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Supplementary Information for

Neural network retuning and neural predictors of learning success associated with cello training

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Supplementary Information Text

Methods.

Training sessions.

Imagining part. As well as within the scan session, participants were given two metronome beats at 50 bpm before they begin to imagine, and they were asked to open their eyes on the last note. The instructor monitored timing of the imagery and self-report of vividness rating was collected after each trial. Vividness ratings were given on a 1 to 7 scale, with higher ratings meaning more vivid or more easily controlled imagery. Short verbal debriefings were also conducted after each trial to ascertain the nature and the quality of the image, and thus confirm the successful imagination of both sound and movements.

Scanner familiarization. At the end of training session 1B, participants underwent a demo run to familiarize themselves with the timeline of events within the scan session. They trained on a practice run in which all tasks were available. In order to minimize amplitude variation within the subsequent scan sessions, participants were asked to remain in the rest position, that is to say keeping their right arm along the body with the bow lying comfortably on the strings and their left hand on the keyboard, as long as the instructions were displayed and to get back to playing position after the offset of visual instructions. At the end of session 1B, all participants had memorized the association of the sequences' names and their corresponding finger placements, even approximate, and all were able to produce a 5-pitches-sequence during the allotted time.

MRI Protocol. The no-auditory feedback condition was achieved by providing masking noise through the headphones connected to the muted MRI-compatible cello. The masking noise was also used during all conditions to allow contrasts for the subsequent analyses.

