The perception of environmental sounds and urban soundscapes by listeners with hearing loss

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Disclosures

- I’m employed by UW—Madison
- I receive funding from the NIH/NIDCD
- I have partnerships with Sonova and Apple
- CAA paid for my travel here





Overview

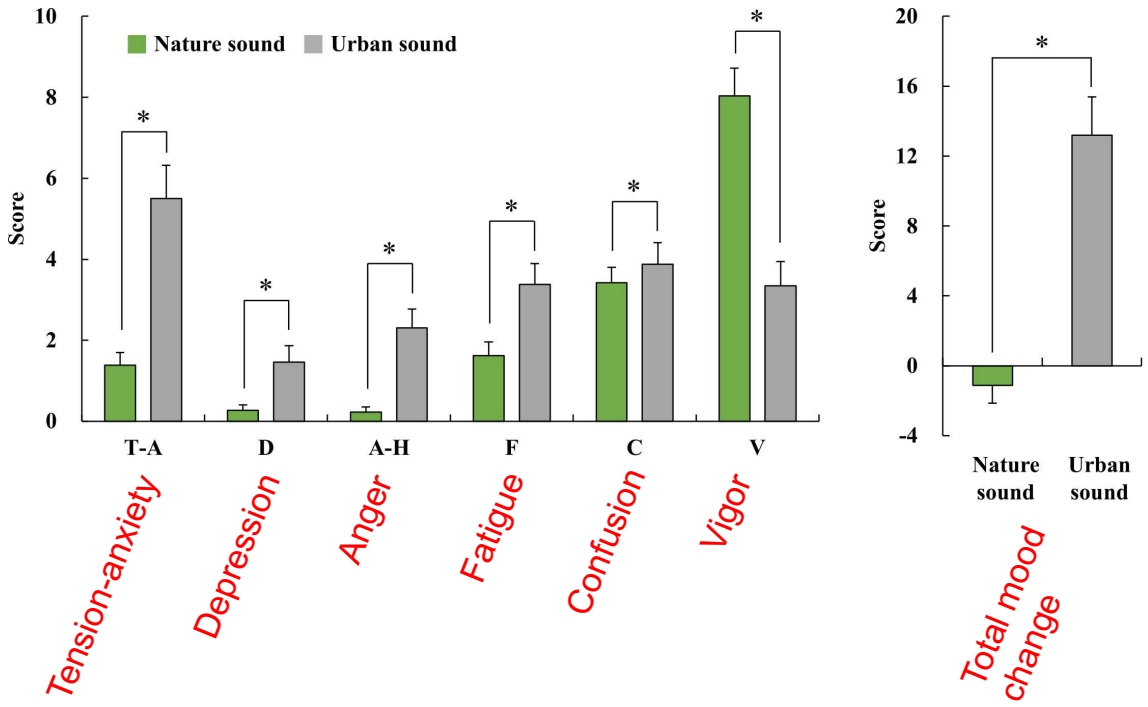
- Some background and the soundscape framework
- Experiment 1: environmental sound ratings in the lab and real world
- Experiment 2: urban soundscape ratings





Nature sounds improve mood; urban sounds worsen it.

Song et al., 2023



It’s not just subjective—EEG shows increases in mental calmness following exposure to sounds of nature.

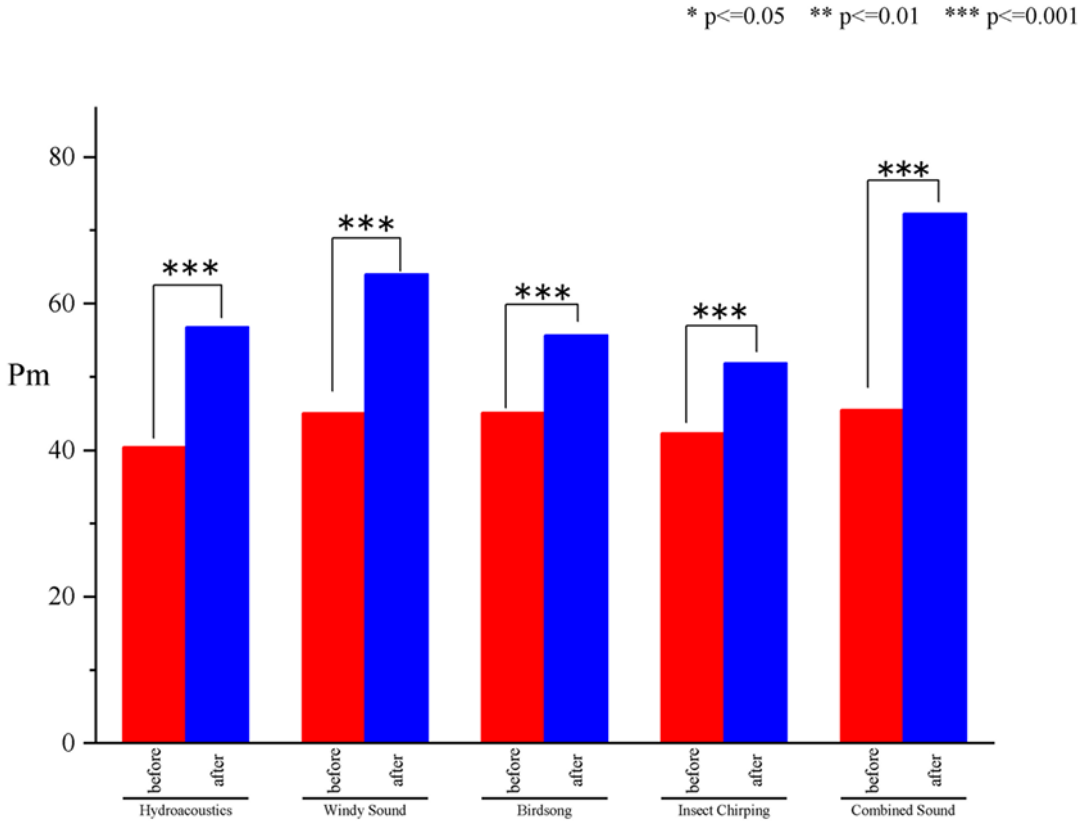
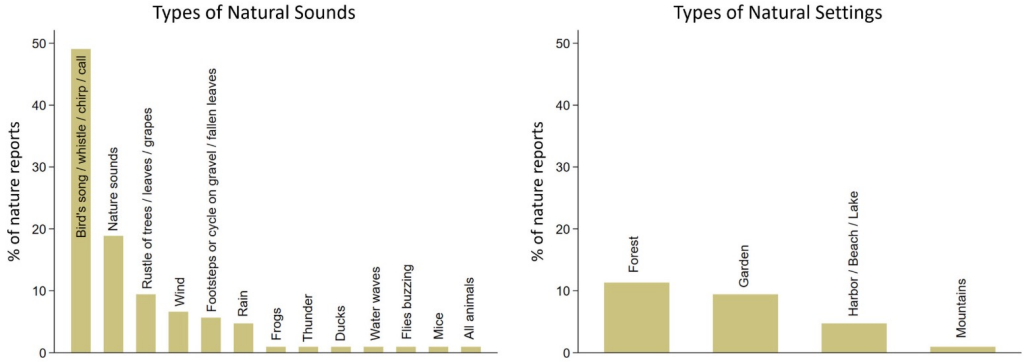


Figure 4. Differences in Pm after listening to the five types of natural soundsc

Bai and Zhang, 2024

HA users don’t expect better nature sounds, but it’s one of the benefits they end up valuing the most.

22% of new users stated hearing natural sounds was a goal of HA fitting (vs. 94% improved TV)—but 83% reported improvements in hearing sounds of nature as a benefit post-fitting



Types of natural sounds (left panel) and settings (right panel) participants described in their positive listening experiences. The percentages are calculated based on the total reports describing natural sounds across all participants.

Lelic et al., 2025

PERSPECTIVES

Check for updates

Sounds of Nature and Hearing Loss: A Call to Action

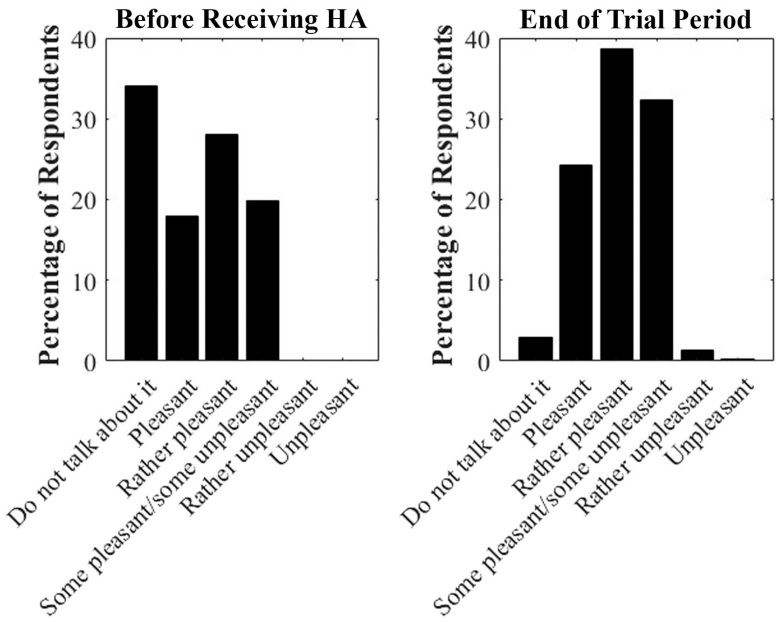
Dina Lelic[1], Erin Picou[2], Valeriy Shafiro[3], Christian Lorenzi[4]

Authors and Affiliations >

Ear & Hearing 46(2):p 298-304, March/April 2025. | *DOI:* 10.1097/AUD.0000000000001601

HA users don't expect better nature sounds, but it's one of the benefits they value most.

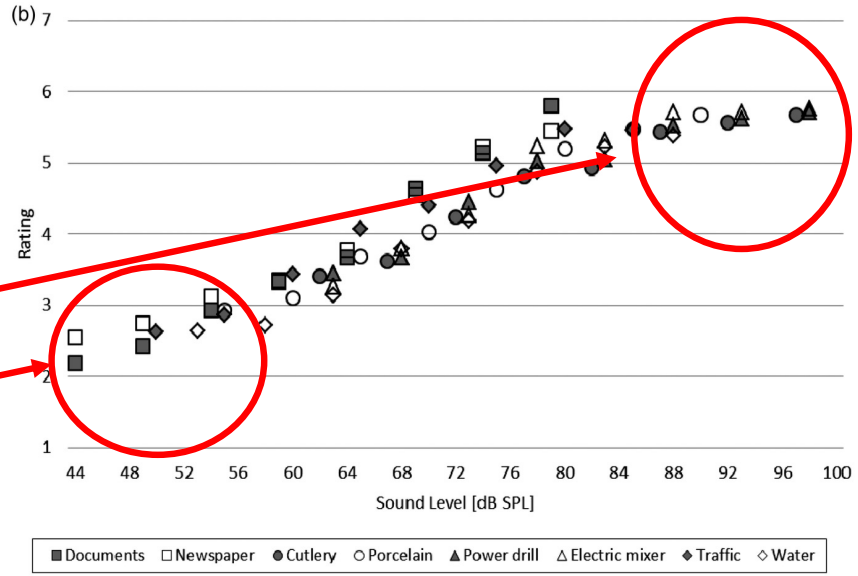
- Similar findings based on data from clinician report—HA patients do not "know what they are missing" until they are fit
- Improvements in sounds of nature specifically are es*pecially* commonly reported as a benefit by HA users in rural areas



HAs also seem to make some sounds more annoying.

Power drill, cutlery, electric mixer are very annoying

Paper, water are not very annoying



Skagerstrand et al., 2014

…Every clinician knows this, but this is (I believe) the only actual study on this

Hearing loss dulls responses to emotional sounds.

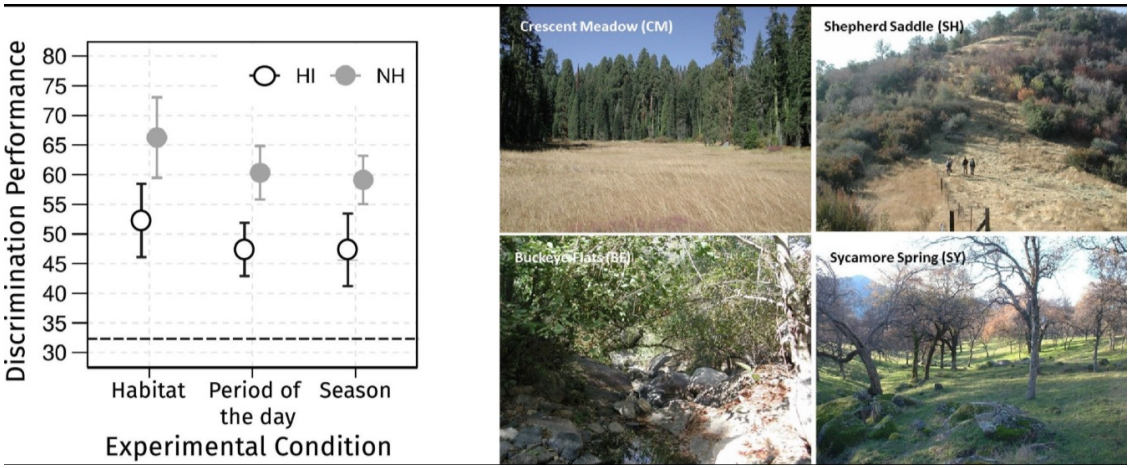
- Most work on non-speech sounds in listeners with hearing loss has focused on emotional responses (valence, or pleasure, and arousal, or degree of activation)
- **Main finding: hearing loss "dulls" responses** (Picou, 2016; Tawdrous et al., 2022)
- Little research, but data suggest HAs don't help in the lab, but might in the real world (Picou, 2016; Tawdrous et al., 2022; Homan & Naylor, 2025)
- Listeners with hearing loss are worse at discriminating emotions than listeners with NH (e.g., Christensen et al., 2019)
- But—this research has been limited to emotional responses and has used highly valent and arousing non-speech sounds—not regular types of environmental sounds common in daily life





We know very little about hearing loss, HAs, and everyday soundscapes.

- One study: like emotion, hearing loss impairs discrimination of habitat, season, and time of day of natural soundscapes



Miller-Viacava et al., 2024

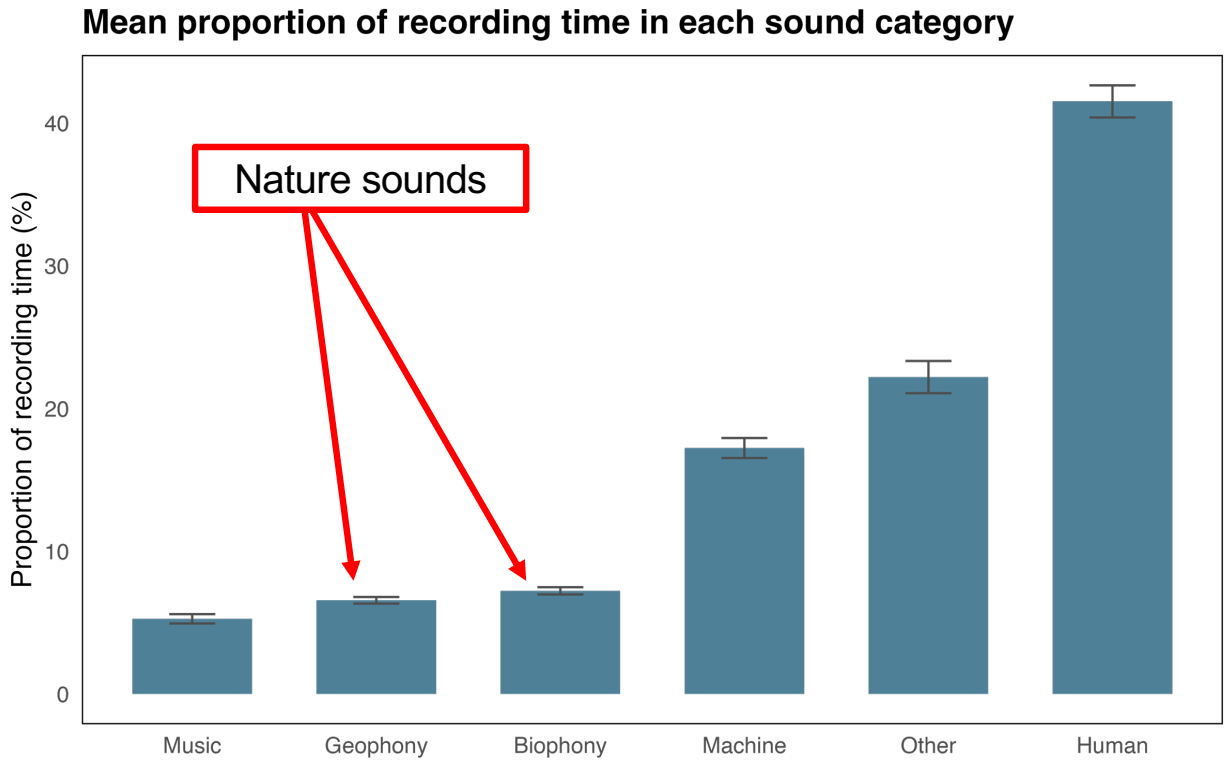
How did we get interested in this?



