SAND2022-8199C

Sandia National Laboratories

Sound quality metrics for improved prediction of hospital sleep disruption

S. Hales Swift & Jo Solet

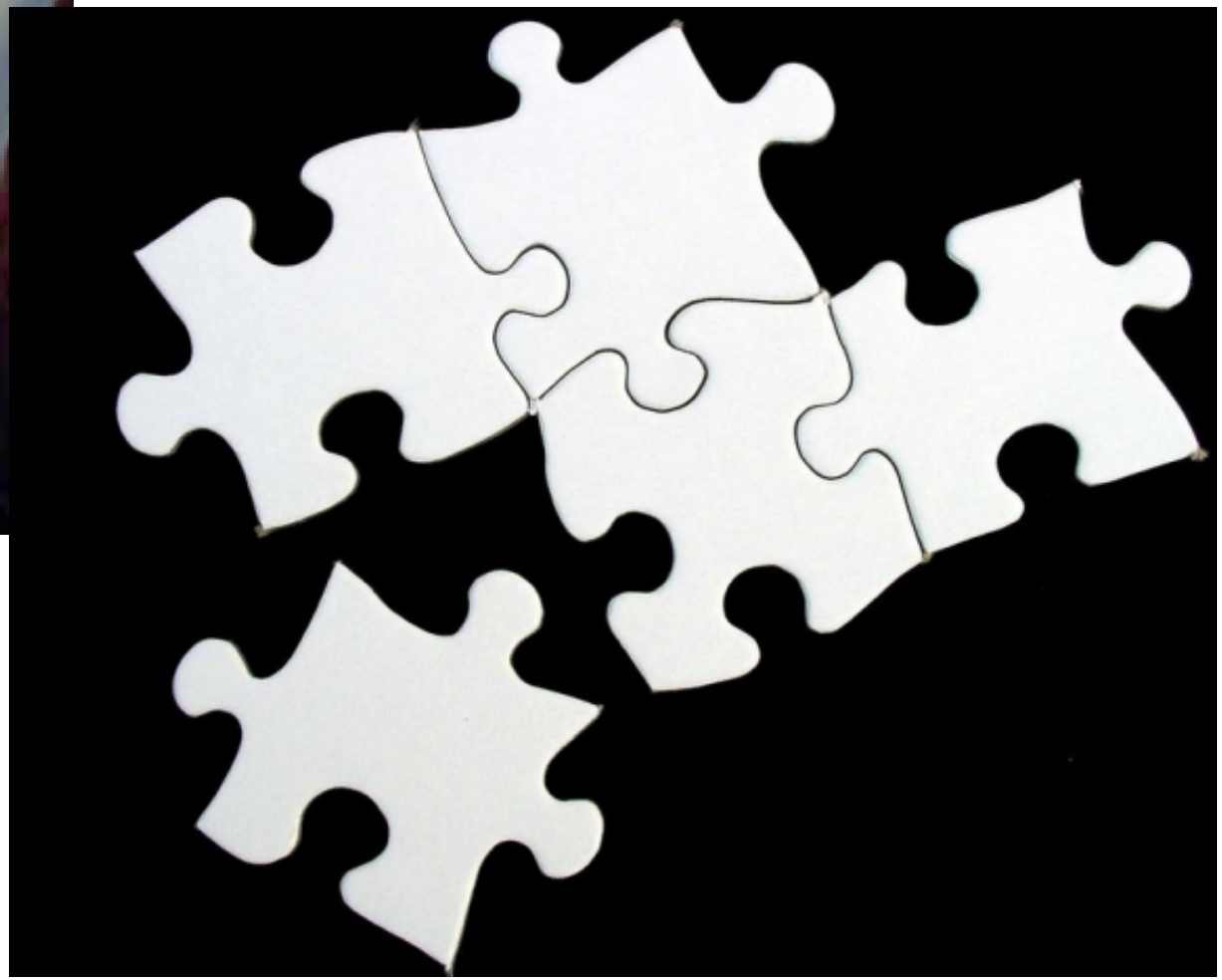
24 May, 2022, Denver, CO
182nd Meeting of the Acoustical Society of America
2aAA Acoustic Comfort in Healthcare Facilities I

U.S. DEPARTMENT OF ENERGY | NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

