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Supplemental Information

Language experience predicts music processing in a half-million speakers of fifty-four languages

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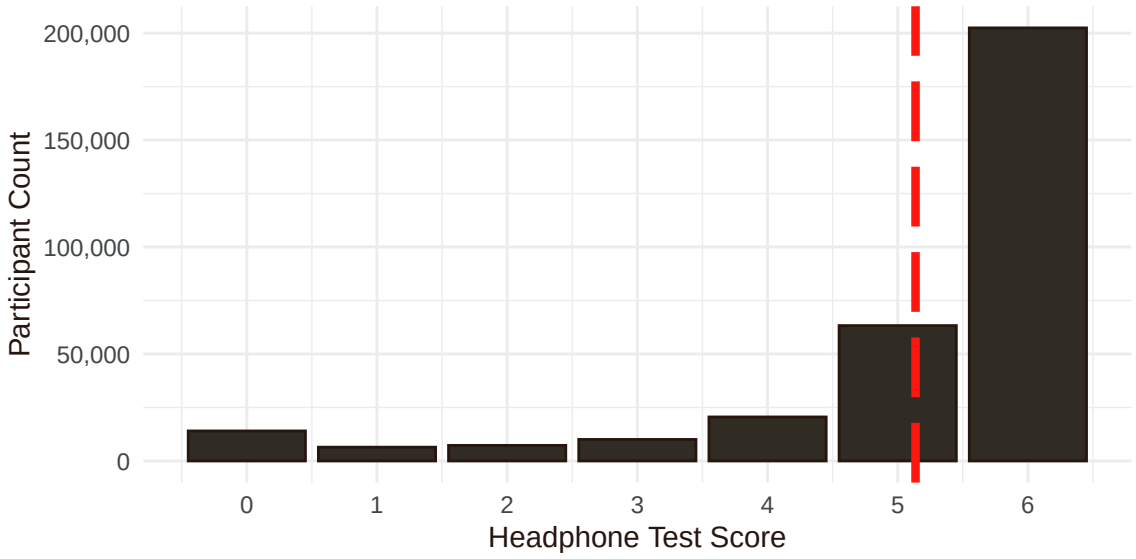

Figure S1. Participants who reported wearing headphones performed well on a headphone detection task, related to STAR Methods Scores on the headphone detection task, from participants who self-reported that they were wearing headphones. The maximum score was 6; the dashed red line indicates the mean score.

