

Supplementary Information for

The origins and development of speech envelope tracking during the first months of life

Maria Clemencia Ortiz Barajas*, Ramón Guevara, Judit Gervain

* Corresponding author: Maria Clemencia Ortiz Barajas

Email: clema_ob@yahoo.com

This PDF file includes:

Figures S1 to S3

Tables S1 to S13

SI References

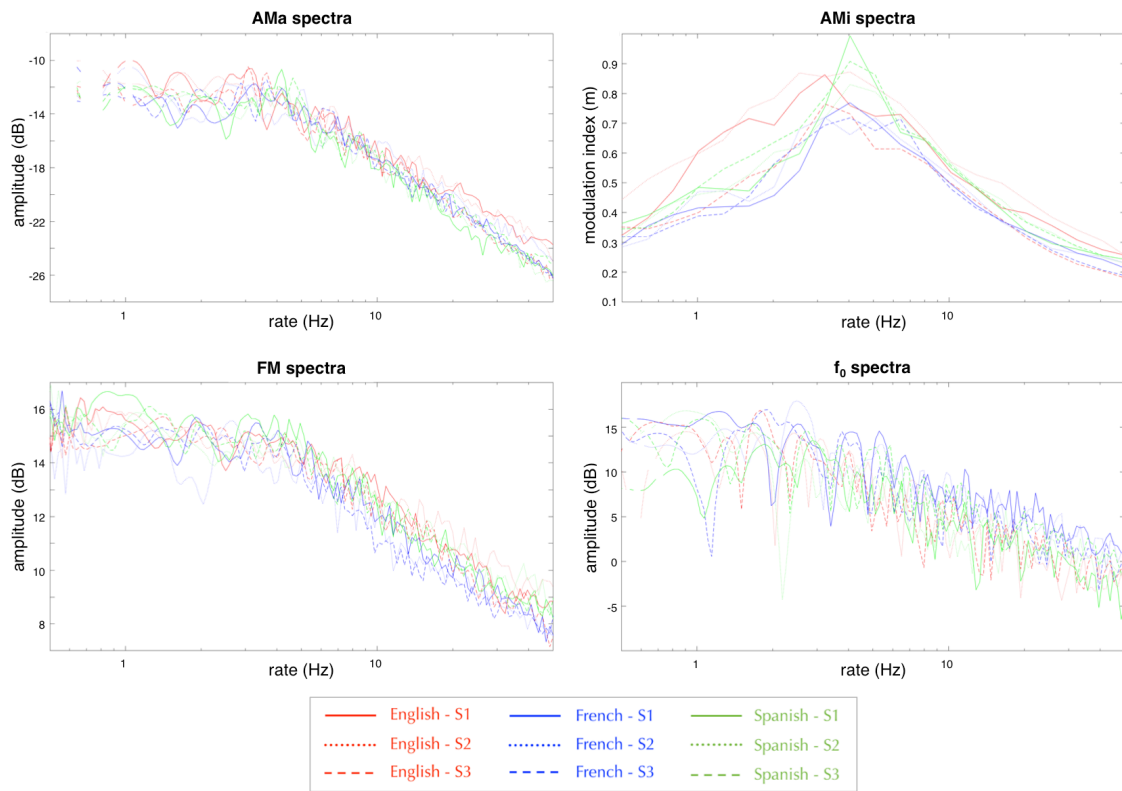


Figure. S1. Amplitude and frequency modulation spectra for the 9 utterances used as stimuli. Red lines: English utterances; blue lines: French utterances; green lines: Spanish utterances. These modulation spectra were obtained following the methodology described by Varnet et al., 2017.

