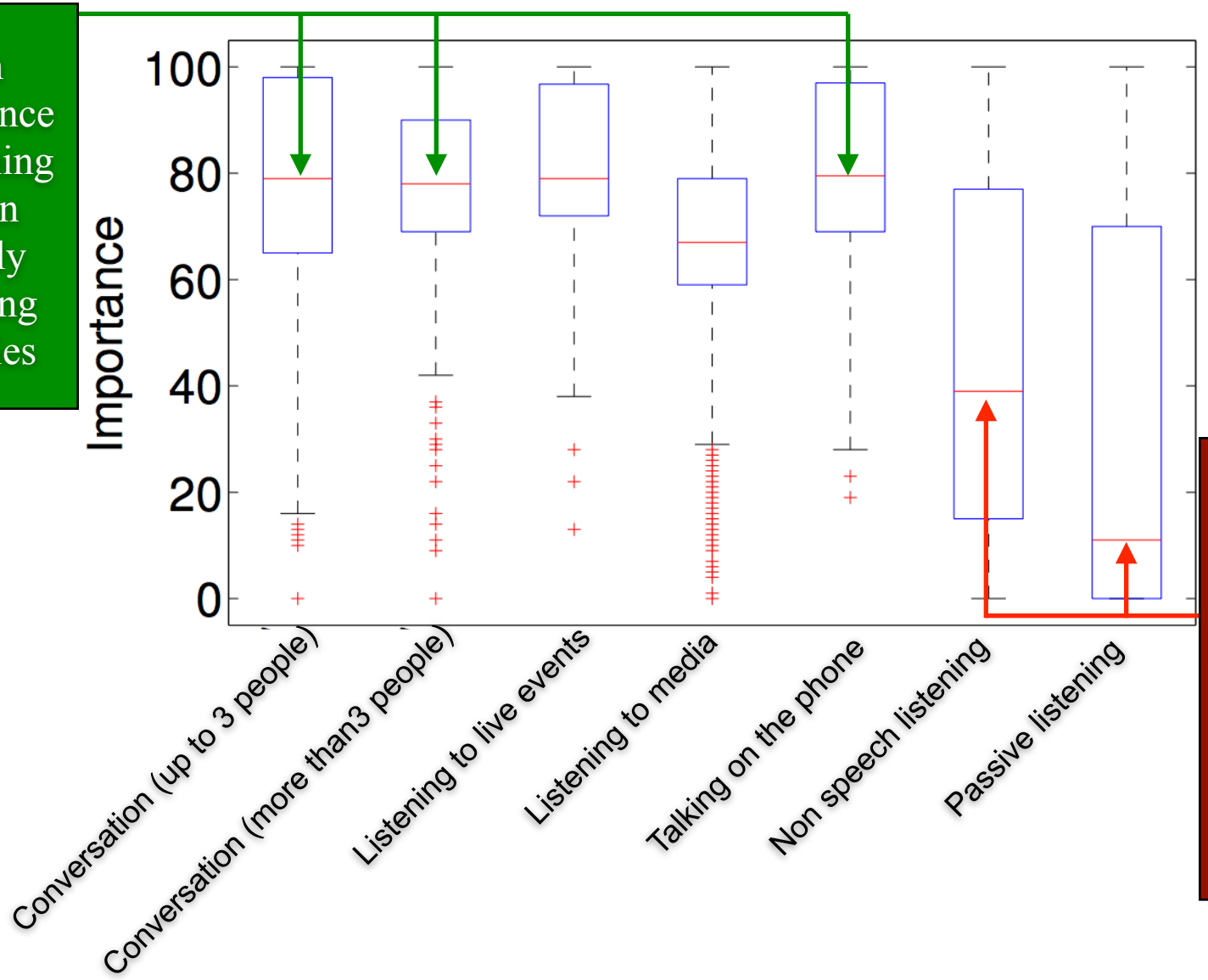
Most of the time is spent at home

Importance of activity context



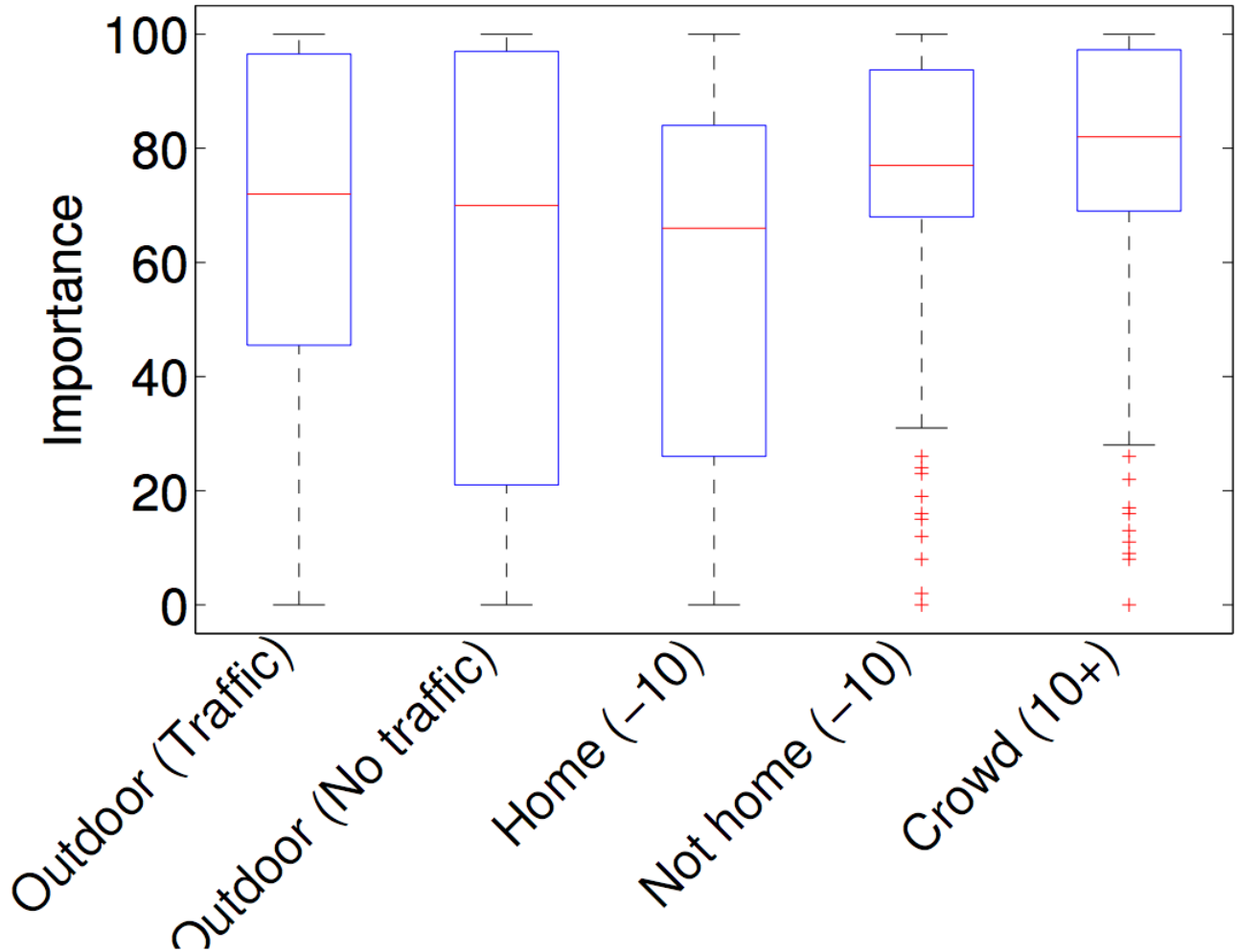
Importance of activity context

High importance to listening well in socially engaging activities



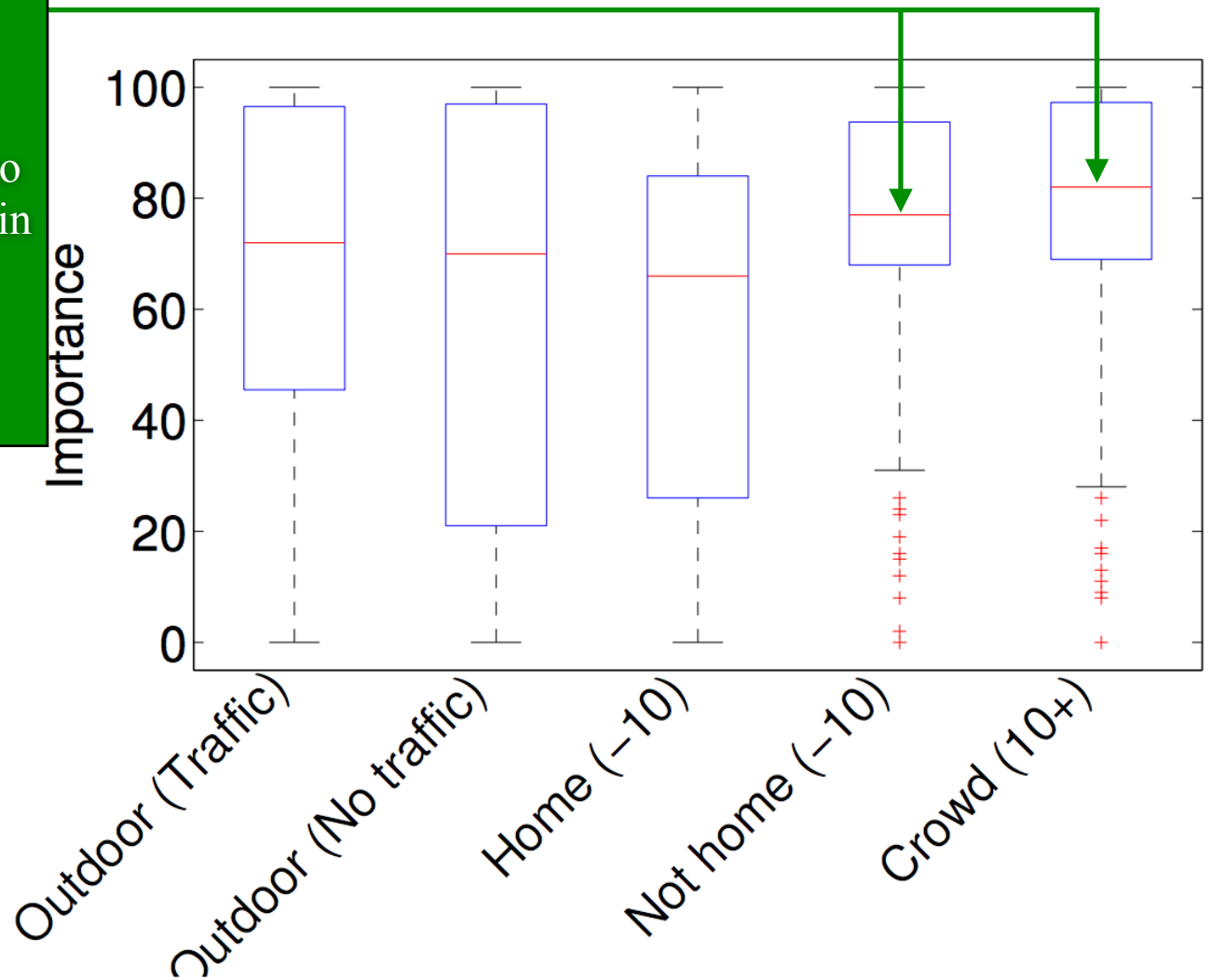
Relatively lower importance to passive listening activities

Importance of location context



Importance of location context

High importance to hearing well in unfamiliar locations



On evaluating auditory contexts

Auditory contexts:

- ***conversations and listening to media are most prevalent***
- ***social engagement necessitates hearing well***

Are the hearing aid outcomes correlated?

Can the hearing aid outcomes be predicted?

Remainder of the talk

Auditory contexts:

- ***conversations and listening to media are most prevalent***
- ***social engagement necessitates hearing well***

Are the hearing aid outcomes correlated?

Can the hearing aid outcomes be predicted?

Remainder of the talk

Auditory contexts:

- ***conversations and listening to media are most prevalent***
- ***social engagement necessitates hearing well***

Are the hearing aid outcomes correlated?

Can the hearing aid outcomes be predicted?

