

Neural control of playing a reversed piano: empirical evidence for an unusual cortical organization of musical functions

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Using functional magnetic imaging techniques and neuropsychological tests, we studied a young male musician (C.S.) who performs at a professional level both on a regular piano keyboard and on a reverse keyboard (reversed right to left). The participant was left-handed, had left dominance for language but, remarkably, right dominance for the control of piano playing on both keyboards. With respect to music perception, C.S. showed left-sided activation dominance within the left superior temporal sulcus, which is

normally associated with higher order auditory processing and right-sided activations in the secondary sensory cortex extending into the supramarginal gyrus. We suggest that C.S.'s pattern of functional asymmetry, characterized by audio-motor control using a right-sided network, could be a factor in his exceptional piano-playing ability on both the standard and reversed keyboard. *NeuroReport* 17:447–451 © 2006 Lippincott Williams & Wilkins.

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Introduction

Recently, one of the authors (L.J.) wrote a theoretical paper about an exceptional pianist who plays professionally on a reversed keyboard (i.e. with pitches descending from left to right on the keyboard) [1]. This pianist (C.S.) initially learned to play on regular pianos, but at a point in his professional career he switched to a reversed keyboard. C.S. currently plays on reversed pianos (digital and forte piano) two thirds of the time, both for professional recording and international performances. From a neuropsychological point of view this case is of interest because little is known about the underlying neurological changes when modifying a highly specialized skill like playing a piano, especially at a professional level. To our knowledge, there is no other professional pianist who is capable of playing both a reversed piano and the regular keyboard and of switching comfortably from using one to the other.

Given the rarity of reversed piano playing, there is little work on this topic, with the exception of Laeng and Park's study [2] of nonprofessional left-handed and right-handed musicians playing on a regular and a reversed electronic keyboard. That study showed an initial preference for the reversed piano, which was specific to left handers but also that this preference diminished or disappeared with more practice. In fact, experienced left-handed players made the same number of errors as the experienced right-handed pianists when playing the reversed piano. This finding fits

with growing evidence demonstrating the potential for plastic changes in the human brain due to both external stimulation and practice [3,4]. The existence of a case like C.S., however, is of interest to the understanding of brain plasticity as a function of practice. Our intent was to explore the lateral dominance patterns in this exceptional individual in the hope of establishing a standard against which we could compare, as the next logical step, dominance patterns in left-handed pianists who do not play on the reversed piano. A series of functional magnetic resonance image (fMRI) experiments were conducted to establish functional lateralization for music perception, language, or motor functions. This was complemented by anatomical (structural MRI) measures of the intrasulcal length of the posterior bank of the central sulcus as an estimation of the size of the hand motor area [5]. In addition, C.S. was given a series of neuropsychological tests to quantify the pianist's functional asymmetries. In an exceptional case like this, there is no compelling a priori set of hypotheses. It can be speculated that C.S. is able to do what he does because the neural centres that process music are located adjacent to the dominant motor control centres (also on the right hemisphere) that control his preferred left hand, because such an arrangement would be efficient in terms of saving inter-hemispheric communication time [1]. It is equally possible that rather than having particular patterns of lateral dominance, however, C.S. will be found to have weakly

established dominance, enabling him to reverse the piano with relative ease.

Methods

Case report

C.S. is a male musician who began playing the piano at the age of 7 years. At the time of examination, he was 39 years old and revealed no sign of neurological or psychiatric disease (tested by routine examination by L.J.). He received his formal musical education at the Royal College of Music in London where he graduated after 5 years. He states that he practises an average 3 h a day on the reversed left-hand piano and 1 h on the regular piano. In addition, he indicates that he uses imagination techniques approximately 1 h a day. He also plays the saxophone professionally. On August 1996, he decided to switch from a regular to a reversed keyboard for the first time by using a digital piano. Two years later, he also switched to a piano with reversed keyboard that was custom built for him. In 1999, he gave his first concert on such a reversed piano. He states that to switch around his playing to a comparable performance level on the reversed piano took him only 5 months. C.S. also indicates that the quality of his performance improved and that he has more control over both hands. C.S.'s claim is that reversing the hand roles has led him to a different and more interesting style when playing, for example, Chopin, Beethoven, Schubert, or Schumann. The switch between keyboards also occurred without substantial problems with respect to the use of the pedals. Hand measurements showed no significant difference in maximum hand extension between the two hands (LH=11 and RH=12). More information on C.S. can be found on his personal website (<http://www.lefthandedpiano.co.uk/about.html>). C.S. gave informed consent to this study and publication.