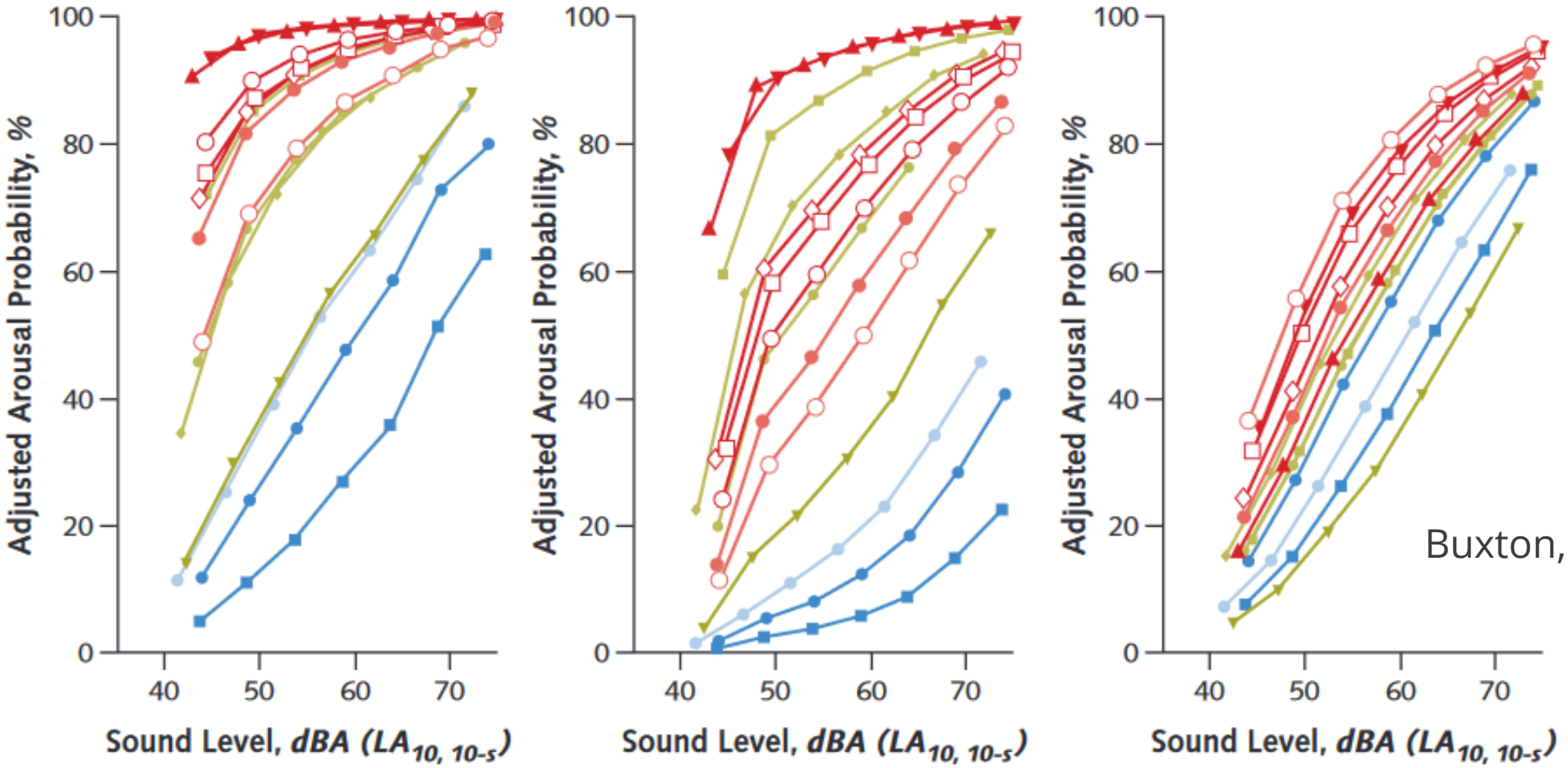
Once upon a time/Why I love ASA



“There is far too much to take in here
More to find than can ever be found…”

The slide that provoked the question/collaboration…

Probability of a sleep state transition as a function of A-weighted 10-s Leq



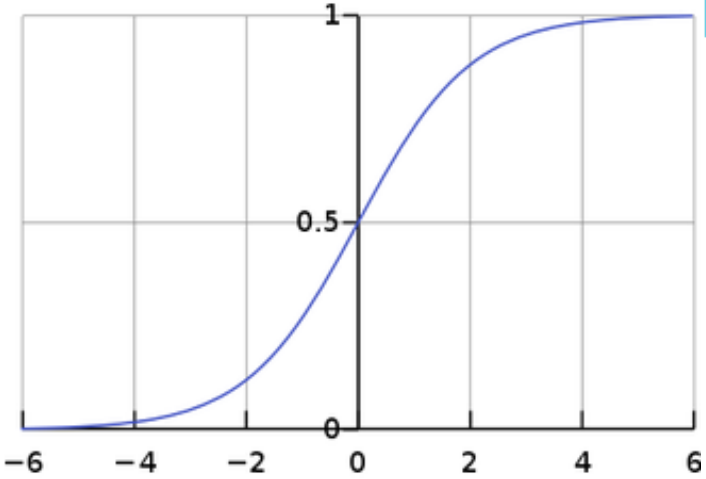
Buxton, et al, 2012

Question: Have you tried applying sound quality metrics to your sounds?