Hearing aid outcome measurement

- Several dimensions are measured:
  - speech perception (**SP**), listening effort (**LE**), loudness (**LD2**), activity participation (**AP**), satisfaction (**ST**), and sound localization (**LCL**)
- Multiple dimensions help in understanding the underlying factors affecting the assessment
- Combining correlated outcomes can
  - reduce inherent noise
  - ease prediction

Existence of correlation

	SP	**LE**	**ST**	**LCL**	LD2	AP
SP	1.0000	0.6178	0.6562	0.5847	0.4785	0.5126
LE	0.6178	1.0000	0.5963	0.5029	0.4732	0.6431
ST	0.6562	0.5963	1.0000	0.5477	0.5429	0.5693
LCL	0.5847	0.5029	0.5477	1.0000	0.3451	0.4030
LD2	0.4785	0.4732	0.5429	0.3451	1.0000	0.4989
AP	0.5126	0.6431	0.5693	0.4030	0.4989	1.0000

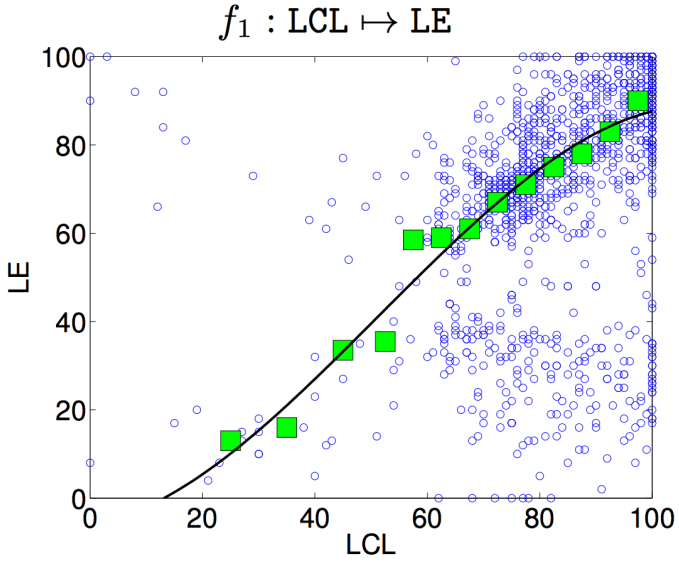
Existence of correlation

- Spearman's rank correlation
- Moderate correlation (0.34 - 0.65)
- Consider the four most correlated outcomes to compute the combined score

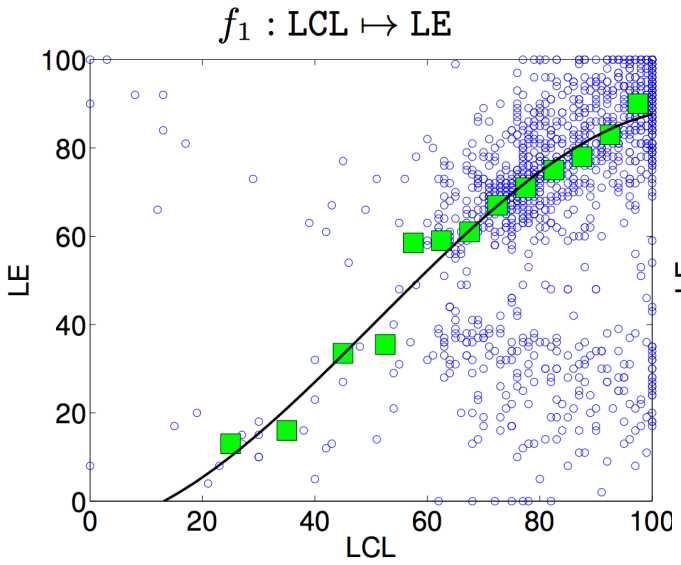
	SP	**LE**	**ST**	**LCL**	LD2	AP
SP	1.0000	0.6178	0.6562	0.5847	0.4785	0.5126
LE	0.6178	1.0000	0.5963	0.5029	0.4732	0.6431
ST	0.6562	0.5963	1.0000	0.5477	0.5429	0.5693
LCL	0.5847	0.5029	0.5477	1.0000	0.3451	0.4030
LD2	0.4785	0.4732	0.5429	0.3451	1.0000	0.4989
AP	0.5126	0.6431	0.5693	0.4030	0.4989	1.0000

