Initial Results from a Psychoacoustic Test for UAM Sound Quality

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Acoustics Technical Working Group Meeting
October 18th-20th, 2022

Urban Air Mobility

- Over the past few years, NASA has become interested in what's called "Urban Air Mobility" (UAM).

- This concept involves passenger air vehicles operating between, for instance, a "vertiport" in an urban center, and a nearby airport.

Psychoacoustic Testing for UAM

- There has been a lot of pontification on the role that noise will play in the rollout of UAM concepts.
- NASA maintains several psychoacoustics labs across the country that may be used to investigate the human response to the noise of UAM, even before recordings of vehicles are available.

Exterior Effects Room (EER) at NASA Langley

Psychoacoustic Testing for UAM

NASA has been executing a series of lab psychoacoustic tests for UAM-like sounds (via the EER as well as other facilities).

The questions we are interested in investigating include:

1. What are the qualitative attributes of UAM sound that lead to annoyance? Do things like the presence of tones from motors, sharpness arising from broadband, or amplitude and frequency fluctuation in the sound lead to more annoyance?
2. What way should we be integrating annoyance over time? How does annoyance build up over the course of a single event? How does it build up over the course of multiple events?
3. What role does background sound play in the annoyance of UAM? How does a preexisting (e.g., urban) soundscape impact the perception of UAM vehicles?

These tests are meant to produce data that will be used in building models of annoyance that are inclusive of these effects.

Psychoacoustic Testing for UAM

What are the qualitative attributes of UAM sound that lead to annoyance? Do things like the presence of tones from motors, sharpness arising from broadband, or amplitude and frequency fluctuation in the sound lead to more annoyance?

- We can investigate the efficacy of existing methods of evaluating SQ:

$$PA = N \times \left(1 + \sqrt{w_{FR}^2 + w_S^2}\right)$$

  - Often attributed to Fastl/Zwicker, though seems to be from Widmann in the early '90s
  - More 2011: Addition of tonality for aircraft noise
  - Di et al. 2019: Extension to more types of noise
  - Torija et al. 2022: Fit to UAV noise specifically

→ We want to look into this for UAM noise in particular. Ultimately, we'd like to incorporate other effects as well (integration, masking, etc.).

Investigating Sound Quality: TUSQ

- To generate data for this, an EER psychoacoustic test was executed
  - Test of UAM Sound Quality (TUSQ)
  - 40 subjects over a week of testing in June/July 2022

- The rest of this presentation will go over details of the test and some initial exploratory data analysis.
  - Models do not have to be restricted to that form, but will probably be roughly:

$$Annoyance = Loudness + f(T, S, R, FS, I, \ldots)$$

→ We need data that determine the function, but also data that determine the parity between the function and loudness.

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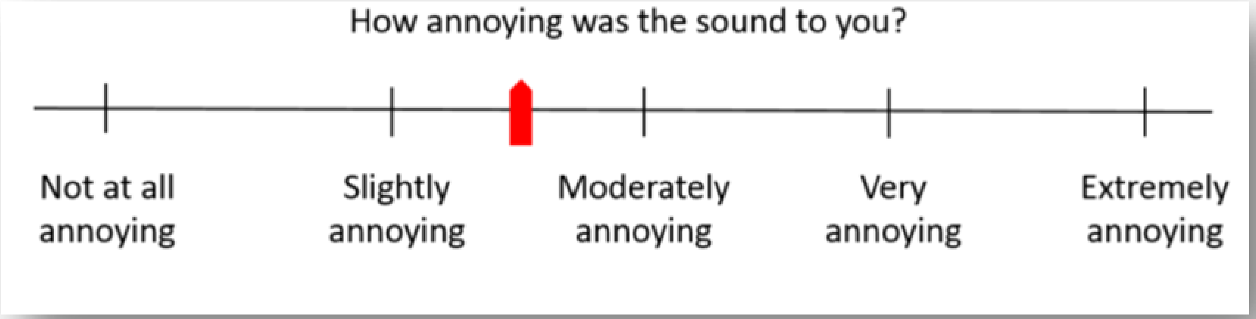
Test of UAM Sound Quality

- Motivation
- Two test questions: Loudness and other SQ
- Start with simulations
- Post-process to get stimuli
  - Change in BPF
  - Factorial test design
- How noise parameters influence sound quality

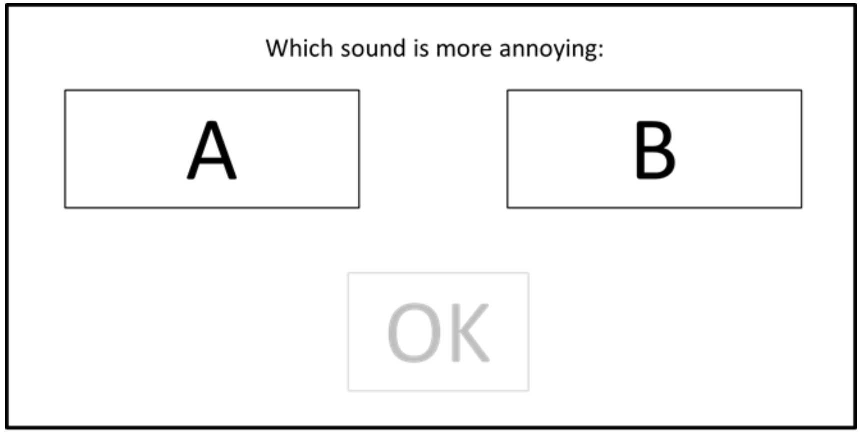
Two test questions: Loudness and other SQ

$$Annoyance = Loudness + f(T, S, R, FS, I, \ldots)$$

- How does annoyance change if loudness is constant?
  - Annoyance ratings
  - 136 sound of various sound quality
  - Constant loudness