Why sound quality metrics

- A-weighting can approximate loudness well at 40-phon; at other levels loudness metrics better predict loudness
- Sound quality metrics allow one to look at attributes of the sound separately – loudness, sharpness, roughness, tonality, fluctuation, etc. (Note: We will only cover some of these in this talk)
- Certain sound quality metrics – loudness, roughness, fluctuation – preserve or analyze temporal structure which Leq-type metrics lose through averaging → help identify important temporal properties

Processing



- Jo and collaborators provided recorded sounds
- Digitized the plots using the MATLAB function "Grabit"
  - This involved a lot of clicking…
- Transformed the sigmoidal output, $y = f(x) = \frac{L}{1+e^{-k(x-x_0)}}$, to a linear function using:

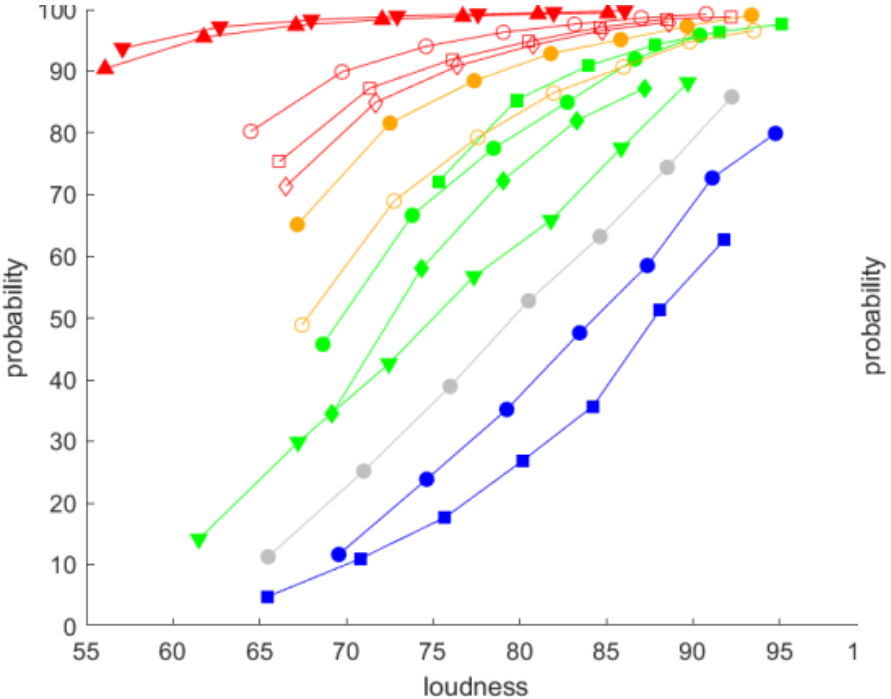
$$x = -\log\left|\frac{(M-y)}{y}\right|$$

- Calibrated signals by assuming that at their base level they were each 70 dB (assumption is naturally conservative)
- Processed sounds using sound quality metrics to obtain values
- Tried a number of different versions of metrics to see which explained the most variance
- Focused on Stage 2 and Stage 3 sleep more than REM

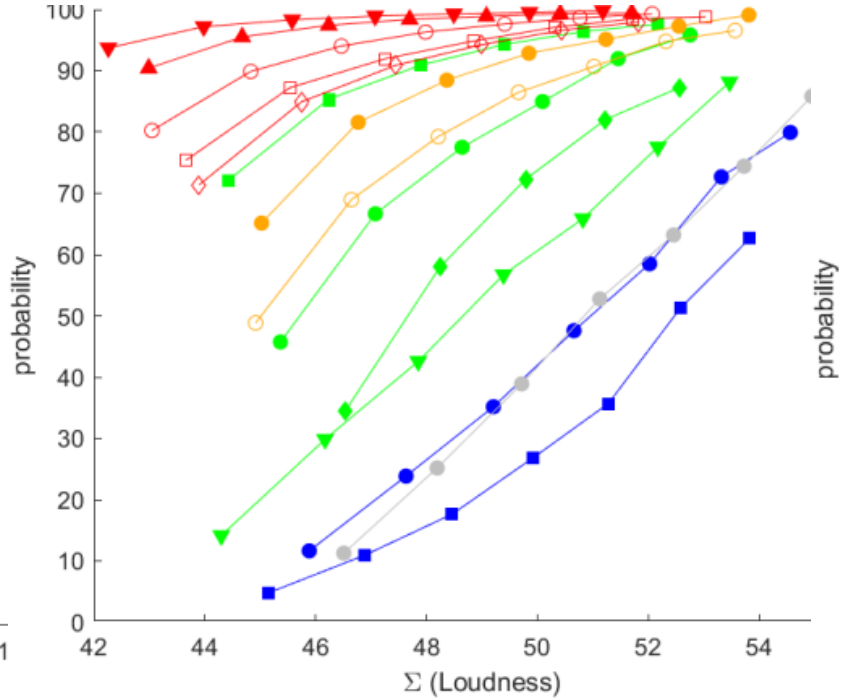
Metrics tried: Loudness variations

- Reasonable to expect loudness is important, but which loudness:
  1. Max loudness?
  2. Integrated loudness?
  3. Max loudness increase?
  - Time to Vote