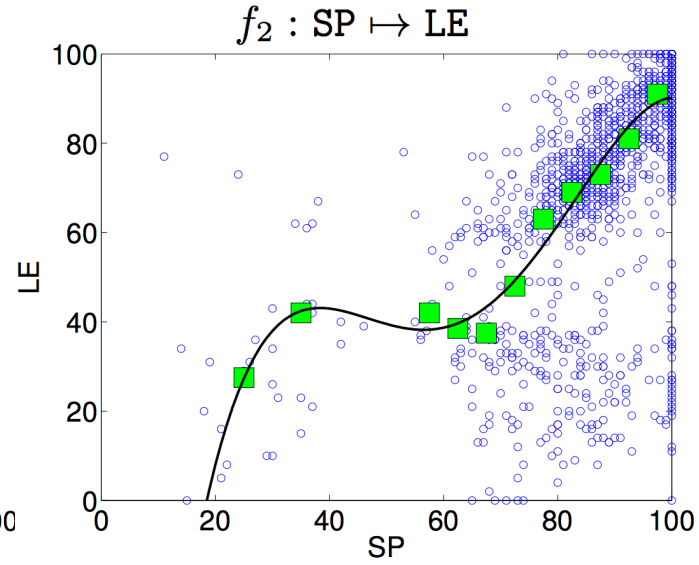
Creating combined score

Creating combined score

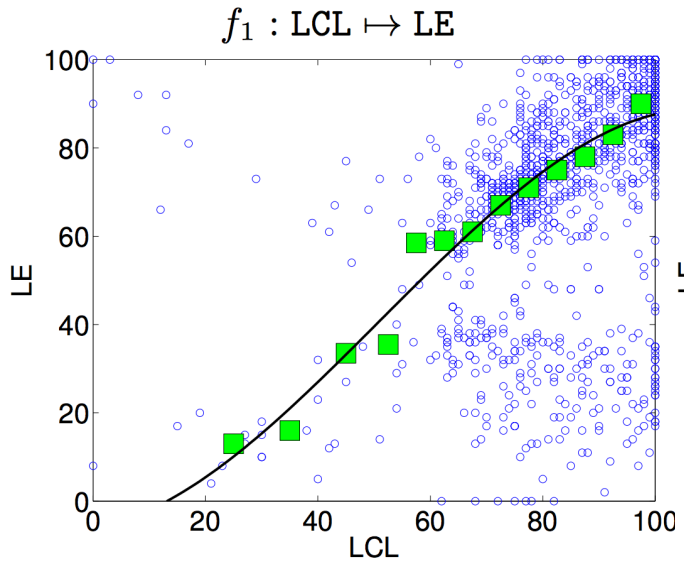


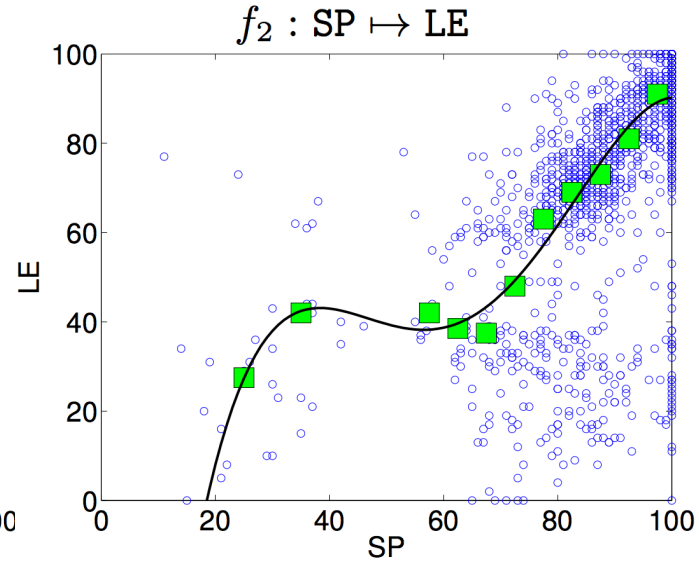
Creating combined score

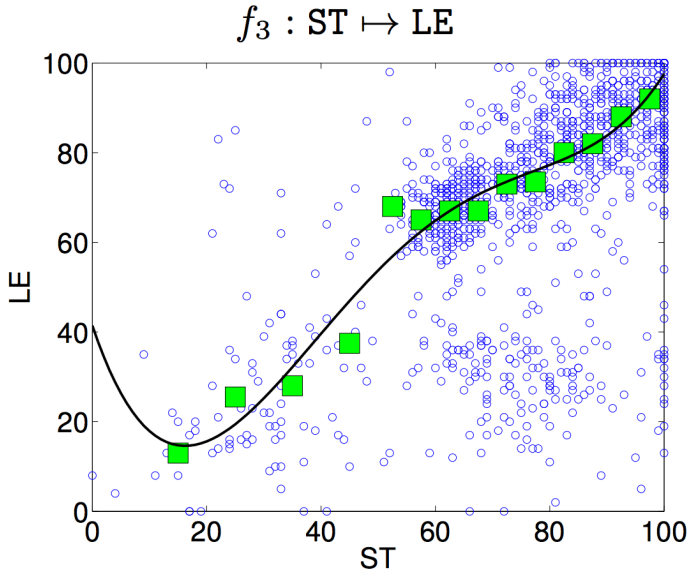




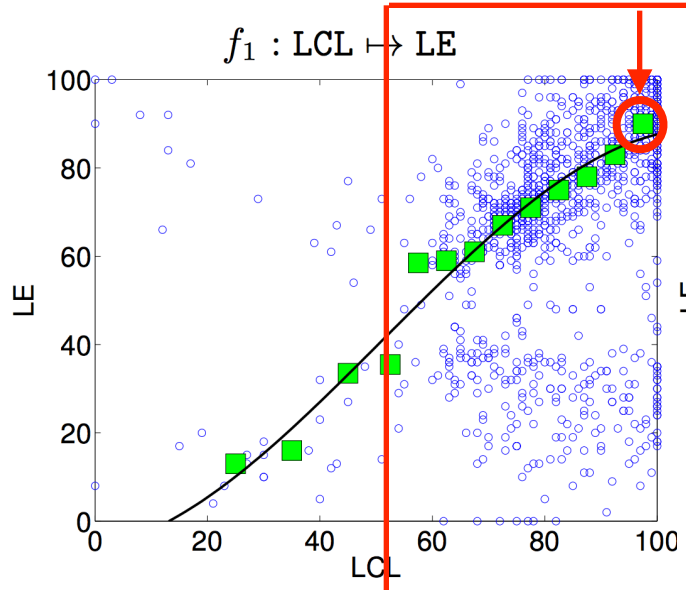
Creating combined score

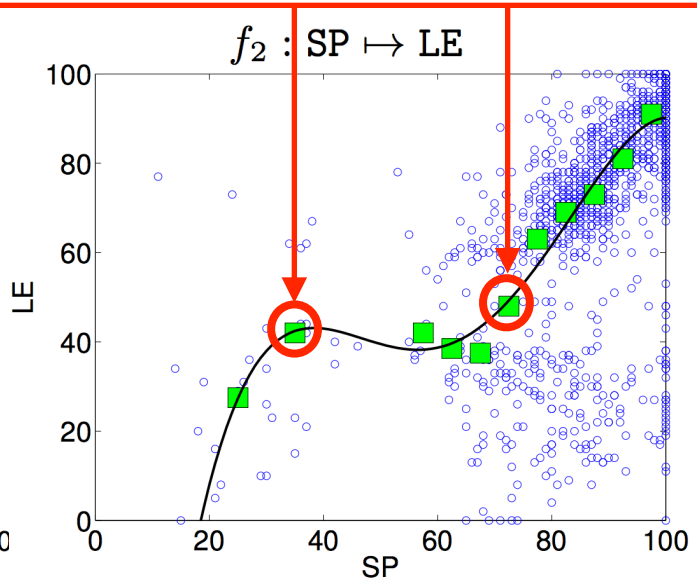


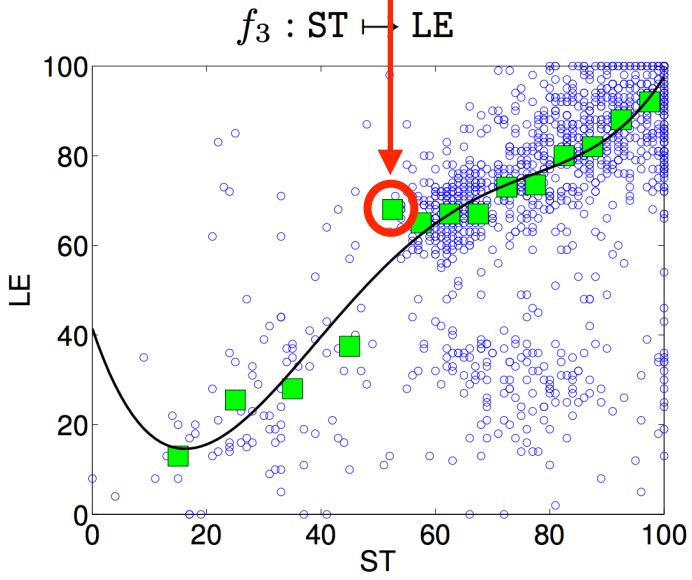




Creating combined score

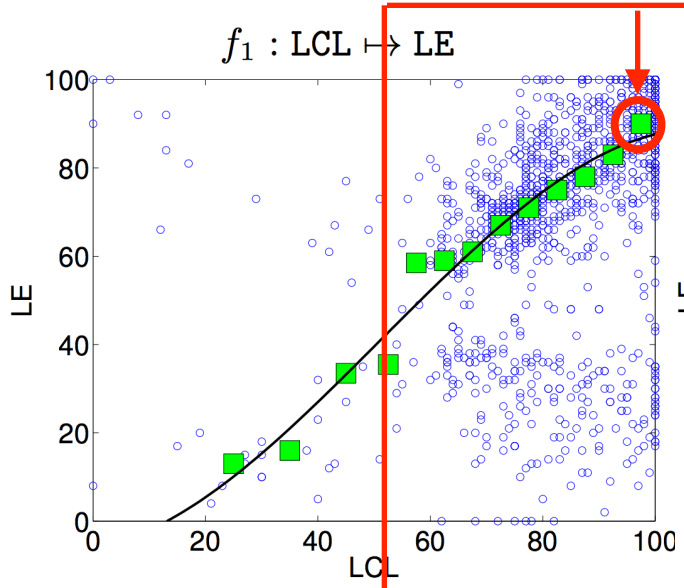


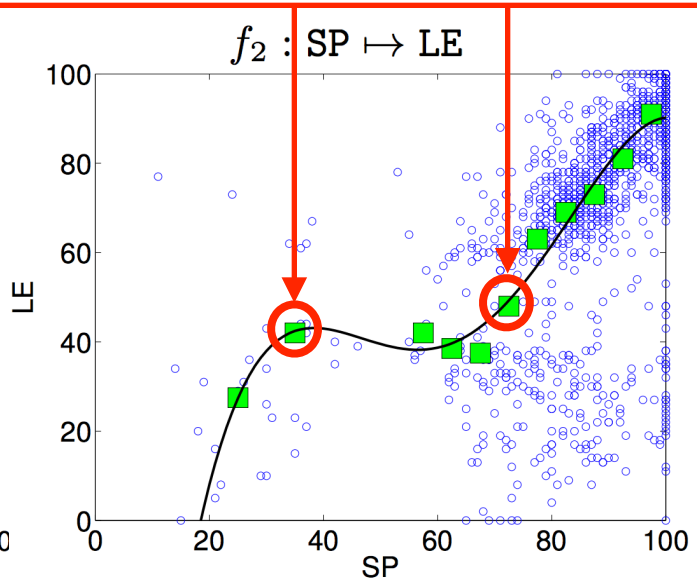


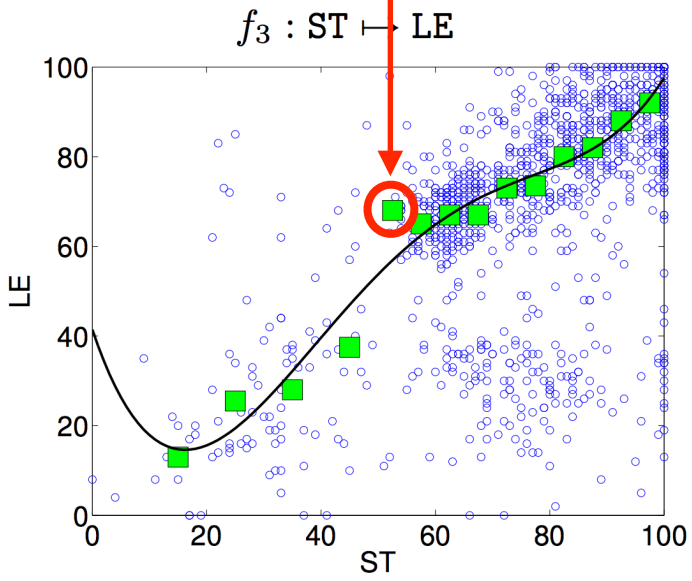


Scores divided into bins, curve fitted through median scores in each bin

Creating combined score







Scores divided into bins, curve fitted through median scores in each bin

- Mapping to LE as it has the widest distribution
  - better discrimination
- f_1, f_2, and f_3 fit a polynomial
- Combined score (**CB**) = avg(**LE**, f_1, f_2, f_3)