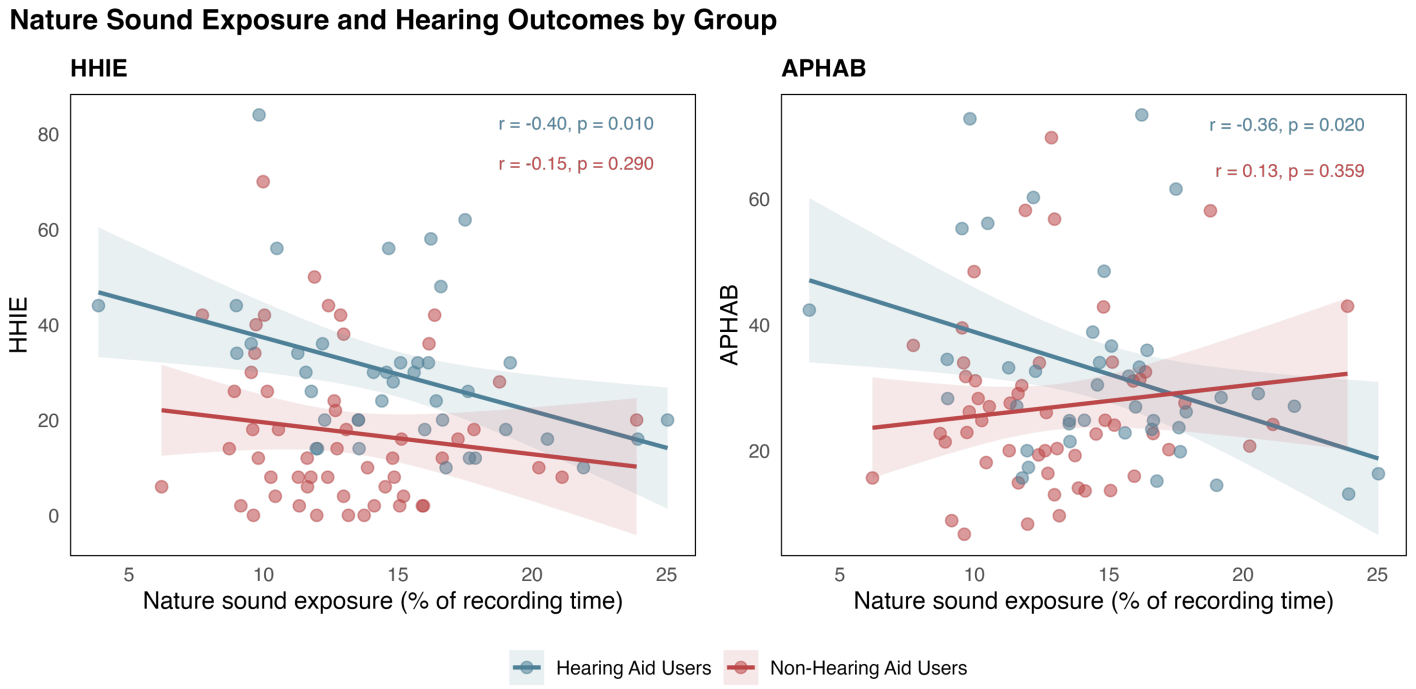
- Our lab has primarily been interested in communication-focused soundscapes.
- **Is there a relationship between exposure time to sounds of nature and hearing-related outcomes?**
- 105 older adults with hearing loss (51 HA users, 54 non-users)
- Continuous audio recording for 2 weeks
- Audio recordings analyzed using YAMNet.
  - 521 audio classes grouped into:
    - Human (speech, etc.)
    - Machine (vehicle, etc.)
    - Music
    - Geophony (wind, rain, etc.)
    - Biophony (birds, etc.—no domestic animals)
    - Other

We grouped these together into “Natural Sounds”

Natural sounds make up only a small share of everyday listening.



HA users (but not non-users) who are exposed to more sounds of nature report better hearing-related outcomes.



How can we build meaningful research around environmental sound perception?

- We want to better understand the effects of hearing aids on the experience of environmental/urban soundscapes
- But how?
  - Environmental sounds can acoustically be almost anything!
  - What do we measure?
  - How do we interpret findings?





The Soundscape framework

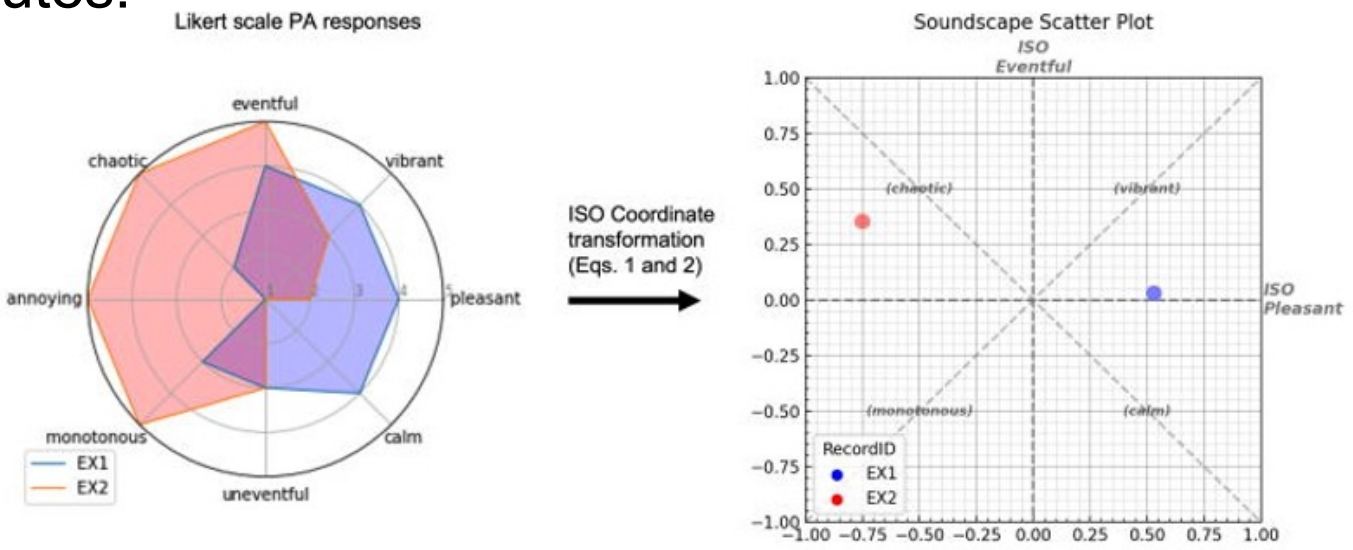
- The soundscape is the "*acoustic environment as perceived or experienced and/or understood by a person or people, in context.*" (ISO, 2014)
  - *As perceived or experienced*
  - *In context*
- Much work on standardizing the soundscape framework, measurement, and reporting (Axelsson et al., 2010; Erfanian et al., 2019; Papadakis et al., 2025)





Soundscape perception is measured on 2 orthogonal axes: pleasant and eventful

- 8 emergent attributes:
  - Pleasant
  - Vibrant
  - Eventful
  - Chaotic
  - Annoying
  - Monotonous
  - Uneventful
  - Calm



Mitchell et al., 2022

The soundscape has 3 primary types of sounds.

Anthrophony



Biophony



Geophony



Can we use this framework to capture how hearing loss and HAs change soundscape perception?

To our knowledge, the soundscape framework has not been applied to hearing loss, hearing aids, or audiology generally.

Eventually, this could result in a useful clinical tool to evaluate impacts of hearing loss and interventions on soundscape perception.

- **Experiment 1:** Effects of hearing loss and hearing aids on environmental sound attribute ratings in the lab and real world
- **Experiment 2:** Effects of hearing loss and hearing aids on urban soundscape attribute ratings

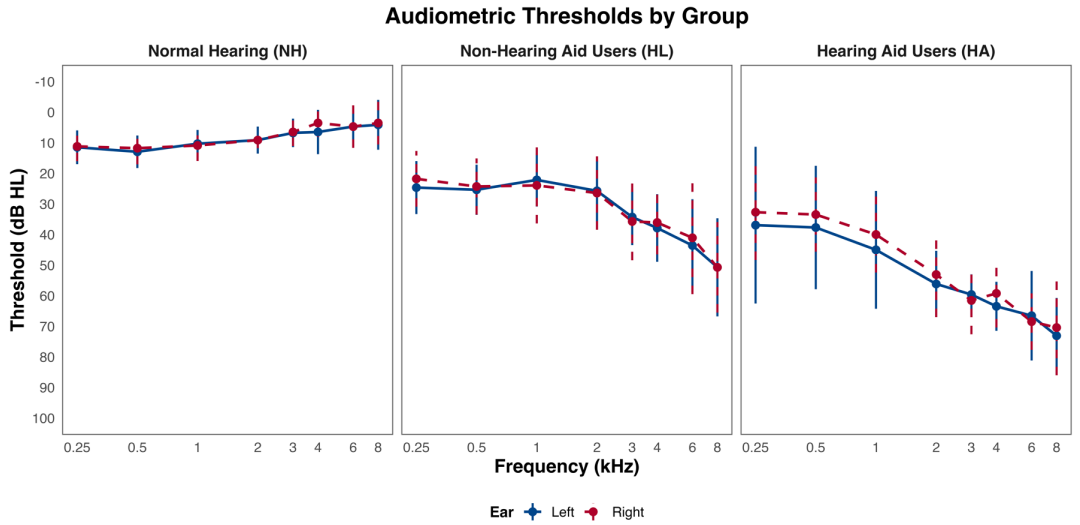


This is early work!



Participants

- **NH:** 17 younger normal hearing listeners
- **HL:** 13 older adults with hearing loss who do not use hearing aids
- **HA:** 13 older adults with hearing loss who do use hearing aids—participants wore their own hearing aids



Experiment #1: Environmental sound ratings in the lab and real world

1. Do environmental sound ratings differ between listeners with normal hearing and listeners with hearing loss?
2. For HA users, do HAs change ratings? Is there a difference between listeners with HL who don't wear hearing aids and those that do?
3. Does the sound category change ratings, and do category effects differ across listener groups?
4. Are ratings driven by the quality of the sound, or recognizing the sound?





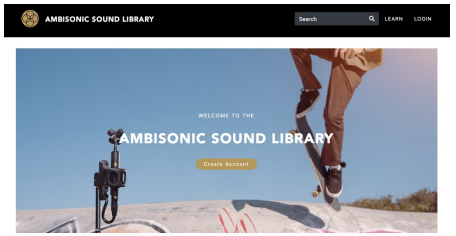
Experiment #1: Procedure

- In the lab, participants rated the pleasantness and eventfulness of each sound
  - -10 (very unpleasant/very uneventful) to +10 (very pleasant/very eventful), with 0 = neutral
  - Then, they had to select what sound category the sound belonged to.
- During one week of EMA, participants reported every 2 hours whether they had heard nature, animal, human, or machine sounds in the prior hour
  - For each category they reported hearing, they rated the pleasantness and eventfulness on the same -10 to +10 scale
  - HA users reported on whether they were wearing their HAs

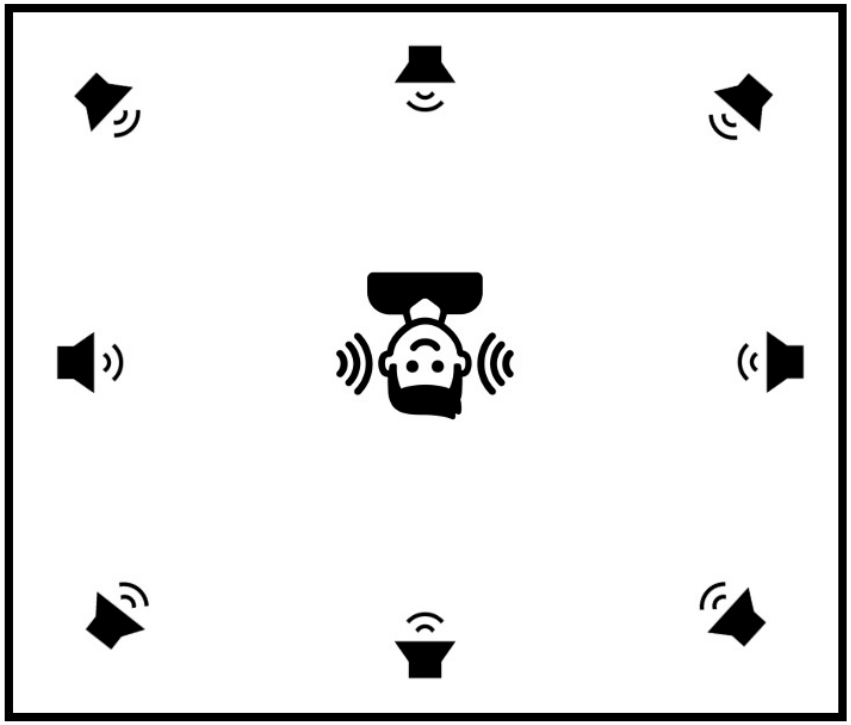




Experiment #1: Lab stimuli

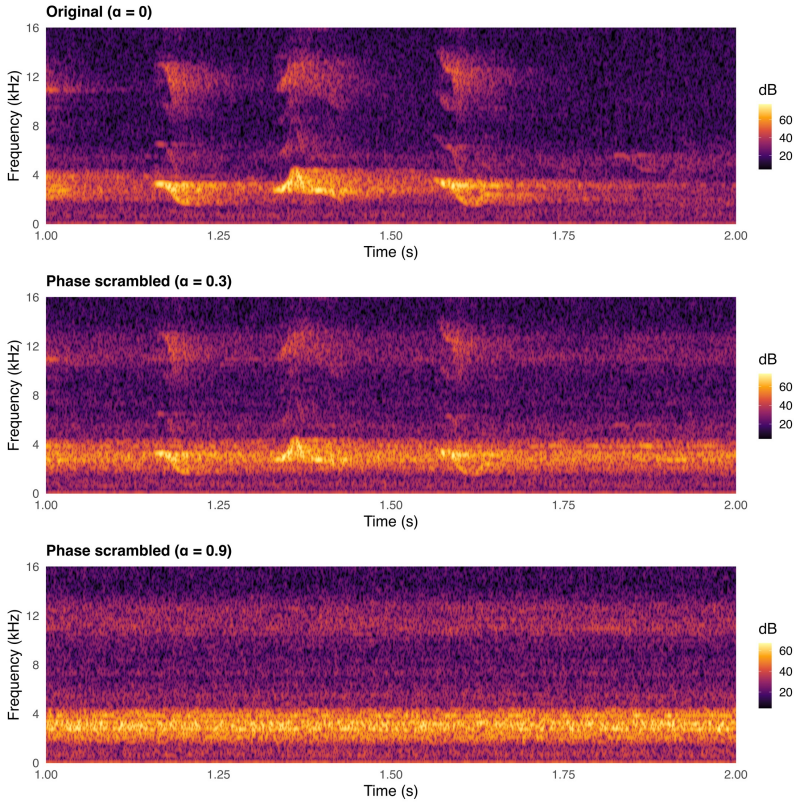


- RODE Ambisonic library
  - **Geophony** (rain, wind, waves, fire)
  - **Biophony** (birds, insects, horses)
  - **Anthrophony** (*humans*—babble in a market, footsteps, small group at a park)
  - **Anthrophony** (*machines*—cars, planes, elevator)



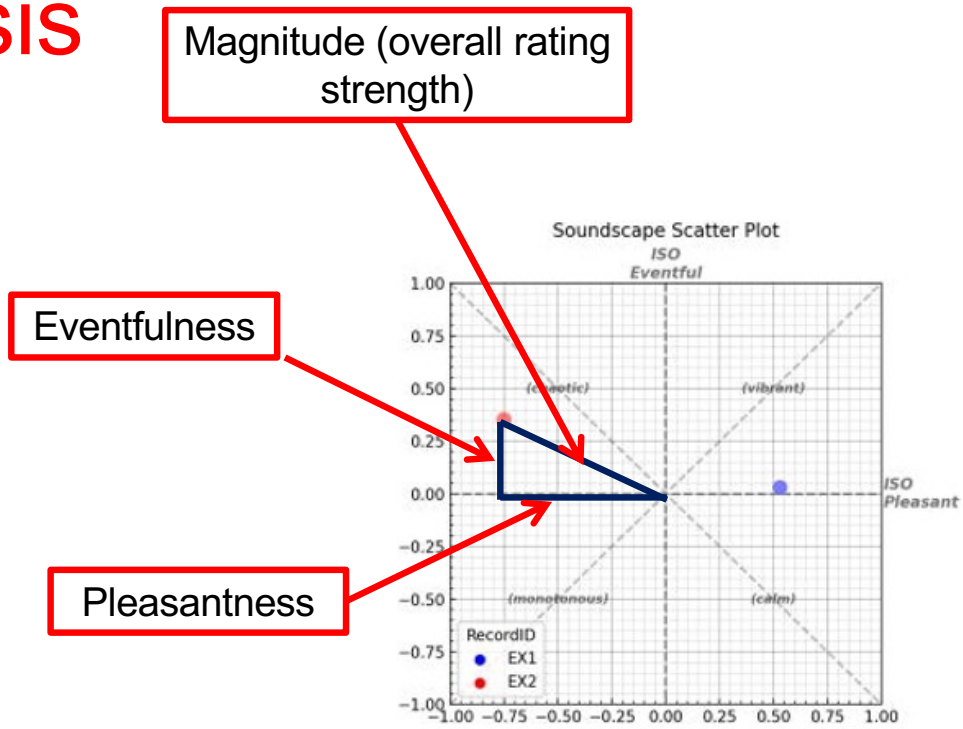
Experiment #1: Lab stimuli

- Some sounds were phase scrambled (0%, 30%, and 90%) so the sound quality would remain, but they would be harder to recognize

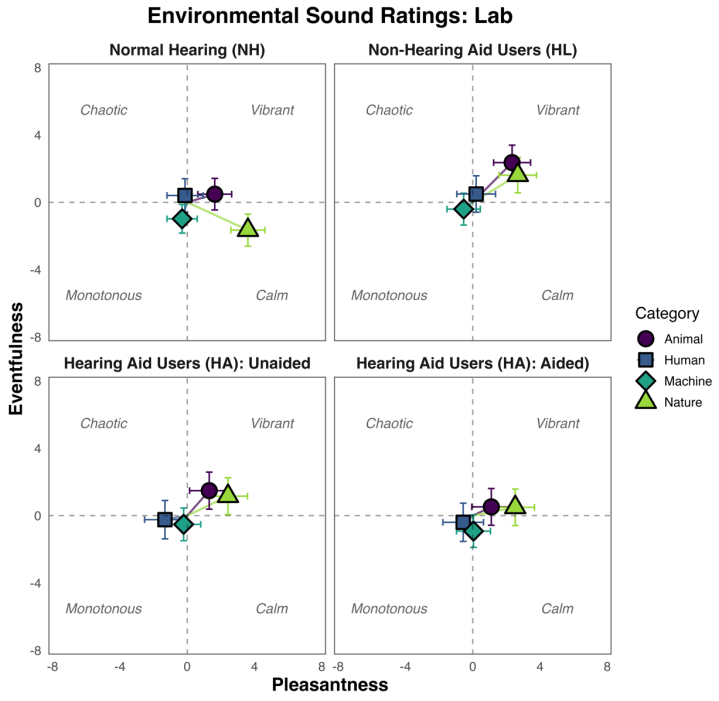


Experiment #1: Analysis

- We analyzed each side of the rating triangle
- Tested interactions of group with category, correct identification (in the lab), and phase scrambling (in the lab)
- Compared lab to real-world ratings (using only the non-phase scrambled, correctly identified tokens from the lab for meaningful comparison)

