

Cortical Systems Associated with Covert Music Rehearsal

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Musical representation and overt music production are necessarily complex cognitive phenomena. While overt musical performance may be observed and studied, the act of performance itself necessarily skews results toward the importance of primary sensorimotor and auditory cortices. However, imagined musical performance (IMP) represents a complex behavioral task involving components suited to exploring the physiological underpinnings of musical cognition in music performance without the sensorimotor and auditory confounds of overt performance. We mapped the blood oxygenation level-dependent fMRI activation response associated with IMP in experienced musicians independent of the piece imagined. IMP consistently activated supplementary motor and premotor areas, right superior parietal lobule, right inferior frontal gyrus, bilateral mid-frontal gyri, and bilateral lateral cerebellum in contrast with rest, in a manner distinct from fingertapping versus rest and passive listening to the same piece versus rest. These data implicate an associative network independent of primary sensorimotor and auditory activity, likely representing the cortical elements most intimately linked to music production.

Key Words: fMRI; prefrontal; music; imagination; parietal.

INTRODUCTION

Closely tied to issues of selective attention and conscious experience, mental imagery has often been considered the covert reflection of overt behavioral performance (Mellet *et al.*, 1998; Ingvar, 1994; Decety *et al.*, 1994). Early studies with positron emission tomography (PET) found similar patterns of activation in both actual and imagined hand movements involving the supplementary motor and premotor areas (Fox *et al.*, 1987). These data suggested that covert processing

utilized the same regions as overt performance, even in the absence of overt behavior (i.e., movement). Similar results were found using functional magnetic resonance imaging (fMRI) and PET, demonstrating activation of the visual cortex when subjects were asked to imagine viewing objects (Cohen *et al.*, 1996; D'esposito *et al.*, 1997; Kosslyn *et al.*, 1999). More recent studies of motor imagery have found activation of contralateral inferoparietal cortex, pre-supplementary motor area (pre-SMA), premotor cortex, and ipsilateral cerebellar and thalamic activation (Porro *et al.*, 1996; Erslund *et al.*, 1996; Deiber *et al.*, 1998). In contrast to these data, studies of auditory imagery have demonstrated that primary auditory cortex is not involved, while higher auditory processing regions are (Zattore *et al.*, 1996; Halpern *et al.*, 1999).

The majority of covert behavioral imaging studies have been performed using motor preparation and planning. We wished to extend this work by using a more complex cognitive and behavioral paradigm—musical performance. Because PET studies during overt musical performance have revealed involvement of the central cerebellum, primary motor cortex, and superior parietal lobule (Sergent *et al.*, 1992; Sergent, 1993), we anticipated activation in these regions. At the same time, we expected to find lateral rather than medial cerebellar activity, as the lateral cerebellum has been implicated in motor and cognitive timing and complex motor skills (Polit and Bizzi, 1979; Penhune *et al.*, 1998; Ivry *et al.*, 1988). A study of comprehension of musical harmony, melody, and rhythm showed mostly posterior cerebellar activation with each and bilateral premotor cortex (Brodmann area (BA) 6) activation for harmony, melody, and rhythm discrimination (Fox *et al.*, 1998). The importance of the cerebellum in musical performance and processing is also suggested by a postmortem study that found musicians to have larger cerebellae than normal controls (Schlaug *et al.*, 1998). To differentiate imagined musical production from simple motor movement, we compared imagined musical performance (IMP) contrasted with rest to bilateral fingertapping (BFT) contrasted with rest. Because of

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TABLE 1
Subject Demographics

Subject	Instrument	Age	Sex	Hand	Edu.	Exp.	Method studied	Piece imagined	Correlation
1	cello	25	M	R	16	23	Suzuki @ 3	Vivaldi II Cello Concerto	0.997
2	piano	23	F	R	16	16	multiple @ 7	Bach Suite Part 2 in C major	
3	violin	33	F	R	20	20	multiple @ 13	Bach Partita #2 Movement 1	
4	violin	32	M	R	20	26	Suzuki @ 6	Bach Partita #3 Movement 1	0.996
5	cello	24	F	R	16	18	Suzuki @ 6	Vivaldi II Cello Concerto	
6	cello	22	F	R	16	15	Suzuki @ 8	Vivaldi II Cello Concerto	0.997