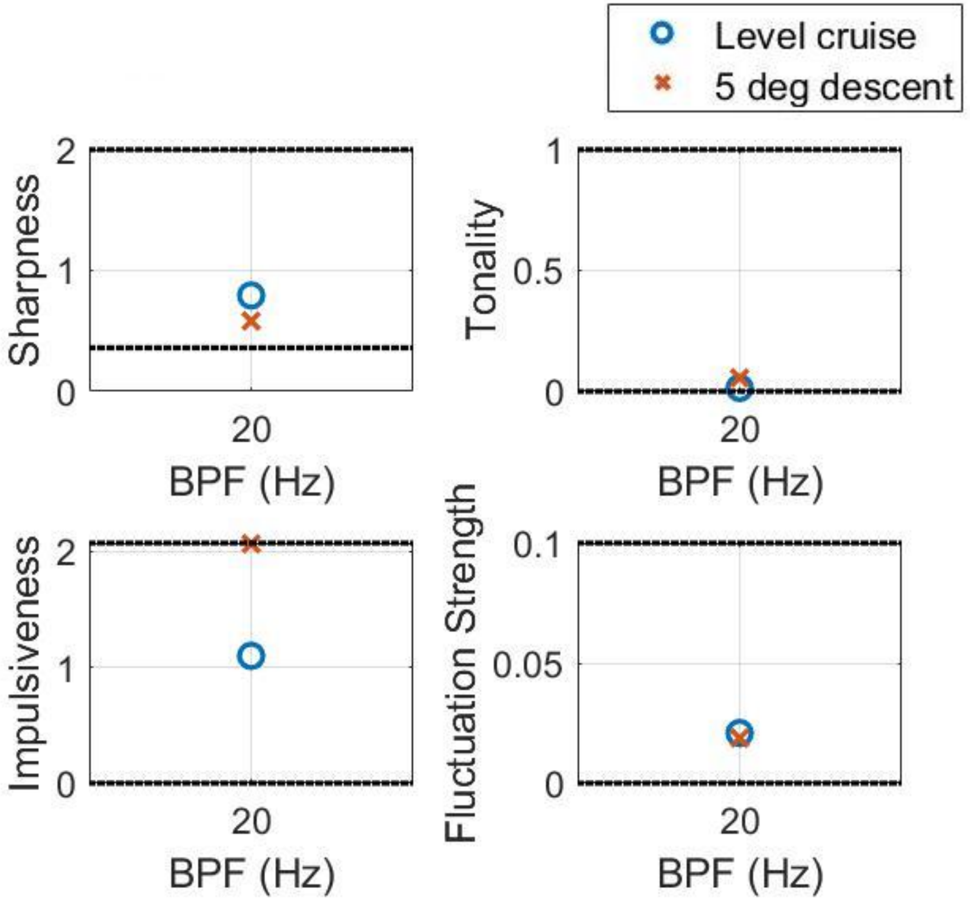


- How does annoyance change with loudness?
  - Paired comparisons
  - 26 sounds selected from above
  - Vary loudness of reference sound



Start with simulations

Blade passage Frequency (Hz)	Level cruise	5 degree descent
20		



Auralizations

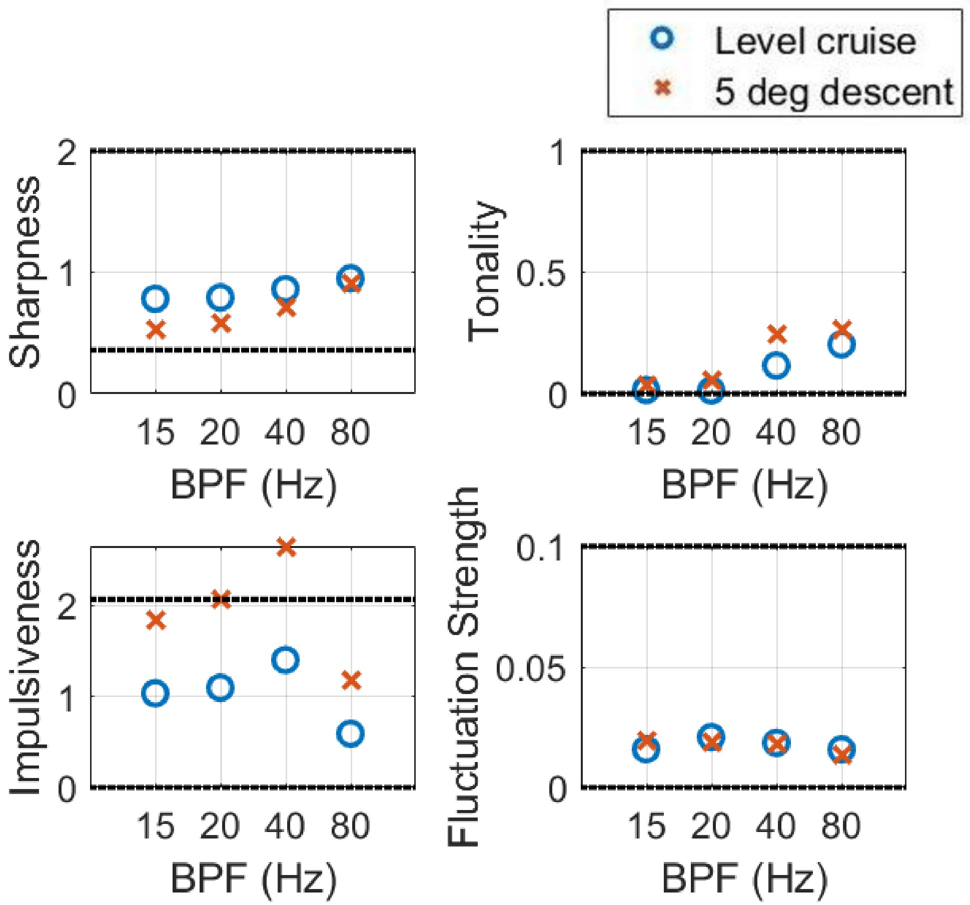
- F1A from Aircraft Noise Prediction Program (ANOPP2)
- Broadband synthesis developed for rotorcraft
- Auralize using NASA Auralization Framework