On correlation between outcomes

Auditory contexts:

- ***conversations and listening to media are most prevalent***
- ***social engagement necessitates hearing well***

Correlation between outcomes:

- ***hearing aid outcomes are moderately correlated***
- ***calculated a combined score***

Can the hearing aid outcomes be predicted?

Remainder of the talk

Auditory contexts:

- *conversations and listening to media are most prevalent*
- *social engagement necessitates hearing well*

Correlation between outcomes:

- *hearing aid outcomes are moderately correlated*
- *calculated a combined score*

Can the hearing aid outcomes be predicted?

Remainder of the talk

Auditory contexts:

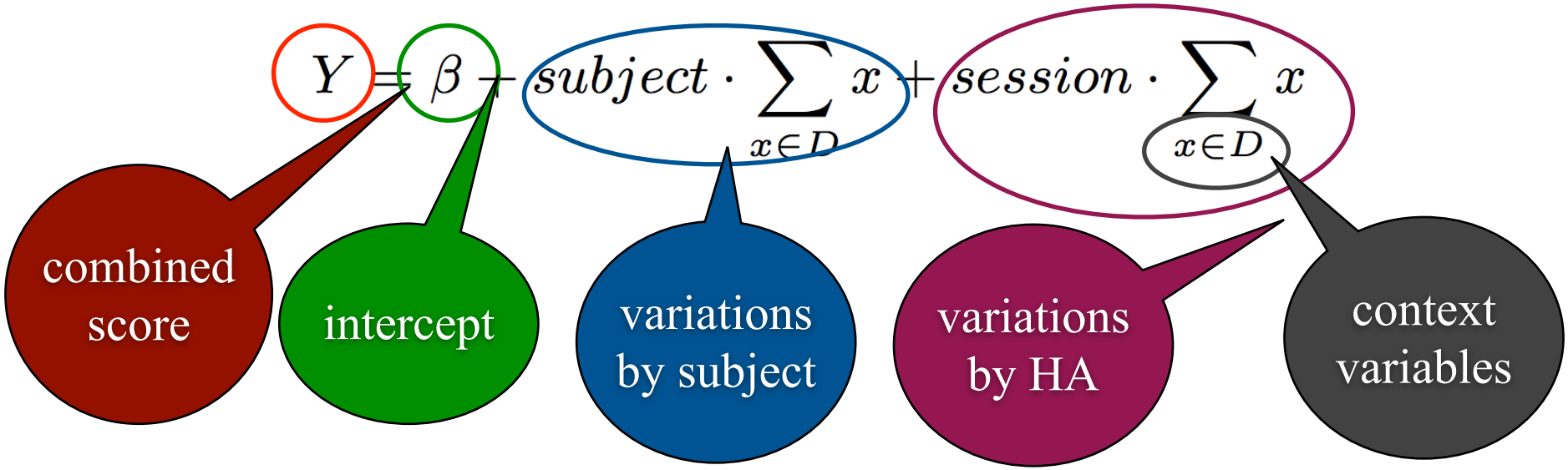
- ***conversations and listening to media are most prevalent***
- ***social engagement necessitates hearing well***