Lateralization tests

These tests comprised measures of hand preference, hand performance, and auditory verbal lateralization (dichotic listening) [6–10]. An asymmetry score ($[(R-L)/(R+L)]$) was computed for all of these tasks.

Brain imaging during piano playing, music listening, and covert language production

fMRIs were recorded while C.S. was involved in (1) two piano tasks, (2) several music listening tasks, and a (3) covert language production task. During the piano task, C.S. played a piece by Bach (Prelude in C minor) on a fibreglass board, pretending to play on either a regular or a reversed keyboard. The covert language generation task included covert noun and verb generation [11]. The music tasks comprised listening to musical pieces. During the first experimental block of listening to music, a short section of either the Bach or the Chopin piece was presented via earphones and C.S. was instructed to listen attentively to these stimuli. Each musical piece was presented in three versions: one played by C.S. himself and the others played by a left-handed (Glen Gould) and a right-handed (Arthur Rubinstein) pianist of his choice. During the second 4-s-block, C.S. was asked to respond by pressing a button indicating the identity of the performer of each music piece (perfect identification). The third 4-s-block was a silent baseline block with the request to fixate a small cross (which was also present in the other two blocks). The combined

three blocks lasted 12 s and were presented 60 times (=12 min total duration). Each task consisted of 16 alternating blocks (active blocks, 30 s duration and fixation baseline blocks, 15 s duration).

Scanning protocol and functional magnetic resonance image parameters

fMRI scanning during the motor tasks was conducted within a classic fMRI box-car design with alternating rest (Off) (20 s) and activation (On) (20 s) blocks. The *piano* task was subdivided into 12 runs consisting of six On and seven Off blocks. Before each run C.S. received visual instructions. Digitized speech sampled indicating 'start' and 'stop' were presented to the participant, also indicating onset and offset of the On periods. During the Off blocks, C.S. was required to fixate a cross in the middle of the screen. fMRI was performed on a Philips Intera 3T whole-body MR unit (Philips Medical Systems, Best, The Netherlands) equipped with an eight-channel Philips SENSE head coil. Anatomical images of the whole brain were obtained by using a T1-weighted three-dimensional, spoiled, gradient echo pulse sequence (repetition time (TR)=20 ms, echo time (TE)=2.30 ms, flip angle=20°, field of view (FOV)=220 mm, acquisition matrix=224 × 224, voxel size=1 mm × 1 mm × 0.75 mm³, 180 slices, slice thickness 0.75 mm). Functional data for the motor tasks were obtained from 130 scans per run, 28 transverse slices covering the whole brain using a Sensitivity Encoded (SENSE) [12] single-shot echoplanar imaging technique with an acceleration factor $R=2.0$ (TR=2000 ms, TE=35 ms, flip angle=75°, FOV=220 mm, acquisition matrix=80 × 80, voxel size=2.75 mm × 2.75 mm × 4 mm³). The recording of functional data for the auditory task differed in the following parameters: 240 scans, 14 slices (covering the Sylvian Fissure), TR=3000 ms, flip angle 82°. The parameters for the language lateralization tasks were 240 scans, 24 transverse slices (covering the whole brain without the cerebellum), TR=1500 ms, flip angle 70°.

Data analysis

Image analysis was performed on a PC using SPM2 running on MATLAB 6.5 (Mathworks Inc., Natick, Massachusetts, USA). All images were realigned to the first volume, corrected for motion artefacts, stereotactically normalized (linear), and smoothed using a 8 mm full-width-at-half-maximum Gaussian kernel. Activated voxels were identified using the general linear model approach. At the first level of analysis, a statistical model was computed, applying a box-car model, convolved with the modelled haemodynamic response comparing the haemodynamic responses obtained during the On vs. Off conditions (regular piano playing vs. rest; reversed piano playing vs. rest; music listening vs. rest; language processing vs. rest). For the piano playing condition, we also compared the haemodynamic responses during playing with a regular vs. reversed keyboard. As we were especially interested in uncovering between-hemisphere differences, activations obtained for the right and left hemisphere were compared in the context of a voxel-wise comparison. For this, the functional maps were flipped along the horizontal axis [12]. Thus, by comparing the flipped with the nonflipped images, significantly lateralized activations were mapped on the individual and stereotactically normalized brain of C.S. For all statistical comparisons, a height threshold of $P=0.05$ (corrected) and a spatial extent of $k=10$

voxels (corrected) was used. Significantly activated brain regions were analysed using prominent anatomical landmarks identified on C.S.'s brain in accordance with standard anatomical textbooks.