Christian, Boucher, and Begault, F

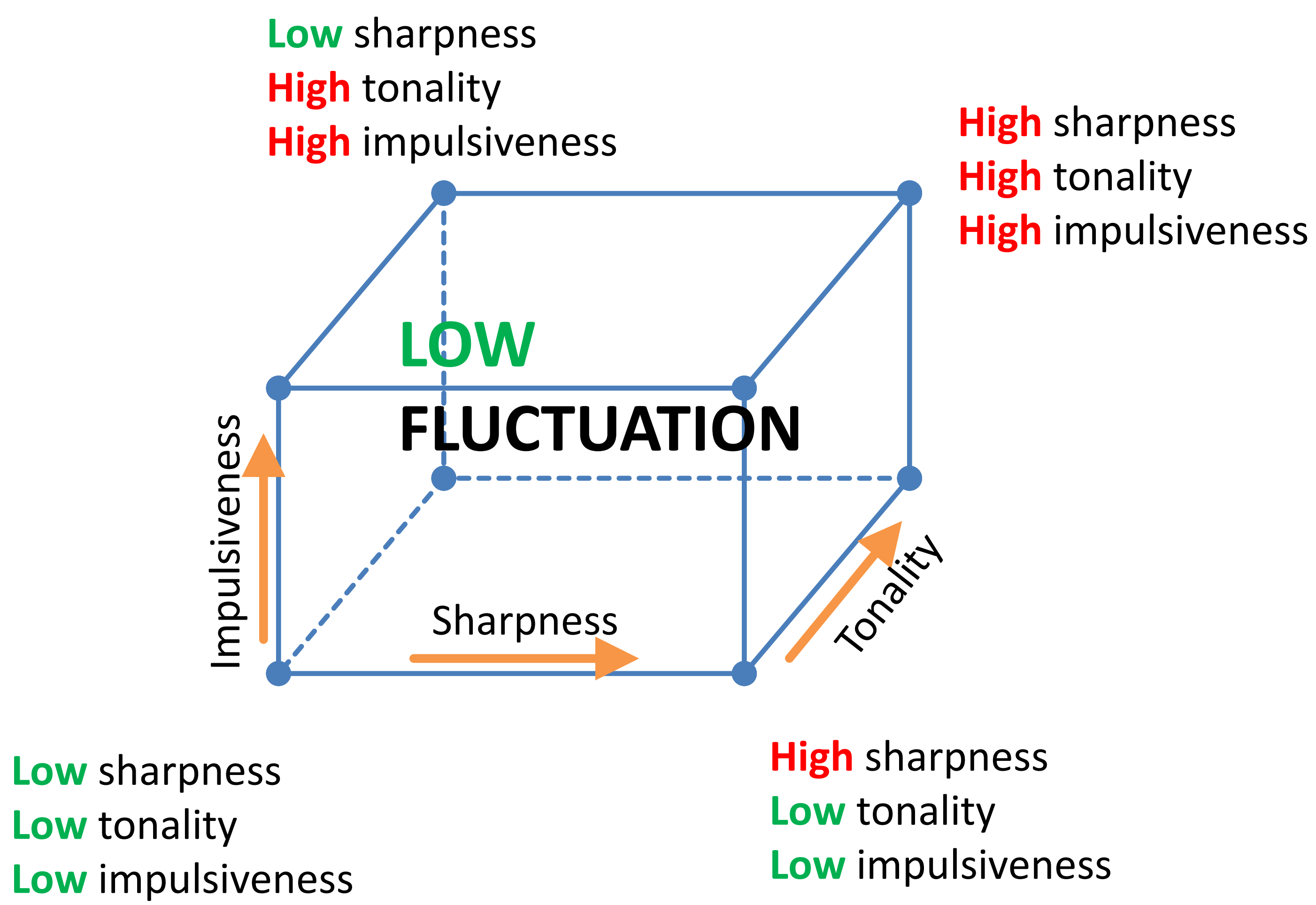
Post-process to get stimuli: change in BPF

- Relate design parameters to changes in sound quality
- How did we generate the 8 baselines?

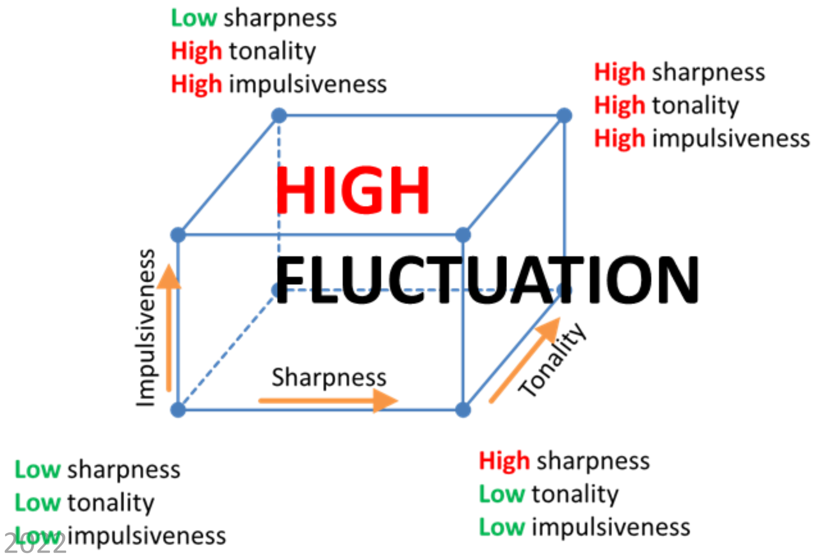
Blade passage Frequency (Hz)	Level cruise	5 degree descent
15		
20		
40		
80		



Post-process to get stimuli: factorial test design



- For fixed BPF and flight condition
- Cube depicts 3-factor,
  - 2-level design
- 4th factor is another cube for high fluctuation strength



How noise parameters influence sound quality

- Baseline: 5-degree descent with 20Hz blade passage frequency
- Broadband gain to change sharpness
- Tone amplitude to change tonality
- Moving average on loading and thickness noise to change impulsiveness
- Modulation amplitude to change fluctuation strength

Low sharpness, tonality, impulsiveness and fluctuation	High	High sharpness, tonality, impulsiveness and fluctuation
	Sharpness	
	Tonality	
	Impulsiveness	
	Fluctuation Strength	

What factors are important for annoyance?