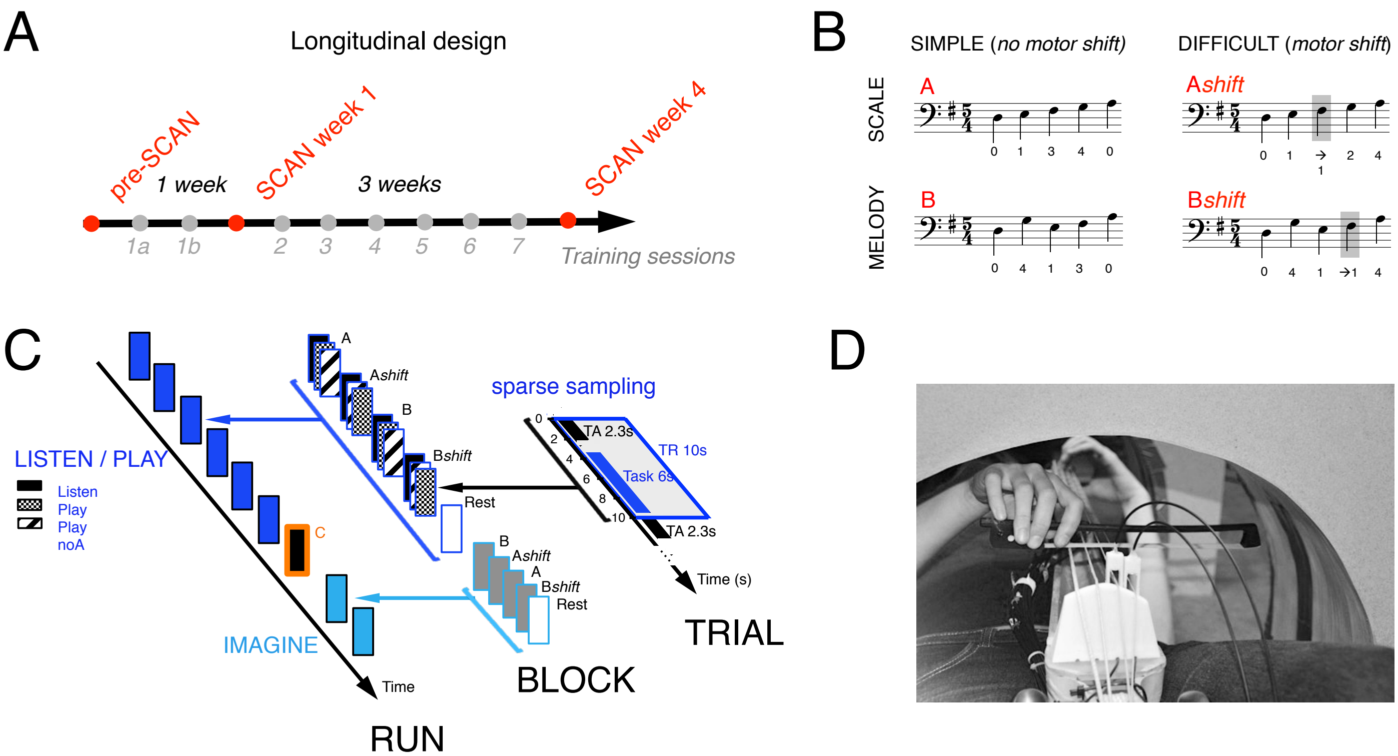

Fig. S1. Cello training procedure. (A) Longitudinal repeated-measure protocol with 3 scans and 8 training sessions. (B) Trained musical sequences. (C) Timeline of events within a functional run in SCAN wk1 and SCAN wk4. We used a sparse sampling design: in each trial, after visual instruction appearing during the EPI sequence acquisition of the preceding trial, participants did the task during the silent period. Trials were presented in blocks of listen/play/playnoA (6 blocks, dark blue), of listen task involving the untrained new sequence only (1 block, black circled orange), of imagine task (2 blocks, light blue). During preSCAN, a run contained only listen trials of trained and untrained sequences. (D) Participant practicing on the MRI-compatible cello within the mock scanner used in training sessions simulating the MRI scanner environment.

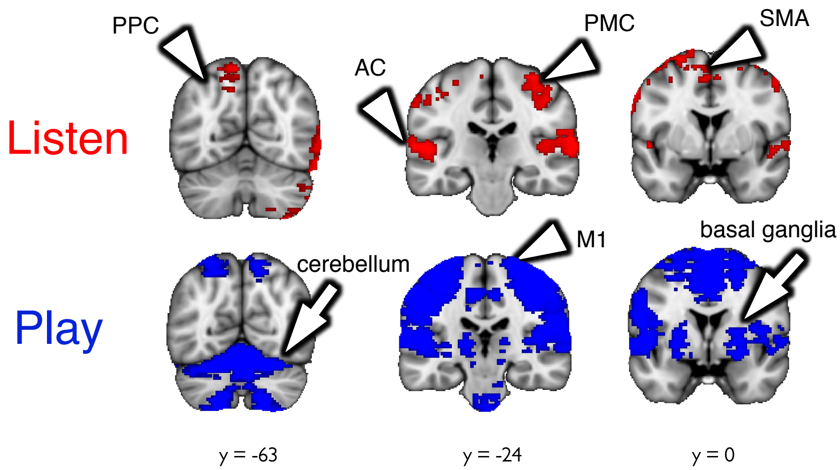

Fig. S2. Task-related networks. Contrast images for task > rest were computed to assess basic task-related activity at SCAN wk4. The network associated with passive listening (top panel) engages bilateral primary and secondary auditory cortices (AC), parts of the motor network (SMA, dorsal PMC) and posterior parietal regions (PPC). The cello-playing network (bottom panel) encompasses the auditory regions, the somatosensory regions, and the motor production network (i.e. cortical and sub-cortical motor regions, including primary motor (M1), premotor, and supplementary motor areas (PMC, SMA), the basal ganglia, and cerebellum).