Correlation between outcomes:

- ***hearing aid outcomes are moderately correlated***
- ***calculated a combined score***

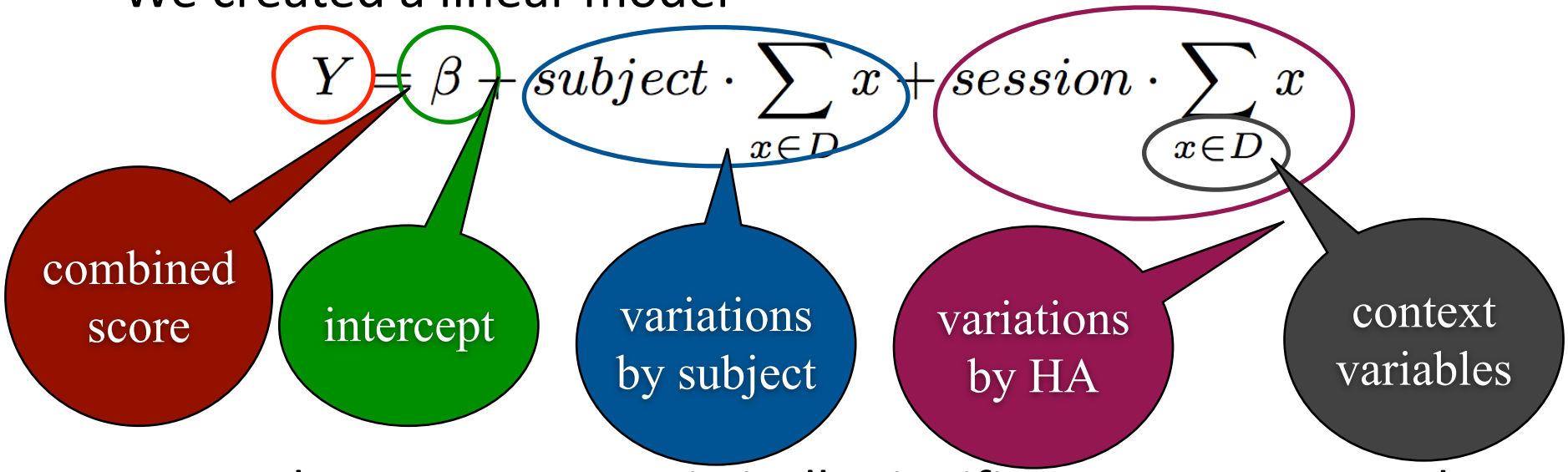
Can the hearing aid outcomes be predicted?

Predicting the combined score



Predicting the combined score

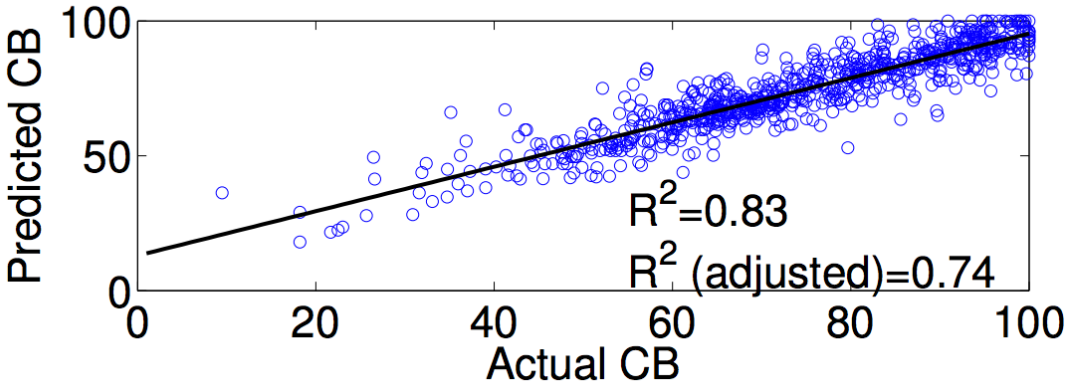
- Challenges
  - incorporate data from all subjects while accounting for individual differences
  - should be able to capture interplay between contexts and outcomes
- We created a linear model



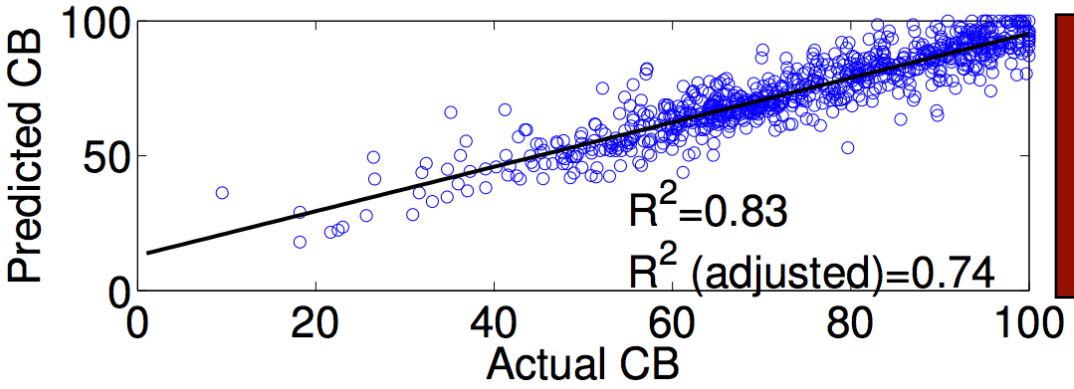
- Terms that were not statistically significant were removed