Note. The column headed "Hand" refers to handedness; R = right handed, judged by the Edinburgh handedness inventory (Oldfield, 1971). The column headed "Edu." refers to number of years of formal education at the time of the study. The column headed "Exp." refers to the number of years of experience playing their respective instrument. The column headed "Method Studied" refers to the musical training method under which the subject studied, followed by the age in years at which they began their formal musical training. The column headed "Correlation" refers to the level of correlation between the time taken to imagine playing portions of the piece and the time taken to actually play portions of the piece which required 60, 45, 30, and 15 s to actually play.

the complex timing involved in music production we expected music to invoke cerebellar activation distinct from that associated with simple fingertapping. Similarly, to differentiate the active mental aspects of imagined musical production from the relatively passive experience of hearing music, we compared IMP contrasted with rest to listening to the same musical piece contrasted with rest. Our goal was to determine whether IMP relies on those primary motor and sensory areas utilized in overt performance or instead recruits a distinct region or network of regions.

METHODS AND MATERIALS

Subjects

We studied six neurologically normal right-handed musicians (four female, two male; mean age 27 years, range 22–32 years); see Table 1 for further information. All subjects were screened for neurological and psychological disorders according to previous studies (Callicott *et al.*, 1998, Mattay *et al.*, 1996). Volunteers had at least 15 years of musical experience (two violinists, one pianist, three cellists; mean length of study 19.6 years, range 15–26 years). The use of heterogeneous instruments and imagined pieces was seen as preferable to demonstrate commonalities across imagined musical performance without the possible confound of closely shared motor programs. Participants were studied using blood oxygenation level-dependent (BOLD) fMRI (Ogawa *et al.*, 1990; Bandettini *et al.*, 1992) while performing both imagined (covert) musical performance and observable (overt) motor and auditory tasks. In addition, three of the subjects performed a control task outside of the scanner to corroborate their ability to imagine musical performance. All aspects of the study were carried out following the Department of Health and Human Services Regulations for Protection of Human Research Subjects. Volunteers were recruited from the staff of the National Institutes

of Health and gave written, informed consent prior to participation.

fMRI Procedure

Participants were scanned on a 1.5 Tesla General Electric Signa scanner (Milwaukee, WI) using fast-gradient hardware and the standard GE quadrature head coil. Data were acquired with multi-slice spiral imaging as described previously: 2000 ms effective whole-brain TR, 24 ms TE, 240 mm FOV, 38 sagittal slices, 3.75-mm³ voxels (Yang *et al.*, 1996) Subjects wore headphones for acoustic stimulation provided by a pneumatic stereo system (Resonance Technology, Van Nuys, CA). Padding was placed around the participants' heads to reduce motion. After acquisition of an axial localizer, each subject underwent a randomized battery of functional scans. Accompanying the functional scans, an anatomical scan was performed for each subject in the same plane as their functional data: 38 sagittal slices, 240 mm FOV, 102 ms TE, 3500 ms TR, 3.75-mm³ voxels. Each functional scan sequence began with 4 whole-brain volumes (discarded to allow for signal stabilization) followed by 120 functional volumes or time points. Thus, each series consisted of 124 whole-brain images (requiring a total of 4 min and 8 s). After the 8 s allotted for signal stabilization, participants alternated between 30-s task performance periods (i.e., rest and imagined musical performance) for 4 min, creating four interleaved blocks of each task. Eyes were closed throughout, and participants were directed to switch tasks with a tap upon the ankle. For each imagined musical performance epoch, subjects were instructed to imagine performing from the beginning of the piece to avoid the potential memory confound of remembering temporal location in the piece over the non-IMP blocks. Different musical selections were chosen by each subject based on technical complexity and familiarity. All selections had been actively practiced during the weeks prior to participation. The three cel-

TABLE 2

Activations and Relative Deactivations Associated with Imagined Musical Performance
(Deactivations Shown as Activations during Rest)