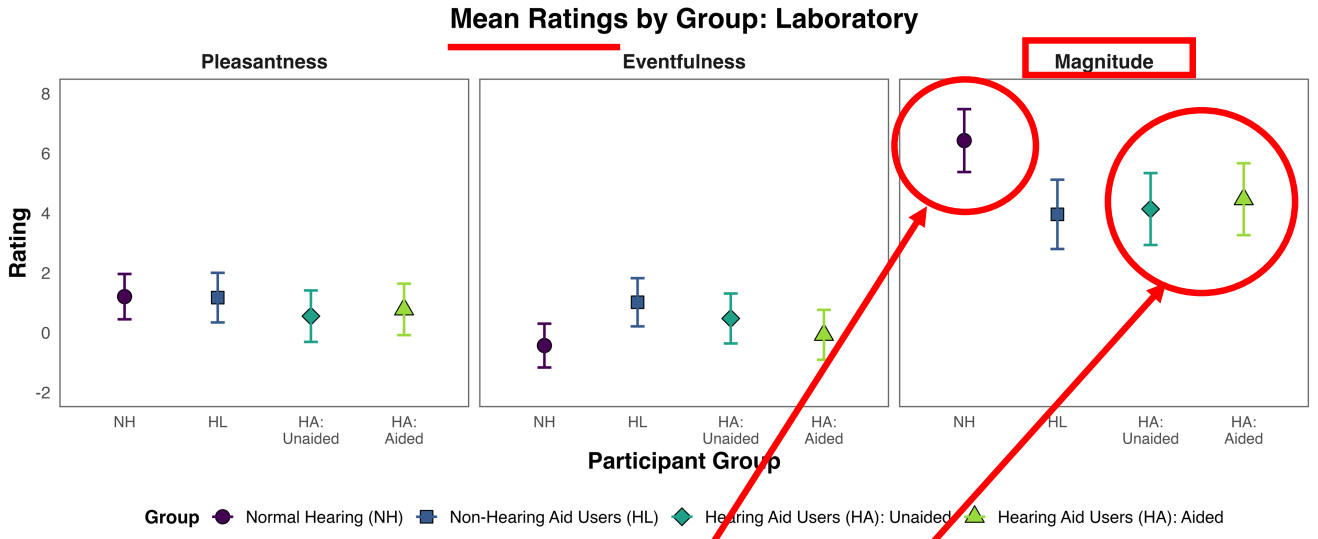


Nature and animal sounds are pleasant; humans and machines are neutral.



- On average, not very strong ratings across groups
  - Lab sounds?
  - Means include +/-
- Animal and nature sounds = vibrant / calm (pleasant)
- Machine and human sounds = monotonous / neutral

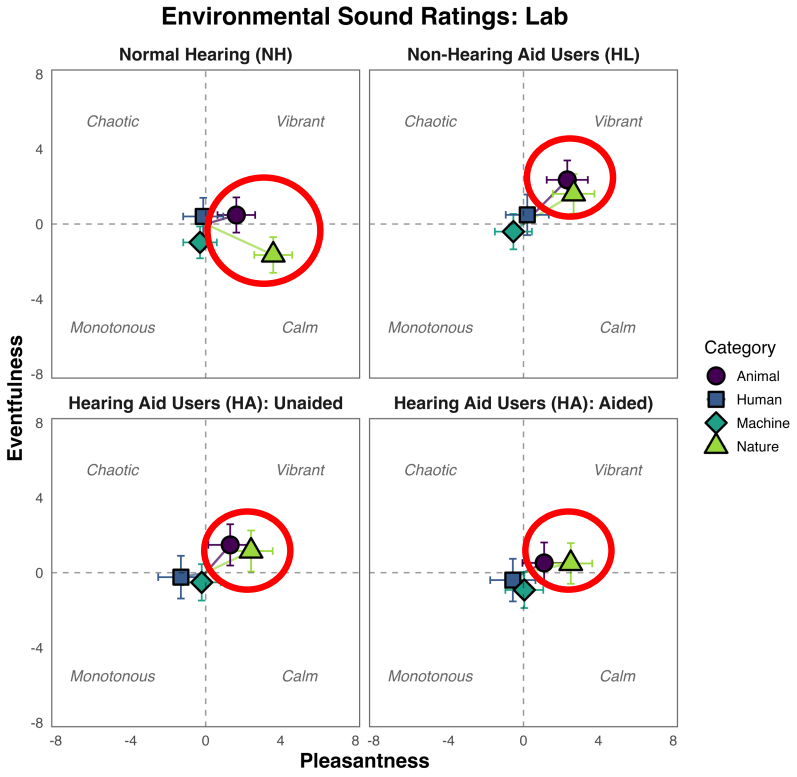
Magnitude: Hearing loss dulls ratings, and hearing aids barely restore them.



- NH participants had **stronger** ratings.

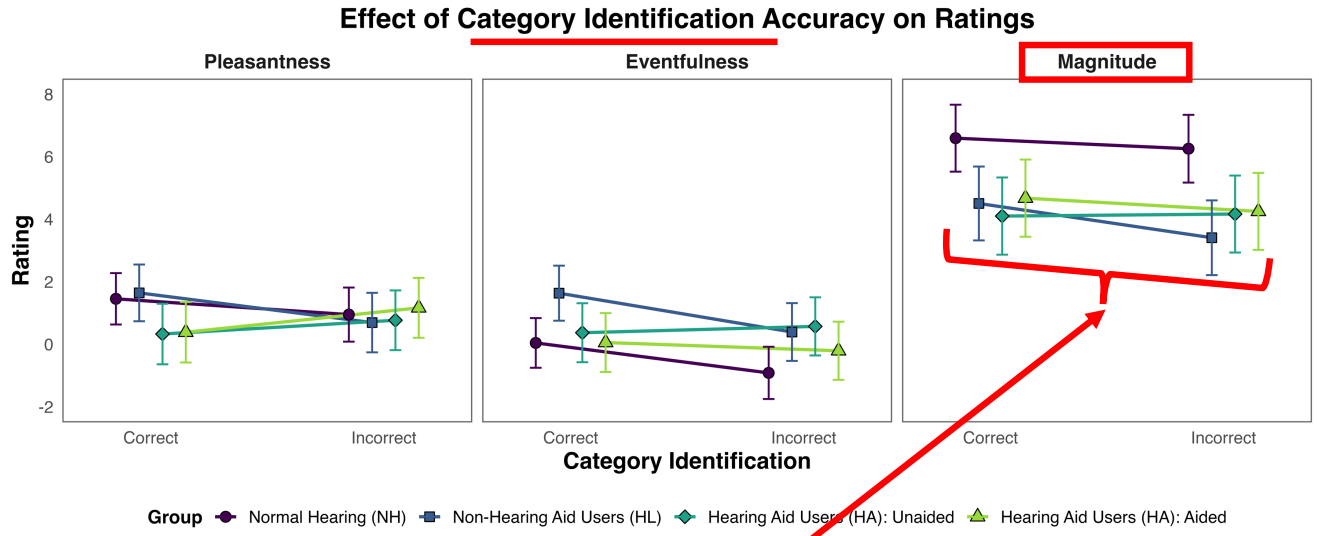
- HA users showed a small **increase** in rating magnitude when aided.
  - Still significantly lower than NH participants.

Magnitude: NH rated machines more strongly, and hearing aids increased rating strength of machines



- Significant group x category interaction:
  - Driven mostly by stronger ratings for machines by NH than all HL/HA
  - Small effect of hearing aids increasing rating magnitudes for machines
- Ratings were strongest for nature and animals

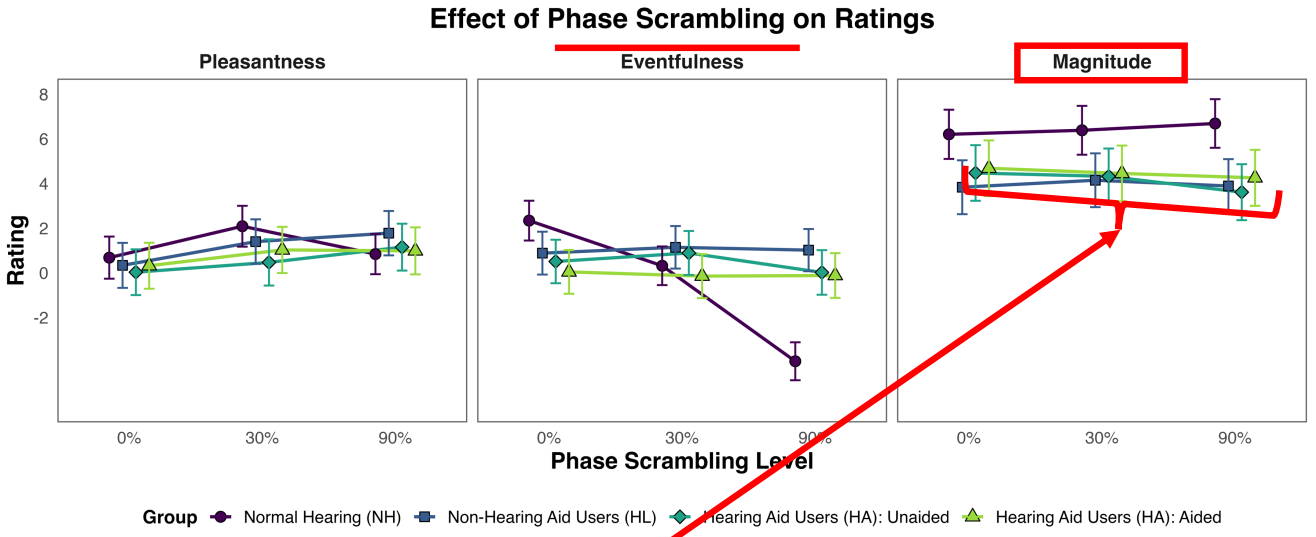
Magnitude: Listeners with hearing loss recognize sounds just as well, and recognition barely changed rating strength.



- No differences in category identification across groups

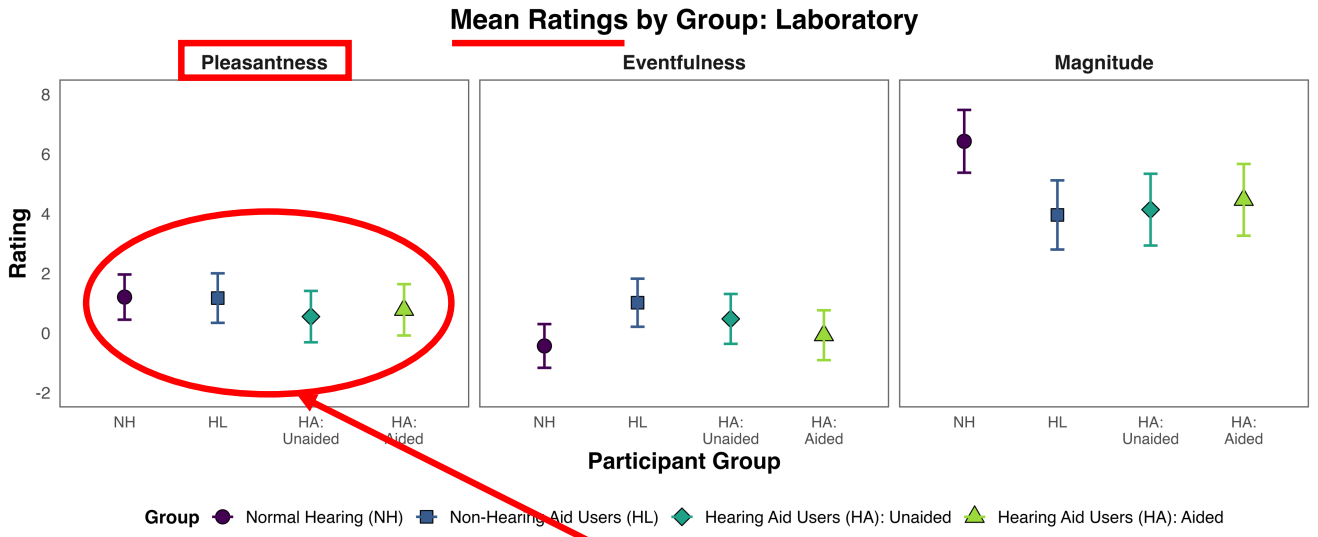
- Correctly identified sounds rated **slightly** stronger than incorrectly identified sounds
  - Effect was largest in HL, but still not a very strong effect

Magnitude: Phase scrambling doesn't dull ratings, except slightly for unaided HA users



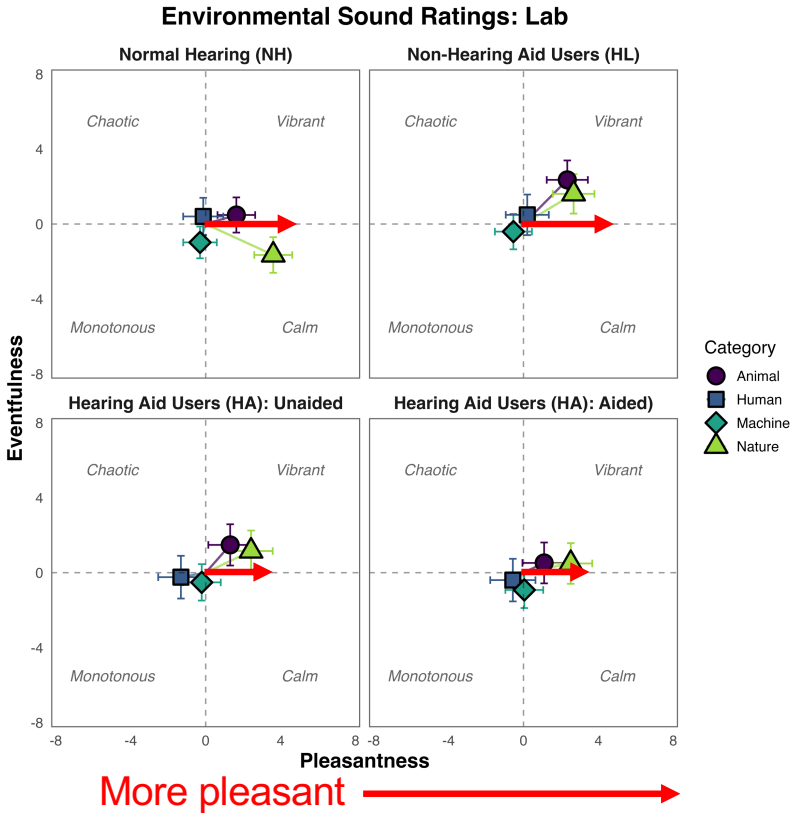
- HA:Unaided participants—**slightly** lower rating magnitude for scrambled sounds, likely because fewer audible peaks reduced rating strength

Pleasantness: hearing loss and hearing aids do not affect how pleasant/unpleasant sounds are



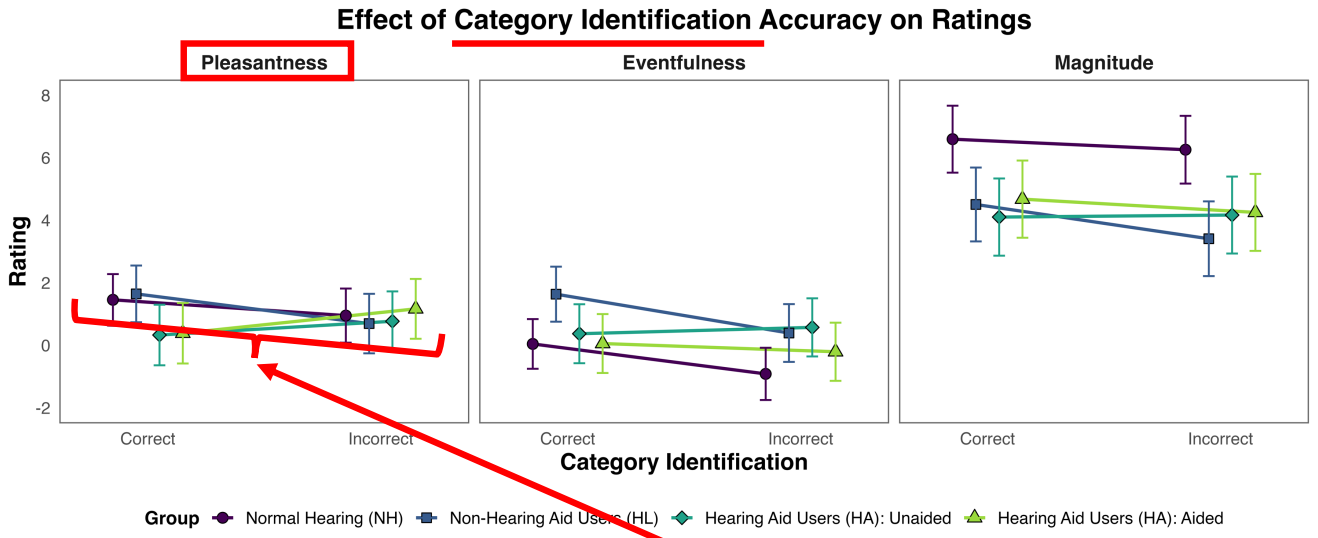
- No overall differences in pleasantness between groups--that's good

Pleasantness: Nature sounds are the most pleasant, machines the least, for everyone