Cross-correlation functions - Newborns

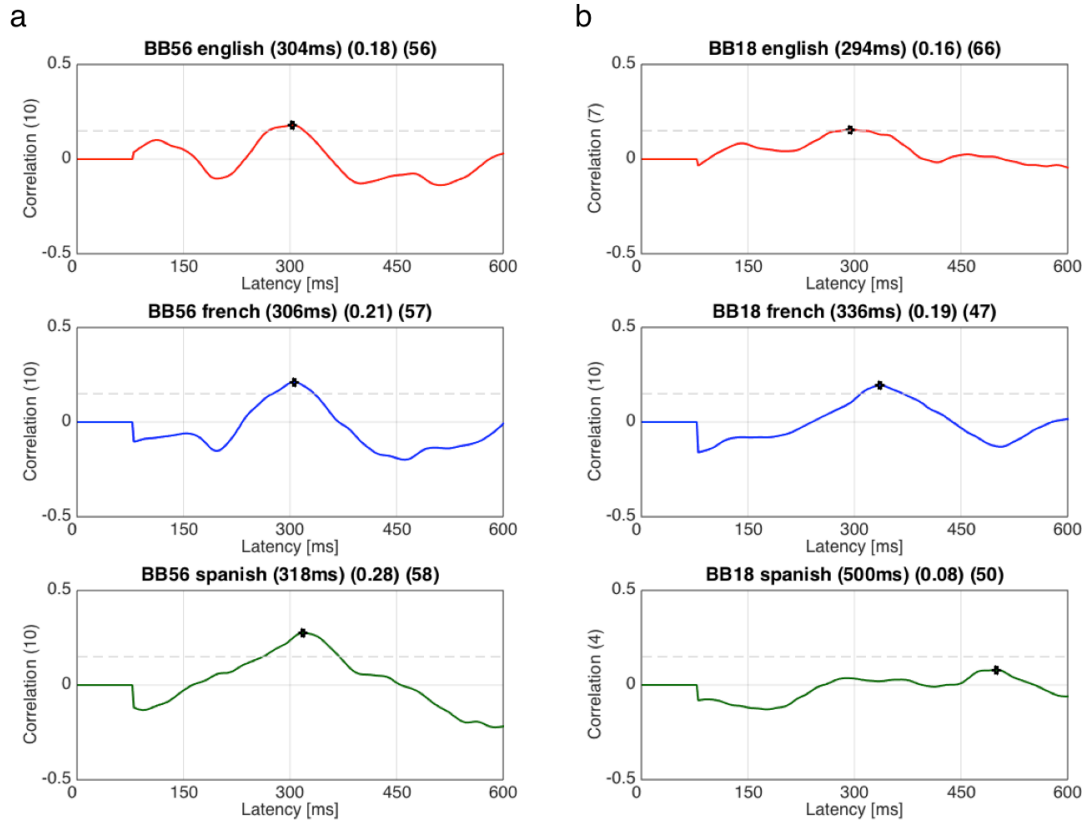


Figure. S2. Mean cross-correlation functions for two newborn participants. These mean functions were obtained for each language by averaging the cross-correlation functions from the channels that were at least weakly correlated ($\rho > 0.15$). (a) The cross-correlation functions for English (red curve), French (blue curve), and Spanish (green curve) for participant BB56 exhibit well defined peaks with correlations > 0.15 . For participant BB56 the cross-correlation functions from the three languages were averaged to obtain a mean time lag. (b) The cross-correlation function for Spanish (green curve) for participant BB18 does not exhibit peaks reaching the minimum correlation threshold ($\rho = 0.15$), therefore it was excluded from the computation of the mean time lag, and only the cross-correlation functions from English and French were averaged to obtain it. The grey dotted horizontal lines corresponds to the $\rho = 0.15$ threshold. The information in parentheses presented at each plot's title corresponds to the latency of the peak, the correlation at the peak, and the number of non-rejected trials, respectively. The information in parentheses presented next to the Y-axis label (correlation) corresponds to the number of channels included when computing the mean cross-correlation function for each language.