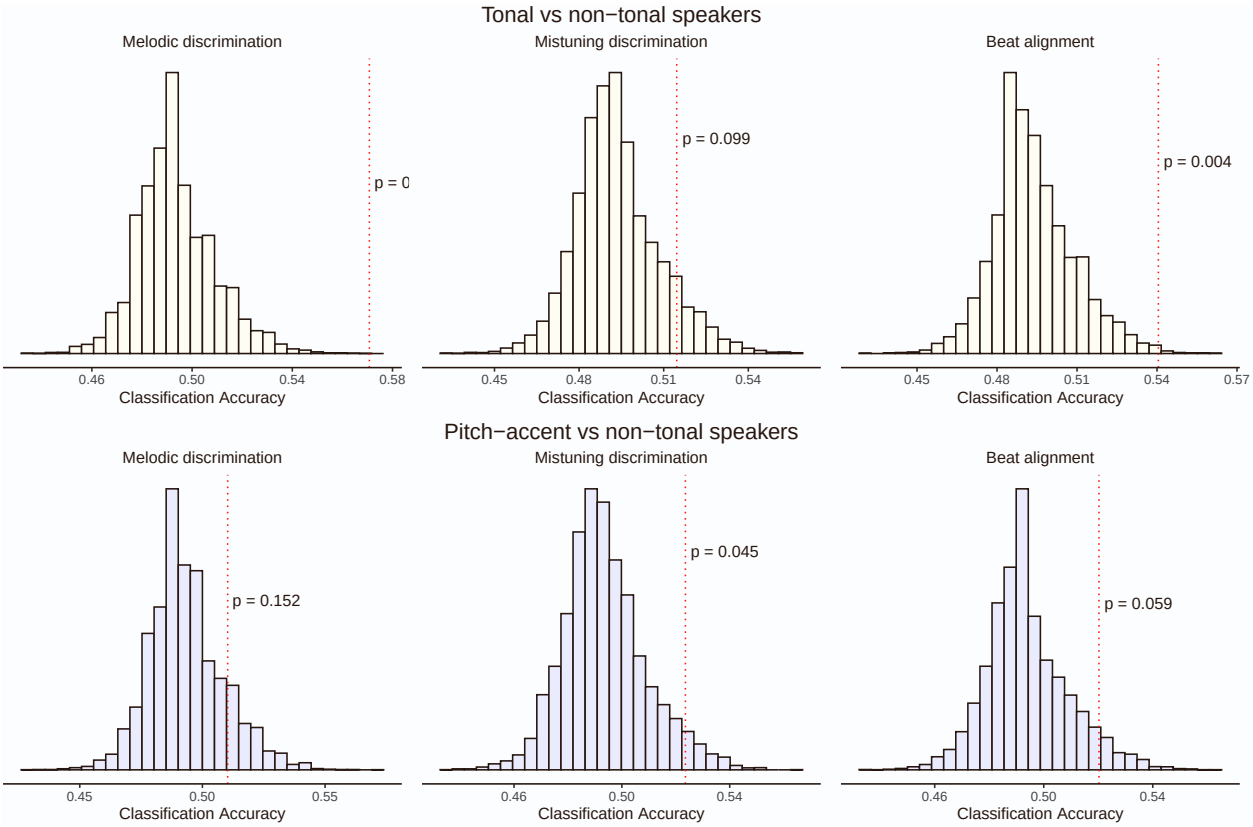

Figure S2. Replication of the main effects using a discriminant function analysis, related to STAR Methods To test whether speakers of different language types could be distinguished on the basis of their music perception scores, we ran a permuted Discriminant Function Analysis (pDFA). The three histograms show the null distributions for each music perception task, representing when language-type labels have been randomly shuffled, resulting from 10,000 permutations. The dotted vertical line then represents the actual discrimination performance on non-shuffled data. And the p-value is computed as a approximate test from this null distribution and actual score. This procedure was repeated for participants who indicated as having not received music lessons for both (A) tonal versus non-tonal speakers, and (B) pitch-accent versus non-tonal speakers.