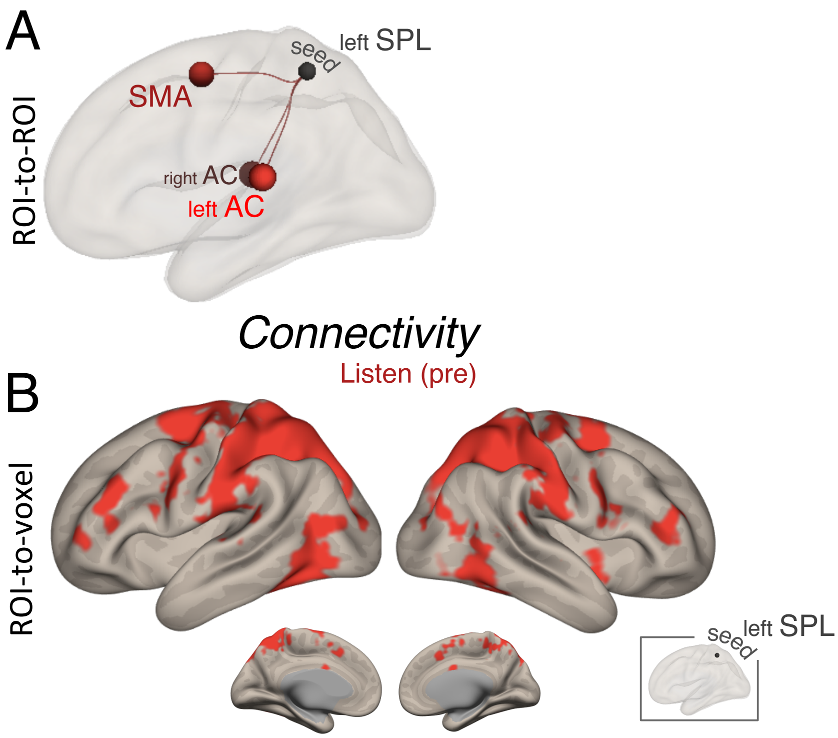

Fig. S3. Pre-training functional connectivity during listening (preSCAN). (A) Significant connectivity between left SPL and bilateral auditory cortex (AC) and SMA (right and left) (a priori defined ROIs, see Methods; p < .05 FDR-corrected). (B) Significant connectivity between left SPL and regions in red (whole brain analysis; (p-thresh = .001, p < .05 cluster-corrected).