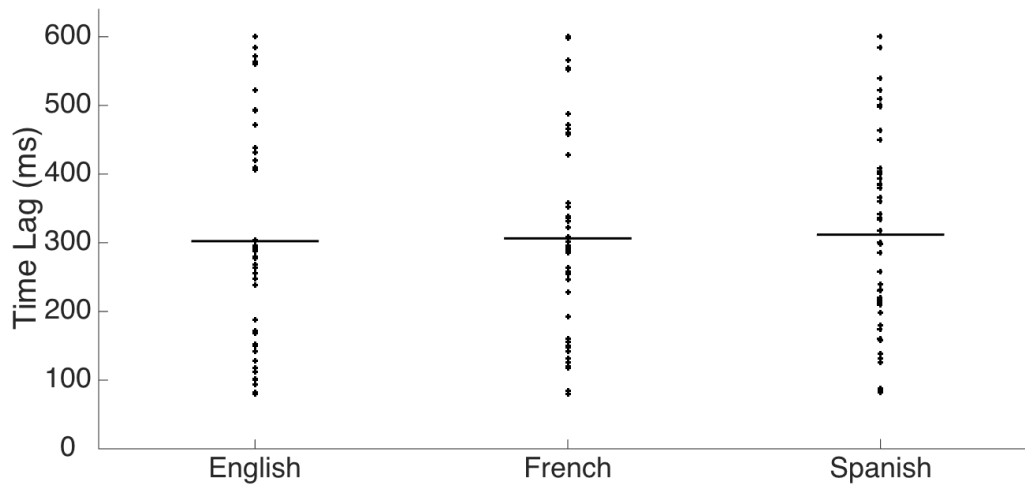


Figure. S3. Times lags of amplitude tracking for individual participants for each language, at birth. These values were submitted to a repeated measure ANOVA to test for the effect of language [$F(2,92) = 0.044, p=0.957$].

Table S1. Stimulus information.

	Set 1	Set 2	Set 3
English	<p><i>The bears lived all together in a beautiful house</i></p> <p>Duration: 2,50 s Syllabic rate: 5 Hz Pitch_min: 142,5 Hz Pitch_max: 700,8 Hz Pitch_range: 558,3 Hz Pitch_mean: 303,4 Hz</p>	<p>The bears decided to take a walk that day</p> <p>Duration: 2,16 s Syllabic rate: 5 Hz Pitch_min: 181,2 Hz Pitch_max: 400,2 Hz Pitch_range: 219,0 Hz Pitch_mean: 261,8 Hz</p>	<p>The little bears saw that their chairs were used by the naughty girl</p> <p>Duration: 2,96 s Syllabic rate: 4 Hz Pitch_min: 171,2 Hz Pitch_max: 735,9 Hz Pitch_range: 564,7 Hz Pitch_mean: 322,1 Hz</p>
French	<p>Les ours habitaient tous ensemble dans une maison</p> <p>Duration: 2,66 s Syllabic rate: 4 Hz Pitch_min: 195,6 Hz Pitch_max: 556,5 Hz Pitch_range: 360,9 Hz Pitch_mean: 307,6 Hz</p>	<p>Les ours décidèrent d'aller se promener</p> <p>Duration: 2,17 s Syllabic rate: 4 Hz Pitch_min: 99,7 Hz Pitch_max: 342,3 Hz Pitch_range: 242,6 Hz Pitch_mean: 224,7 Hz</p>	<p>Les ours virent que leurs chaises avaient été utilisées</p> <p>Duration: 2,93 s Syllabic rate: 6 Hz Pitch_min: 95,7 Hz Pitch_max: 263,2 Hz Pitch_range: 167,5 Hz Pitch_mean: 190,1 Hz</p>
Spanish	<p>Los osos vivían juntos en una casa</p> <p>Duration: 2,60 s Syllabic rate: 4 Hz Pitch_min: 164,4 Hz Pitch_max: 287,3 Hz Pitch_range: 122,9 Hz Pitch_mean: 219,8 Hz</p>	<p>Los osos tomaron un gran paseo</p> <p>Duration: 2,19 s Syllabic rate: 3 Hz Pitch_min: 178,2 Hz Pitch_max: 423,5 Hz Pitch_range: 245,3 Hz Pitch_mean: 245,9 Hz</p>	<p>Los osos vieron sus sillas siendo utilizadas</p> <p>Duration: 3,00 s Syllabic rate: 4 Hz Pitch_min: 99,0 Hz Pitch_max: 420,8 Hz Pitch_range: 321,8 Hz Pitch_mean: 260,0 Hz</p>