Language	Language Type	Total n	Top country/region	Source
Chinese/Mandarin	Tonal	13,795	China	LAPSyD, WALS
Chinese/Cantonese	Tonal	7,784	Hong Kong	WALS
Chinese/Hokkien	Tonal	4,156	Taiwan	WALS
Vietnamese	Tonal	3,426	Vietnam	LAPSyD, WALS
Thai	Tonal	2,676	Thailand	LAPSyD, WALS
Chinese/Other languages	Tonal	1,586	China	WALS
Burmese	Tonal	223	Myanmar	WALS
Punjabi	Tonal	95	India	Evans et al. (2018)
Hmong	Tonal	59	United States	WALS
Yoruba	Tonal	42	Nigeria	WALS
Shona	Tonal	33	Zimbabwe	Jefferies (1990)
Zulu	Tonal	33	South Africa	Niesler et al. (2009), WALS*
Twi	Tonal	31	Ghana	Manyah 2006
Igbo	Tonal	26	Nigeria	Eme & Odinye (2008)), WALS*
Xhosa	Tonal	21	South Africa	Niesler et al. (2009)
Lao	Tonal	18	Laos	Westermeyer & Westermeyer (1977)
Bemba	Tonal	12	Botswana, Brazil	Hamann & Kula (2015)
Kinyarwanda	Tonal	10	Rwanda, United States	Goldsmith & Mpiranya (2010)
Ewe	Tonal	8	Ghana	Ameka (2001), WALS*
Swedish	Pitch-accented	6,445	Sweden	LAPSyD, Bailey (1988)
Norwegian	Pitch-accented	4,261	Norway	LAPSyD, WALS
Croatian	Pitch-accented	1,859	Croatia	Inkelas & Zec (1988); Van der Hulst et al. (2010)
Serbian	Pitch-accented	1,626	Serbia	Inkelas & Zec (1988); Van der Hulst et al. (2010)
Japanese	Pitch-accented	1,390	Japan	LAPSyD, WALS
Lithuanian	Pitch-accented	1,287	Lithuania	LAPSyD
English	Non-tonal	191,319	United States	LAPSyD, WALS
Spanish	Non-tonal	77,571	Spain	LAPSyD, WALS
Turkish	Non-tonal	33,361	Turkey	LAPSyD, WALS
German	Non-tonal	20,099	Germany	LAPSyD, WALS
French	Non-tonal	18,092	France	LAPSyD, WALS
Polish	Non-tonal	14,540	Poland	LAPSyD, WALS
Russian	Non-tonal	12,399	Russia	LAPSyD, WALS
Portuguese	Non-tonal	11,259	Brazil	PHOIBLE, Van der Hulst et al. (2010)
Italian	Non-tonal	8,516	Italy	LAPSyD
Dutch	Non-tonal	6,852	The Netherlands	LAPSyD
Indonesian	Non-tonal	5,783	Indonesia	LAPSyD, WALS
Finnish	Non-tonal	5,011	Finland	LAPSyD, WALS
Tagalog	Non-tonal	4,475	Philippines	LAPSyD, WALS
Greek	Non-tonal	3,430	Greece	LAPSyD, WALS
Korean	Non-tonal	3,338	South Korea	LAPSyD, WALS
Romanian	Non-tonal	3,033	Romania	WALS
Danish	Non-tonal	2,720	Denmark	PHOIBLE, Van der Hulst et al. (2010)
Arabic	Non-tonal	2,673	Egypt	LAPSyD, WALS
Hungarian	Non-tonal	2,357	Hungary	LAPSyD, WALS
Catalan	Non-tonal	2,242	Spain	LAPSyD, WALS
Hindi	Non-tonal	2,230	India	LAPSyD, WALS
Czech	Non-tonal	2,118	Czech Republic	LAPSyD
Hebrew	Non-tonal	1,841	Israel	LAPSyD, WALS
Farsi	Non-tonal	1,749	Iran	LAPSyD, WALS
Ukrainian	Non-tonal	1,422	Ukraine	PHOIBLE, Van der Hulst et al. (2010)
Bulgarian	Non-tonal	1,072	Bulgaria	LAPSyD, WALS
Malay	Non-tonal	949	Malaysia	PHOIBLE
Slovak	Non-tonal	878	Slovakia	PHOIBLE, Van der Hulst et al. (2010)
Estonian	Non-tonal	869	Estonia	Van der Hulst et al. (2010)

Table S1. Detailed language sample information, related to STAR Methods The languages studied here, with sample sizes, largest-sample-size country, and the source of the language classification. Abbreviations: WALS (The world atlas of language structures), LAPSyD (Lyon-Albuquerque phonological systems database). *WALS classified as simple tone.

Demographics	Tonal (n = 34,034)	Non-tonal (n = 442,198)	Pitch-accented (n = 16,868)
Gender			
Female	49.5%	34.1%	32.4%
Male	49.6%	64.4%	66.6%
Other	0.9%	1.5%	1.0%
Mean age (SD)	23.61 (8.12)	24.84 (10.1)	26.07 (10.17)
Music lesson			
Yes	74.0%	69.0%	65.0%
No	26.0%	31.0%	35.0%
Mean age at onset of music lessons (SD)	8.6 (5.24)	10.13 (5.35)	9.75 (4.46)