Synthesis parameters

- Flight condition
- Blade passage frequency
- Self-noise (broadband) level
- Tone amplitude
- Crispness of loading & thickness noise (mov. avg.)
- Modulation amplitude

→

Sound quality

- Loudness
- Sharpness
- Tonality
- Roughness
- Impulsiveness
- Fluctuation Strength

→

Annoyance

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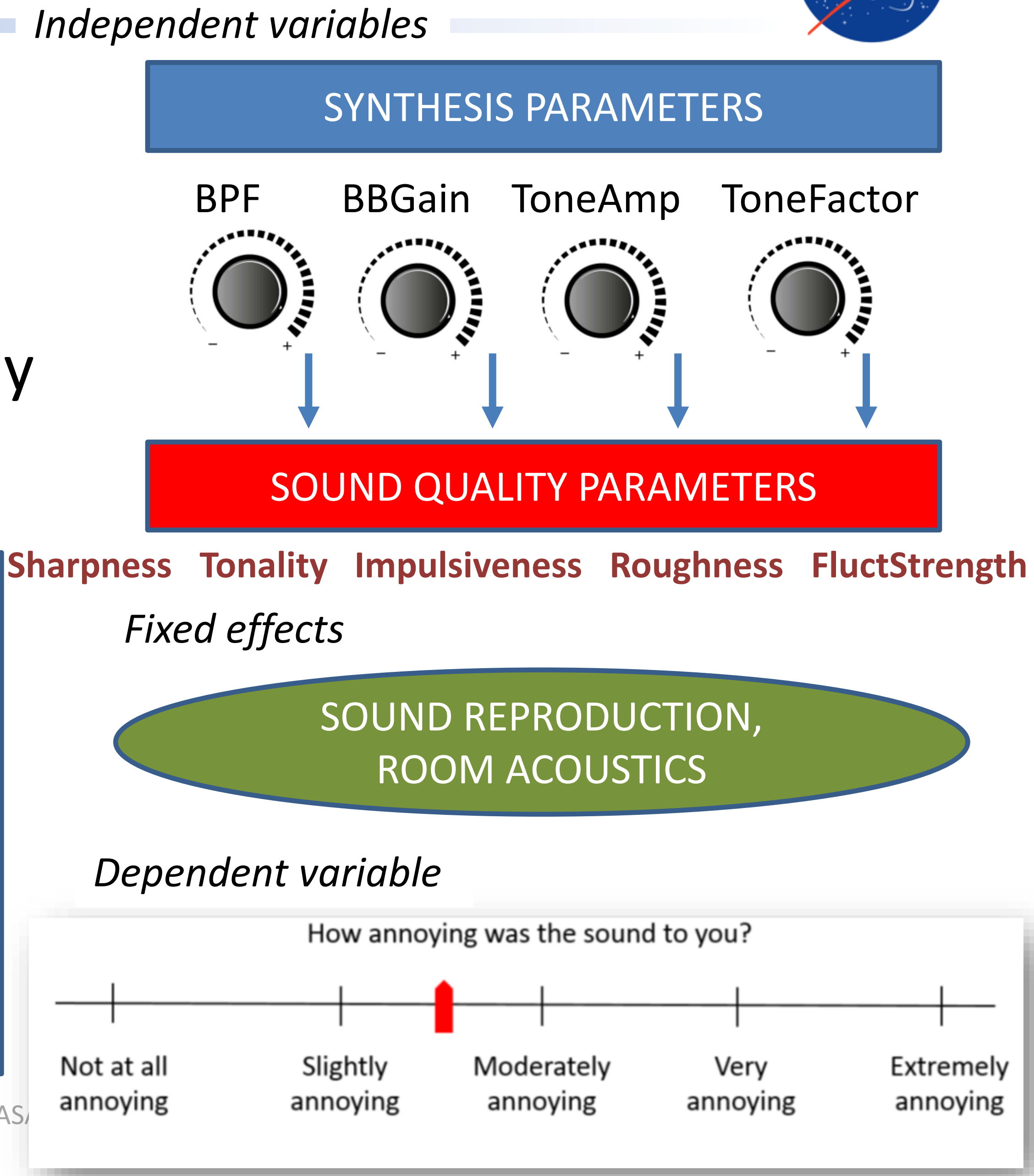
Initial data results (a "first cut")

- Subject's annoyance responses to vehicle design ("**synthesis**") and objective **Sound Quality** (**SQ**) parameters were evaluated **separately**, and for the "flyover" stimuli only *(n =2560)*



- Do **either** synthesis or SQ parameters **predict annoyance** in a linear fashion? What is the **effect size**?
- How **consistent** are inter- and intrasubject annoyance judgements?

Initial data results: linear regression, ANCOVA

SOUND QUALITY PARAMETERS

Sharpness Tonality Impulsiveness Roughness FluctStrength

SOUND QUALITY PARAMETER ANALYSIS:

- Regression R^2 indicated that only **6% of the variability** in overall subjective responses explained by **sound quality** factors.
- ANCOVA (Analysis of Covariance) analysis includes subjects as an independent variable. The R^2 indicated **44% of the variability** due to both sound quality factors **and** subjects, with **subjects** being the most influential parameter.