Condition	Contrasted with	Corrected Z	x	y	z	BA	Region	
Imagined musical performance	Rest	7.71	22	-66	56	7	right superior parietal lobule	
		7.55	2	6	56	6	right superior frontal gyrus	
		4.49	0	-16	8		Va of the left thalamus	
		4.2	-12	4	8		left caudate nucleus	
		4.02	54	14	0	47/45	right inferior frontal gyrus	
		7.09	-26	-62	-29		left lateral cerebellum	
Rest	Imagined musical performance	6.22	36	-72	-28		right lateral cerebellum	
		4.33	4	-60	28	18/31	right precuneus	
		4.17	-26	-48	-24	22	right superior temporal gyrus	
		3.89	54	-14	-8	21	right middle temporal gyrus	

Note. Coordinates (x, y, z) correspond to the atlas of Talairach and Tournoux (1993), while BA refers to Brodmann areas. Right = right; therefore positive x coordinates refer to the right. Z scores represent the values calculated in SPM96 for corrected voxel-level statistics (Friston *et al.*, 1994, 1995).

lists imagined playing the second cello part to Vivaldi's "Concerto in G minor for 2 cellos," the pianist visualized the Bach "Suite in C major, part 2," and the violinists mentally rehearsed the first movements of Bach's "Partita 2" and "Partita 3." In addition, five of the subjects were scanned while alternating both passive listening (LISTEN) of their chosen musical piece with rest and bilateral fingertapping with rest. All bilateral fingertapping was self-paced at approximately 2 Hz and consisted of synchronized finger to thumb opposition in the order 2, 3, 4, 5, 5, 4, 3, 2. No motor movement was executed throughout the nonmotor tasks. This was ensured through visual surveillance of subjects during all scans. Three of the subjects also performed a control task outside of the scanner similar to the timing controls found in earlier auditory imagery studies (Zattore *et al.*, 1996; Halpern *et al.*, 1999). Subjects were asked to perform their chosen piece on their instrument and were halted at 60 s. The point within the piece at which the subject was stopped was noted. These subjects were then asked to close their eyes and imagine performing the piece up to the point at which they had been stopped, and the time elapsed was noted. This procedure was repeated for 45-, 30-, and 15-s sections. The time taken to play the piece section and the time taken to imagine performing the same section produced correlation coefficients considerably higher than chance (0.997, 0.996, 0.997).

Data Analysis

fMRI data were reconstructed and spatially registered to the first time point using a cubic spline interpolation to correct for minor head motion (Ostuni *et al.*, 1997). These registered fMRI images were then viewed in cine-loop to rule out uncorrected interscan movement. No data were excluded based upon this review. The anatomical scan from the same scan session was registered to a mean of the functional images and

stereotactically normalized to standard brain space (Montreal Neurological Institute MNI template) using AIR-3.0 (Woods *et al.*, 1998a,b). The resultant warp matrix was then applied to the registered functional data. The fMRI time series were smoothed spatially using a Gaussian filter ($5.6 \times 5.6 \times 5.6$ mm) and temporally by 2.8 s using Statistical Parametric Mapping (SPM96) (Friston *et al.*, 1994, 1995). After scaled global normalization, individual and group BOLD activation was assessed in SPM96 using a 6-s delayed boxcar waveform, highpass filtering at 0.5 cycles per minute, and a cutoff period of 120 s. Our statistical threshold was set at $P \leq 0.001$, corrected at the voxel level.

RESULTS

Imagined musical performance activated a distributed network of regions (Table 2) on both group (Fig. 1) and individual (Fig. 2) brain maps. These regions included right inferior frontal gyrus (IFG) (BA 45/47), right and left lateral cerebellum (superior posterior fissure), right superior frontal gyrus (BA 6), and right superior parietal lobule (BA 7). Activation of SMA was also noted within the same SPM cluster attributed to premotor BA 6. When contrasted with rest, IMP demonstrated greatest activation in the superior parietal lobule. While not typically seen in motor paradigms, the superior parietal lobule has been implicated in encoding/retrieval and complex cognitive processing tasks such as working memory and selective attention (Berman *et al.*, 1995; Callicott *et al.*, 1999; Rypma *et al.*, 1999; Carter *et al.*, 1995). Concomitantly, compared to the rest period, a relative decrease in activity in the right precuneus (BA 18/31), right superior temporal gyrus (BA 22), and right middle temporal gyrus (BA 21) appeared to occur during imagined musical performance (Table 2). This decrease in activation of the