Table S2. Demographic composition by language type, related to STAR Methods

	Melodic Discrimination			Mistuning Perception			Beat Alignment		
Term	β	SE	t	β	SE	t	β	SE	t
Language: Tonal	**0.310**	**0.074**	**4.189*** **	**-0.162**	**0.068**	**-2.372***	**-0.233**	**0.047**	**-4.927*** **
Language: Pitch-accented	-0.024	0.179	-0.132	-0.152	0.145	-1.045	0.219	0.146	1.499
Music lessons: Yes	0.577	0.009	62.859***	0.441	0.007	62.793***	0.278	0.008	34.94***
Age	0.001	0.000	3.634***	0.001	0.000	2.027*	-0.004	0.000	-14.458***
Gender: Male	0.109	0.007	14.851***	-0.046	0.006	-8.198***	0.118	0.006	18.538***
Gender: Other	0.066	0.027	2.466*	-0.043	0.020	-2.089*	0.102	0.023	4.396***
Income: $10,000 to $19,999	0.037	0.019	1.899	0.022	0.015	1.472	0.036	0.017	2.138*
Income: $20,000 to $29,999	0.024	0.018	1.329	0.055	0.014	3.894***	0.076	0.016	4.819***
Income: $30,000 to $39,999	0.030	0.018	1.662	0.032	0.014	2.335*	0.079	0.016	5.039***
Income: $40,000 to $49,999	0.044	0.018	2.4*	0.075	0.014	5.421***	0.088	0.016	5.589***
Income: $50,000 to $74,999	0.045	0.016	2.852**	0.070	0.012	5.838***	0.082	0.014	6.048***
Income: $75,000 to $99,999	0.062	0.016	3.859***	0.086	0.012	6.956***	0.078	0.014	5.6***
Income: $100,000 to $150,000	0.093	0.015	6.144***	0.103	0.012	8.865***	0.096	0.013	7.323***
Income: Over $150,000	0.121	0.015	7.897***	0.087	0.012	7.385***	0.087	0.013	6.54***
Pitch-accented × music lessons	0.207	0.188	1.105	0.217	0.145	1.498	0.016	0.160	0.099
Tonal × music lessons	-0.044	0.043	-1.028	0.047	0.033	1.411	0.089	0.037	2.396*
Intercept	-0.150	0.040	-3.779***	0.132	0.037	3.603***	0.032	0.026	1.263

Table S3. Results replicate after adjusting for income, related to Table 1

Fixed-effect output from random-effects model applied to each musical task controlling for participant annual income (Baseline = Income under 10,000) in the US sample with available income data. Language type effect remains after controlling for income in this group. Language is included as random-effects. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

	Melodic Discrimination			Mistuning Perception			Beat Alignment		
Term	β	SE	t	β	SE	t	β	SE	t
Language: Tonal	**0.206**	**0.047**	**4.419*** **	**-0.091**	**0.044**	**-2.048***	**-0.233**	**0.033**	**-7.087*** **
Language: Pitch-accented	0.016	0.059	0.27	0.030	0.058	0.522	0.092	0.040	2.282*
Music lessons: Yes	0.501	0.003	145.3***	0.418	0.003	147.625***	0.274	0.003	85.656***
Age	0.000	0.000	2.027*	0.001	0.000	9.378***	-0.005	0.000	-32.532***
Gender: Male	0.101	0.003	32.633***	-0.046	0.003	-17.971***	0.134	0.003	46.737***
Gender: Other	0.047	0.012	3.849***	-0.071	0.010	-7.067***	0.045	0.011	3.971***
Education: Secondary School	0.245	0.006	38.217***	0.161	0.005	30.479***	0.254	0.006	42.769***
Education: Undergraduate	0.307	0.007	47.096***	0.173	0.005	32.321***	0.327	0.006	54.068***
Education: Graduate School	0.339	0.007	48.36***	0.170	0.006	29.423***	0.320	0.007	49.223***
Pitch-accented × music lessons	0.086	0.017	5.115***	0.058	0.014	4.178***	-0.007	0.016	-0.46
Tonal × music lessons	-0.020	0.013	-1.508	-0.012	0.011	-1.095	0.067	0.012	5.486***
Intercept	-0.382	0.026	-14.44***	-0.008	0.025	-0.31	-0.219	0.018	-11.889***

