
**Evaluating the Effect of COVID on Hearing Aid
Performance and the Relationship between Entropy
Auditory Environments using Ecological Momentary
Assessment**

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Objectives



- **To establish the validity of Shannon Entropy as a measurement of auditory environment diversity.**
- **To determine if individuals with higher auditory diversity benefit more from the use of prescription hearing aids with advanced technology**

EMA Data

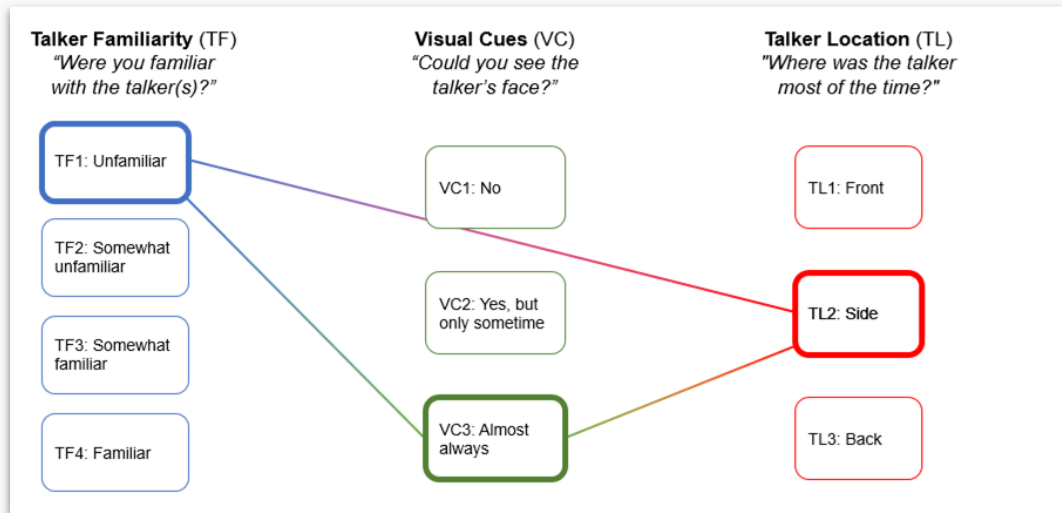
(Ecological Momentary Assessment)

Collect data from recent or current responses of survey questions from participating patients or clients.

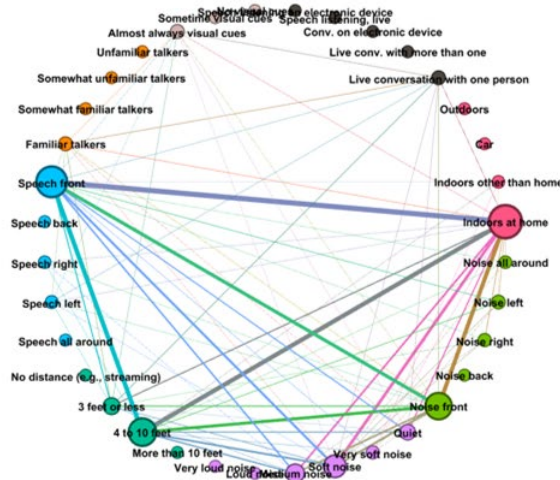
- Collected via smartphones
- Multiple surveys throughout the day
 - Listening environments, listening activities, feelings/experiences
- Avoids recall distortion
- Complex data structure

Entropy

The complexity of a system quantified by its predictability (or uncertainty).



Entropy Calculation



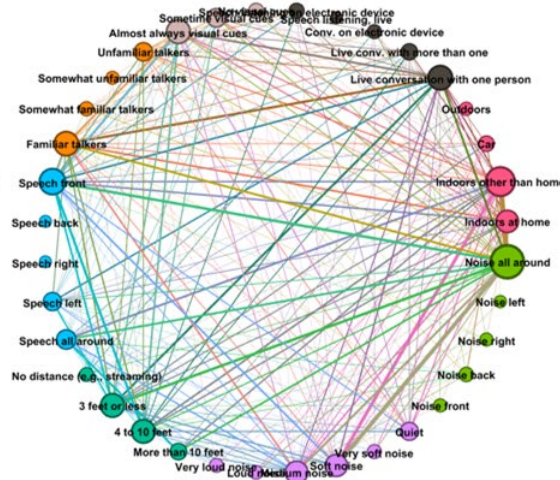
ID: P50020

Entropy: 8.12 (low complexity)

EMA survey counts: 41

→ Entropy_Original

→ Entropy_NormByNode



ID: P50077

Entropy: 15.68 (high complexity)