For anatomical comparisons, the intrasulcal length of the posterior bank of the central sulcus was measured on five consecutive horizontal slices within the hand motor area. The hand motor area was identified according to fMRI images obtained during functional measurement. These length measurements were summed for each hemisphere and computed to asymmetry coefficients used in our original publication ($AC = (L - R)100 / (R + L) / 2$). Left handers typically show a larger depth of the CS in the hand motor area on the right hemisphere indicated by a negative AC [5].

Results

Lateralization tests

C.S. turned out to be a strong left hander as indicated by hand preference and performance (consistent left hander and a laterality score of -0.08 for hand performance). The strong left handedness corresponds with the strong right-sided asymmetry of the depth of the central sulcus ($AC: -5.5\%$). The pegboard test revealed similar performance for both hands. Although he turned out to be a strong left hander, C.S. showed a right-ear advantage, which indicates left-hemispheric proficiency in language perception (laterality score: 0.15).

Functional brain imaging

Comparing the haemodynamic responses obtained during the motor tasks with rest revealed distributed activations in the frontoparietal areas (mostly bilateral), including the superior and inferior parietal lobule, the primary motor and sensorimotor cortex, as well as the dorsal and ventral premotor cortex. The auditory tasks

evoked distributed activations in the temporal lobe (including the primary and secondary auditory cortex) and the inferior frontal gyrus. Comparing the flipped with nonflipped maps revealed a clear pattern of functional lateralization for all tasks. During piano playing a right-sided cortical network was active, including the ventral and dorsal premotor cortex (vPMC, dPMC), the primary motor cortex in the hand area (M1), a dorsal part of M1, a ventral part of the motor strip within the face representation, and the superior parietal lobe (SPL). In addition, there was also the left intermediate cerebellum active (CB) (Fig. 1).

Comparing the activations obtained when playing on a regular keyboard with the activations found when playing a reversed keyboard revealed stronger activation on the right hemisphere in a distributed network including the dPMC, the SPL extending into the IPS, and a small activation cluster in the anterior tip of the middle frontal gyrus. Two activation peaks were present with stronger activations on the left hemisphere comprising the primary motor cortex and a small spot in the SPL. No additional activation cluster for the contrast comparing regular vs. reversed was noted (Fig. 2).

A different picture emerged for the language tasks with a clear left-sided activation in the inferior frontal gyrus extending into Broca's area, the posterior superior temporal sulcus (STS) extending into the angular gyrus, the anterior part of the middle temporal gyrus, and the postcentral gyrus extending into the SPL. A small activation cluster was also observed in the right planum temporale. The music listening task evoked a different pattern of activation with stronger activation in the right secondary sensory cortex (SII), extending slightly into the supramarginal gyrus and the subcentral gyrus. This distinct pattern of activation obtained in both tasks was confirmed by directly comparing both tasks (Fig. 3).