Evaluating the prediction

Evaluating the prediction

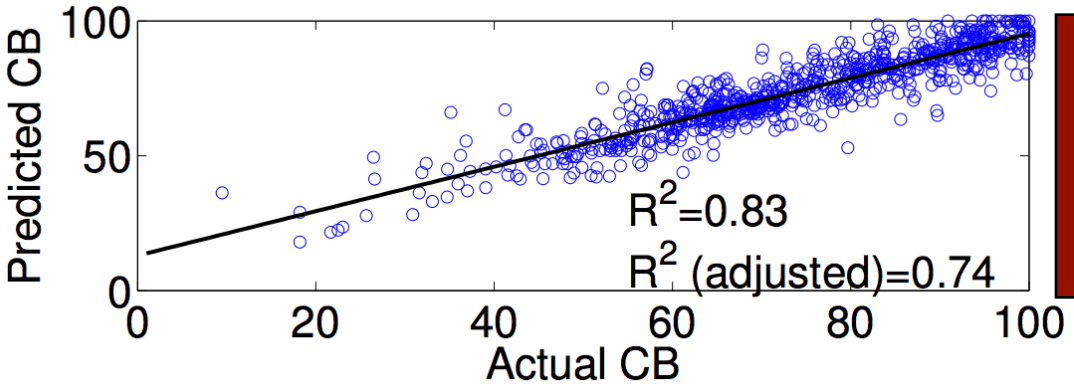


Evaluating the prediction

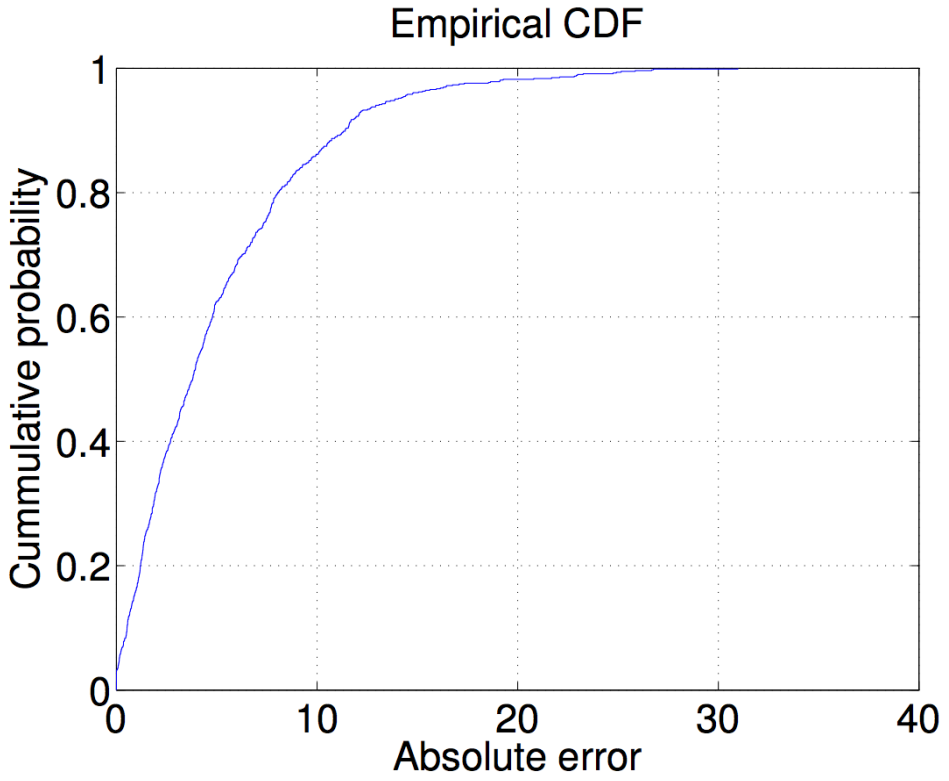


The high R^2 supports the goodness of fit

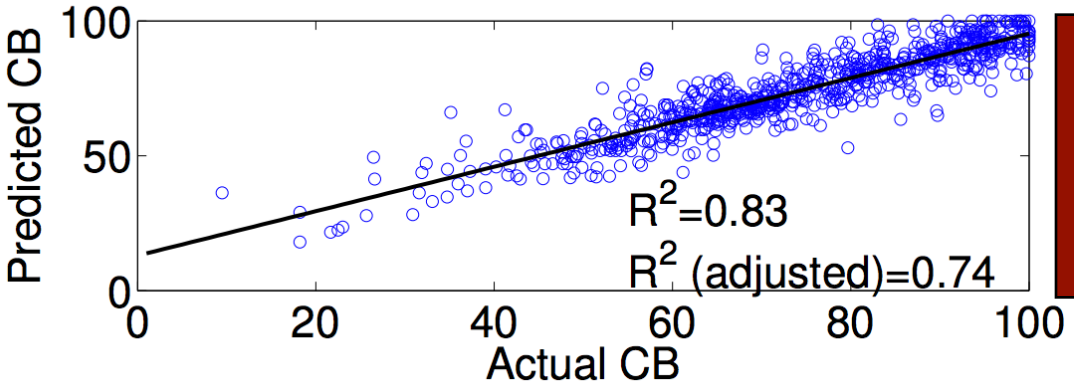
Evaluating the prediction



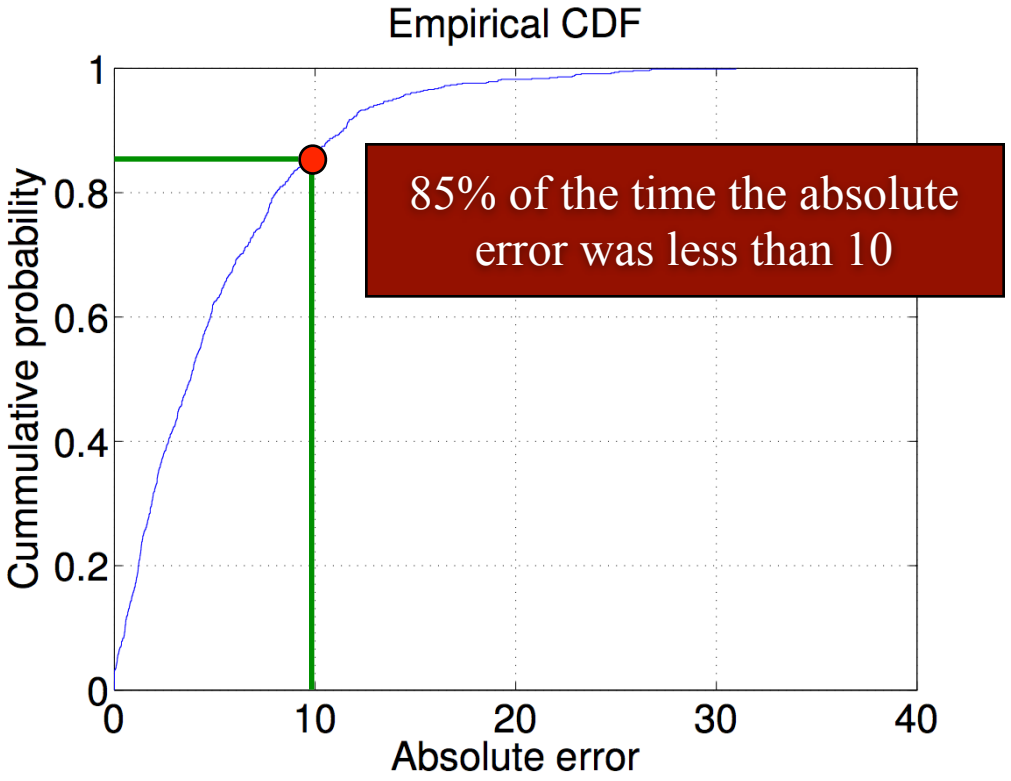
The high R^2 supports the goodness of fit