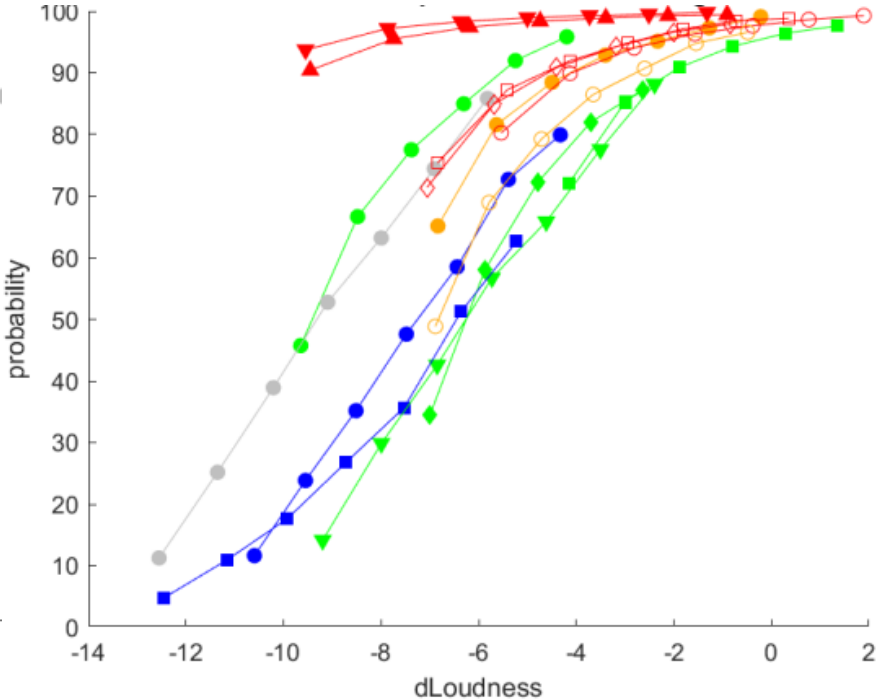
Max loudness, $r^2 = 0.1309$



Sum loudness, $r^2 = 0.066$

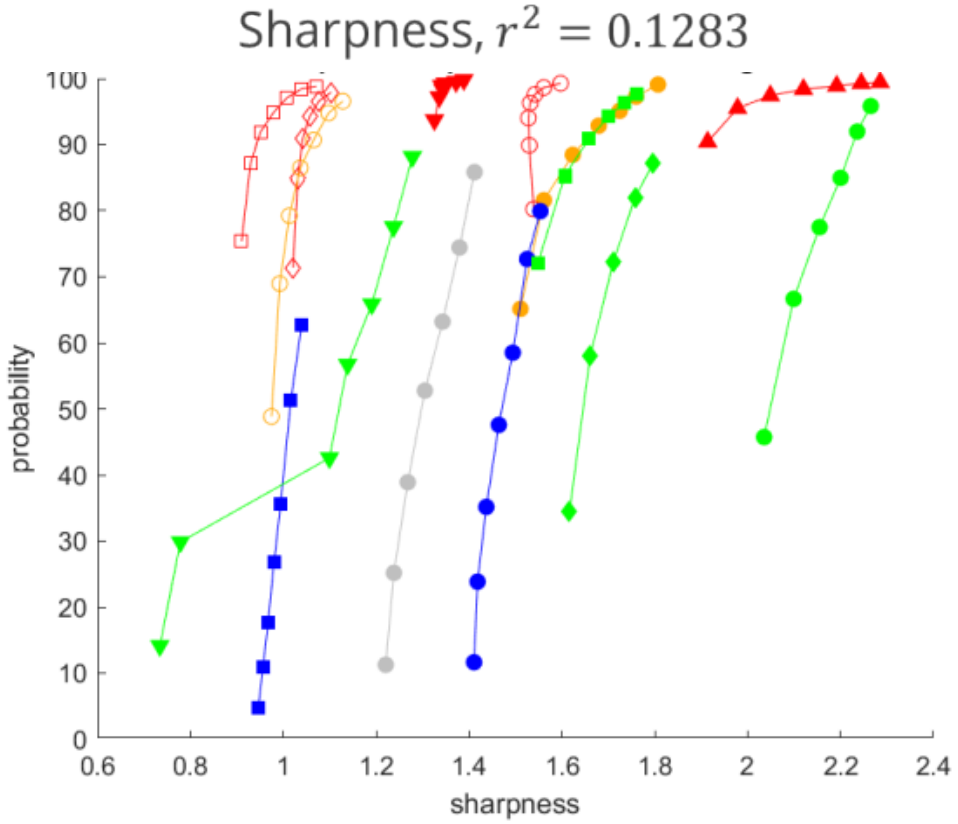


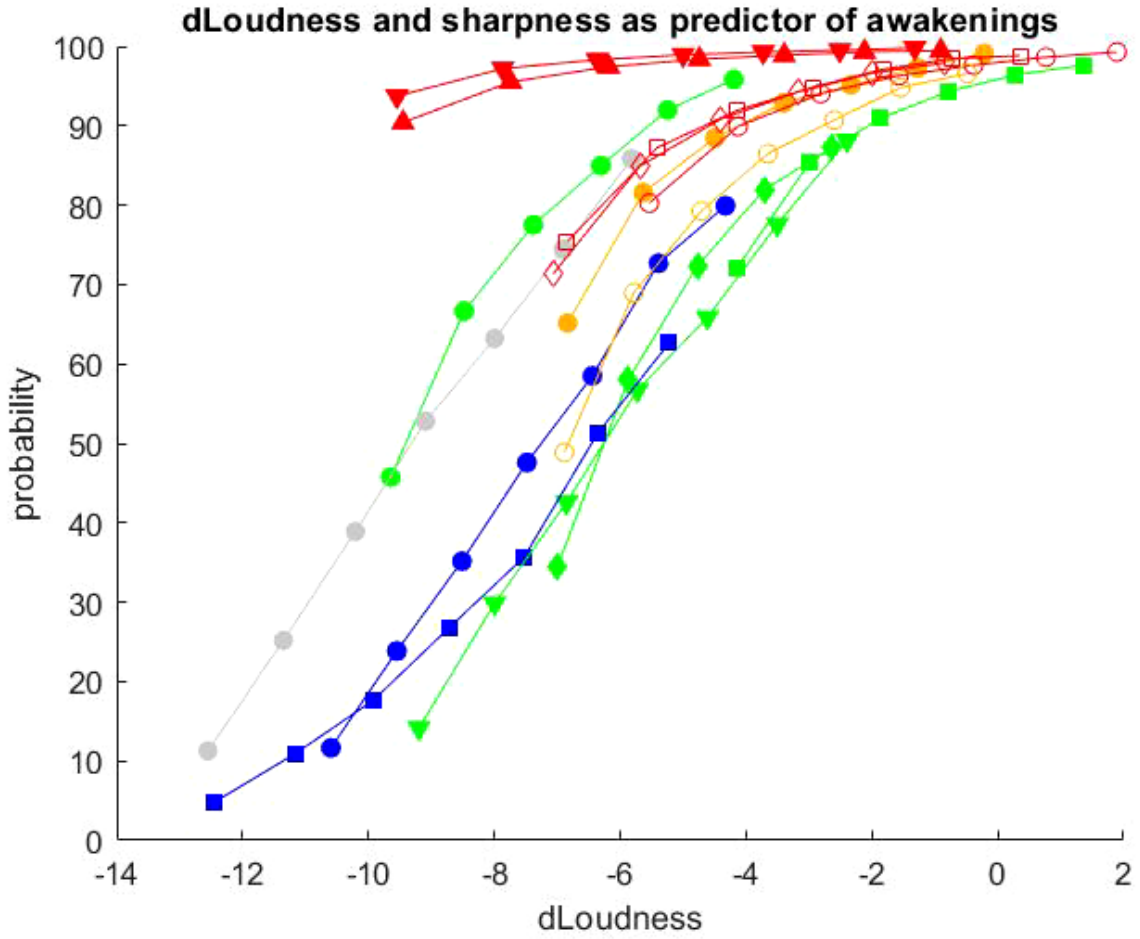
Max loudness increase, $r^2 = 0.635$