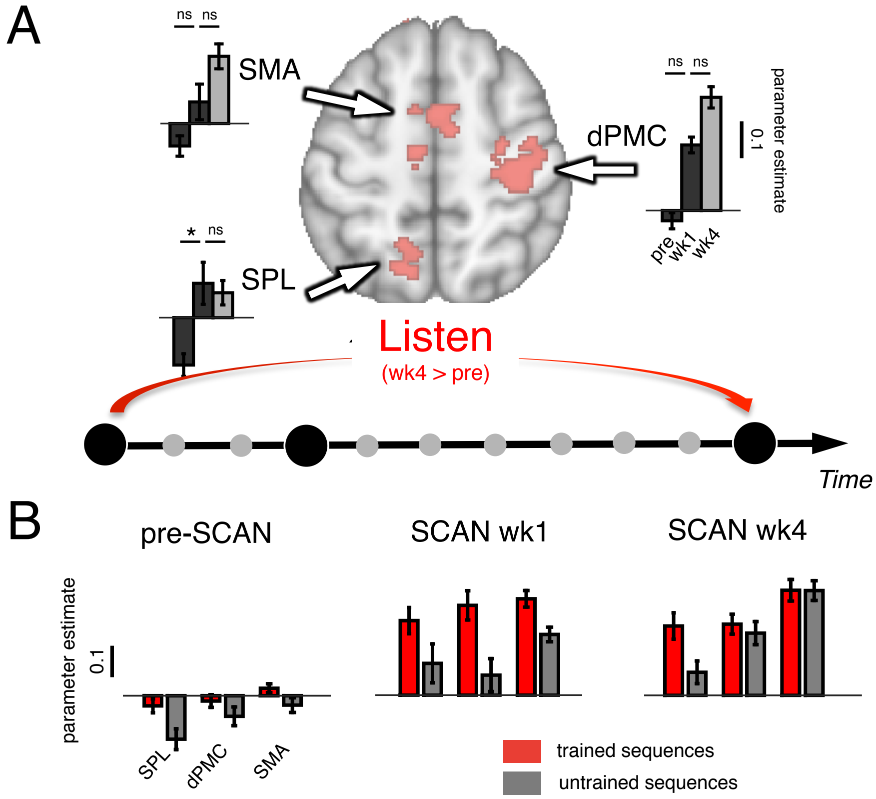

Fig. S4. Training-related effects for the untrained sequence. (A) Insets show bar plots of BOLD signal within the three ROIs identified on the contrast image displayed in background 'Listen to the learnt sequence wk4 > pre', across the pre, wk1 and wk4 scans (paired-sample t-tests, * p < .05 after Bonferonni correction) during passive listening to the untrained sequences. (B) Bar plots of BOLD signal within regions of the dorsal auditory to motor pathway as identified in A (including left parietal region SPL, right dorsal premotor cortex dPMC, and SMA/preSMA) comparing passive listening to untrained vs. trained sequences. Increased activation across scans operated in a similar fashion for both trained and untrained sequences (rm-ANOVA show no significant interaction (p > .05) between scan session and type of sequence (trained/ untrained)).

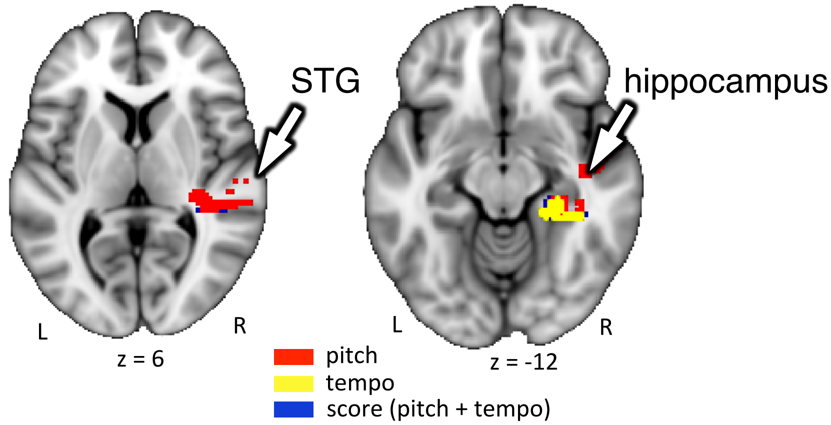

Fig. S5. Regression analyses between pitch score (red), tempo score (yellow), or the global performance score (blue) at SCAN wk4 and BOLD signal variations in the play task (wk4 > wk1) demonstrate that more accurate performance relies on a finer-grained encoding of pitch information in the right auditory cortex, across learning and finer-grained encoding of both pitch and timing information in the right hippocampus, across learning.