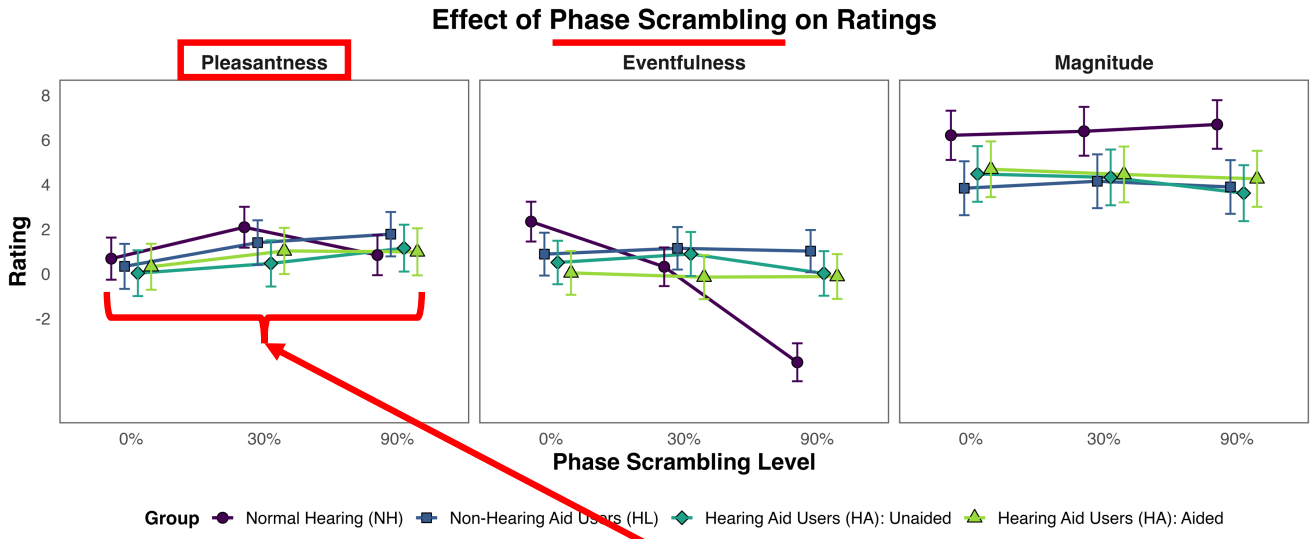
- Pleasantness, like magnitude, was strongly driven by category:
  - Nature > Animal > Human & Machine—it's not just that ratings are stronger for nature and animal, they're stronger in the pleasant direction

Pleasantness: Knowing what the sound is makes it slightly more pleasant for NH/HL, but not for HA



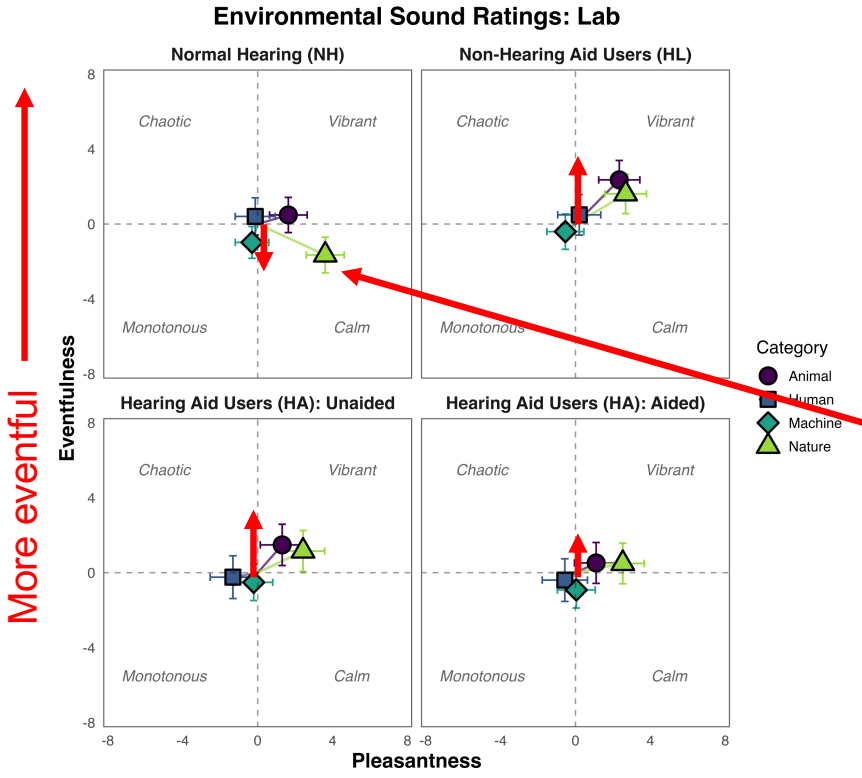
- Significant group x identification interaction—correct identification slightly increased pleasantness for NH and HL relative to HA

Pleasantness: Phase scrambling slightly increases pleasantness for NH/HL but not HA



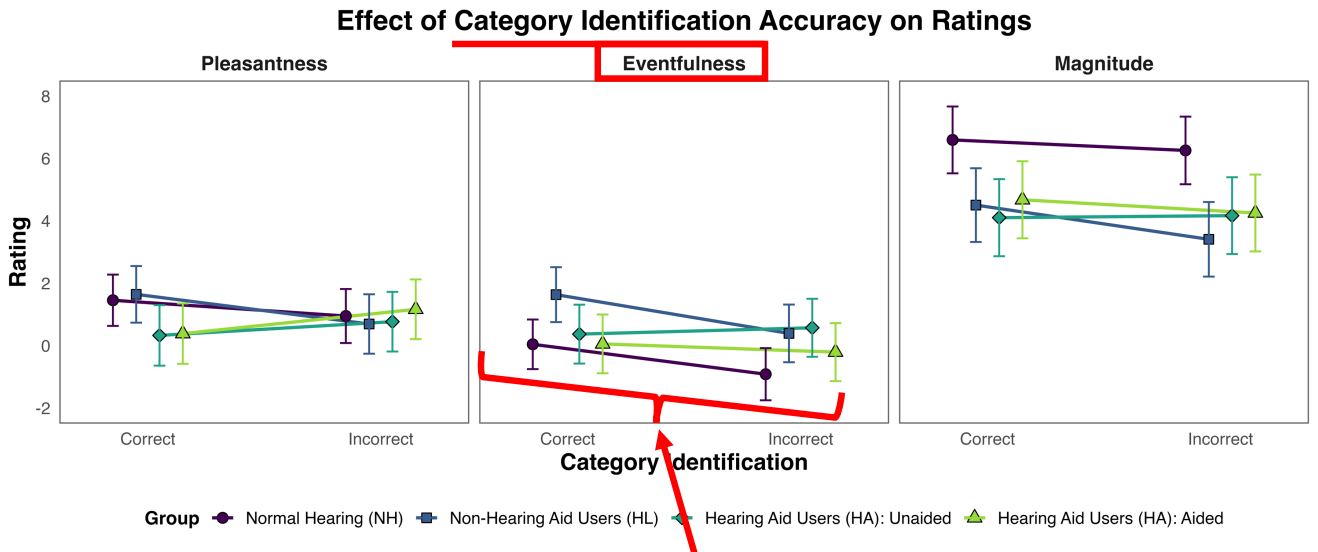
- Phase scrambling **slightly** increased pleasantness for NH and HL, particularly at 30% scrambled

Eventfulness: NH listeners hear animal and human sounds as less eventful than HA/HL



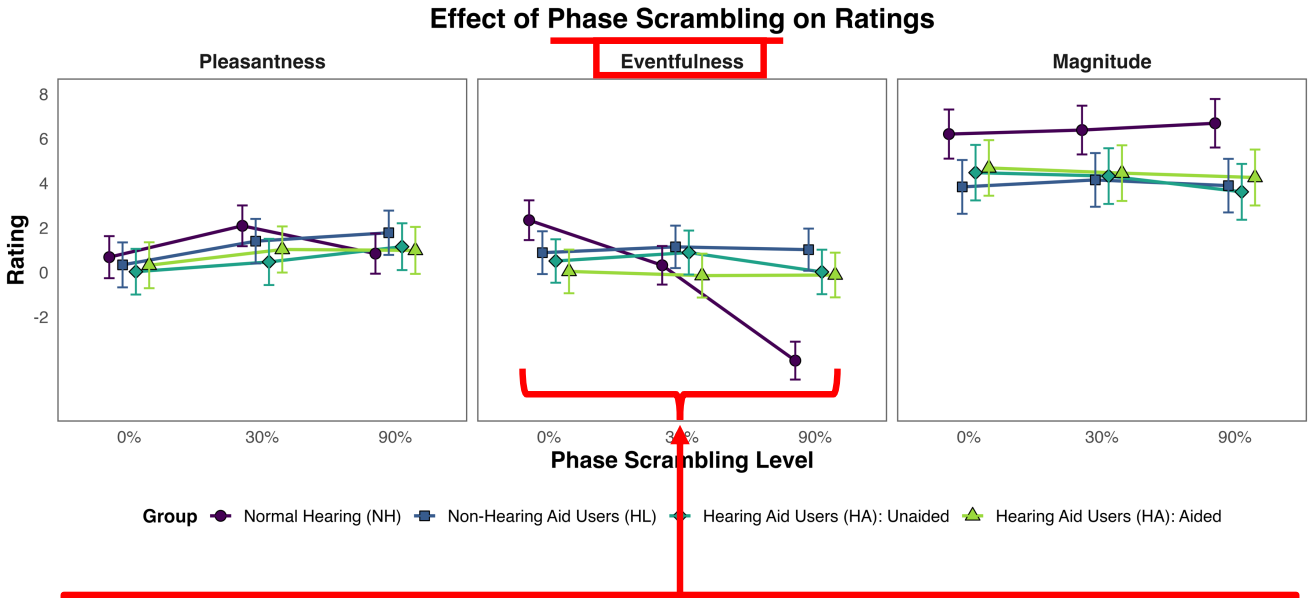
- Eventfulness was strongly driven by category:
  - Animal > Nature & Human > Machine
- Significant group x category interaction:
  - NH participants rated animal and human sounds as less eventful than HL/HA

Eventfulness: Recognizing a sound makes it slightly more eventful for NH and HL



- Again, we see a pattern where things like recognition, phase scrambling seem to impact NH and HL, but not HA users

Eventfulness: NH listeners use temporal cutes to judge eventfulness; listeners with hearing loss don't



- Phase scrambling had LARGE effect on eventfulness ratings for NH—but not for any of the HL/HA participants

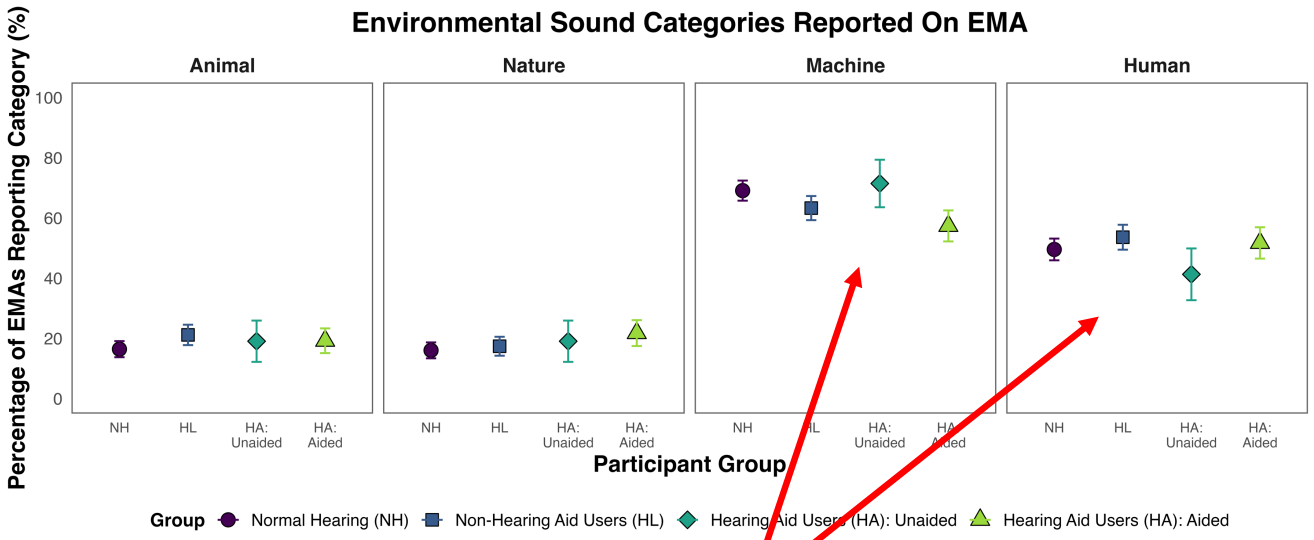
In the lab, hearing loss dulls responses, but doesn't change what sounds people like

- **Category is the main driver of ratings for everyone,** regardless of hearing loss.
  - The biggest exception is eventfulness and temporal fine structure for listeners with NH
- **Hearing loss weakens responses, and hearing aids don't really help**.
  - Hearing aids generally don't make things worse either, except maybe machines.
  - This is consistent with work on emotions.
- **Ratings seem largely driven by sound quality or timbre**, rather than semantic knowledge about the sound.
  - The category effect is not about *knowing* the category, it's about the acoustics of that category
  - This may have implications for hearing aid processing for environmental sounds
- ***Do these findings extend to the real world?***



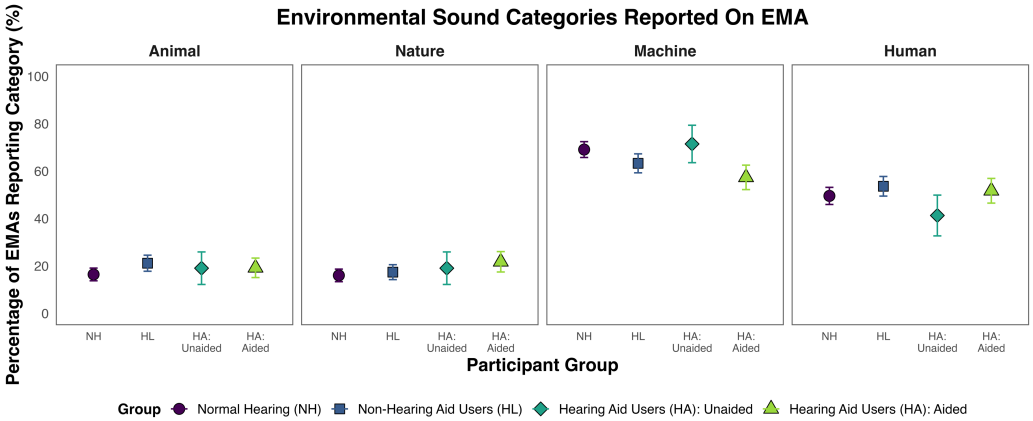


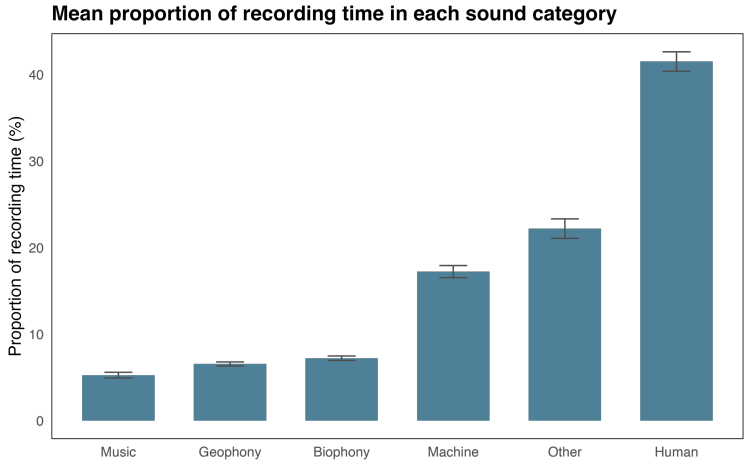
Human and machine sounds dominate daily life across groups.