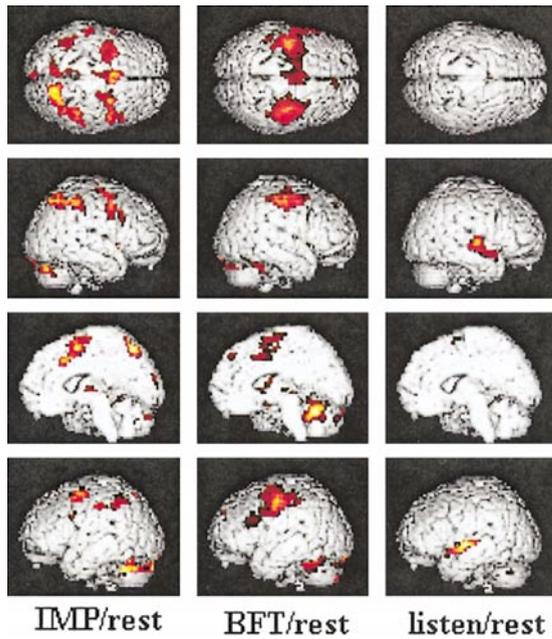


FIG. 1. Group activation maps in response to imagined musical performance versus rest ($n = 6$, $P < 0.001$), bilateral fingertapping versus rest ($n = 5$, $P < 0.001$), and passive listening versus rest ($n = 5$, $P < 0.001$). Data are displayed in neurological convention (right = right). Significant voxels are displayed using a color scale ranging from red (lesser significance) to yellow (greatest significance).

superior temporal gyrus during IMP is noteworthy, especially in conjunction with the absence of motor cortex activation during IMP, both of which might have been expected due to the nature of music performance. There appeared to be a greater number of subcortical

regions active during IMP than during BFT. While the left thalamus and caudate were active during IMP (Table 2), right putamen activity was present only for BFT (Table 3).

Predictably, bilateral fingertapping robustly activated bilateral primary sensory motor cortices (BA 3/4) in individual and group maps (Table 3). It should be noted that while this cluster of activation was significantly centered in primary sensory motor cortex, some SMA activity was encompassed by this cluster and likely indicates involvement during BFT versus rest (see Fig. 1). During this contrast, primary sensory motor cortex and medial cerebellum (primary fissure) were active bilaterally, differing significantly in foci of activation, from those cerebral and cerebellar areas activated during IMP.

Similarly, passive listening to the same musical piece imagined by these musicians contrasted with rest, robustly activated the bilateral superior and medial temporal gyri (Table 3). These regions were also consistently active across individual analyses. Interestingly, four of the musicians demonstrated a trend toward bilateral activation in the cerebellum during passive listening. Though not statistically significant, this possible cerebellar activity may have been consistent with subjects' comments on the difficulty of repressing thoughts of performance while listening to the pieces.

DISCUSSION

In this study of imagined musical performance, we found activation in a distributed network that included