- What is the source of **subject variability**?

Initial data results: linear regression, ANCOVA

SYNTHESIS PARAMETERS		
BPF	BBGain	ToneAmp

SYNTHESIS PARAMETER ANALYSIS:

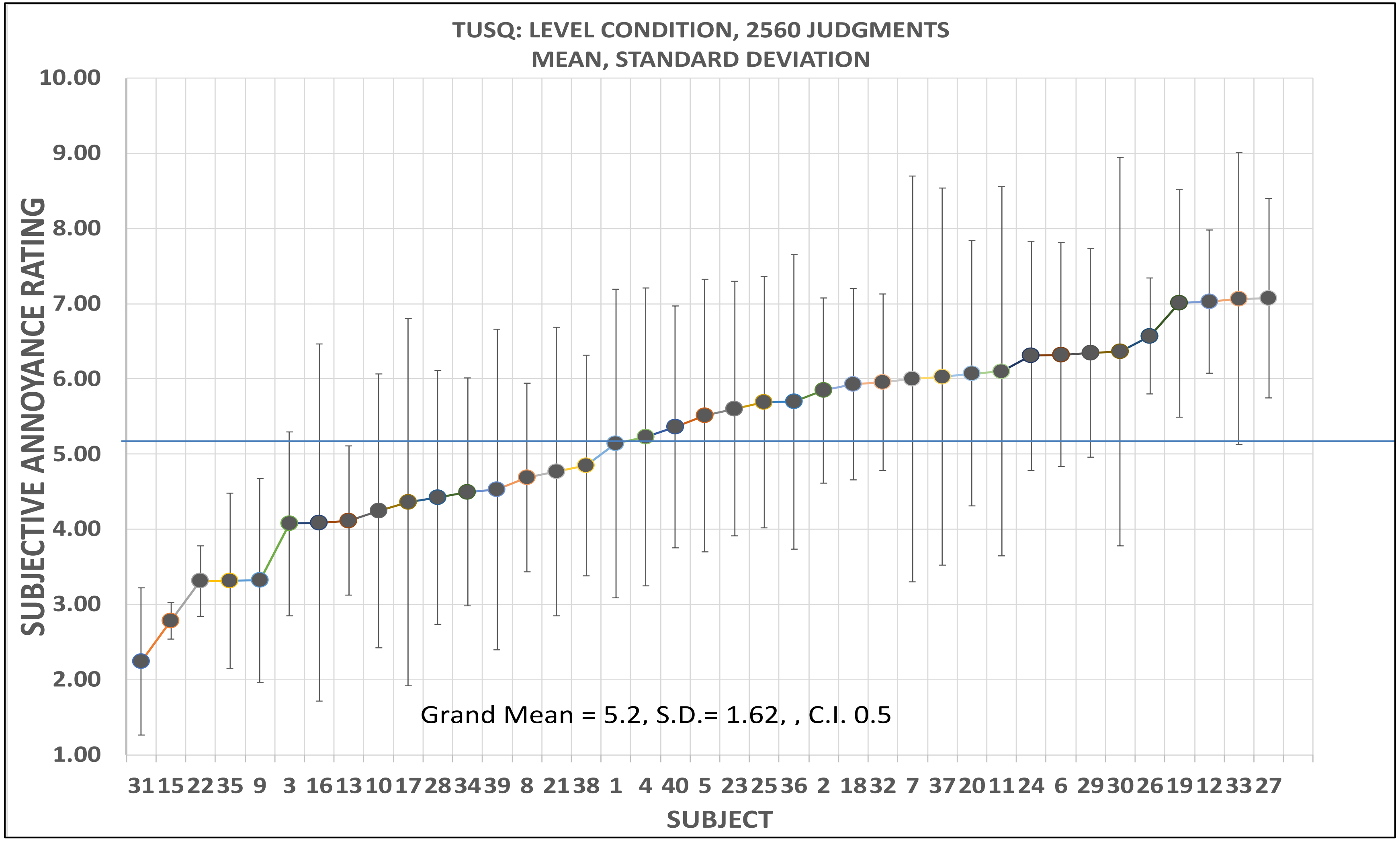
- Regression R2 indicated that only 10% of the variability in overall subjective responses explained by sound synthesis parameters. (31 out of 40 subjects are significantly affected by at least one parameter.)
- ANCOVA analysis includes subjects as an independent variable.

The R^2 indicated **47% of the variability** due to both sound quality parameters **and** subjects, with **subjects** being the most influential parameter.

- Again, what is the source of **subject variability**?