- Machine and human sounds were most commonly reported across 1,865 EMAs
- No significant differences in category frequency or overall number of sounds reported between groups (though some marginal evidence for HA reporting fewer sounds)

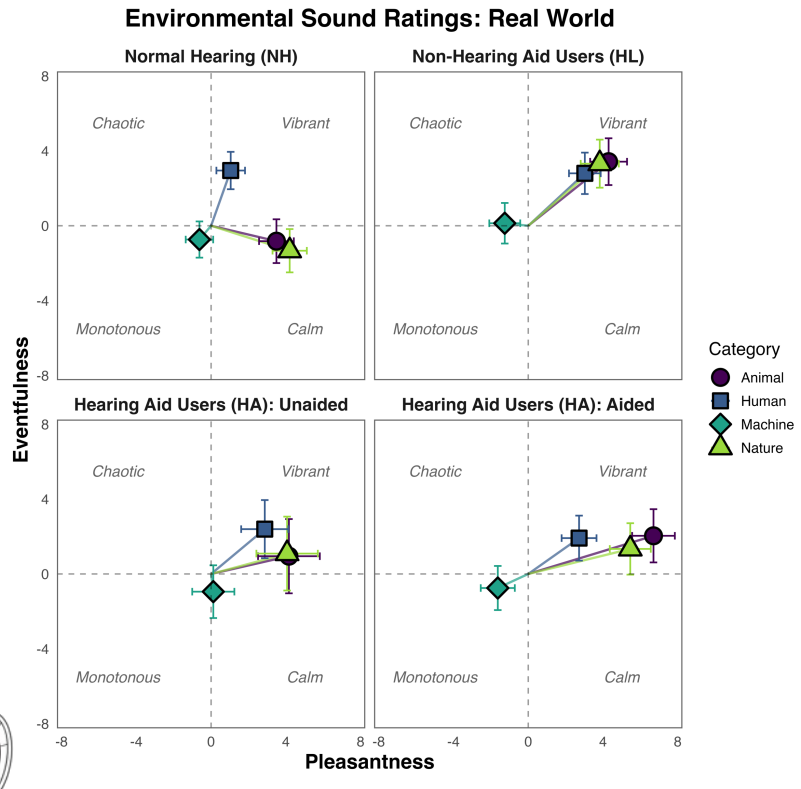
Listeners report more machine and nature sounds than recordings show—EMA captures what is salient





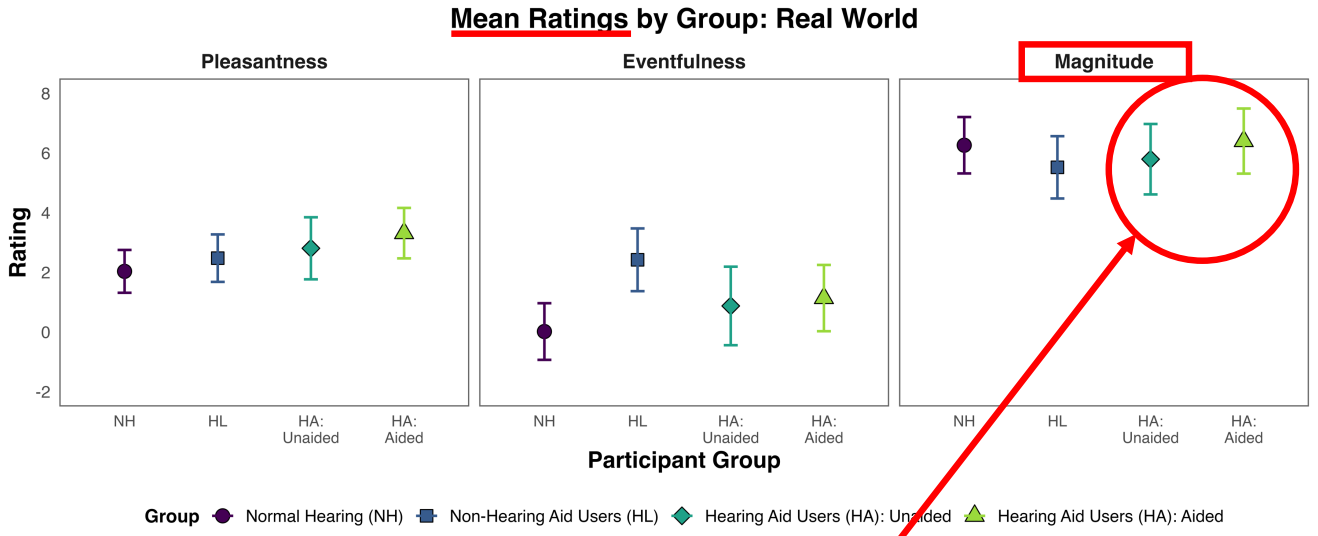
- Human and machine most common on recordings and EMA
  - Good agreement on human sounds
- Machine was much more commonly reported on EMA
  - Geophony/Biophony also more common on EMA

In daily life, human sounds become pleasant, and all ratings get stronger.



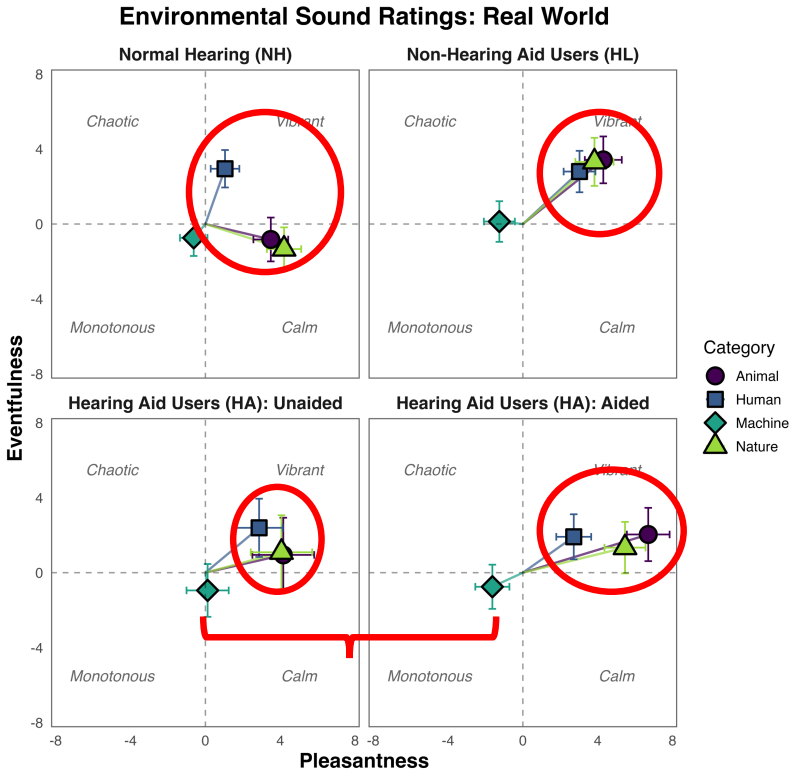
- Stronger ratings in the real world across groups
- Same pattern as in the lab for animal, nature, machines:
  - Animal and nature sounds = vibrant / calm
  - Machine = monotonous / neutral
- Different for human:
  - Human sounds = pleasant in real life

Magnitude: In the real world, the dulling effect of hearing loss disappears.



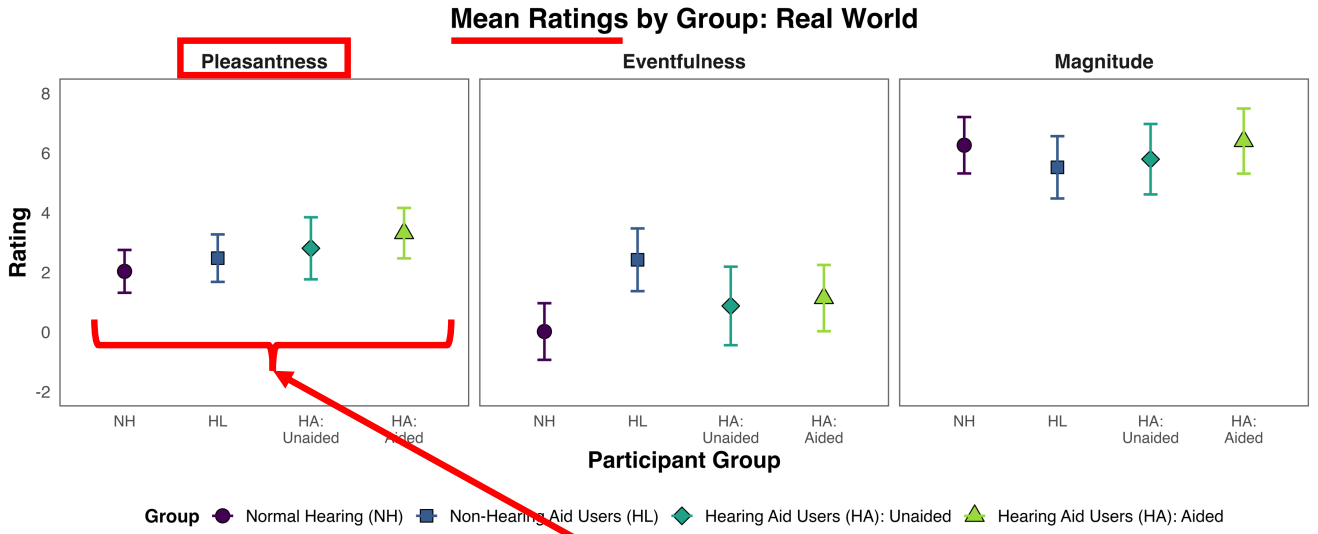
- Magnitude did not differ on average between NH and HL/HA groups—ratings were more extreme in real world for HL/HA but NH didn't change
- HA use resulted in **small increase** in rating magnitude (0.65 units)

Magnitude: HAs really strengthen ratings of machines in the real world.



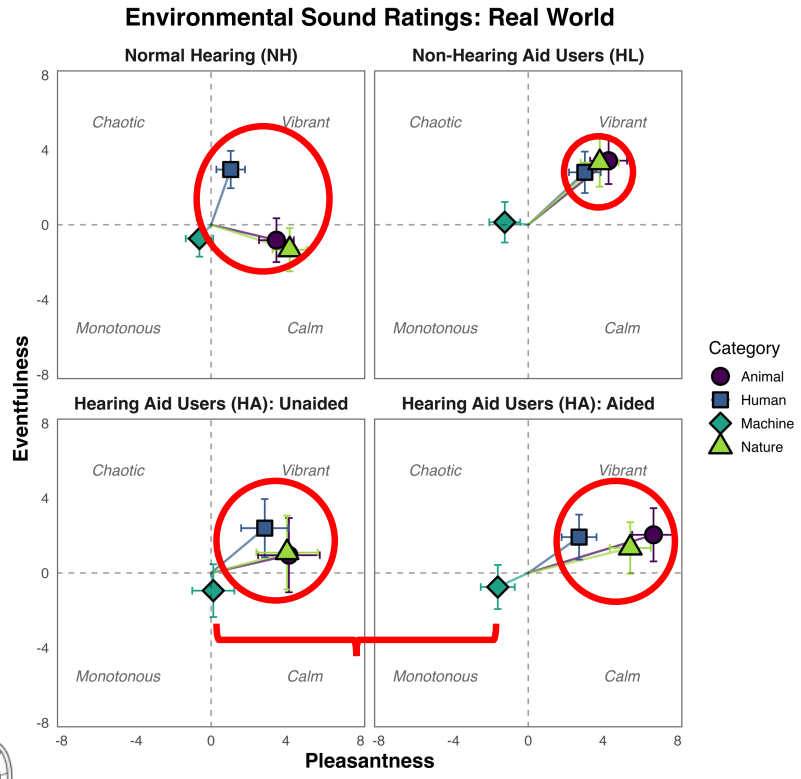
- Like the lab, the strongest ratings were for nature and animal sounds
- Significant group x category interaction:
  - Hearing aids increased rating magnitudes for machines (1.2 units)

Pleasantness: As in the lab, hearing loss doesn't change pleasantness



- No differences in pleasantness across groups

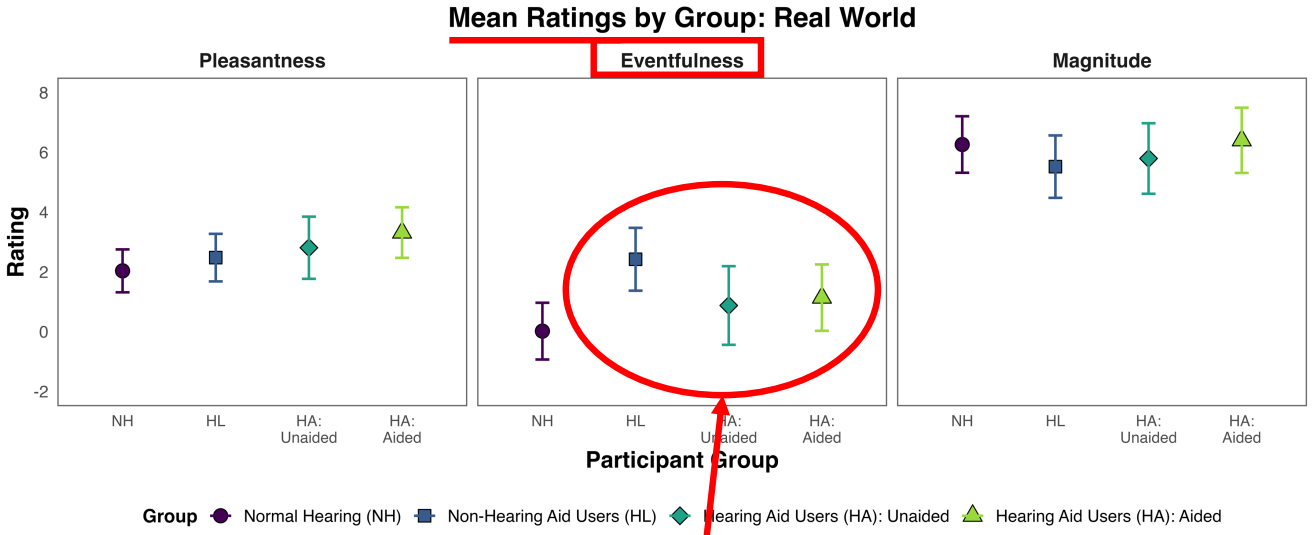
Pleasantness: As in the lab, category is the key predictor



More pleasant →

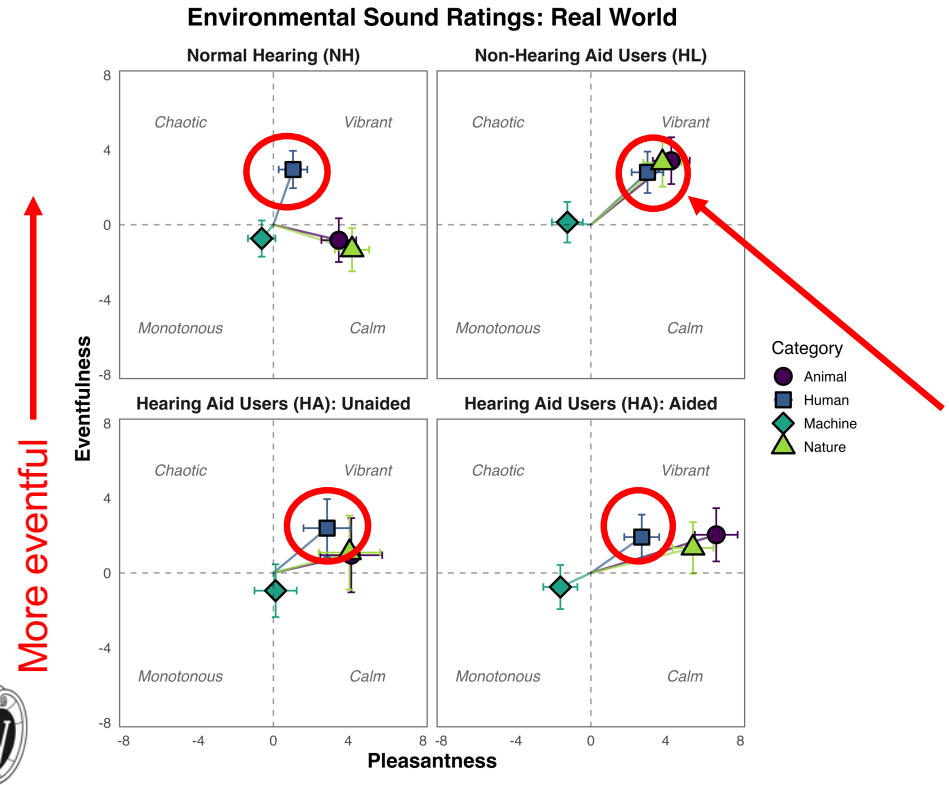
- Pleasantness was strongly driven by category:
  - Animal & Nature > Human & Machine
- Significant category x group interaction:
  - Machine sounds tended to be rated less pleasant for HA:Aided than HA:Unaided

Eventfulness: Listeners with hearing loss find real-world sounds more eventful than NH



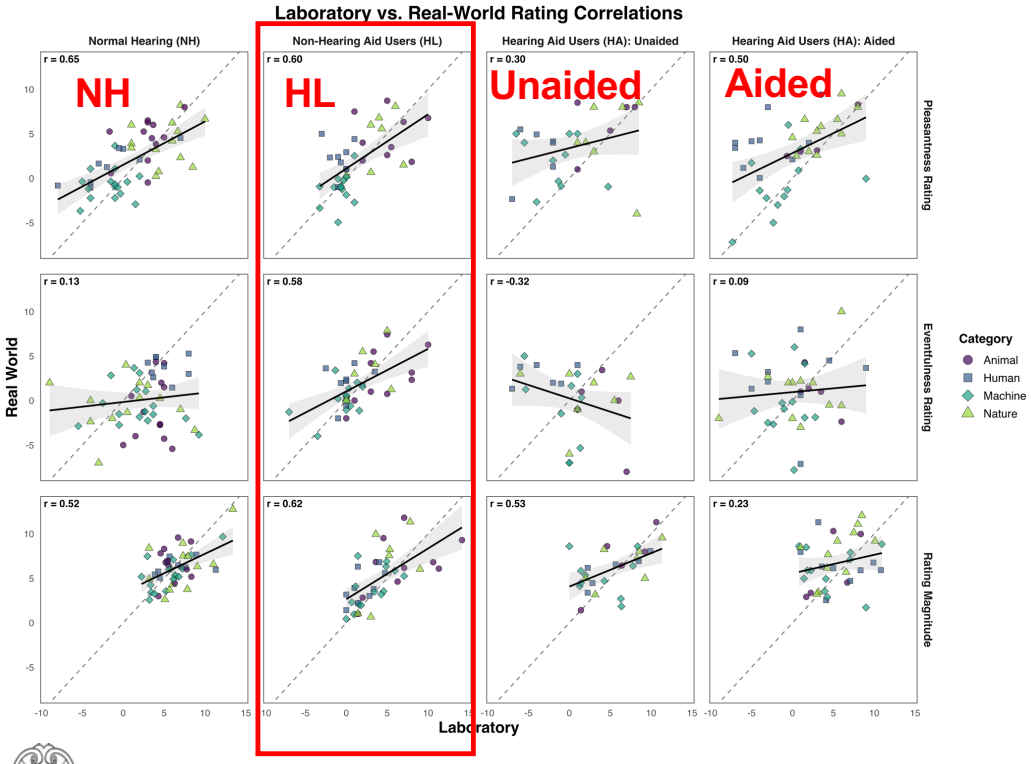
- Eventfulness ratings were **higher** for hearing loss participants—particularly for HL
  - Less audibility makes reported/salient sounds more eventful?