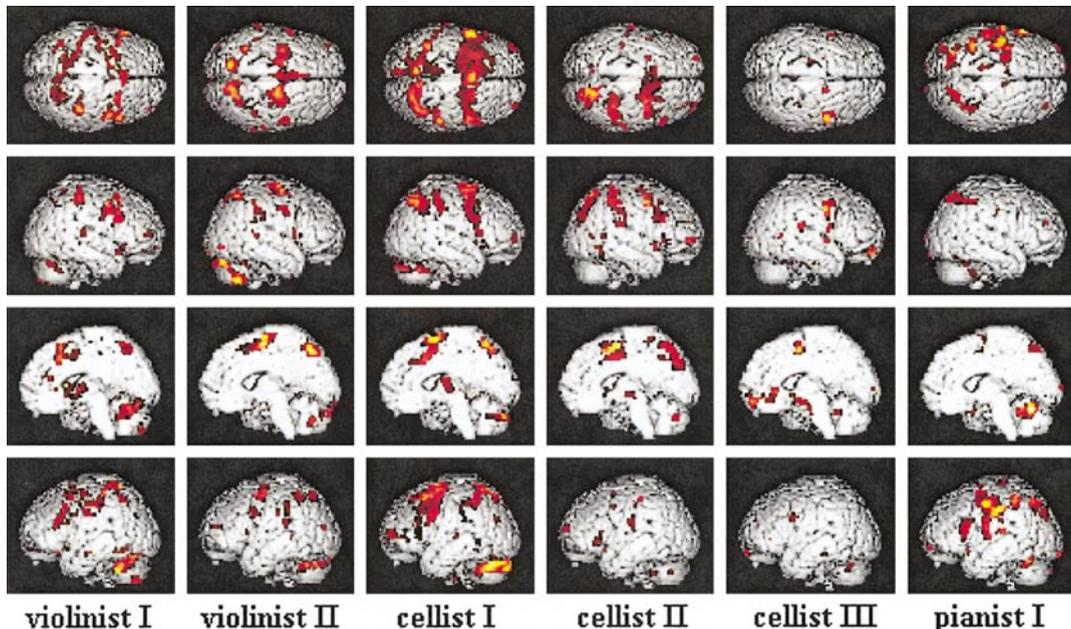


FIG. 2. Individual activation maps in response to imagined musical performance versus rest ($P < 0.001$) (right = right).

TABLE 3

Areas Activated during Bilateral Fingertapping and Passive Listening to Music

Condition	Contrasted with	Corrected Z	x	y	z	BA	Region
Bilateral fingertapping	Rest	8.43	-16	-60	-20		left cerebellum
		8.19	20	-52	-24		right cerebellum
		8.36	40	-14	56	3/4	right primary sens. Motor.
		8.04	50	-22	56	3/4	left primary sens. Motor.
		4.81	28	-2	0		right putamen
Passive listening	Rest	7.44	-56	-6	-8	21	left medial temporal gyrus
		4.18	-54	-26	8	42	left superior temporal gyrus
		6.31	54	0	-8	21	right medial temporal gyrus
		7.17	52	10	-16	42	right superior temporal gyrus

Note. Coordinates (x, y, z) correspond to the atlas of Talairach and Tournoux (1993), while BA refers to Brodmann areas. Right = right; therefore positive x coordinates refer to the right. Z scores represent the values calculated in SPM96 for corrected voxel-level statistics (Friston *et al.*, 1994, 1995).

the right superior parietal lobule, right inferior frontal gyrus, and bilateral lateral cerebellum. These data are similar to Sergent's functional neuroimaging findings of overt musical performance wherein the motor and auditory aspects were separated (Sergent *et al.*, 1992; Sergent, 1993). However, in the present study, differentiation of the covert aspects of music production was accomplished by utilizing a solely imagined paradigm. These data suggest that the conscious experience of covert musical rehearsal is not closely tied to the primary sensorimotor regions active during execution of the performance or to the auditory sensory areas active during listening to it. Instead, our data suggest that the internal experience of musical performance involves cortical pathways recruited for the integration of auditory information with the temporal- and pitch-related aspects of the musical rehearsal itself. This network involving prefrontal cortex, parietal cortex, and lateral cerebellum likely functions to coordinate the complex spatial and timing components of musical performance and appears to function independently of primary sensorimotor and auditory cortices.

While the primary sensorimotor cortex did not appear to be active during IMP, the premotor and supplementary motor areas demonstrated activity during IMP versus rest. With regard to the high level of motor programming and planning necessary to conduct the complex movements inherent in musical performance, it is not surprising to have found these higher-level motor regions active during our task. In support of this interpretation, the spatial extent of SMA activation was smaller in the less complex BFT versus rest task comparison (Fig. 1).

The lateral activation of the cerebellum during imagined musical performance is consistent with the covert motor aspects of IMP, as suggested in both animal and human studies. Nonhuman primates acquiring complex motor skills increase neural activity in the ipsilateral cerebellum (Polit and Bizzi, 1979). Studies of humans suffering from cerebellar lesions implicate the