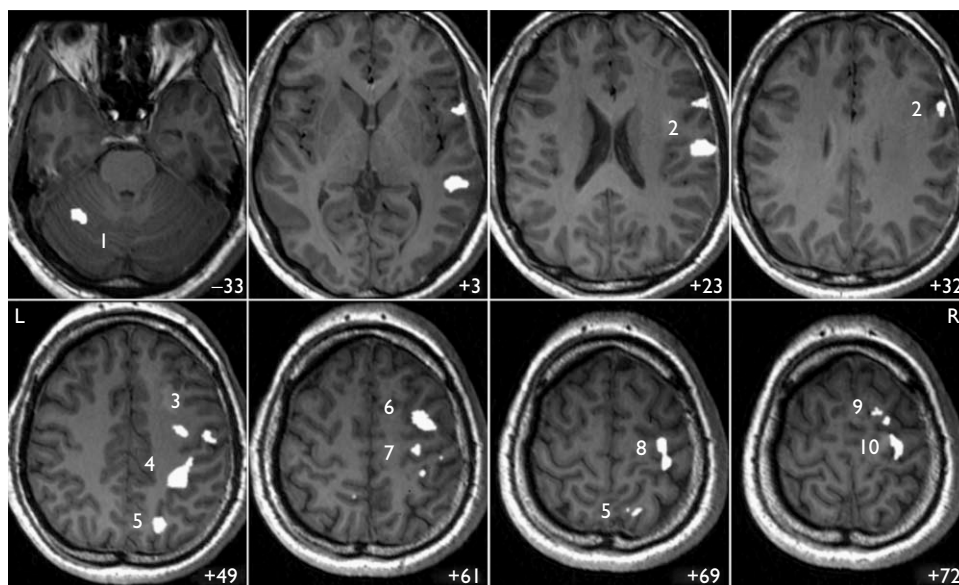


Fig. 1 Stronger haemodynamic responses on the right hemisphere during piano playing overlaid on the stereotactically normalized digital reconstruction of C.S. brain. Statistical comparison between flipped and nonflipped images ($P < 0.01$, corrected). 1: left cerebellum, 2: ventral premotor cortex, 3: dorsal premotor cortex, 4: primary motor cortex – hand area, 5: superior parietal lobe, 6: rostral part of the dorsal premotor cortex, 7: dorsal part of the primary motor cortex, 8: similar to 7 but extending into the dorsal part of the sensorimotor cortex, 9: dorsal premotor cortex, 10: caudal part of the dorsal premotor cortex.

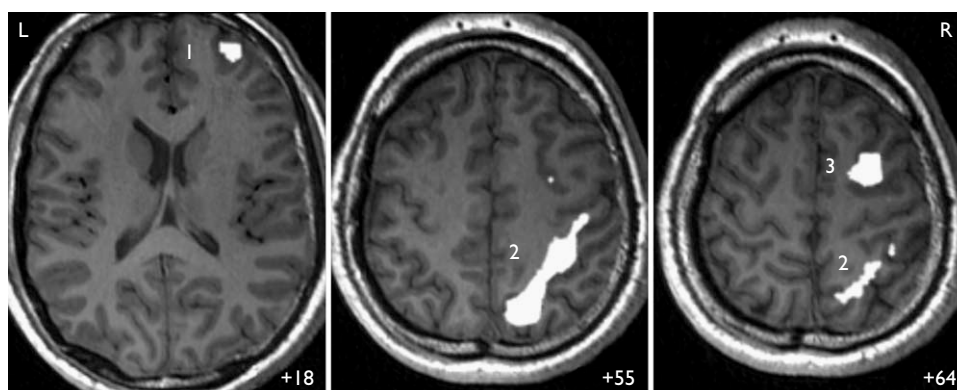


Fig. 2 Stronger haemodynamic responses on the right hemisphere obtained for the comparison between haemodynamic responses obtained while playing on a reversed keyboard and a regular piano. Brain areas that are more strongly activated while playing the reversed keyboard are shown ($P < 0.01$, corrected). 1: anterior part of the middle frontal gyrus, 2: superior parietal lobe and intraparietal sulcus, 3: dorsal premotor cortex.