EMA survey counts: 41

$$p_{ij} = \frac{V_{ij}}{\sum_{j=1}^k V_{ij}}$$

$$H(i) = \frac{-\sum_{j=1}^k p_{ij} \log(p_{ij})}{\log(k)}$$

$$H(N) = \sum_{i=1}^n H(i)$$

Dataset

- COVID dataset:
 - 2 conditions: Pre-COVID and During COVID
 - Use 11 EMA questions to calculate entropy (yellow highlighted)
 - A total of 48 questions responses
 - Aggregated by patient
- HA dataset:
 - 2 conditions: On and Off
 - Use 8 EMA questions to calculate entropy (yellow highlighted)
 - A total of 32 question responses
 - Also contain outcome data (DV)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Survey ID	Condition	p50 ID	LC	ACS	YC	TF	SD	SL	NZ	NL	SN	G	NT	PI											
1	PreCOVID	p50-0001	1	6	11	16	19	25	28	35	38	42	47												
2	PreCOVID	p50-0001	2	5	11	13	20	25	30	31	36	40	43												
3	PreCOVID	p50-0001	2	5	11	13	20	21	29	35	36	42	46												
4	PreCOVID	p50-0001	1	6	11	15	19	21	29	33	36	40	47												

	sp	le	ld2	st	ap
1	71	50	81	50	68
1	73	72	79	50	67
1		50	92	50	91

Survey ID	patient	HA_condit	ac	lc	tf	yc	tl	nz	nl	rv
1	EMAD1	Off	1	8	16	18	21	25	30	31
2	EMAD1	Off	1	8	16	18	21	25	30	31
3	EMAD1	Off	6	10				24	27	31
4	EMAD1	Off	4	10	14	18	20	24	27	31
6	EMAD1	Off	1	10	16	19	20	24	30	31

Other Variables

sp	Speech understanding
le	Listening effort
st	Hearing aid satisfaction
ld2	Loudness satisfaction
ap	Participation restriction
HA_condition_OnVsOff	Hearing aid advanced features on vs off
ALDQ_Overall_demand_score & ALDQ_Often_total	Auditory Lifestyle and Demand Questionnaire
SNI_High_Contact & SNI_Social_Network	Social Network Index
Proportion_NZandVeryNZ	Proportion of results in noisy and very noisy environments

Statistical Methodology

Validating Entropy as a Measurement

- Compare Entropy Pre and During COVID
- Paired t test
 - Entropy Original
 - Entropy Normalized by Node
 - EMA count

```
t.test(x=Entropy$Entropy_Original_Pre,  
       y=Entropy$Entropy_Original_During,  
       alternative = "two.sided",  
       mu = 0,  
       paired=TRUE,  
       conf.level = 0.95)
```

Linear Regression

- 2 Entropy Statistics:
 - Entropy_Original
 - Entropy_NormByNode
- Test for correlation between entropy and
 - SNI
 - ALDQ
- Test Pre-COVID, During COVID, and the difference between Pre and During COVID