Note: Three sets of sentences were used during the study. Each set contained one sentence translated into the three languages. The translations were slightly modified in order to match sentence duration across languages within the same set. The duration, syllabic rate, and pitch details are included for each sentence.

Table S2. Group mean correlation values for the measured EEG data at birth.

Channel	ENGLISH			FRENCH			SPANISH		
	mean	p-value	t-value	mean	p-value	t-value	Mean	p-value	t-value
F7	0.121	0.00	5.118	0.121	0.00	4.627	0.120	0.00	4.453
F3	0.116	0.00	5.520	0.123	0.00	5.025	0.147	0.00	6.096
Fz	0.097	0.00	4.374	0.124	0.00	5.178	0.152	0.00	6.297
F4	0.128	0.00	5.551	0.140	0.00	5.605	0.142	0.00	5.189
F8	0.112	0.00	4.825	0.142	0.00	5.847	0.120	0.00	4.287
T7	0.075	0.05	2.921	0.095	0.00	3.771	0.088	0.01	3.705
C3	0.111	0.00	4.265	0.141	0.00	6.331	0.124	0.00	5.389
Cz	0.120	0.00	5.451	0.140	0.00	5.891	0.129	0.00	5.015
C4	0.091	0.00	4.134	0.141	0.00	6.256	0.135	0.00	5.086
T8	0.048	0.54	1.981	0.090	0.00	3.764	0.059	0.09	2.717

Note: The correlation distributions were submitted to one-sample t-tests (two-tailed) to compare them to zero. The p-values (Bonferroni corrected) and t-values of these t-tests are presented here per channel. Non-significant results are highlighted in red.

Table S3. Group mean correlation values for the permuted data at birth.

Channel	ENGLISH		FRENCH		SPANISH	
	mean	p-value	mean	p-value	mean	p-value
F7	0.001	p < 0.001	0.043	p < 0.05	0.003	p < 0.01
F3	-0.002	p < 0.001	0.051	p < 0.05	0.011	p < 0.001
Fz	0.006	p < 0.01	0.045	p < 0.05	0.015	p < 0.001
F4	-0.016	p < 0.001	0.044	p < 0.01	0.017	p < 0.01
F8	-0.014	p < 0.001	0.024	p < 0.01	0.009	p < 0.01
T7	0.009	p < 0.05	0.027	p > 0.05	0.006	p < 0.05
C3	0.009	p < 0.01	0.065	p < 0.05	0.039	p < 0.05
Cz	0.004	p < 0.001	0.057	p < 0.05	0.032	p < 0.01
C4	-0.004	p < 0.01	0.058	p < 0.05	0.027	p < 0.01
T8	-0.013	p > 0.05	0.026	p > 0.05	0.003	p > 0.05

Note: The correlation distributions for the measured EEG data were submitted to paired samples t-tests to compare them to the correlation distributions for the permuted data. The p-values for the permuted data were derived as the number of permutations out of the 1000 whose correlation distributions were not significantly different from the correlation distributions obtained for the measured data. Non-significant results are highlighted in red.

Table S4. Linear regression analyses of single trial amplitude tracking results at birth.