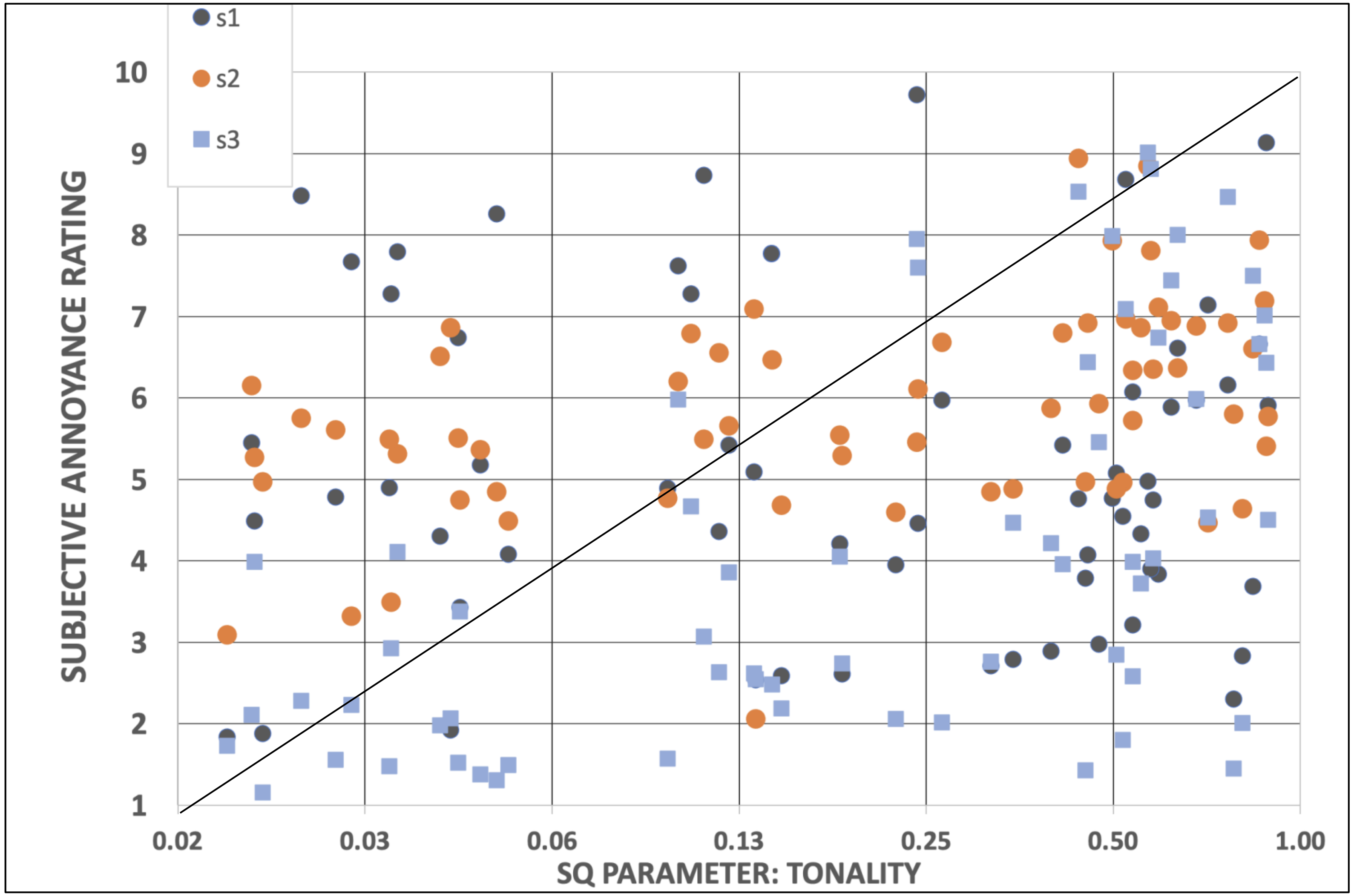
Initial data results: raw data

- Subjects sorted by mean annoyance judgments shows intersubject differences, different use of annoyance scale