Evaluating the prediction

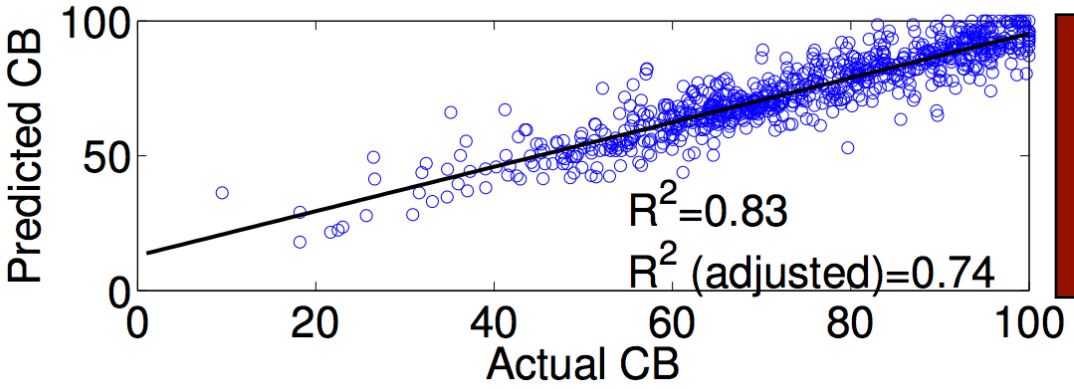


The high R^2 supports the goodness of fit



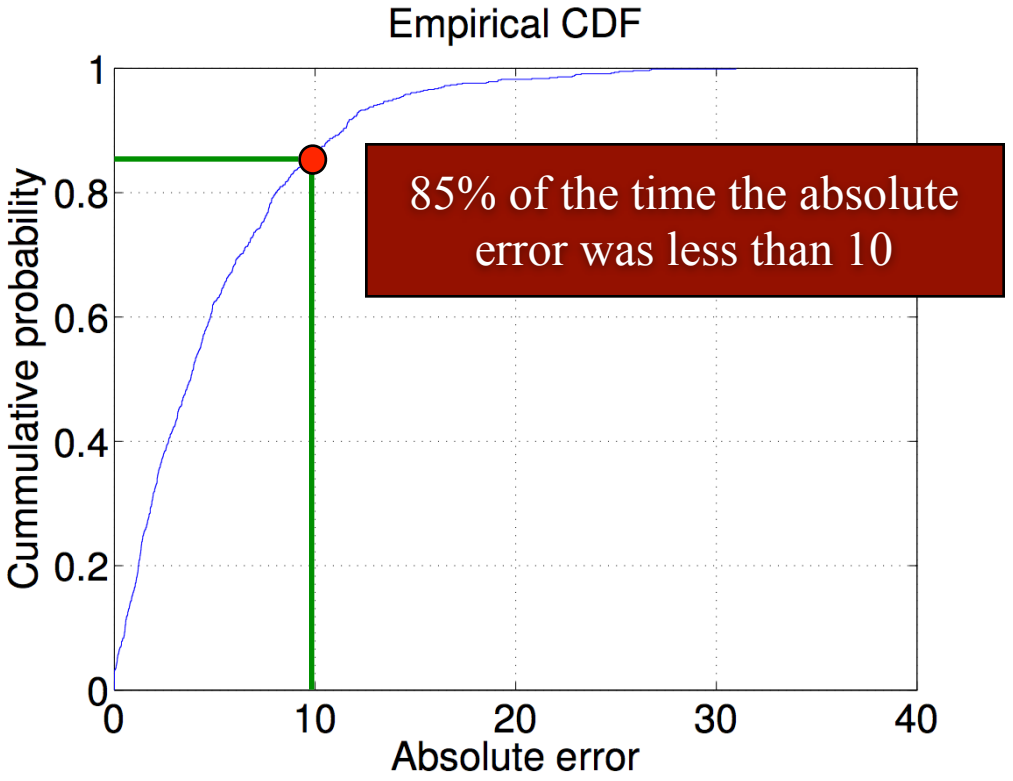
85% of the time the absolute error was less than 10

Evaluating the prediction



The high R^2 supports the goodness of fit

10 fold cross validation based classification of good and bad outcomes was 78% accurate



85% of the time the absolute error was less than 10

On prediction of outcomes

Auditory contexts:

- ***conversations and listening to media are most prevalent***
- ***social engagement necessitates hearing well***

Correlation between outcomes:

- ***hearing aid outcomes are moderately correlated***
- ***calculated a combined score***

Outcome prediction:

- ***auditory contexts + hearing aid features help in understanding outcomes***

Conclusion

- Hearing aid outcomes depend on auditory contexts
  - AudioSense characterizes auditory contexts and outcomes accurately using subjective and objective data captured in-situ
- The proposed methodology enables new insights
  - prevalence of auditory contexts
  - highlighting the dependence of outcomes on contexts
- Future work
  - extend study to 55 users (largest study to date)
  - use audio data to characterize auditory contexts
  - novel sampling techniques to reduce the evaluation burden

Acknowledgements

Collaborators:

Yu-Hsiang Wu
Communication Sciences and Disorders

Elizabeth Stangl
Communication Sciences and Disorders

Shabih Hassan
Computer Science

Ryan Brummet
Computer Science

Acknowledgements

Funding agencies:

- National Science Foundation (1144664)
- Roy J. Carver Foundation (14-43555)
- National Institutes of Deafness and Other Communication Disorders - National Institutes of Health (R03 DC012551)