	Channel	R ²	Corrected p-value
English	F7	0.001	0.306
	F3	0.001	0.318
	Fz	0.002	0.270
	F4	0.001	0.227
	F8	0.001	0.273
	T7	0.001	0.361
	C3	0.000	0.507
	Cz	0.001	0.368
	C4	0.002	0.270
	T8	0.000	0.432
French	F7	0.000	1.000
	F3	0.000	1.000
	Fz	0.000	1.000
	F4	0.000	0.940
	F8	0.000	0.928
	T7	0.002	0.220
	C3	0.000	1.000
	Cz	0.000	1.000
	C4	0.000	0.888
	T8	0.001	0.785
Spanish	F7	0.001	0.330
	F3	0.000	0.540
	Fz	0.000	0.929
	F4	0.001	0.258
	F8	0.002	0.190
	T7	0.001	0.297
	C3	0.000	0.468
	Cz	0.001	0.323
	C4	0.002	0.430
	T8	0.002	0.215

Note: The amplitude tracking correlations at the single trial level were submitted to simple linear regression analyses investigating the potential effects of habituation over the trials in each channel for each language. The p-values were subjected to False Discovery Rate correction for multiple comparisons (Benjamini & Hochberg, 1995).

Table S5. Group mean phase-coherence values for the measured EEG data at birth.

Channel	ENGLISH			FRENCH			SPANISH		
	Mean	p-value	t-value	mean	p-value	t-value	Mean	p-value	t-value
F7	0.350	0.00	15.263	0.338	0.00	15.591	0.355	0.00	14.622
F3	0.298	0.00	13.781	0.339	0.00	15.016	0.343	0.00	14.648
Fz	0.321	0.00	13.544	0.335	0.00	14.534	0.344	0.00	15.508
F4	0.338	0.00	15.368	0.338	0.00	14.322	0.312	0.00	12.450
F8	0.334	0.00	12.986	0.337	0.00	14.769	0.332	0.00	13.020
T7	0.314	0.00	13.917	0.332	0.00	13.168	0.377	0.00	14.199
C3	0.304	0.00	12.367	0.349	0.00	13.964	0.368	0.00	16.661
Cz	0.302	0.00	12.700	0.302	0.00	12.169	0.342	0.00	15.117
C4	0.337	0.00	13.274	0.309	0.00	13.979	0.321	0.00	13.106
T8	0.292	0.00	12.120	0.327	0.00	14.882	0.337	0.00	14.188

Note: The phase-coherence distributions were submitted to one-sample t-tests (two-tailed) to compare them to zero. The p-values (Bonferroni corrected) and t-values of these t-tests are presented here per channel. All channels were significantly higher than zero for the three languages.

Table S6. Group mean phase-coherence values for the permuted data at birth.

Channel	ENGLISH		FRENCH		SPANISH	
	mean	p-value	mean	p-value	mean	p-value
F7	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
F3	0.036	p < 0.001	0.037	p < 0.001	0.035	p < 0.001
Fz	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
F4	0.036	p < 0.001	0.036	p < 0.001	0.036	p < 0.001
F8	0.036	p < 0.001	0.036	p < 0.001	0.036	p < 0.001
T7	0.035	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
C3	0.035	p < 0.001	0.036	p < 0.001	0.036	p < 0.001
Cz	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
C4	0.036	p < 0.001	0.036	p < 0.001	0.035	p < 0.001
T8	0.036	p < 0.001	0.036	p < 0.001	0.036	p < 0.001

Note: The phase-coherence distributions for the measured EEG data were submitted to paired samples t-tests to compare them to the phase-coherence distributions for the permuted data. The p-values for the permuted data were derived as the number of permutations out of the 1000 whose phase-coherence distributions were not significantly different from those obtained for the measured data. Phase-coherence distributions for the measured data were significantly higher than those for the permuted data for all channels in the three languages.

Table S7. Group mean correlation values for the measured EEG data at 6 months.