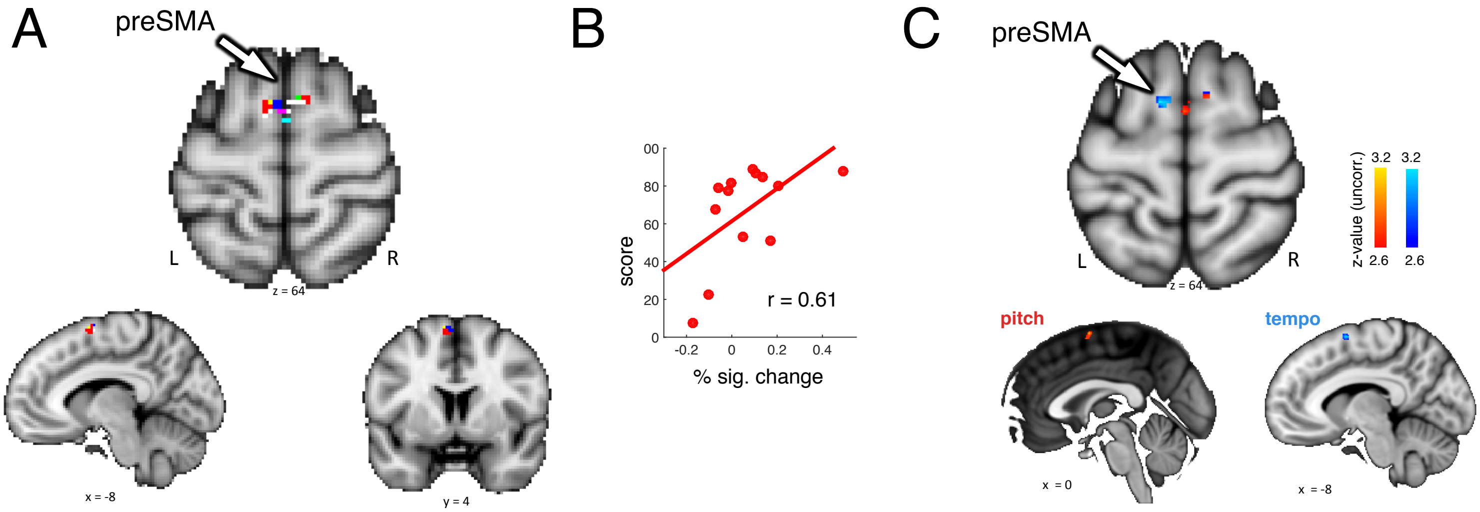

Fig. S6. Predispositions. (A) Superimposition of the 13 functionally defined ROIs from the leave-one-participant-out cross-validation procedure; all 13 analyses reveal a cluster in preSMA (in closely adjacent regions and often broadly overlapping), whose activity significantly correlated with the behavioral measure across subjects (one color corresponds to one analysis; the red color corresponds to the initial regression analysis presented in the paper, taking all 13 subjects). (B) Robust Spearman correlation computed between parameter estimate in preSMA at preSCAN (x-axis) during listening from the leave-one-participant-out cross-validation procedure and score at SCAN wk4 (y-axis) (C) Regression analyses with (-pitch errors) and (-tempo errors) at the end of the training (wk4) testing for correlations between pre-training activity during listening and training achievements ($z > 2.6$ uncorrected). Individual differences in preSMA activity pre-training were predictive of training achievements for both the pitch and tempo accuracy.