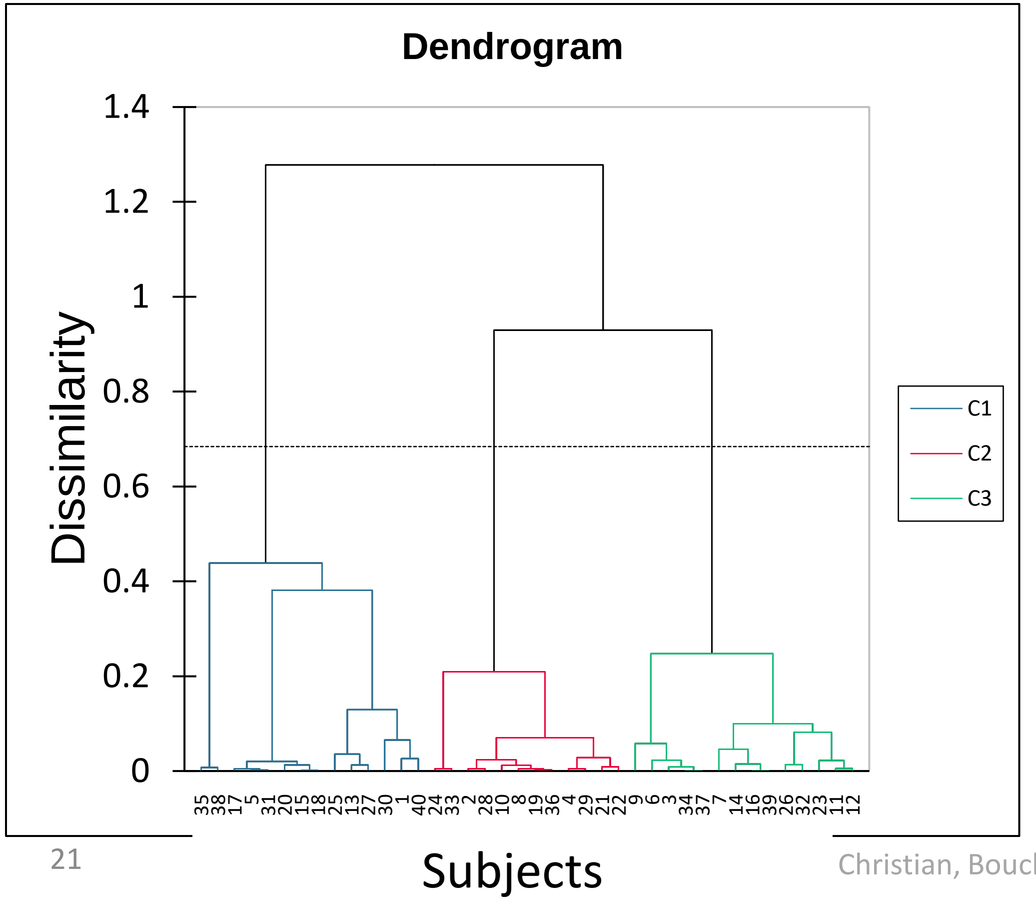
Initial data results: raw data

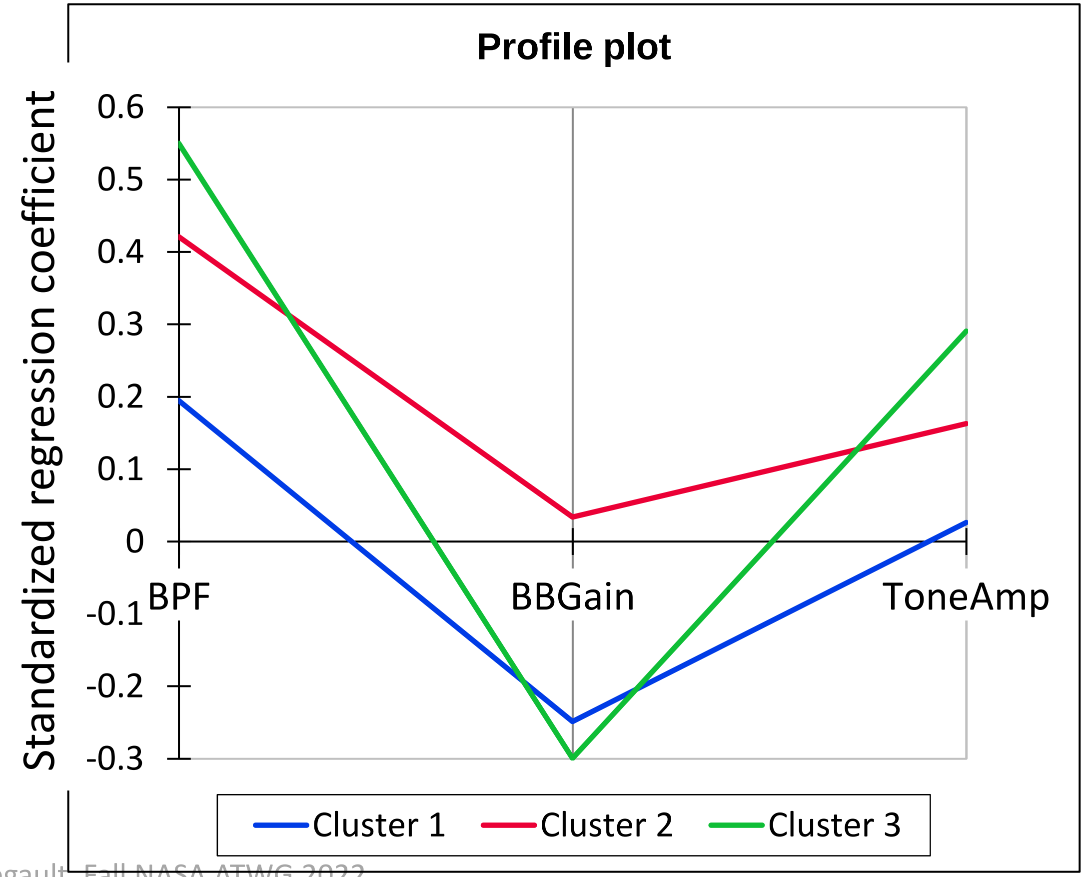
- **Example showing 3 out of 40 subjects who do not respond to changes in the SQ parameter *tonality* consistently** (due to other **covariates;** criteria shift; and/or scale use).



Agglomerative hierarchical clustering (AHC)

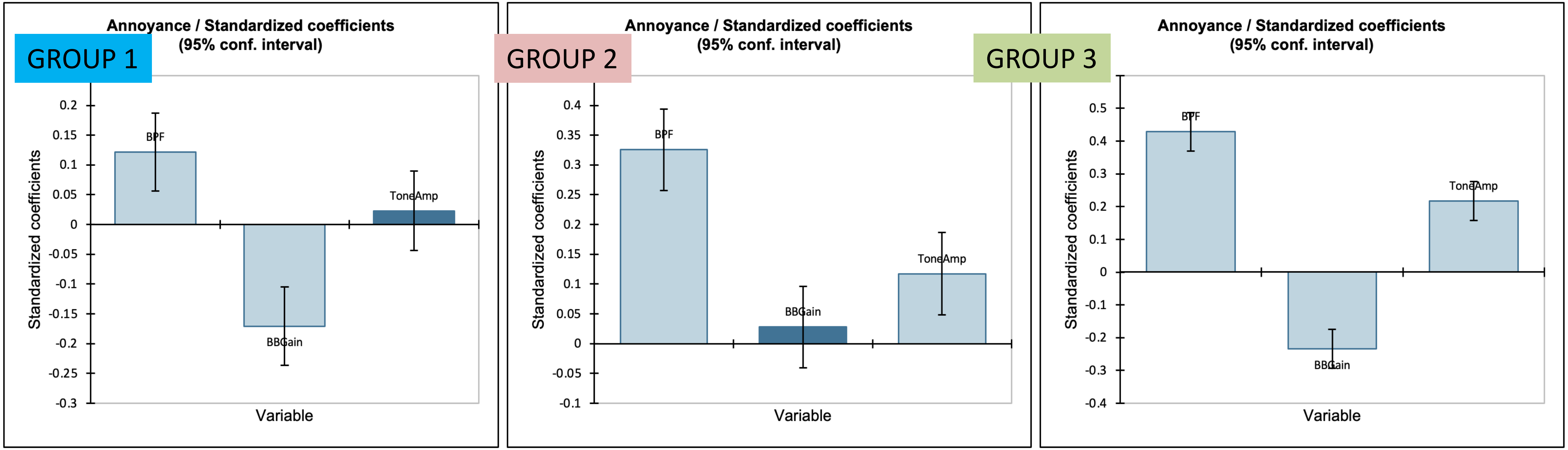
- **Synthesis data** (normalized coefficients) for BPF, Bbgain and ToneAmp fits a model with 40 subjects divided into **3 clusters** (subject groups) of 14, 12 and 14 members