Metrics tried sharpness/sharpness + loudness

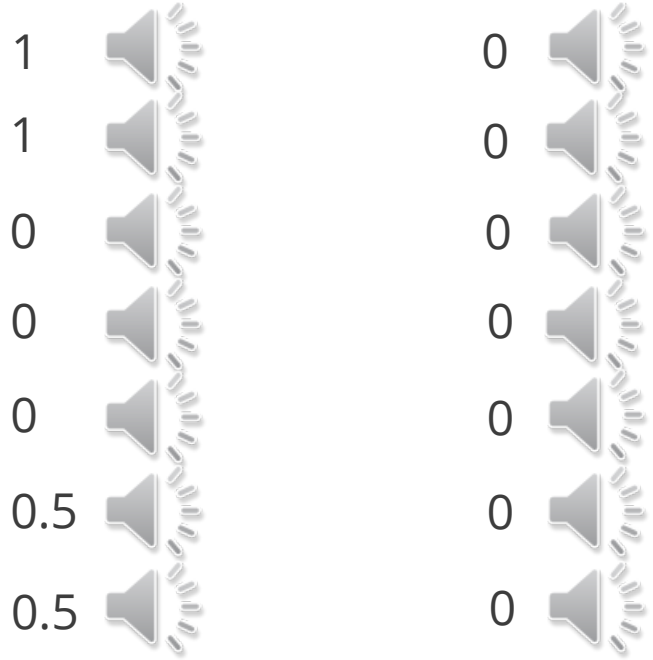
- We adopted Max loudness as our loudness descriptor
- Sharpness by itself is not a great predictor;
- does contribute both locally and globally