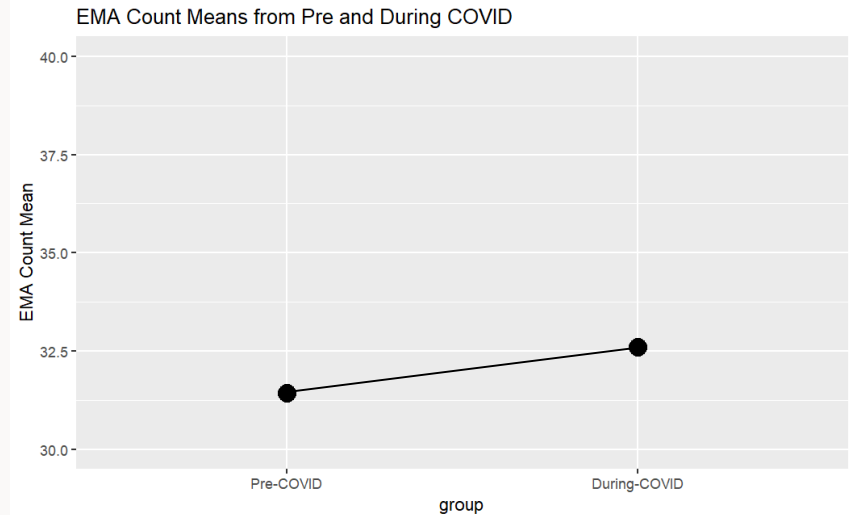
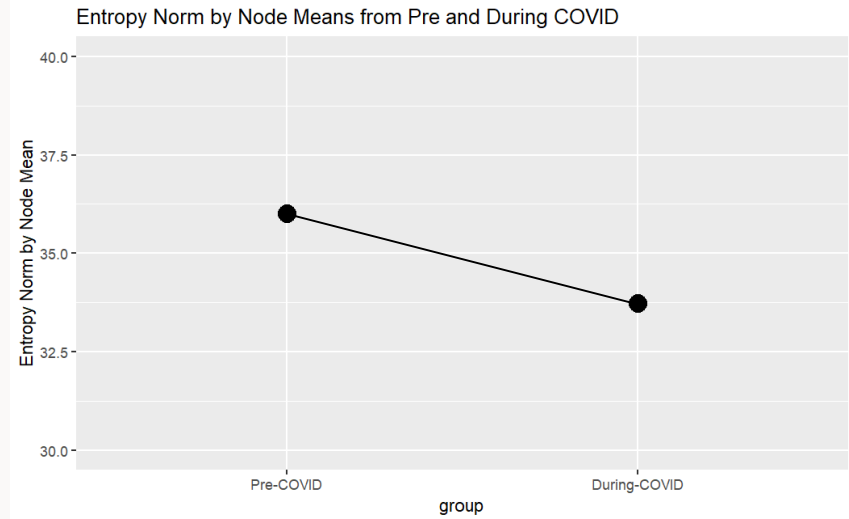
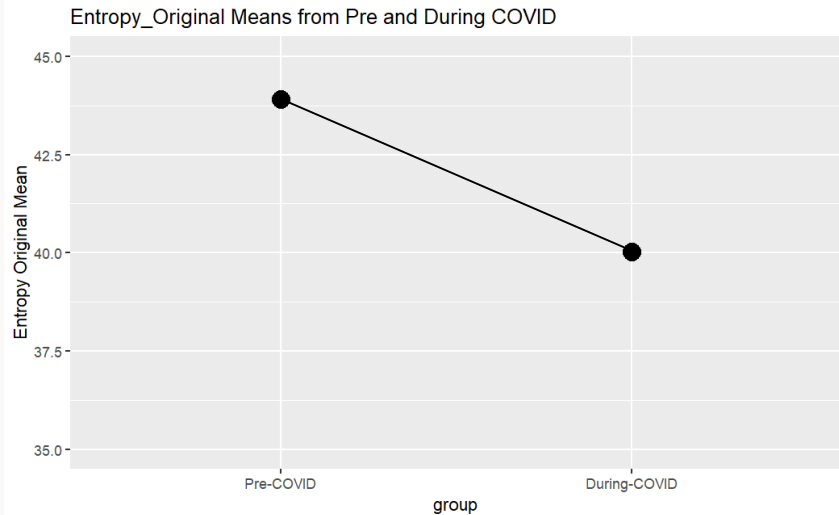
Mixed Model Analysis

- Linear mixed model using lmer
 - Terms:
 - HA condition (On vs Off)
 - Entropy group (High vs Low)
 - Proportion of noisy environments
 - Interaction term for HA condition and entropy group
 - Random intercept term to account for correlation within patient
- Estimated marginal means with emmeans package
 - Calculated mean response for each hearing aid condition for high entropy or low entropy
- Outcome variables:
 - Speech understanding
 - Listening effort
 - Hearing aid satisfaction
 - Loudness satisfaction
 - Participation restriction

Results

t-Tests

Entropy levels were significantly higher before COVID compared to during COVID



Linear Regression

SNI:

- Correlation with entropy decreased during COVID
- Correlation decreased after standardizing by Node

	Slope Est.	Slope p-value	Pearson coef.
	Entropy Original vs SNI High Contact		
Pre	1.10	0.0173	0.36
During	0.91	0.0974	0.25
Diff	1.83	0.0476	0.31
	Entropy Norm By Node vs SNI High Contact		
Pre	0.65	0.0256	0.34
During	0.36	0.2688	0.17
Diff	0.90	0.0823	0.27
	Entropy Original vs SNI Social Network		
Pre	0.20	0.0140	0.37
During	0.15	0.1315	0.23
Diff	0.11	0.4100	0.13
	Entropy Norm by Node vs SNI Social Network		
Pre	0.12	0.0194	0.36
During	0.07	0.2785	0.17
Diff	0.04	0.6002	0.08