Channel	ENGLISH			FRENCH			SPANISH		
	mean	p-value	t-value	mean	p-value	t-value	mean	p-value	t-value
F7	0.164	0.00	6.007	0.117	0.02	3.402	0.105	0.06	3.036
F3	0.165	0.00	5.536	0.139	0.00	4.427	0.130	0.01	3.786
Fz	0.186	0.00	6.519	0.120	0.01	3.744	0.106	0.02	3.505
F4	0.189	0.00	6.752	0.133	0.00	5.286	0.097	0.12	2.728
F8	0.152	0.00	7.627	0.108	0.02	3.378	0.103	0.12	2.704
T7	0.140	0.00	4.442	0.082	0.03	3.264	0.068	0.69	1.902
C3	0.186	0.00	5.421	0.119	0.00	4.662	0.089	0.14	2.655
Cz	0.217	0.00	8.198	0.098	0.03	3.299	0.075	0.44	2.130
C4	0.186	0.00	7.358	0.149	0.00	5.917	0.069	0.77	1.847
T8	0.094	0.03	3.355	0.103	0.01	3.717	0.076	0.33	2.266

Note: The correlation distributions were submitted to one-sample t-tests (two-tailed) to compare them to zero. The p-values (Bonferroni corrected) and t-values of these t-tests are presented here per channel. Non-significant results are highlighted in red.

Table S8. Group mean correlation values for the permuted data at 6 months.

Channel	ENGLISH		FRENCH		SPANISH	
	mean	p-value	mean	p-value	Mean	p-value
F7	0.002	p < 0.001	0.082	p > 0.05	0.003	p < 0.05
F3	-0.002	p < 0.001	0.078	p > 0.05	-0.005	p < 0.01
Fz	0.006	p < 0.001	0.061	p > 0.05	-0.011	p < 0.01
F4	0.006	p < 0.001	0.083	p > 0.05	0.004	p > 0.05
F8	0.012	p < 0.001	0.087	p > 0.05	0.012	p > 0.05
T7	0.009	p < 0.01	0.081	p > 0.05	0.013	p > 0.05
C3	-0.006	p < 0.001	0.091	p > 0.05	0.014	p > 0.05
Cz	-0.006	p < 0.001	0.070	p > 0.05	-0.009	p > 0.05
C4	-0.006	p < 0.001	0.080	p > 0.05	0.004	p > 0.05
T8	0.007	p < 0.05	0.091	p > 0.05	0.032	p > 0.05

Note: The correlation distributions for the measured EEG data were submitted to paired samples t-tests to compare them to the correlation distributions for the permuted data. The p-values for the permuted data were derived as the number of permutations out of the 1000 whose correlation distributions were not significantly different from the correlation distributions obtained for the measured data. Non-significant results are highlighted in red.

Table S9. Linear regression analyses of single trial amplitude tracking results at 6 months.

	Channel	R²	Corrected p-value
English	F7	0.000	1.000
	F3	0.000	1.000
	Fz	0.000	1.000
	F4	0.000	1.000
	F8	0.000	1.000
	T7	0.000	1.000
	C3	0.000	1.000
	Cz	0.001	1.000
	C4	0.000	1.000
	T8	0.000	0.952
French	F7	0.004	0.440
	F3	0.000	0.963
	Fz	0.000	0.980
	F4	0.000	1.000
	F8	0.001	0.894
	T7	0.002	0.620
	C3	0.004	0.810
	Cz	0.002	0.607
	C4	0.000	1.000
	T8	0.000	0.874
Spanish	F7	0.003	1.000
	F3	0.001	0.516
	Fz	0.002	0.657
	F4	0.003	0.655
	F8	0.001	0.587
	T7	0.001	0.638
	C3	0.001	0.742
	Cz	0.001	0.533
	C4	0.001	0.591
	T8	0.000	0.839

Note: The amplitude tracking correlations at the single trial level were submitted to simple linear regression analyses investigating the potential effects of habituation over the trials in each channel for each language. The p-values were subjected to False Discovery Rate correction for multiple comparisons (Benjamini & Hochberg, 1995).

Table S10. Repeated measures ANOVAs of amplitude tracking results evaluating the effect of block order at 6 months.