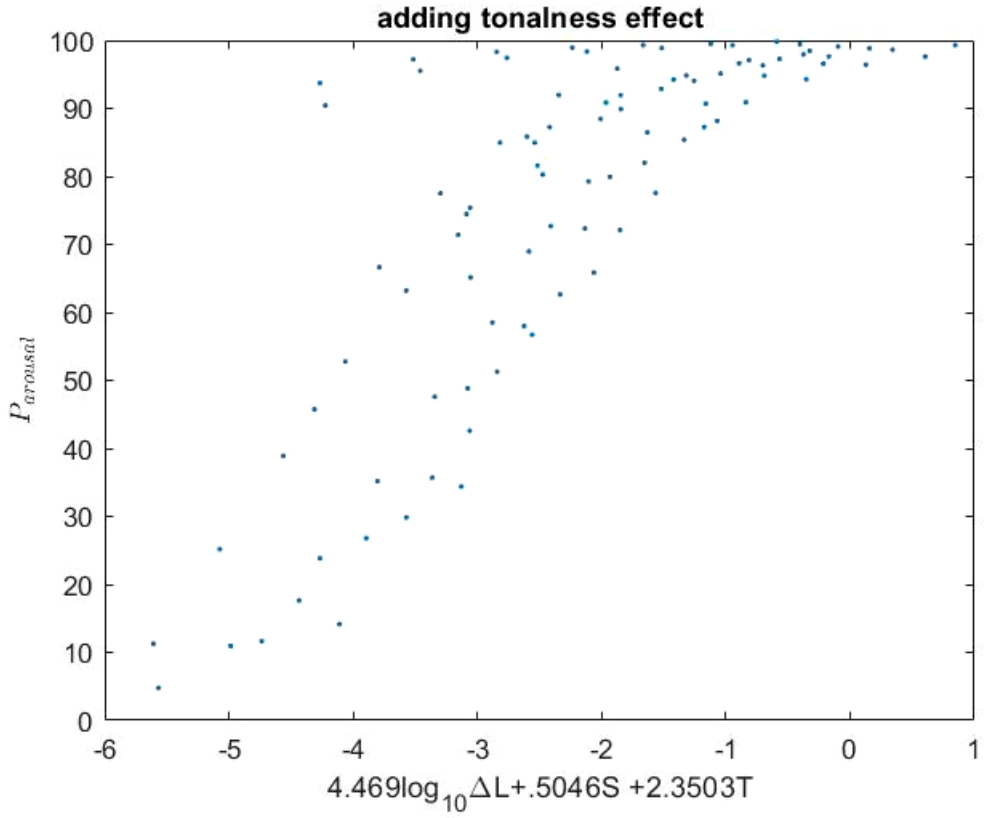
What attributes could be missing?

- Let’s listen to a few sounds?
- What attributes do you hear that might wake you up?
- The beepy noise is more likely to wake you up? Why?
- Which sounds are tonal (by hand raise)?
  Please close your eyes in order to avoid being biased by the group
- I took these informal tonalness ratings and added them to the analysis



Loudness + Tonalness + Sharpness

- By itself, tonalness predicts $r^2 = 0.2879$ of the variance
- However, different parameters covary to some extent
- Adding variables one at a time shows how each improves the model
- Combined model explains $r^2 = 0.8625$ of the variance leaving much less on the table