lateral cerebellum in motor timing (Ivry *et al.*, 1988). This observation was further supported by a PET study that found both lateral cerebellar cortex and vermis activation in response to the reproduction of complex rhythms (Penhune *et al.*, 1998). Furthermore, recent PET studies implicate active participation of the cerebellum during musical harmony, rhythm, and melody comprehension (Fox *et al.*, 1998). Results from passive listening versus rest do not strongly support involvement of cerebellum in harmony and melody discrimination, as it is possible that trends toward cerebellar activation arose in part from imagined motor movements during passive listening as much as from music comprehension. Presumably, this confound of difficulty in suppressing thoughts of musical performance in response to passive listening would function to minimize the stark differences between the two tasks that we found. At the same time, though some overlap was present, a clear distinction was made between the more lateral foci of cerebellar activation in declive and superior posterior cerebellar fissure associated with imagined musical performance and the more central/anterior primary cerebellar fissure foci of activation associated with overt bilateral fingertapping. It is important to note that the cerebellar activations were consistently bilateral during IMP. Right cerebellar activation may be associated with imagined right-arm bowing movements in string players and complex right-hand motions in the pianist. Event-related fMRI paradigms may make it possible to differentiate possible nonmotor/musical functions of the cerebellum from motor coordination.

With respect to musicality, it has been hypothesized that superior parietal lobule activation may represent the spatial-like pitch information encoded in the musical composition and in the motor performance (Sergent *et al.*, 1992; Sergent, 1993). This was further corroborated by evidence of left cuneus and precuneus PET activation in pitch discrimination (Platel *et al.*, 1997). More recently, a PET study found that right

precuneus and superior parietal lobule activation were correlated with increasing "unpleasantness" elicited by a melody when played with increasing levels of dissonance (Blood *et al.*, 1999).

It is of interest here to discuss the relative increase in significance of the superior temporal gyri during rest when contrasted with IMP. These results suggest that contrary to participation of the superior temporal gyri during IMP, brain activity in these regions may be suppressed. While running contrary to functional imaging studies of imagination in the visual system, this interpretation would be consistent with musicians' attempts to prevent external auditory stimuli (such as scanner noise) from interfering with the higher-level cortical circuits involved in the imagined auditory aspects of imagined musical performance. Given that the confound of fMRI scanning noise is present throughout control periods and task conditions alike, it is unlikely that auditory activity during IMP was masked. At the same time, lack of primary auditory cortex activation during auditory imagery is consistent with earlier studies (Zattore *et al.*, 1996; Halpern *et al.*, 1999). However, it must be noted that these previous studies did identify activation in higher auditory processing areas. This particular discrepancy may be a result of the inherent difference between these earlier studies of imagined audition and our current investigation of imagined musical performance.

Finally, the right inferior frontal gyrus demonstrated increases in activation when contrasted with rest. It may be that this premotor region holds a strong influence over musical production. However, the prefrontal cortex has been shown to activate during selective attention tasks and working memory in general (Carter *et al.*, 1995; Hager *et al.*, 1998). More complex paradigms could be used to differentiate attentive activation in this region from that associated with music performance. In support of a right IFG role in music production, it was shown that the right inferior frontal gyrus was activated in fMRI studies by continuation of a motor synchronization task with a previously presented auditory cue (Rao *et al.*, 1997). Their work argued that the right IFG, functionally interconnected with the auditory cortex, mediated auditory sensory memory input in motor timing. Similarly, electroencephalography was used to show that as musical novices gained skill in piano playing, activation focused in the right prefrontal-temporobasal region (Bangert *et al.*, 1998). As this correlated with the localization of activation in expert pianists (>15 years of experience), Bangert *et al.* (1998) argued that this right prefrontal-temporobasal region may be the seat of audiomotor integration associated with piano playing. It is interesting to consider this right inferior frontal gyrus activation in the context of that region as a right hemisphere homologue to Broca's area. However, this

necessarily raises questions of laterality which are outside the scope of this work.

A potential confound of this study is the pooling together of musicians trained on different instruments. Nevertheless, predictable patterns emerged. For instance, the left-hand supplementary motor areas tended to activate in the violinists and cellists whose performances rely more heavily on left hand movements, while the pianist's predominantly right-handed performance resulted in significant left hemisphere activations (Fig. 2). Indeed, a magnetic source imaging study showed string players to have larger cortical representations of the left hand (Elbert *et al.*, 1995). At the same time, correlation across subjects was quite high for the core regions of right superior parietal lobule, right inferior frontal gyrus, and bilateral lateral cerebellum. Through the use of different instruments and pieces, these common areas of activation may be argued to control common aspects of imagined musical processing inherent across instruments and therefore not specific to any particular set of motor programs.