Channel	F-value	Corrected p-value
F7	0.920	0.579
F3	0.618	0.603
Fz	2.655	0.405
F4	1.978	0.497
F8	0.869	0.533
T7	2.025	0.400
C3	1.808	0.372
Cz	5.340	0.120
C4	1.668	0.342
T8	0.272	0.730

Note: The amplitude tracking results were classified according to their order of presentation (1st block, 2nd block, 3rd block), and submitted to repeated measures ANOVAs to evaluate whether they varied across blocks in each channel. There were no significant differences across blocks. The p-values were subjected to False Discovery Rate correction for multiple comparisons (Benjamini & Hochberg, 1995).

Table S11. Group mean phase-coherence values for the measured EEG data at 6 months.

Channel	ENGLISH			FRENCH			SPANISH		
	Mean	p-value	t-value	mean	p-value	t-value	mean	p-value	t-value
F7	0.276	0.00	8.392	0.253	0.00	9.326	0.243	0.00	9.793
F3	0.308	0.00	8.559	0.280	0.00	9.822	0.273	0.00	8.893
Fz	0.312	0.00	10.689	0.274	0.00	10.015	0.288	0.00	9.251
F4	0.336	0.00	9.816	0.260	0.00	9.269	0.296	0.00	8.741
F8	0.323	0.00	9.678	0.268	0.00	11.338	0.322	0.00	10.343
T7	0.316	0.00	9.469	0.289	0.00	8.555	0.289	0.00	10.062
C3	0.301	0.00	8.951	0.309	0.00	12.556	0.342	0.00	9.918
Cz	0.313	0.00	10.162	0.307	0.00	9.927	0.333	0.00	12.340
C4	0.296	0.00	8.455	0.292	0.00	9.632	0.297	0.00	9.932
T8	0.335	0.00	8.763	0.351	0.00	11.399	0.313	0.00	8.046

Note: The phase-coherence distributions were submitted to one-sample t-tests (two-tailed) to compare them to zero. The p-values (Bonferroni corrected) and t-values of these t-tests are presented here per channel. All channels were significantly higher than zero for the three languages.

Table S12. Group mean phase-coherence values for the permuted data at 6 months.

Channel	ENGLISH		FRENCH		SPANISH	
	Mean	p-value	mean	p-value	mean	p-value
F7	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
F3	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
Fz	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
F4	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
F8	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
T7	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
C3	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
Cz	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
C4	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001
T8	0.036	p < 0.001	0.037	p < 0.001	0.036	p < 0.001

Note: The phase-coherence distributions for the measured EEG data were submitted to paired samples t-tests to compare them to the phase-coherence distributions for the permuted data. The p-values for the permuted data were derived as the number of permutations out of the 1000 whose phase-coherence distributions were not significantly different from those obtained for the measured data. Phase-coherence distributions for the measured data were significantly higher than those for the permuted data for all channels in the three languages.

Table S13. Repeated measures ANOVAs of phase tracking results evaluating the effect of block order at 6 months.

Channel	F-value	Corrected p-value
F7	0.293	1.000
F3	0.309	1.000
Fz	0.356	1.000
F4	1.043	1.000
F8	2.414	1.000
T7	0.286	1.000
C3	0.189	1.000
Cz	0.328	1.000
C4	0.003	0.997
T8	0.106	1.000

Note: The phase tracking results were classified according to their order of presentation (1st block, 2nd block, 3rd block), and submitted to repeated measures ANOVAs to evaluate whether they varied across blocks in each channel. There were no significant differences across blocks. The p-values were subjected to False Discovery Rate correction for multiple comparisons (Benjamini & Hochberg, 1995).

SI References

- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: series B (Methodological)* **57**(1), 289-300.
- Varnet, L., Ortiz-Barajas, M. C., Erra, R. G., Gervain, J., & Lorenzi, C. (2017). A cross-linguistic study of speech modulation spectra. *The Journal of the Acoustical Society of America* **142**, 1976-1989.