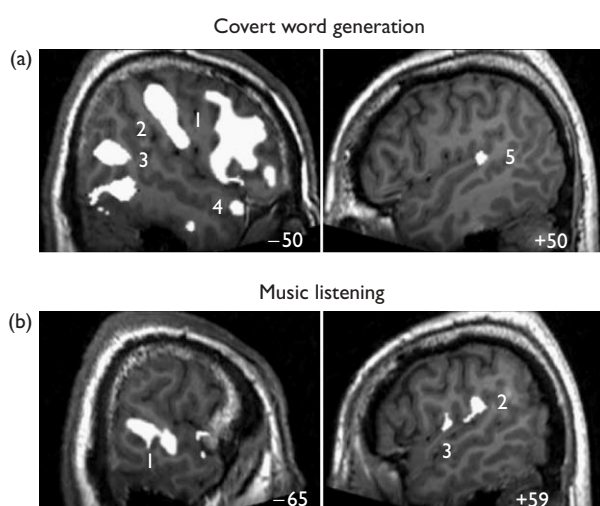


Fig. 3 (a) Stronger haemodynamic responses for the contrast comparing the flipped vs. unflipped images for the covert language generation task ($P < 0.01$). 1: left frontal lobe including Broca's area, 2: left-sided sensorimotor cortex and superior parietal lobe, 3: left-sided angular gyrus, 4: left-sided temporal pole, 5: planum temporale on the right hemisphere. (b) Haemodynamic responses for the contrast comparing the flipped vs. unflipped images for the music-listening task ($P < 0.01$). 1: Left-sided superior temporal sulcus, 2: right-sided SII slightly extending into the supramarginal gyrus, 3: right-sided subcentral gyrus.

Discussion

Our hypothesis [1] was that C.S. should rely on a right-sided network, including brain areas specialized for motor control, music perception, and audio-motor integration. This right-sided network might allow the processing of audio-motor information within adjacently located brain areas located in one hemisphere, thus reducing the amount of interhemispheric transfer. Indeed, it was found that C.S. predominantly uses a right-sided network for bimanual motor control (i.e. during piano playing) as well as for audio-motor integration. Motor control during piano playing relied strongly on a right-sided network that included parietal and frontal areas (M1, vPMC, dPMC, IPS, SPL, and the left-sided CB). This pattern of activation is typical for left handers as it has been shown in several brain imaging studies that right-sided motor areas take the lead during

bimanual movements in strongly left-handed participants [13,14].

In this context, it is most interesting that C.S. showed a strongly right-sided activation pattern within a parieto-frontal network including the SPL, IPS, and dPMC when playing the reversed keyboard as compared with the regular keyboard. Thus, his dominant right-sided parieto-frontal network takes the lead during the preferred (reversed) performance mode. As this condition is described by C.S. to be more comfortable and less demanding, it is not possible to attribute the activation in this right-sided network to greater difficulty or effort while playing the reversed keyboard. Although effort was inferred from C.S.'s statements rather than through objective measures, we take the results as an indication for a more proficient use of the right hemisphere areas when playing the reversed piano.

C.S. had left hemisphere dominance for language but right hemisphere dominance for the control of piano playing. During music perception, C.S. had a stronger left-sided activation in the STS and a right-sided activation dominance in SII. In this, he differs from both nonmusicians [15–17] and professional musicians [18] because left-sided activations in the STS have not been associated with music tasks in either of these groups (except when perception of irregular chords is studied [19]). In right-handers, left-sided lateralization of SII activation is related to audio-sensorimotor integration processes. Activations in this region have been linked to higher order auditory processing, such as the identification of intelligible speech or imagining to hear speech sounds [20–23]. The right-sided activation dominance in this area found for C.S. might indicate an unusual pattern of functional coupling between auditory processing of musical material and sensorimotor control processes. The only study reporting increased blood flow in the left STS (but also in the right STS) for music was a study of deaf participants suffering from musical hallucinations [24]. The reason why C.S. shows stronger activation in this area is difficult to explain but we suspect that C.S. uses an idiosyncratic strategy when processing musical stimuli. Perhaps music perception (controlled by the left STS) and music processing used for guiding motor control (controlled by the right supramarginal gyrus and SII) are dissociated in C.S. so as to implement a more efficient working auditory-motor integration process which helps in supporting the right-sided motor control network.

Conclusion

In this study, we examined brain functions in the exceptional pianist C.S. who has trained himself to perform standard hand movements on the regular keyboard as well as their mirror image on a reversed keyboard. C.S. demonstrated an unusual pattern of functional asymmetry with strong left-sided dominance for language processing, right-sided dominance for the control of piano playing, and – much to our surprise – strong handedness as determined by behavioural measures. With respect to music perception, there was left-sided dominance in a brain area associated with higher order auditory processing (the left STS) and a right-sided dominance in a brain area involved in audio-motor integration. This unusual functional asymmetry is thought to benefit the exceptional ability of C.S. and may also be responsible for enabling him with an efficient audio-motor control using a right-sided network. The next obvious step is to contrast the lateral dominance patterns in C.S. with those found in exceptional left-handed piano players who do not play on a reversed keyboard.

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