Eventfulness: Also driven by category, but in the real world, human sounds are the most eventful



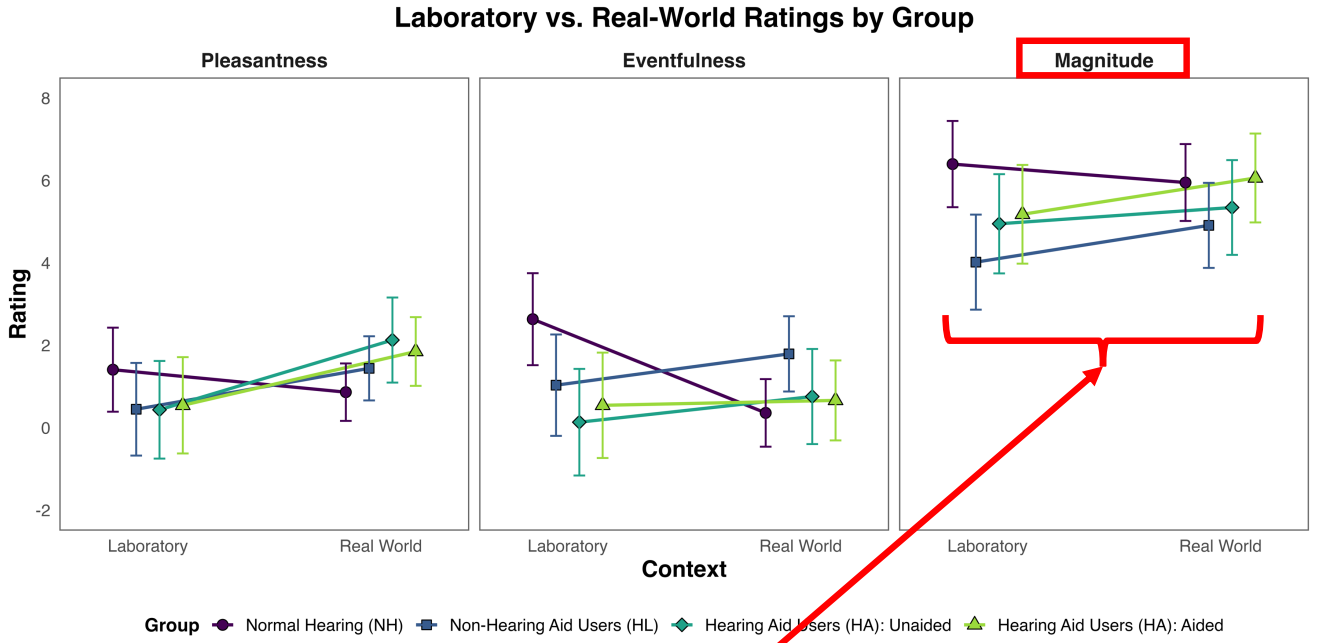
- Eventfulness was strongly driven by category:
  - Human > Animal & Nature > Machine
- Significant category x group interaction:
  - HL participants rated animal and nature sounds more eventful than NH and HA

Lab ratings only loosely predict real-world experience.



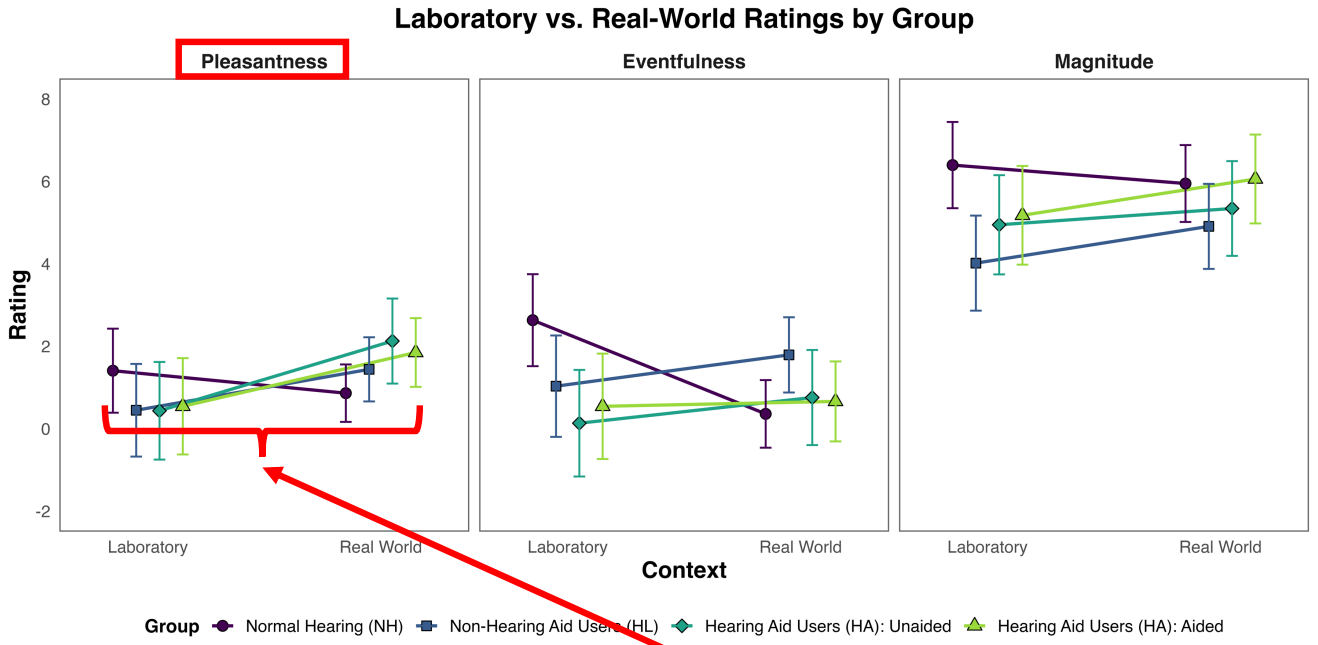
- Magnitude and pleasantness were moderately correlated
  - Eventfulness was not
- HL generally showed best correlations
- Nature and animal sounds showed stronger correlations

Outside the lab, ratings from listeners with hearing loss get stronger and catch up with NH.



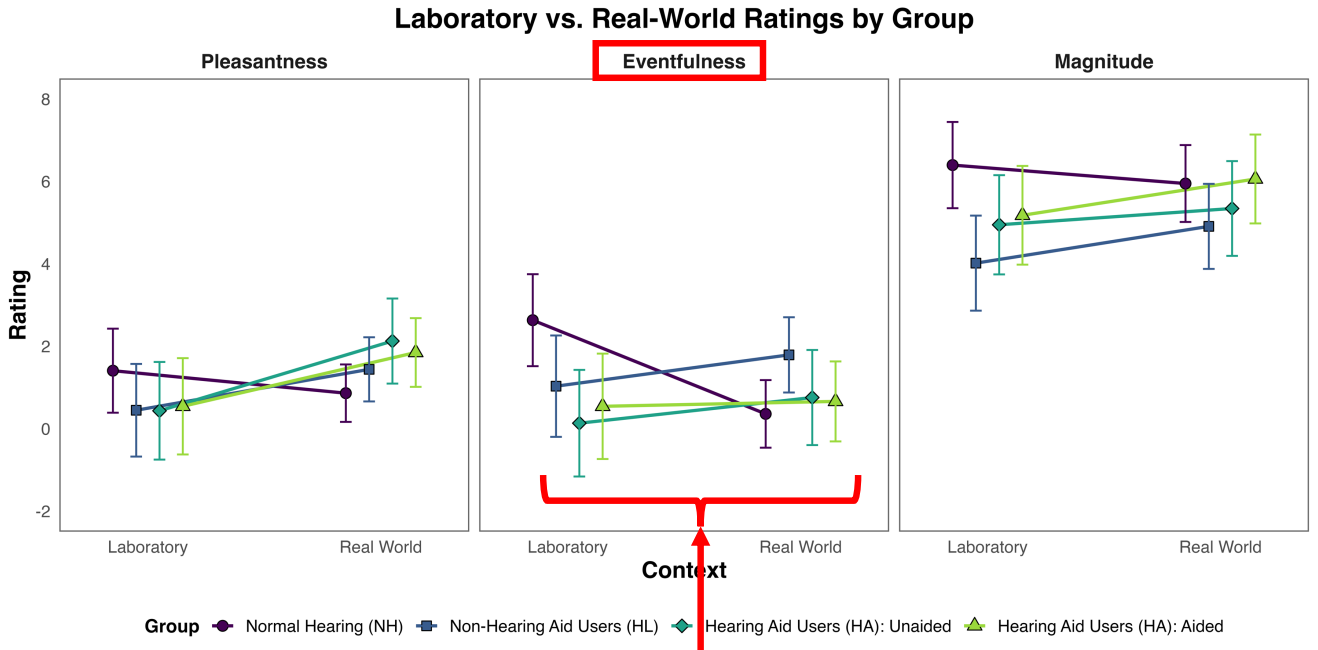
- HL/HA magnitudes rose in the real world, closing the gap with NH

Real-world sounds are more pleasant only for listeners with hearing loss.



- Significant **increase** in pleasantness in the real world for all hearing loss participants—no difference for NH

Eventfulness: NH listeners find real-world sounds less eventful than in the lab.



- Significant **decrease** in eventfulness for NH in the real world, no difference for hearing loss participants

Outside the lab, listeners with hearing loss respond as strongly as NH, at least to the sounds they notice.

- **Hearing aids mainly make machines more annoying.**
- **Lab and real-world ratings only loosely agree, so context matters—consistent with the idea of soundscape**
  - The lab may not be a good place to study this
- **Strongest predictor of ratings is still category, but human sounds rated more pleasant and eventful in the real world**
- **Audibility matters: EMA means only audible, salient sounds are reported**
  - May explain stronger, more eventful ratings in the real world for HL/HA
  - Decrease in eventfulness ratings in the real world for NH may mean that NH listeners tune out more sounds
- HAs did not increase pleasantness of natural sounds in the lab or real world

Experiment #2: Urban soundscape ratings

1. How do ratings of urban soundscapes differ between listeners with normal hearing and listeners with hearing loss who do and do not use hearing aids?
2. Are psychoacoustic metrics related to ratings or group differences?
3. How well does the soundscape model apply to listeners with hearing loss?

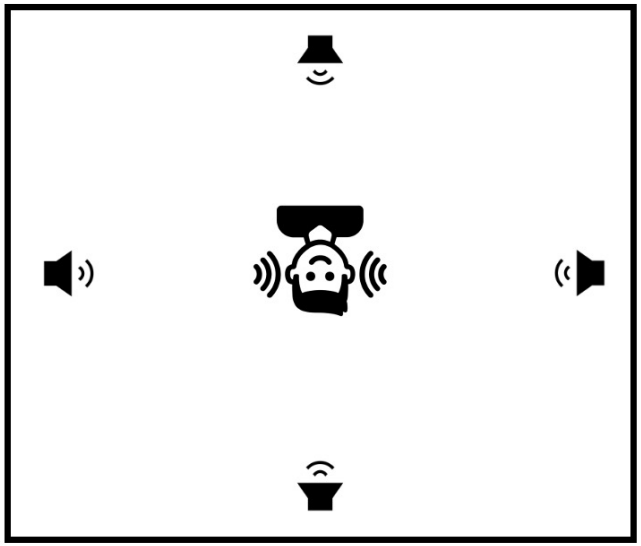




Experiment #2: Stimuli and procedure

- Urban Soundscapes of the World Database
  - 4-channel Ambisonics
- We used just New York City
  - 17 locations across the city
  - Wide representation: busy urban centers along with pastoral parks
  - Presented at real-world sound level
- Participants rated ***each*** attribute

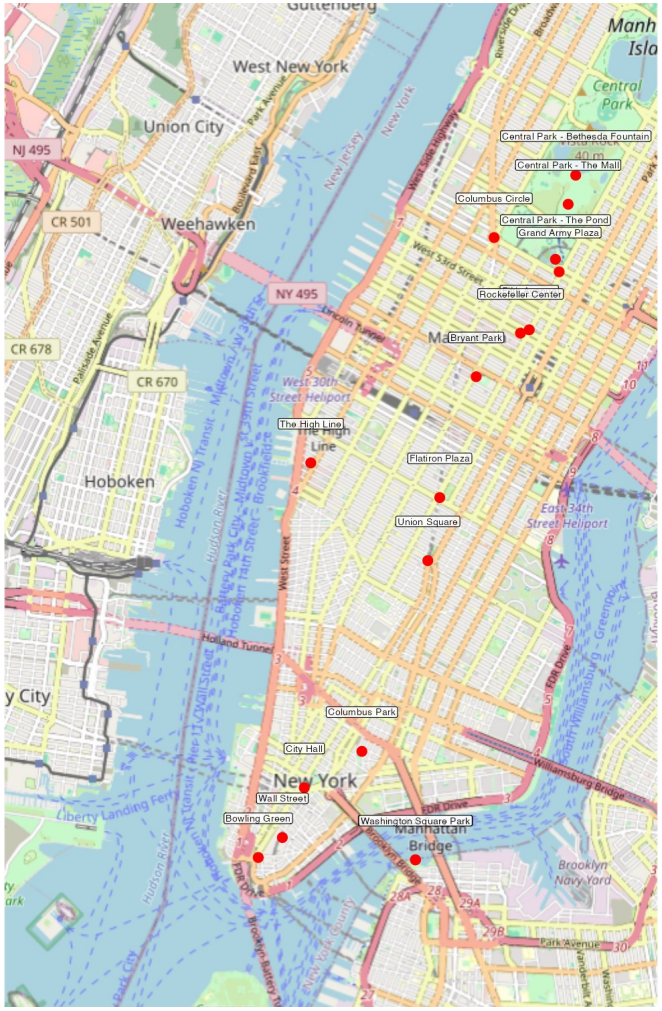
Urban Soundscapes of the World



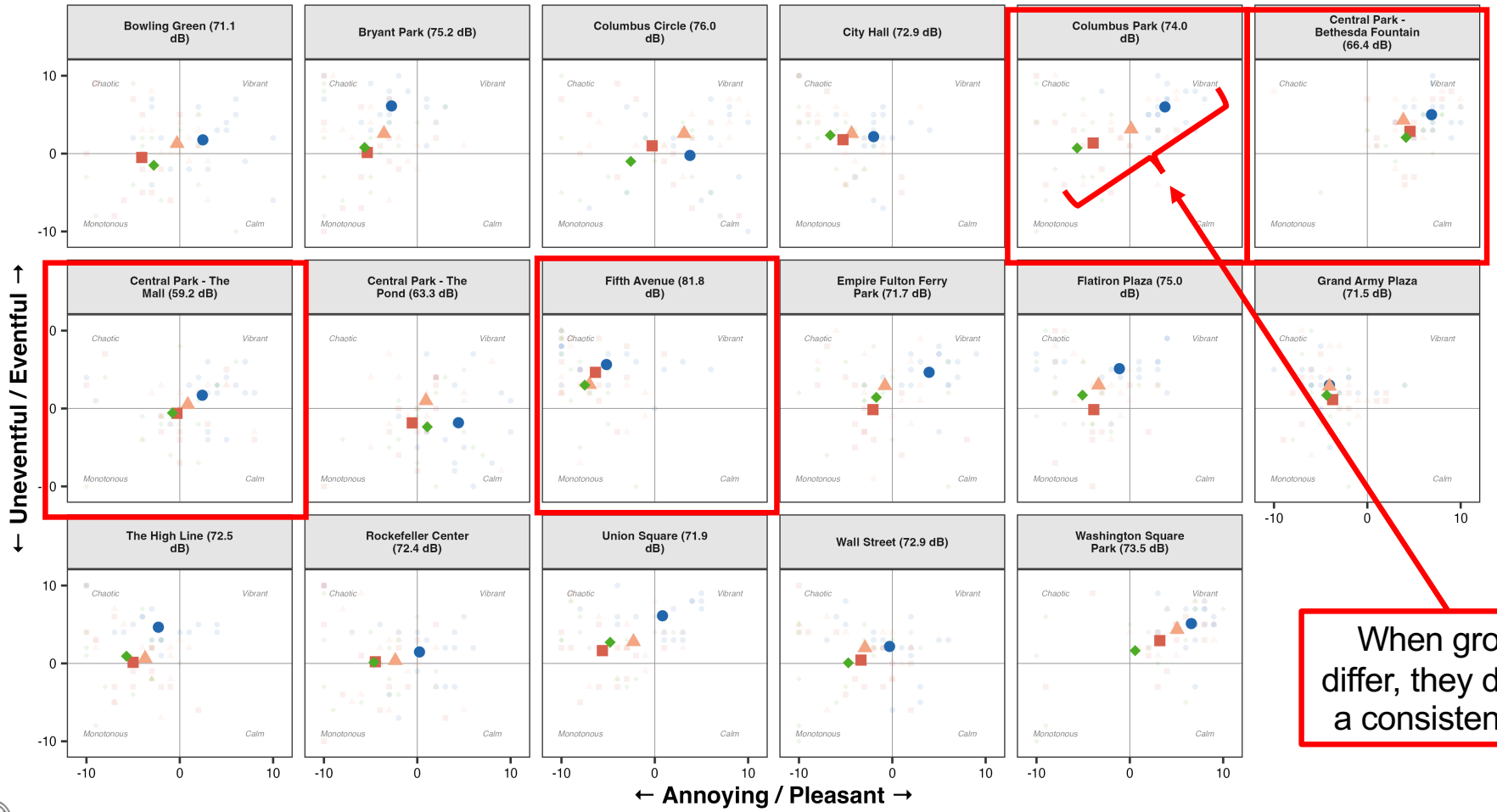




Location	dBA
Bowling Green	69.4
Bryant Park	74.3
Columbus Circle	75.7
City Hall	71.1
Columbus Park	72.1
Central Park - Bethesda Fountain	65.3
Central Park - The Mall	58.9
Central Park - The Pond	61.8
Fifth Avenue	83.2
Empire Fulton Ferry Park	70.1
Flatiron Plaza	72
Grand Army Plaza	68.9
The High Line	71.5
Rockefeller Center	70.4
Union Square	70.4
Wall Street	70.7
Washington Square Park	72.2