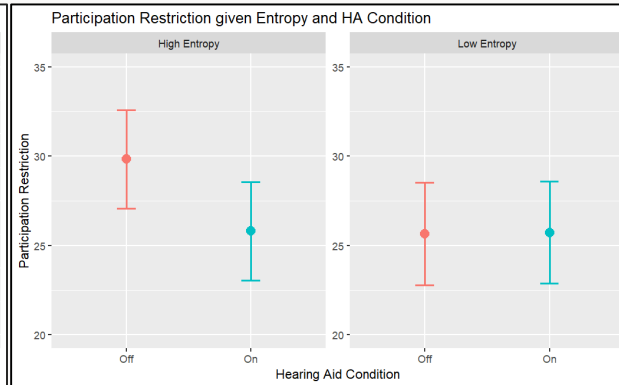
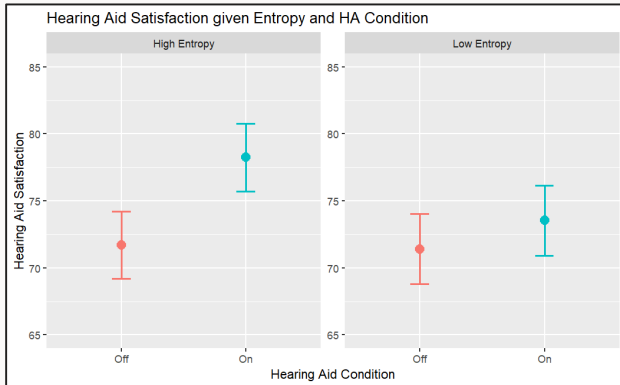
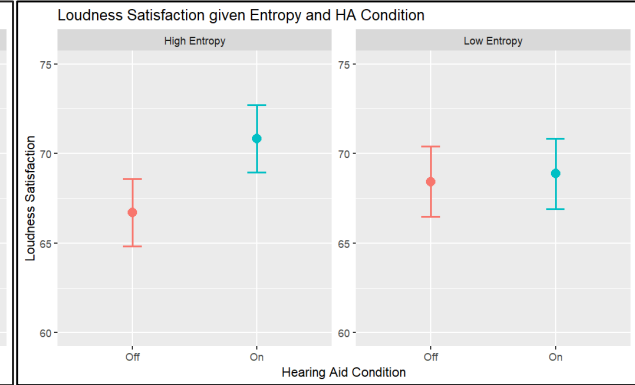
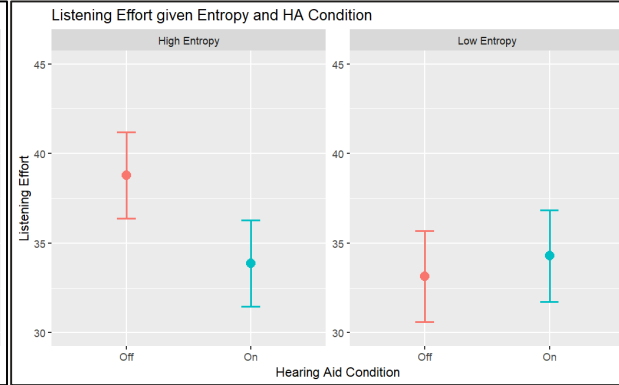
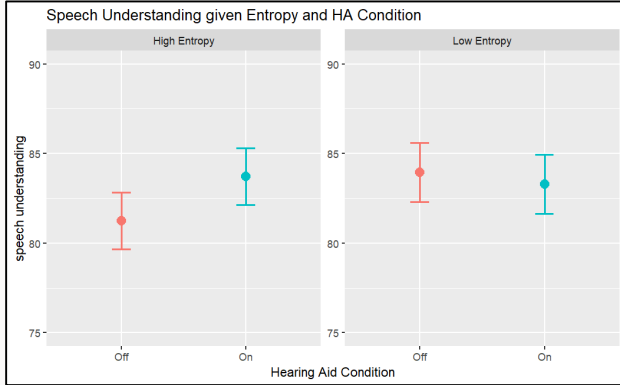
Linear Regression

ALDQ:

- Correlation tended to decrease during COVID
- Similar to SNI, correlation decreased with standardization

	Slope Est.	Slope p-value	Pearson coef.
Entropy Original vs ALDQ Overall Demand Score			
Pre	0.14	0.0214	0.34
During	0.11	0.1765	0.21
Diff	-0.11	0.3583	0.14
Entropy Norm By Node vs ALDQ Overall Demand Score			
Pre	0.07	0.0563	0.29
During	0.05	0.3080	0.16
Diff	-0.07	0.3014	0.16
Entropy Original vs ALDQ Often Total			
Pre	0.30	0.0434	0.30
During	0.31	0.1021	0.25
Diff	0.00	0.9887	0.00
Entropy Norm BY Node vs ALDQ Often Total			
Pre	0.15	0.1003	0.25
During	0.15	0.1773	0.20
Diff	0.02	0.8867	0.02

Mixed Model Analysis



For all outcome variables, there is a significant difference in the outcome between hearing aid conditions only in the high entropy group

Implications

t-Tests and Linear Regressions:

- Entropy is a valid measurement of auditory environment diversity
 - ALDQ and SNI, like Entropy can be used to assess auditory environment diversity

Mixed Model Analysis:

- Expensive prescription hearing aids are more useful for high entropy
- Cheap hearing aids may suffice for individuals with less auditory environment diversity

Next Steps

- Accounting for correlation between low EMA count and Entropy
 - Remove observations with $\text{EMA count} < \text{cutoff}$
- Normalize by EMA count

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