Table S4. Results replicate after adjusting for education, related to Table 1
Fixed-effect output from random-effects model applied to each musical task controlling for education (Baseline = Primary School) in the sample that reported their educational background. Language and country are included as random-effects. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

	Melodic Discrimination			Mistuning Perception			Beat Alignment		
Term	β	SE	t	β	SE	t	β	SE	t
Language: Tonal	**0.285**	**0.060**	**4.765*** **	**-0.066**	**0.047**	**-1.403**	**-0.201**	**0.035**	**-5.826*** **
Music lessons: Yes	0.573	0.006	96.863***	0.441	0.005	94.699***	0.276	0.005	52.023***
Age	0.003	0.000	13.536***	0.002	0.000	12.282***	-0.003	0.000	-14.772***
Gender: Male	0.105	0.005	23.364***	-0.050	0.004	-14.004***	0.128	0.004	31.699***
Gender: Other	0.048	0.015	3.132**	-0.086	0.012	-7.077***	0.056	0.014	4.029***
Region: West	-0.040	0.040	-1.008	0.082	0.034	2.378*	0.058	0.021	2.792
Tonal × music lessons	-0.109	0.015	-7.478***	-0.044	0.011	-3.887***	0.052	0.013	4.038***
Intercept	-0.138	0.044	-3.171**	0.051	0.036	1.419	-0.015	0.025	-0.59

Table S5. Results replicate after adjusting for world region, related to Table 1
Fixed-effect output from random-effects model applied to each musical task controlling for region (East vs West, baseline = East). Language and country were entered as random-effects. Only speakers of tonal and non-tonal languages from countries/regions China, Hong Kong, Taiwan, Thailand, Vietnam (East) and United States, United Kingdom, New Zealand, Canada, Australia (West) are included in this analysis. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Data	Term	Melodic Discrimination	Mistuning Perception	Beat Alignment
Exploratory	**Main Analysis**			
	Language: Pitch-accented	0.086***	0.158***	0.124***
	Language: Tonal	0.403***	-0.111***	-0.158***
	Matched			
	Language: Pitch-accented	0.074***	0.127***	0.133***
	Language: Tonal	0.348***	-0.175***	-0.185***
	Matched (No Lessons Only)			
	Language: Pitch-accented	0.086*	0.102***	0.176***
	Language: Tonal	0.474***	-0.113***	-0.188***
	Inverse Probability Weighted			
	Language: Pitch-accented	0.082***	0.149***	0.116***
	Language: Tonal	0.347***	-0.144***	-0.209***
Confirmatory	**Main Analysis**			
	Language: Pitch-accented	0.071***	0.141***	0.173***
	Language: Tonal	0.418***	-0.094***	-0.102***
	Matched			
	Language: Pitch-accented	0.061***	0.128***	0.156***
	Language: Tonal	0.351***	-0.138***	-0.174***
	Matched (No Lessons Only)			
	Language: Pitch-accented	0.044	0.174***	0.209***
	Language: Tonal	0.437***	-0.024	-0.129***
	Inverse Probability Weighted			
	Language: Pitch-accented	0.054***	0.122***	0.154***
	Language: Tonal	0.344***	-0.136***	-0.161***

Table S6. Results replicate across four covariate adjustment approaches in both exploratory and confirmatory samples, related to STAR Methods Summary of main results from linear regressions, repeated across the four analysis approaches for adjusting for covariate imbalance. The Data column indicates whether the exploratory or confirmatory sample was used for each analysis. ***$p < 0.001$, *$p < 0.05$.