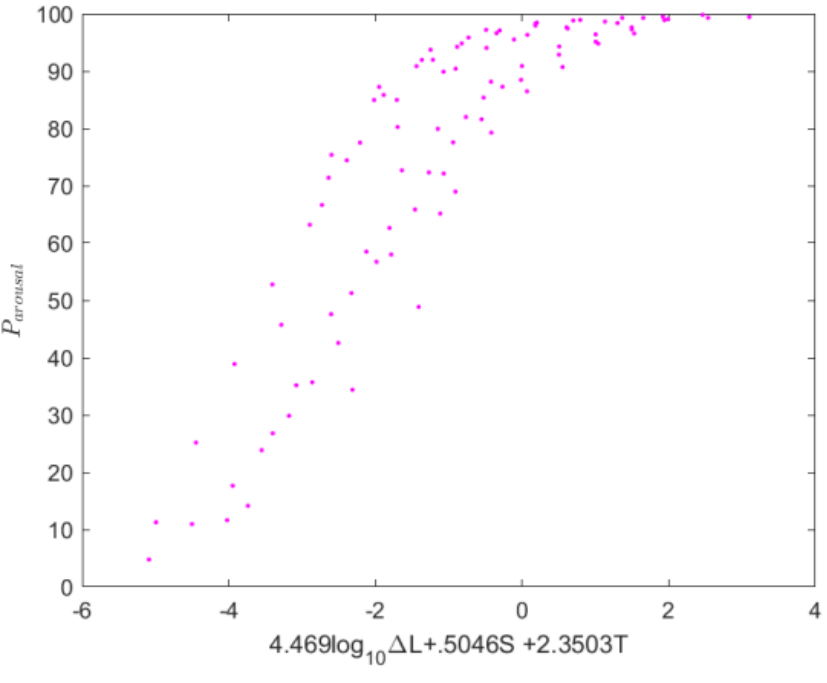


Same values work well for stage 3 sleep

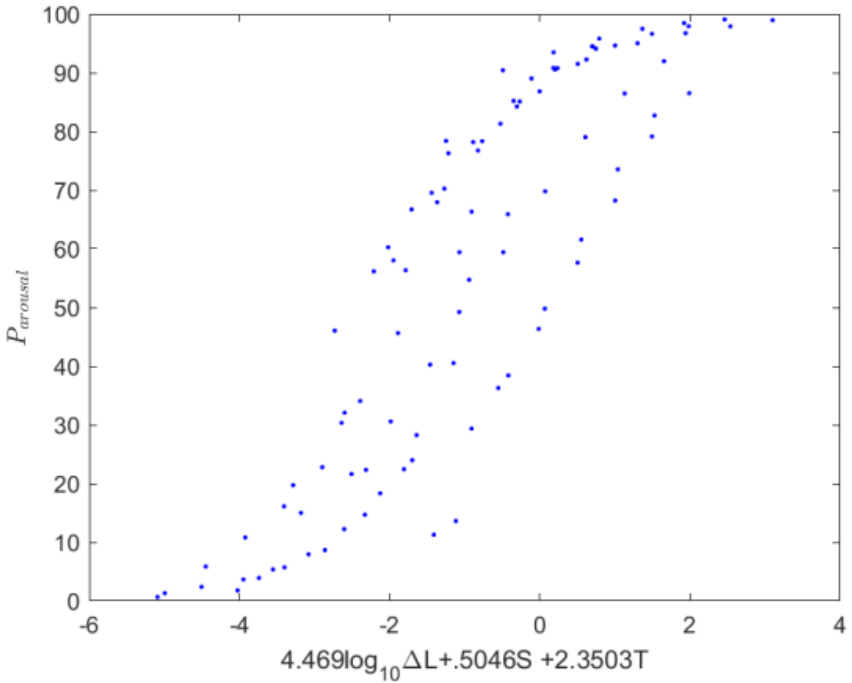
Because similar values fit stage 3 sleep as stage 2 sleep, we likely have not have overfit

Note: Stage 3 sleep does appear to change the threshold for awakening, as we would expect of a deeper stage of sleep

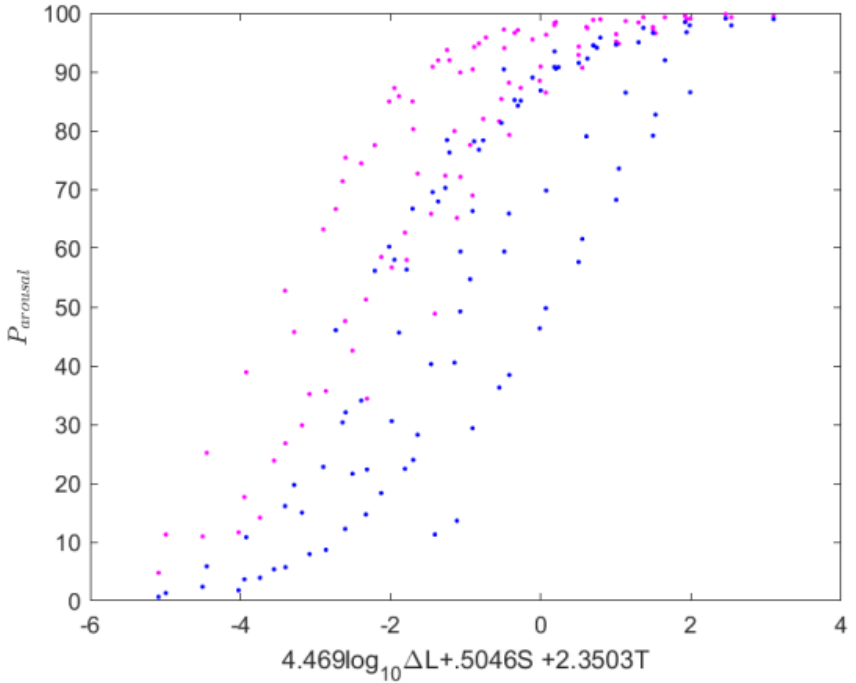
Stage 2 Sleep



Stage 3 Sleep



Stage 2 + 3 Sleep



REM note

REM does not follow the same rules as the other sleep stages, possibly because you can incorporate some pretty strange sounds into dreams.