One may raise the argument that these areas appear to be quite similar to regions identified in studies of episodic memory recall and working memory (Nyberg *et al.*, 2000; Cabeza *et al.*, 2000; Fletcher and Henson, 2001 [review]). While imagined musical performance undoubtedly incorporates aspects of working memory and recall, we would argue that areas highlighted by our study reveal more delineated roles for those regions that are similar to traditional episodic recall and working memory tasks. While IMP activates lateral cerebellar regions, studies in episodic recall have shown verbal cerebellar activation (Nyberg *et al.*, 2000). At the same time, while verbal/numeric and problem-solving working memory appear to activate lateral cerebellum, spatial working memory (more relevant to our task) does not appear to activate lateral cerebellum or cerebellum in general (see the review of 275 PET and fMRI studies by Cabeza and Nyberg (2000)). This suggests that the lateral cerebellum may play a role in the motor aspects of working memory involved in our task. Similarly, activation in the inferior frontal gyrus during memory tasks appears often to be lateralized to the left (Broca's area) and to be associated with subvocal speech approaches to the tasks (Fletcher and Henson, 2001 [review]). At the same time, the aforementioned Cabeza and Nyberg (2000) review listed some spatial, object, and problem-solving working memory localization to the right inferior frontal gyrus. These results, particularly the spatial working memory results, are not inconsistent with our task or our above discussion of the right IFG role. Finally, a number of working memory studies indicate a spatial role for the precuneus and superior parietal lobule (Cabeza and Nyberg, 2000 [review]). Again, these data are in agreement with our discussion. However, given the previously described research linking

superior parietal lobule to pitch discrimination, it may be necessary to devise more complex contrasts to separate working memory components of our task from those involved solely in imagined musical performance.

Most importantly, without behavioral data, uncertainty necessarily surrounds the interpretation of the imagined task activation. However, we selected highly cooperative subjects and noted consistent results across individuals and contrasts. While cognitive psychologists studying mental imagery have demonstrated creative ways in which to ascertain that the imagined task is in fact being imagined, our study had no such control. We would argue, however, that to the musically experienced, imagining performance of a musical instrument can more closely be compared to imagining the production of language in the form of subvocal speech, as has been studied in the past, often without controls (Brockway, 2000; Hernandez *et al.*, 2000). The ease with which experienced musicians may imagine a musical performance is in part defended by the high correlation noted in our timing task. While we do not deny the relevance of this potential confound, we do feel it is of note to consider the similarities between cellists and violinists in this study in comparison to the pianist. It also is of interest to compare our results with prior work in the area of imagined musical performance. In their 1996 article, Petsche *et al.* reported an EEG study of “mentally playing an instrument.” Their EEG coherence analysis of a single subject over 2 days found significant coherence patterns in the supplementary motor area while overtly playing scales, imagining playing a piece, and listening to that same piece. These findings are consistent with our results. In a final note on this topic, it may have been to our advantage to include an imagined bilateral fingertapping task. This task could have been used to further demonstrate the continuity shown in previous studies of covert and overt motor movement (Porro *et al.*, 1996; Erslund *et al.*, 1996; Deiber *et al.*, 1998).

While this study demonstrates the possibilities for mapping the musical brain, future work is required. To better localize aspects of music production, a larger study contrasting imagined performance of works of music with imagined scale production would be necessary. At the same time, it may be feasible to contrast imagined “musical” performance with an imagined “technical” performance of the same musical piece. However, this necessarily decreases the certainty of “what” task is being performed.

Notwithstanding the need for elaboration, these data effectively demonstrate fMRI activation associated with imagined music production. We have argued that the right superior parietal lobule, bilateral lateral cerebellum, and right inferior frontal gyrus are integral components in musical rehearsal. Based on these results and previous work, imagined musical production appears to recruit a specific cortical network. In this

context, it is of interest to hypothesize the involvement of the right superior parietal lobule in the spatial aspects of motor and musical pitch representation, the bilateral lateral cerebellum in musical and motor timing, and the right inferior frontal gyrus in integrating the motor and musical–auditory maps necessary (perhaps via premotor and supplementary motor planning areas) for playing an instrument. These data speak to the possibility that a complex interaction of these regions, rather than primary sensorimotor and auditory cortices, may represent the cortical experience of imagined musical performance. At the same time, this study confirms the power of fMRI to explore the covert components of complex behaviors and cognition.

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