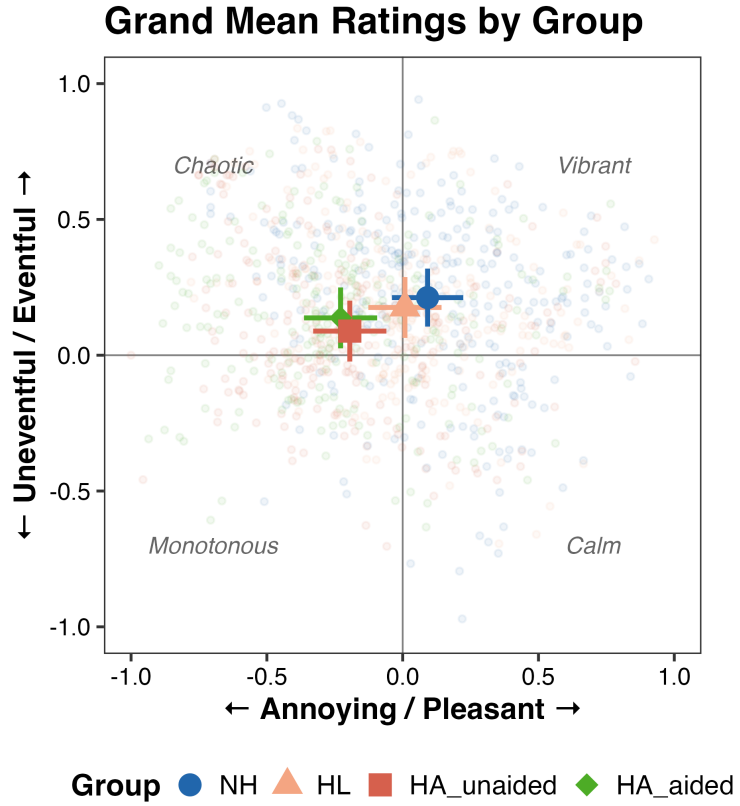


Soundscape Ratings by Group and Location



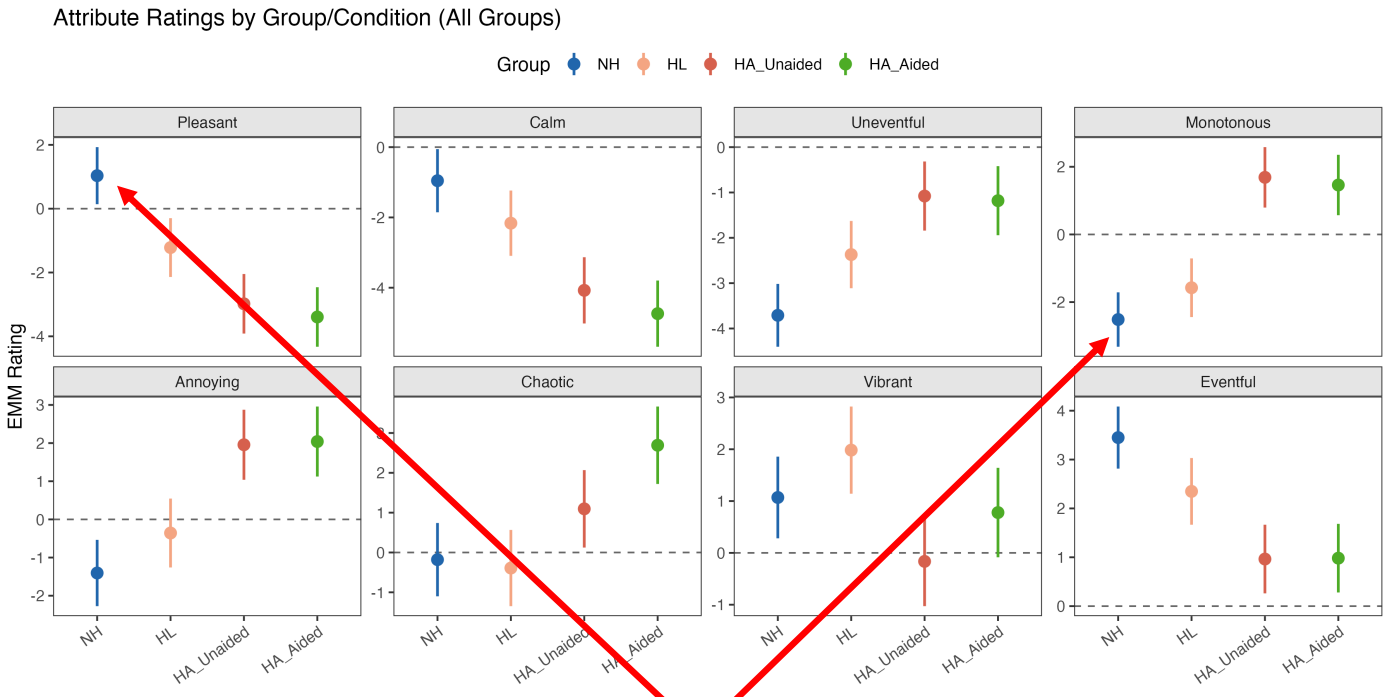
When groups differ, they differ in a consistent way

Listeners with hearing loss, especially HA users, experience city soundscapes as less pleasant.



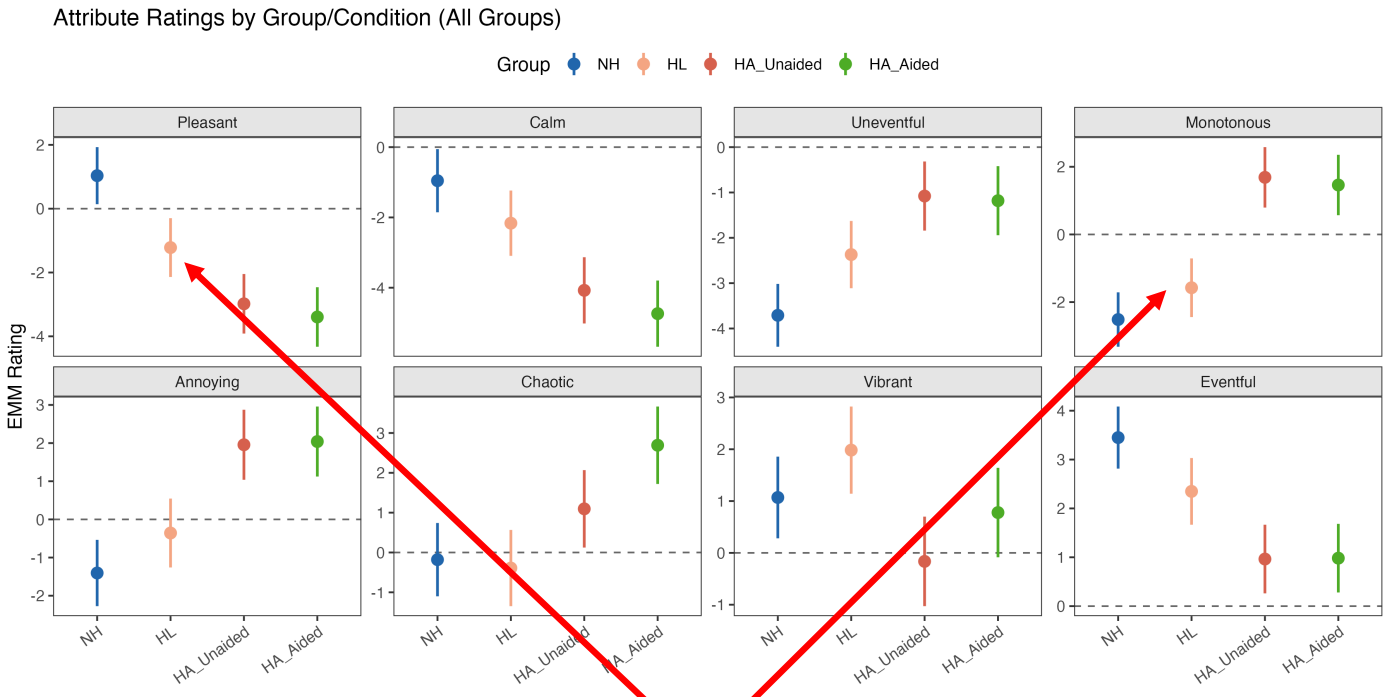
- On average—NH rated soundscapes more positively (more pleasant, more towards vibrant) than all HL/HA
- HA rated soundscapes least positively—mostly chaotic, few differences with hearing aid use

NH listeners like the city.



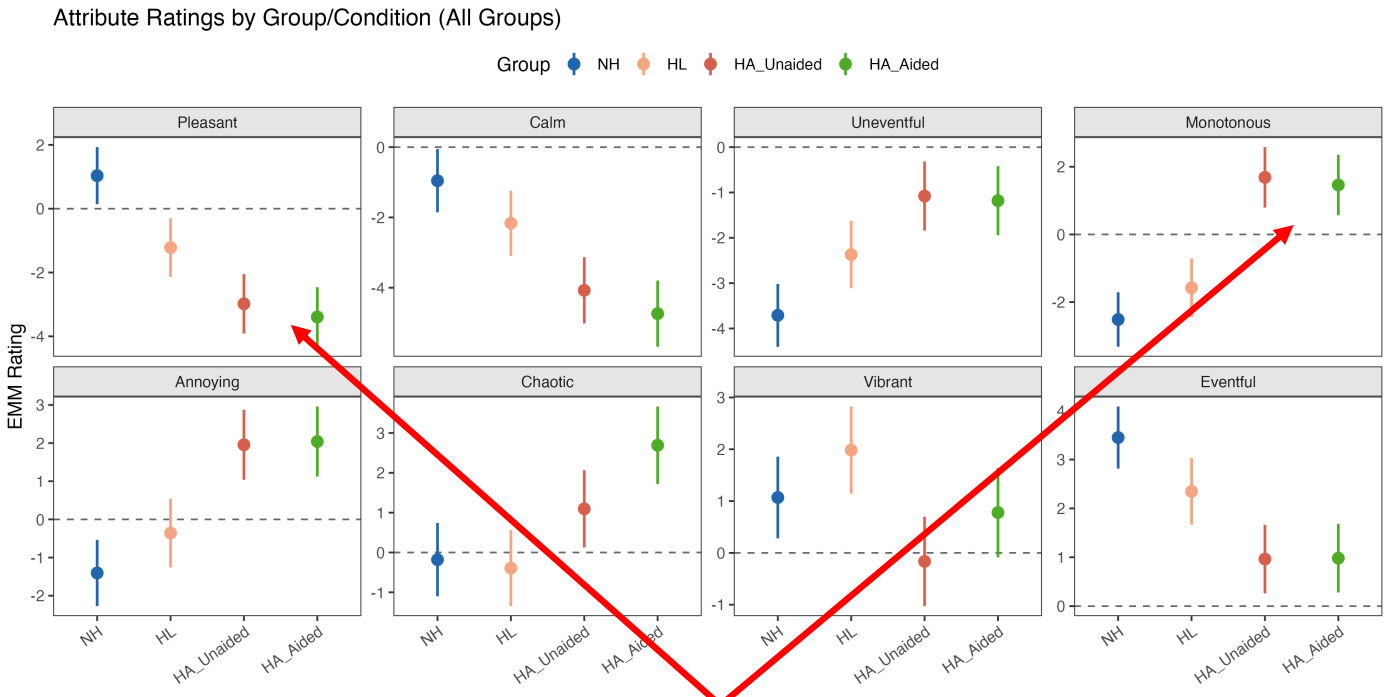
For most attributes, NH rated most positively (more pleasant, more calm, less monotonous, etc.)

It could be age rather than hearing loss, but HL sits right between NH and HA

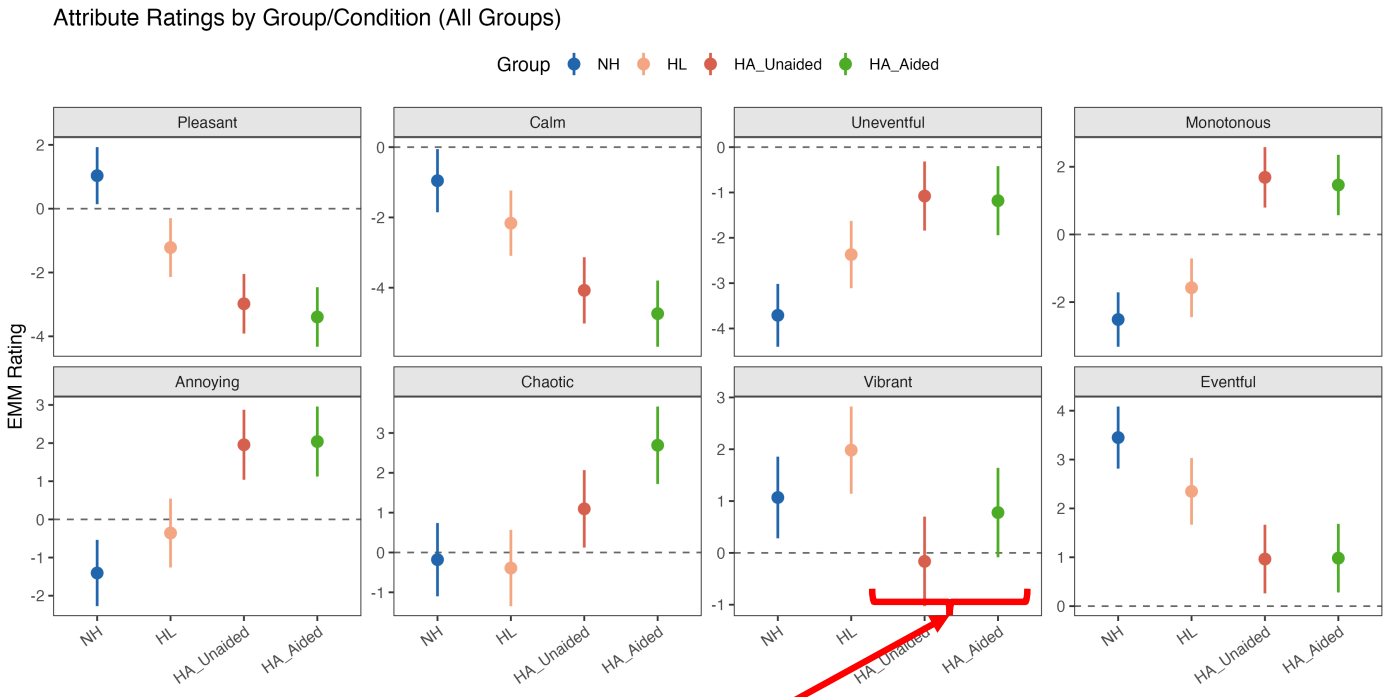


HL in the middle

HA users don’t like the city.



HAs don’t change how the city sounds, except slightly more vibrant.



Essentially no effect of wearing hearing aids except here.

Do psychoacoustic metrics predict ratings?

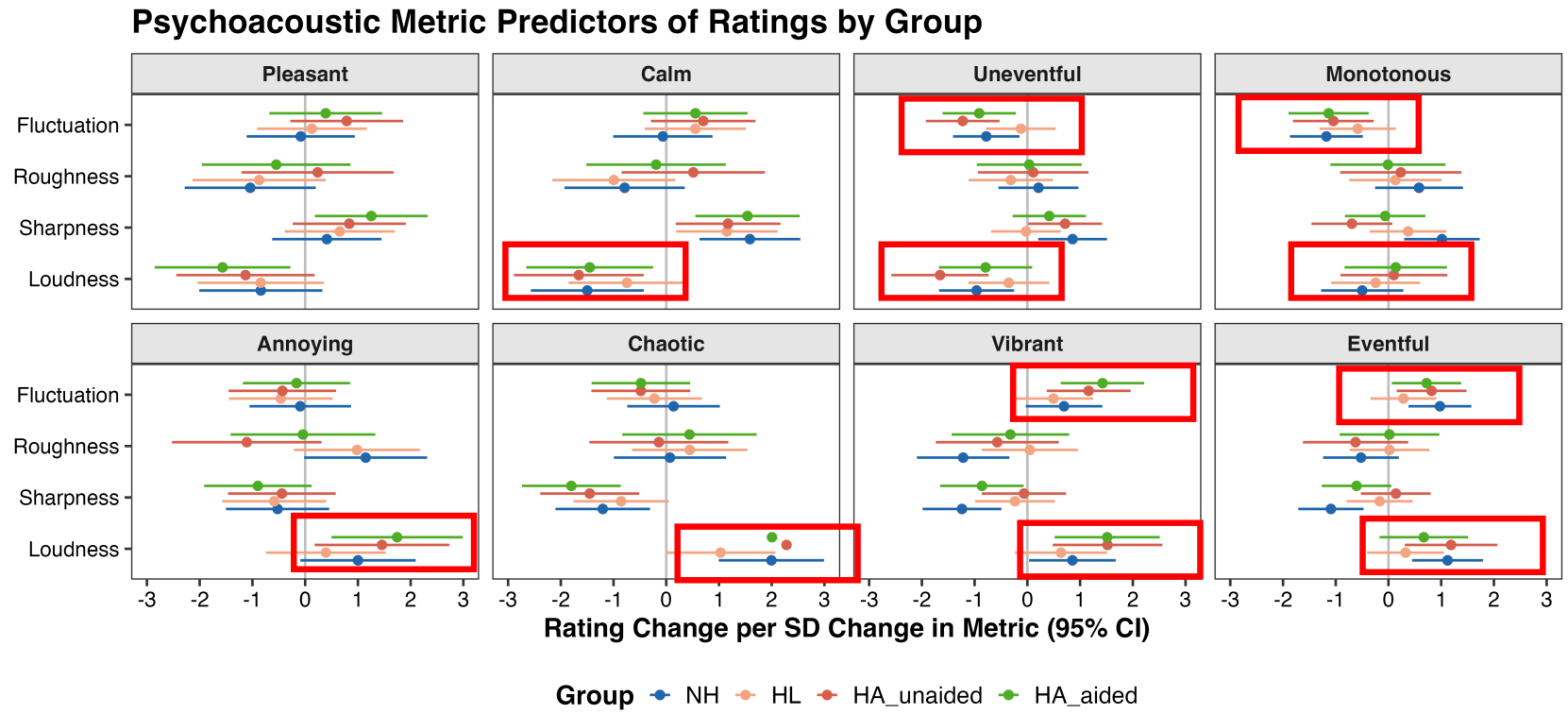
Can we get any insight into what acoustic properties might drive these differences, which could lead to hearing aid programming specifically for different environments?