Thanks! Questions?

Examples and illustrations

What types of effects are proposed; how do they work?

- Possibly grab figure from Health Effects of Noise FAA Report

- Stress reactions while awake
  - HPA-axis
  - Cortisol
- Sleep disruption when asleep (shortened, disrupted, or structurally changed)
  - Sleep disruption → munchies (messes up leptin/ghrelin regulation)
  - Sleep disruption → hypertension
  - Sleep disruption → mortality (cite study)
- Most concerning physical health outcomes tend to be **heart disease** and (along the way) **hypertension**

What needs to be considered (experimental general practice)

- Repeatability
- Publication bias – only publishing “successful” studies implies *reported* **causative factor → negative outcome** relationships are always greater than *average*
- Limitations of cross-sectional versus longitudinal design

Extreme danger of proxy variables

- Annoyance is often used as a measure of exposure, which introduces massive systematic bias
- Annoyance (in general) is also strongly related to poor physical and psychological health which, understandably, complicates using an annoyance subcategory as a measure of exposure to noise
- Hearing loss is sometimes used as a proxy for past community exposure, but this risks confusing past history of playing with firecracker with aircraft noise

What needs to be considered (potential confounders)

- Personal factors:
  - Age/sex/BMI
  - Employment?
  - Smoking (found to covary with distance to airport in Japan)
  - Air pollution: particulate matter, etc
  - Diet (though this should be evaluated both as an input and an output to other conditions)
  - Socio-economic status/education
  - Typical hours in bed/hours slept
  - Psychological constitution
  - Relational support/marital status
  - Major stressful life events
  - Time in residence
  - Discursive frame (what does the subject believe about noise and its likely effects)
- Other environmental factors:
  - Green space (e.g., lilacs)
  - Other environmental hazards, e.g., lead
  - Temperature
- Bias:
  - Be careful **how** you ask questions to avoid introducing bias
  - Beware of those who don't respond to surveys ([non] response bias)
  - Beware of subjective measures of exposure and outcomes

What needs to be considered (exposure)

- Assessment of exposure is often inadequate:
  - Use of something else as a proxy for exposure or effect:
    - Noise annoyance as a proxy for exposure
    - Complaints as a proxy for annoyance, community annoyance, etc
    - Use of sleep aids as a proxy for sleep disruption
    - Number of general practitioner (doctor) visits as a proxy for health effects
    - Hospital admissions as proxy for health effects
    - Remembered awakenings as proxy for sleep disturbance
    - Parental report as proxy for child's sleep disturbance
  - Use of modeled exposure rather than actual exposure
  - Use of noise measured over a seasonally limited or otherwise inadequate sample
  - Use of noise measured or estimated at or in home without ensuring the subject is present
  - Use of measured exposure outside the home
  - Use of actual exposure measured using some form of dosimetry
  - Assumption of adequacy of energy averaged values
  - Some other measure based on loudness, or noisiness (effectively how annoying it is)
  - Differing building standards and patterns can be geographically stratified by common development
  - Subjects may change their sleeping location to the "quiet side" of the house if possible
  - Different source types (road, aircraft, etc) often do not elicit similar annoyance at similar levels
  - Know what you are measuring: *loudness=/=annoyance=/=speech interference=/=sound level*, though they are related in some ways; **metrics should match the question you are asking**; SEL values and long-term levels also convey different information about the sound environment
  - Metrics must be well-defined in order ensure repeatability

What would a perfect study look like

- Design is longitudinal or experimental (with randomization)
- Noise exposure is measured individually with sound quality metric dosimeters using well-defined metrics appropriate to both the sounds and ends considered, and preferably a range of metrics to increase inter-study comparison potential
- Heart rate + Blood Oxygen measured continuously
- Blood pressure measured by standardized measurement applied consistently

What does noise actually do?

- Interrupts:
  - Sleep
  - Conversation
  - Tasks
  - Learning
- Threatens
- Annoys

About the Sandia Brand Templates

Create impactful presentations, reports, and visuals with Sandia branded PowerPoint templates.

Want more?

Browse additional design templates at creative.sandia.gov

FEATURES

- 16:9 HD widescreen format
- Embedded Sandia font, colors, and MS Office Theme
- Professional photo and text layouts available in the Sample Layouts deck
- Access fully editable charts, maps, and icons in the PowerPoint Graphics Library
- Easy to use placeholders crop photos without distortion

  Note: To reduce file sizes, templates do not include Images. UUR photos can be accessed at Sandia's Flickr page.
- Before submitting to Sandia Review and Approval, ensure only the appropriate markings are applied to content slides and Slide Masters.

Questions?

Get immediate support from Creative Services.

NM: (505) 844-7167 | **CA:** (925) 294-1010 | creative.sandia.gov

Revised 06.18.21