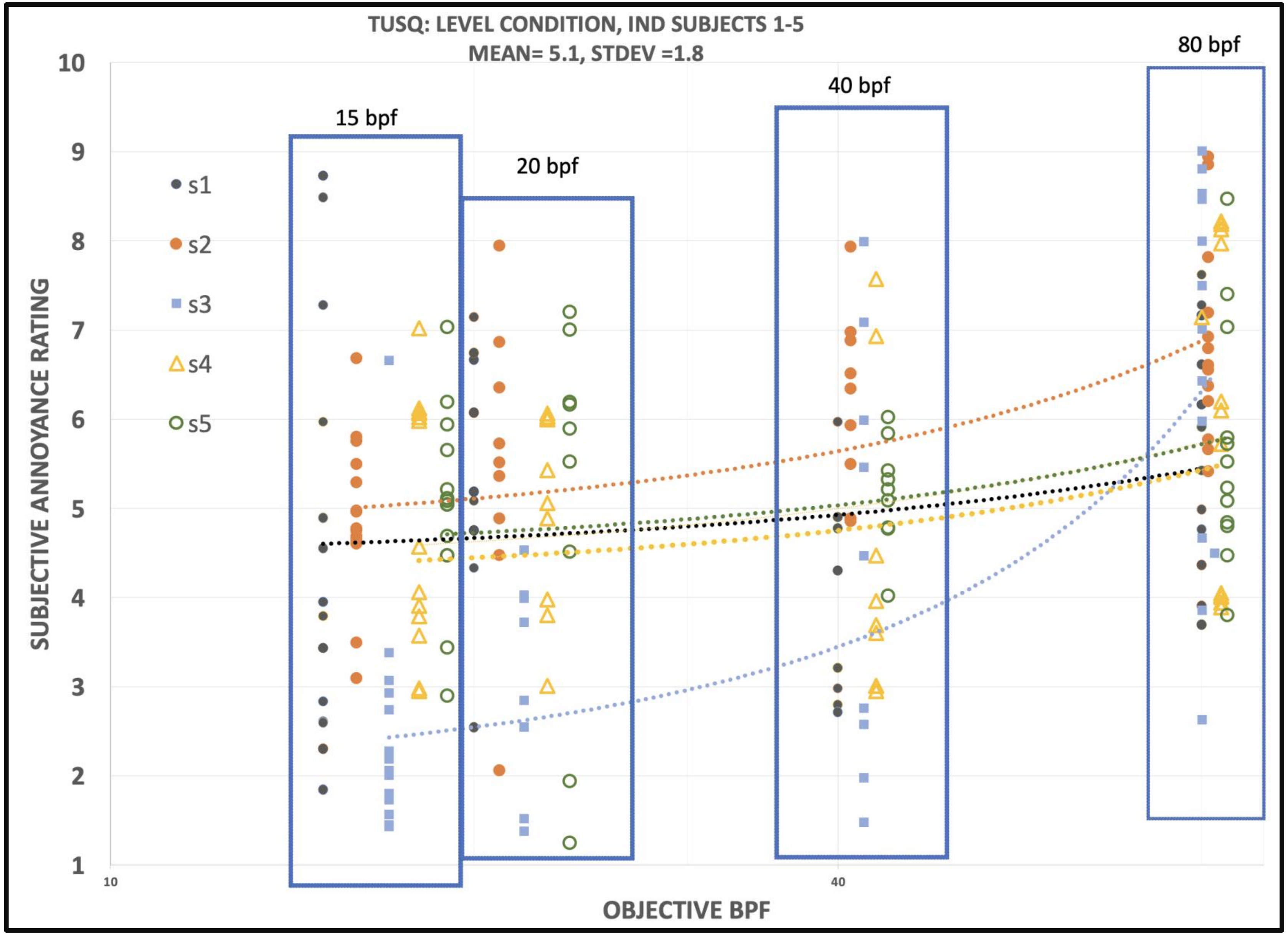


Initial data results: linear regression by cluster

- **Synthesis parameters**: normalized coefs., subject group 1 vs 2 vs 3
- All groups **significantly affected** by increase in BPF; **and….**
  - Group 1 also *inversely* sensitive to BBgain, but not to ToneAmp
  - Group 2 also sensitive to ToneAmp, but not BBgain
  - Group 3 also *inversely* sensitive to BBgain **and** sensitive to ToneAmp



Initial data results: need to determine effect size



- **5 of 40 subjects' data for BPF. While significant, the average effect size varies between subjects.**

- Large effect size for s2, s3
- Small effect size for s1, s4, s5

Disclaimers

- These results are a **PRELIMINARY** look at a subset of the total data (level flyover); no final conclusions should be drawn.

- Note that the subset of data for simulation of a 5-degree descent have a different sound characteristic, and likely a different subjective response.

Ongoing Work

- Further analyses are planned for these data:
  - Determination of the relative importance of the sound quality parameters.
  - Fitting models of psychoacoustic annoyance to the data.
  - Comparison of results with tests from other authors.
- Combination with datasets from other tests (both results of similar SQ tests, and results of other types of tests from this series).
- Further presentation and dissemination of the data.

Acknowledgements

Credit is due to many others for their support of this work:

- Kevin Shepherd, for guidance and expert opinion
- Erin Thomas, for human subject recruitment
- Aric Aumann, for support of the EER software
- Brian Tuttle, for support of the signal generation process
- LaRC Safety, Industrial Hygiene, Health Services, and others who helped guide this (in-person) test in the wake of COVID-19

This work is funded through the Revolutionary Vertical Lift Technology project at NASA. Thanks to Susan Gorton, Benny Lunsford, Noah Schiller, and others for the opportunity to pursue these questions.

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