Supplementary materials for ‘Language exposure predicts children’s phonetic patterning: Evidence from language shift’, by Margaret Cychosz. *Language* 98(3).461–509, 2022.

Bilingual language exposure and use predict children’s phonetic patterning: Evidence from language shift: Supplementary Materials II

Margaret Cychosz

Vowel and formant cleaning procedures

Removing outliers and hand-removal

Additional cleaning procedures were conducted on the formant frequencies to remove measurements where all three trackers may have erroneously tracked the wrong formant or reported a measurement that did not seem likely given a speaker's median formants. The median absolute deviation (MAD) of each speaker's vowels, and an upper and lower MAD boundary (plus or minus three MADs from the median), was computed. All tokens outside these boundaries were removed. This resulted in the loss of approximately 4-12% of the data by age group (see Tables 1 and 2). No large differences in data removal were noted by age group, vowel, or individual formant.

Table 1

Token counts and percentage of each vowel removed, by age, using three MADs from median criterion

Age	[a]	[e]	[i]	[o]	[u]
4	20 (4.85 %)	13 (10.16 %)	13 (5.51 %)	0 (0 %)	13 (7.93 %)
5	26 (4.09 %)	13 (7.07 %)	22 (4.74 %)	4 (3.23 %)	14 (7 %)
6	35 (5.79 %)	11 (5.5 %)	26 (4.71 %)	19 (8.96 %)	14 (6.14 %)
7	45 (5.04 %)	24 (6.9 %)	40 (5.13 %)	22 (6.63 %)	20 (5.05 %)
8	38 (6.93 %)	14 (6.48 %)	20 (4 %)	14 (7 %)	18 (8.04 %)
9	24 (6.59 %)	7 (6.73 %)	15 (4.21 %)	9 (6.08 %)	5 (2.55 %)
10	35 (8.33 %)	18 (9.18 %)	18 (4.09 %)	14 (5.93 %)	21 (8.9 %)
adult	35 (5.87 %)	16 (6.9 %)	24 (4.69 %)	20 (7.14 %)	17 (7.2 %)
Average	5.94 %	7.36 %	4.64 %	5.62 %	6.60 %

One additional cleaning procedure was conducted before continuing with the formant

Table 2

Token counts and percentage of each formant removed, by age, using three MADs from median criterion

Age	F1 (MAD)	F2	F3	F4
4	30 (12.24 %)	19 (7.76 %)	10 (4.08 %)	NA
5	32 (7.96 %)	21 (5.22 %)	26 (6.47 %)	NA
6	49 (10.91 %)	33 (7.35 %)	23 (5.12 %)	NA
7	42 (6.11 %)	53 (7.71 %)	56 (8.15 %)	NA
8	41 (9.72 %)	29 (6.87 %)	34 (8.06 %)	NA
9	22 (7.53 %)	25 (8.56 %)	13 (4.45 %)	NA
10	30 (7.85 %)	43 (11.26 %)	33 (8.64 %)	NA
adult	29 (6.25 %)	32 (6.9 %)	31 (6.68 %)	20 (4.31 %)
Average	8.57 %	7.70 %	6.46 %	NA

analysis. After removing measurements that fell out of the pre-determined range, the author additionally inspected each speaker's vowel space for extreme outliers. After identifying the source of the outlier, the author returned to the spectrogram to compare the automated formant measurement (median) and the actual formant measurement. When the automated measurement and hand measurement differed by more than approximately 400Hz (F1) or 800Hz (F2), the token was removed from analysis. In some cases one or other of the formants was also not visible in the spectrogram and so the token was also removed. This resulted in the removal of 35 additional tokens (See Table 3 for the distribution by age and phone.) On the basis of the triple formant tracker, removal of measurements outside of three MADs, and the visual comparison with the spectrogram, the author confidently proceeded with the clean formant measurements.

Table 3

Hand-removed tokens by vowel and age group

Age	Phone	n
4	u	3
6	o	1
6	u	6
7	o	2
7	u	10
8	o	2
8	u	3
9	o	2
9	u	5
10	u	1

Normalization

The final preparatory step was normalizing the vowel data in order to compensate for anatomical differences between children. This was especially important given the children's different ages, and thus vocal tract lengths. The Lobanov vowel normalization technique, which is essentially z-score normalization, was used to factor out individual anatomical differences (Lobanov, 1971). This normalization technique is a vowel-extrinsic, meaning that it takes into account information from all available vowels and multiple formants for the normalization of each formant measurement.

Preparing vowels to measure variation

Because this study addresses variation, the number of vowel observations from each speaker was standardized to the extent possible. First, speaker vowel categories with fewer than four

F1-F2 observations were removed from analysis (e.g. fewer than four observations of [i] from a given speaker). These categories were removed because category dispersion estimates made over two or three tokens are not likely to be representative of a speaker's variation. The number of tokens per vowel category differed between speakers because of data cleaning procedures and occasional wind interference in the recordings. Under this criterion, seventeen peripheral vowel categories were removed (see Table 4 for distribution by age group and vowel). To further standardize the number of vowel measurements between children, a random subset of 10 observations was selected for those speaker vowel categories with more than 10 observations. In this way, no individual child contributed more than 10 or fewer than 4 data points for a given vowel, making the measurements between children more uniform.

Table 4

Number of vowel sets removed by age and phone to standardize measurements across age groups.

Age	a	i	u
4	NA	1	4
5	NA	NA	1
6	1	1	2
7	1	NA	3
8	1	NA	2

For the statistical modeling of vowel variability, the dependent variable was the vowel dispersion coefficient of each speaker's vowel category or, ideally, five vowel dispersion coefficient estimations (one for each vowel) per speaker. Some vowel categories (n=29) were removed because they did not meet this minimum threshold (See Table 5). This data removal is substantial for some vowels, notably [o], but was preferable to estimating dispersion on the basis of only two or three vowel tokens.

Table 5

Number of categories removed for statistical modeling by phone.

Phone	Categories Removed
e	12
o	17

Table 6

Number of tokens by vowel category and maternal language profile.

	[a]	[e]	[i]	[o]	[u]
Monolingual Quechua	65	43	80	44	35
Quechua-dominant	41	21	54	22	19
Bilingual Quechua-Spanish	173	95	174	63	69

References

Lobanov, B. M. (1971). Classification of Russian Vowels Spoken by Different Speakers. *The Journal of the Acoustical Society of America*, *49*(2B), 606–608. doi: 10.1121/1.1912396