- Loudness (sone): perceived loudness
- Sharpness (acum): high frequency tilt
- Roughness (asper): fast modulations
- Fluctuation strength (vacil): slow modulations

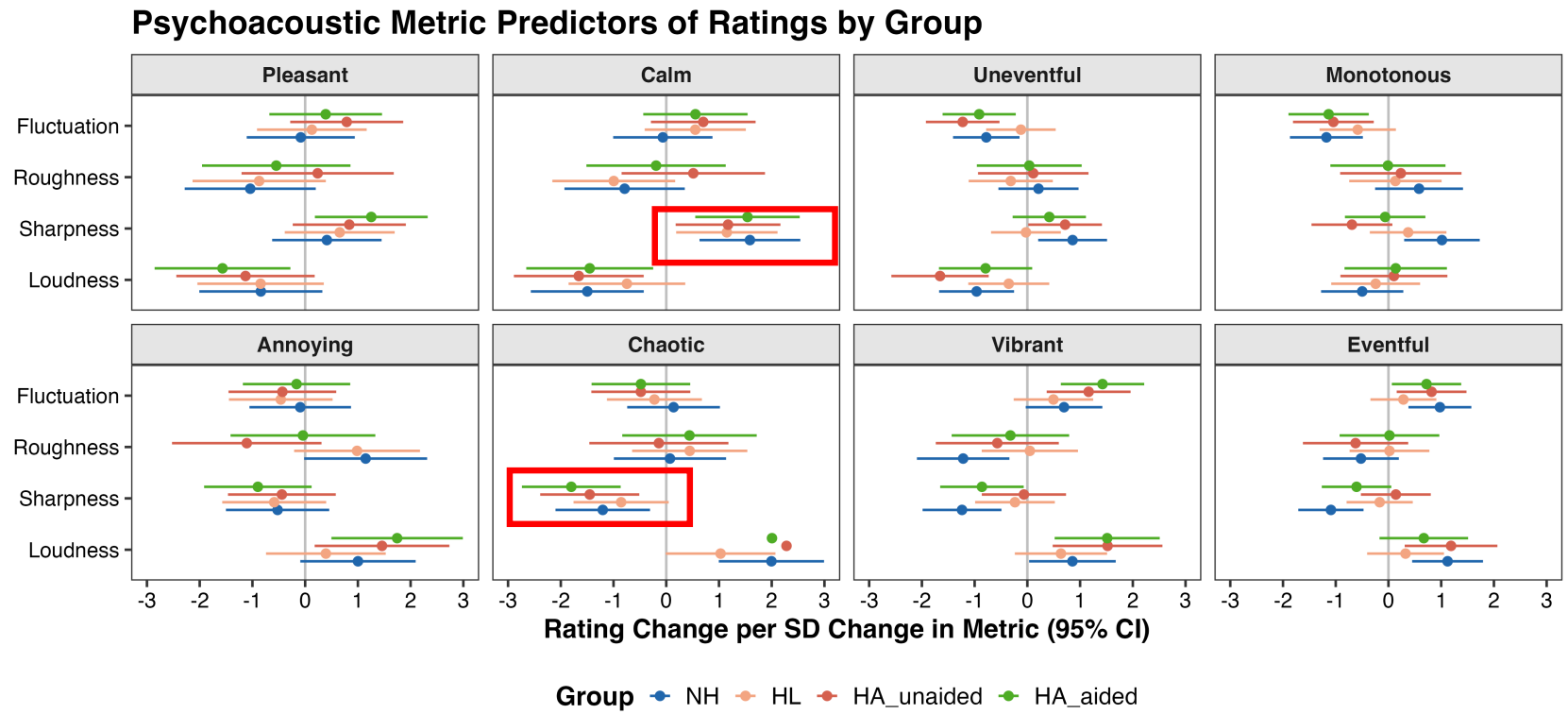




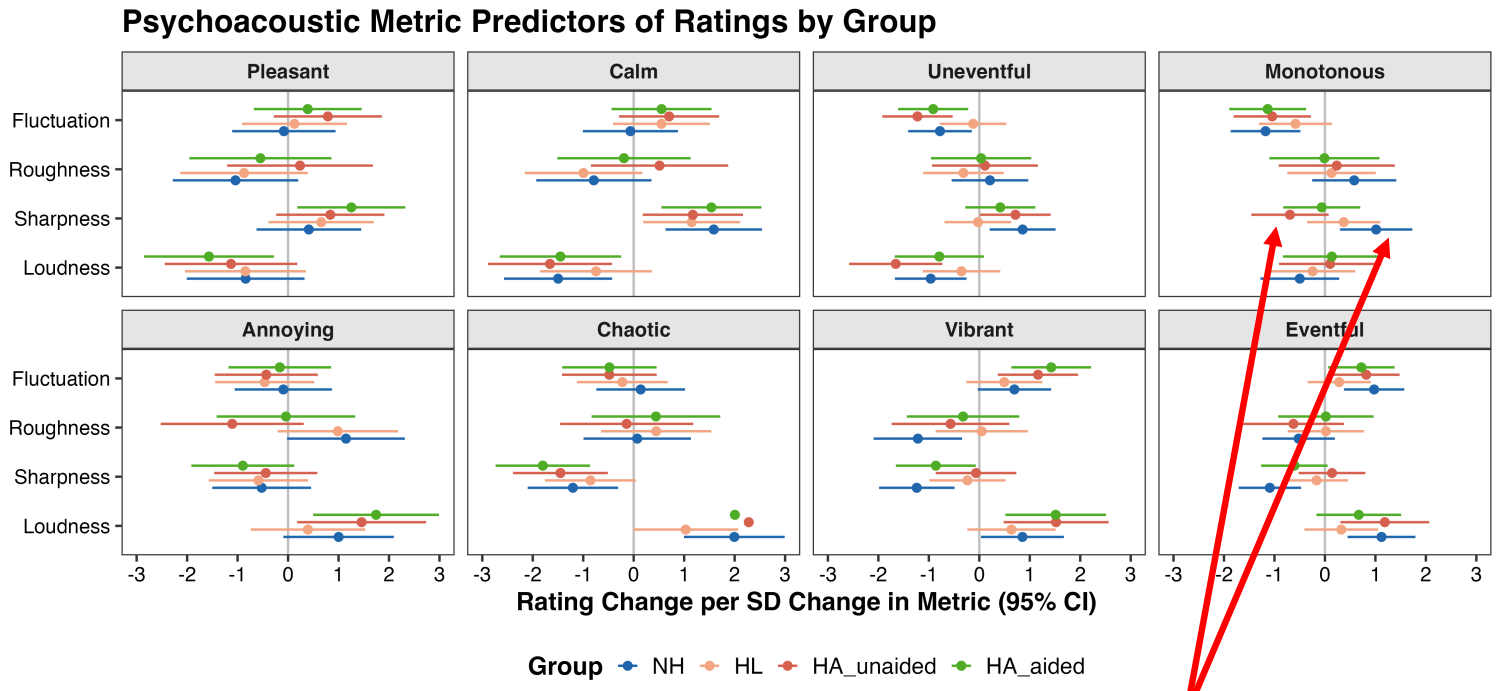
Louder, more fluctuating soundscapes feel more eventful, chaotic, and annoying for everyone.



Sharp soundscapes are calmer and less chaotic.

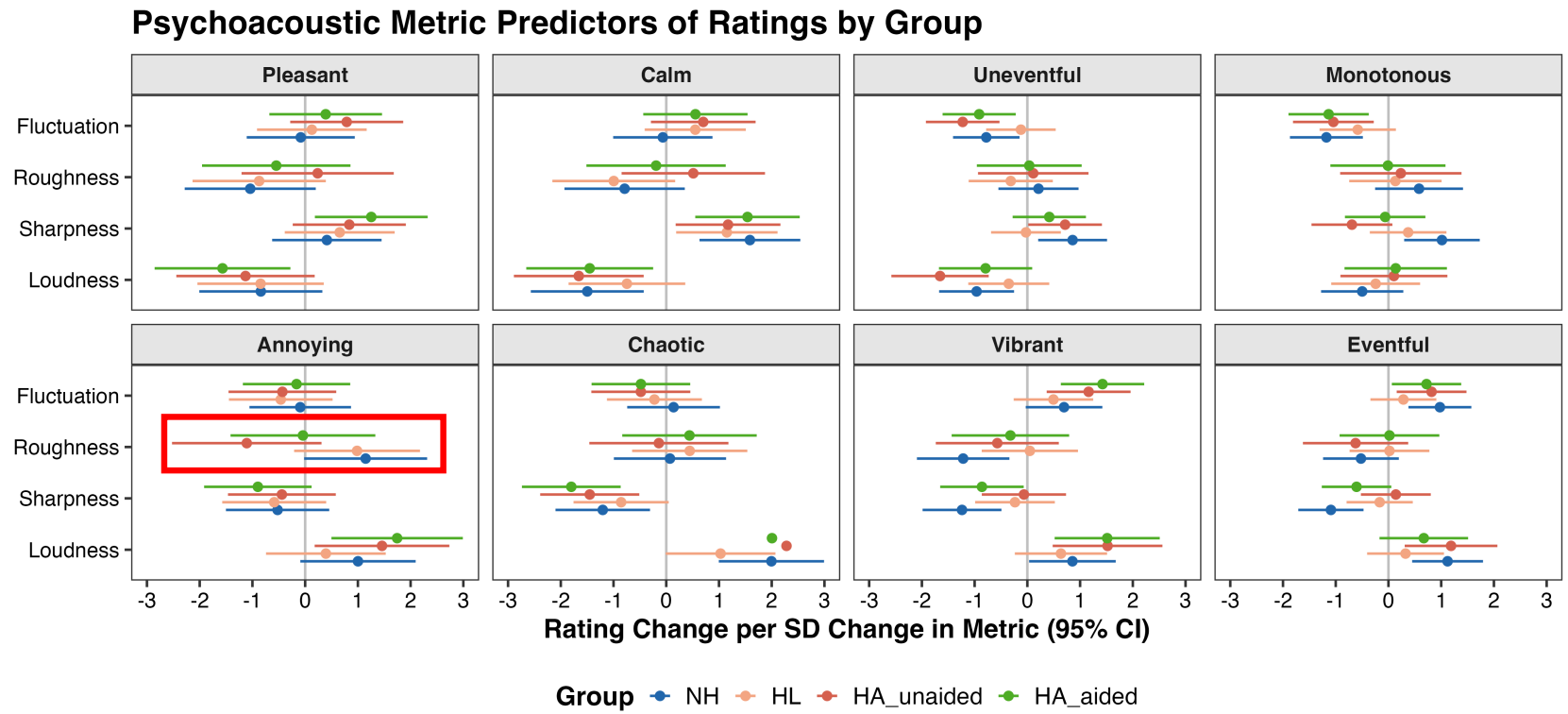


Sharpness is also the most group-dependent, likely due to high-frequency audibility.



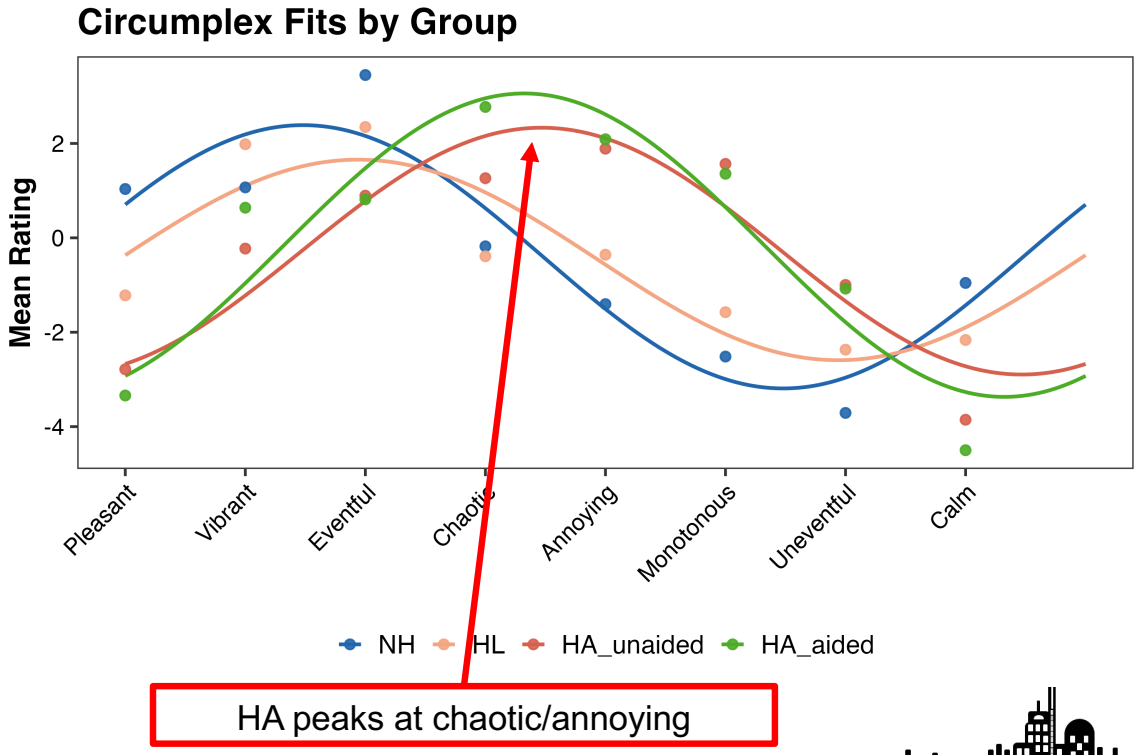
For example—sharp soundscapes were more monotonous for NH, but less monotonous for HA users

Roughness annoys NH and HL, but not HA—maybe due to reduced temporal sensitivity.



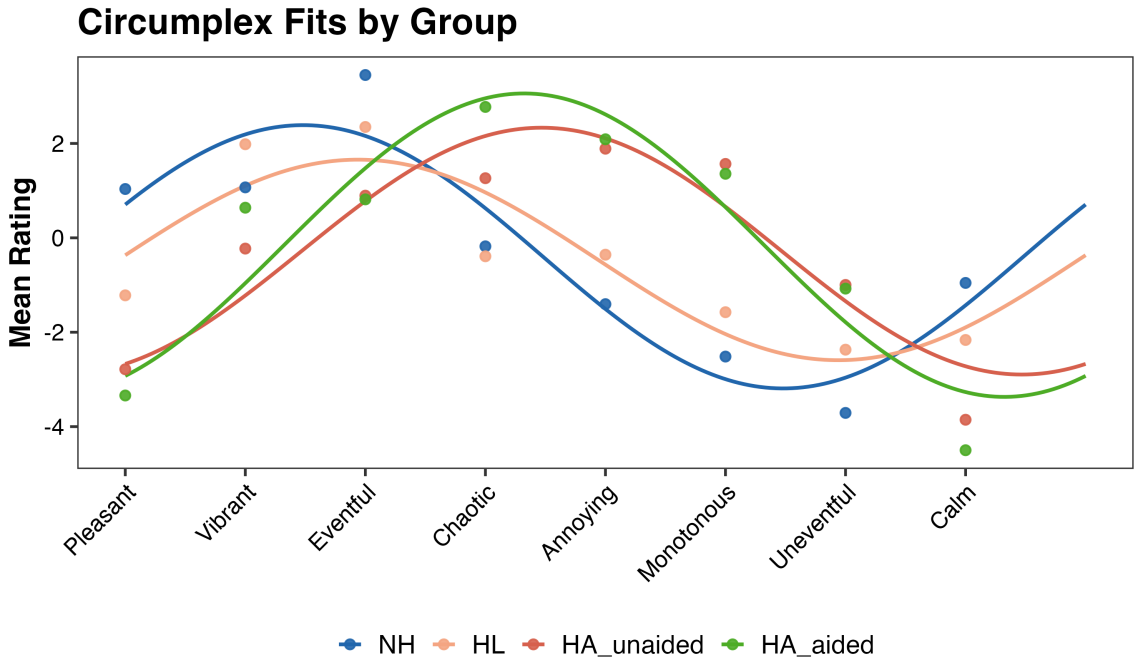
The soundscape model works for listeners with hearing loss, but HA users' perception rotates toward chaotic/annoying.

- The circumplex model shows a good fit to all groups (R^2 = 0.81-0.88).
- But counter-clockwise rotation for HA users
  - NH/HL had mean profile locations at 67° and 87° (vibrant), the HA (unaided and aided) group clustered around 150–156° (chaotic)



Attributes relate slightly differently for HA.

- Some interesting correlations among the attributes:
  - Monotonous was weakly and negatively correlated with pleasantness for NH, but strongly positively correlated with HA
  - Similar result for Vibrant
  - Correlations did not change between HA conditions



The urban soundscape is worse for hearing aid users, and hearing aids don't fix it.

- HA participants had greater degrees of hearing loss than HL: the gradient of negative ratings from NH to HL to HA suggests the effect is hearing-related
- Mostly no effects of hearing aids—hearing aids did not "restore" ratings to those of NH listeners
- Data support the soundscape framework for listeners with hearing loss
- This is an early study…much more to do. We are open to ideas!





Putting it together

- Audibility—at least as normally considered for speech—may not be enough. Hearing aids had small effects in improving rating strength for environmental sounds, didn't improve pleasantness, and made machine sounds worse.
- Appraisal of environmental sounds depended more on sound quality, so recognition isn't the main goal, unlike speech.
- The lab is probably a bad place to study this. Soundscapes exist in context, and reactions to sounds in the booth probably don't extend to the real world
- Negative ratings may reflect the hearing loss, not the hearing aid fitting. HA users rated cities negatively even when aided.





Putting it together

- Is optimizing hearing aids for environmental sound perception possible?
  - Results suggest high frequency audibility but not too loud overall may result in more pleasant perceptions of the soundscape…but modern targets already take this approach, and we did not see large hearing aid benefits for isolated environmental sounds or urban soundscapes.
  - However, we did not manipulate hearing aid settings in this study. We need theory-driven, systematic investigation of hearing aid settings to improve environmental sound listening.
  - Ideally, this should be done in the field.





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