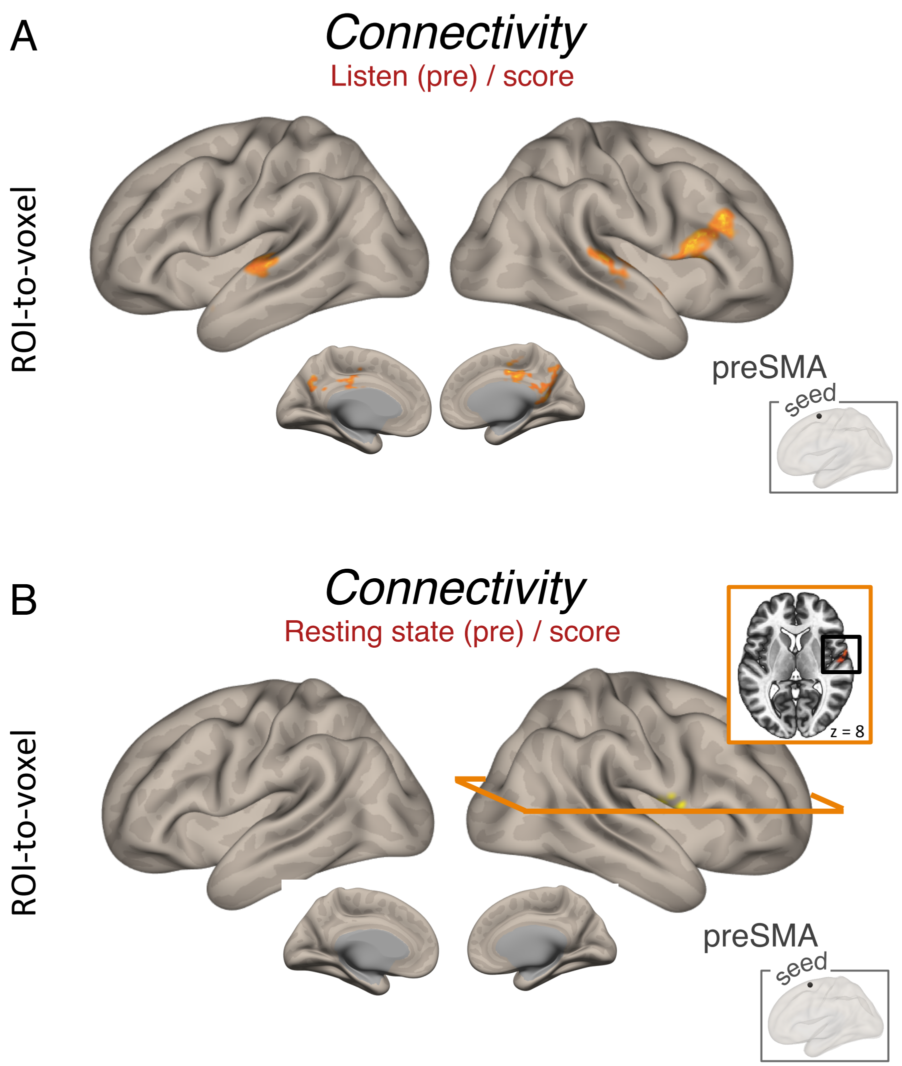

Fig. S7. (A) Predisposition in functional connectivity (FC) analyses in the listening task: regression analyses of pre-training FC with performance score at last scan (wk4) shows in particular positive correlation between connectivity between preSMA and bilateral auditory cortex AC (in orange) and training achievements (p-thresh = .05, p < .05 cluster-corrected). (B) Predisposition in functional connectivity (FC) analyses in resting state: regression analyses of pre-training FC with score at last scan shows positive correlation between connectivity between preSMA and right auditory cortex AC (in orange) and training achievements (p-thresh = .001, p < .05 cluster-corrected).

Table S1. (A) Peak coordinates of fMRI clusters activated in the Listen task for the post-training minus pre-training contrast (scan wk4 > pre). (B) Functional connectivity in the Listen task for the post-training minus pre-training contrast (scan wk4 > pre) with a seed in left SPL (as defined in the default atlas of the CONN toolbox).

A

Anatomical description	MNI coordinates			Z	p-value (cluster corr.)
	x	y	z		
SMA	10	-4	52	3.59	0.00684
right dPMC	34	-22	64	3.7	1.29e-05
left SPL	-2	-78	48	3.48	0.0187

B

Anatomical description	peak t	p-value (FDR correction)
left SMA	3.95	.008
right SMA	5.63	.001
left AC	2.91	.035
right AC	2.69	.040

Table S2. Peak coordinates of fMRI clusters activated (A) in the Listen task for the regression between post-training minus pre-training contrast (scan wk4 > pre) and performance score at SCAN wk4 and (B) in the Play task (scan wk4 > pre) with score at scan wk4 as regressor.

A

Anatomical description	MNI coordinates			Z	p-value (cluster corr.)
	x	y	z		
right STG	44	-28	10	3.32	.048
right Putamen	26	-10	4	2.58	.001
left Middle Frontal gyrus	-34	2	32	4.14	< .001
left Somatosensory cortex	-38	-16	-28	3.61	.023

B

Anatomical description	MNI coordinates			Z	p-value (cluster corr.)
	x	y	z		
right STG	54	-36	14	3.32	0.036
right Hippocampal gyrus	28	-30	-10	4	< .001

Table S3. Regression analyses of pre-training functional connectivity (A) in the Listen task and (B) during resting state, with score at scan wk4 as regressor and using a seed in preSMA. The seed was functionally defined based on the results of the regression that tested for correlations between pre-training BOLD response during listening and performance score at SCAN wk4

A

Anatomical description	peak t	p-value (uncorr. / one sided)
right AC	1.80	.049
left AC	2.41	.017

B

Anatomical description	peak t	p-value (uncorr.)
right AC	2.20	.049