

BECOMING A PIANIST: AN FMRI STUDY OF MUSICAL LITERACY ACQUISITION

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ABSTRACT

Musically naïve participants were scanned before and after a period of 15 weeks during which they were taught to read music and play keyboard. When participants played melodies from musical notation after training, activation was seen in a cluster of voxels within bilateral superior parietal cortex. A subset of these voxels were activated in a second condition in which musical notation was present, but irrelevant for task performance. These activations suggest that music reading involves the automatic sensorimotor translation of a spatial code (written music) into a series of motor responses (keypresses).

1. BACKGROUND

When a child or adult starts to play the keyboard, a significant part of the initial musical training is devoted to learning to read musical notation. Musical pieces which, at first sight, appear meaningless in their written form, will eventually be translated into a recognisable melody. Just as written language becomes meaningful and even compelling to read, so does musical notation. A key question is how the artificial process of sight-reading for keyboard performance becomes a natural process. How do brain areas become recruited for such a skill? The present study was designed to look at music reading in a learning context. The advent of functional magnetic resonance imaging (fMRI) has permitted longitudinal studies of the neural correlates of skill acquisition. Music reading is a skill which lends itself to such an approach, since only a small fraction of the population are musically literate and many are motivated to learn. Thus a unique opportunity exists for investigating the acquisition of an artificial and culturally valued skill.

Surprisingly few studies have used fMRI to look at skill learning (Karni et al., 1995; Karni et al., 1998; Poldrack et al., 1998; Poldrack and Gabrieli, 2001; Toni and Passingham, 1999) and almost all such studies have measured changes in brain activation as a function of the improvement in task performance where task performance, pre-training, is already above baseline. The present study, by contrast, measures functional brain changes before and after the acquisition of music reading skill from scratch. Such an approach presents unique experimental design issues. Studies which look at the neural correlates of improvement in an already existing skill can, and indeed must, use the same task,

pre- and post-training. Studies of novel skill acquisition, by definition, cannot do this; if the participant is required to provide a meaningful behavioural response before and after training, different tasks must be used. However, this makes interpretation of the imaging data particularly challenging. How, for instance, is it possible to disentangle a post-training/pre-training activation change which is related to task differences from a post-training/pre-training activation change which is related to an effect of learning? The present study aims to solve this conundrum by using two different tasks, an explicit music reading task and an implicit music reading task. The explicit music reading task, by definition, could not be given in an identical format, before and after training, since music reading was only possible after training, the implicit music reading task was identical, before and after training. Activation changes, post-learning, in this condition, cannot be unequivocally interpreted to be learning-related. In contrast, the implicit music reading task, was identical before and after training thus changes in activation can be interpreted as learning-related. If changes in activation for explicit music reading overlap with those seen in implicit music reading, they can also be inferred to be learning-related.

2. AIMS

The purpose of this study was to uncover which brain areas became recruited for music reading, both explicit and implicit, after a period of musical training.

3. METHOD

3.1. Training

Subjects attended a 90 minute music lesson once a week for 15 weeks. Practical keyboard skills and music theory were taught to Grade 1 (Associated Board, U.K.) level. After the training was complete, an external music teacher examined participants individually on keyboard skills (scales, a prepared piece from the Grade 1 syllabus and sight reading). Participants also sat a Grade 1 music Theory examination. A more cognitive measure of music reading ability was obtained using a musical Stroop task (Stewart et al., in press) in which music reading ability skill was measured indirectly by ascertaining the degree to which musical notation for pitch interferes with the required number to finger mapping.

3.2. Tasks Used During Scanning

3.2.1. Explicit Music Reading

See figure 1. This task required subjects to produce a series of keypresses in response to the appearance of a sequence of five musical notes. Pre-training, subjects used the superimposed numbers to play the sequences; post-training, they relied solely on the musical notation.

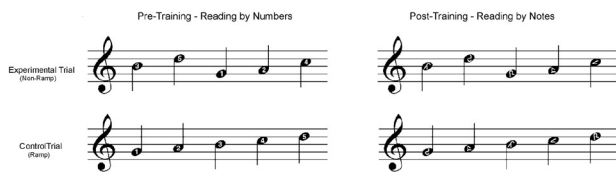


Figure 1: Explicit Music Reading Task. Pre-training, the participants performed a number to finger mapping; post-training, they performed a note to finger mapping.

3.2.2. Implicit Music Reading

See figure 2. The task was identical before and after training. Subjects indicated whether the target was ascending or descending, using an arbitrary up/down mapping to the index and middle fingers.

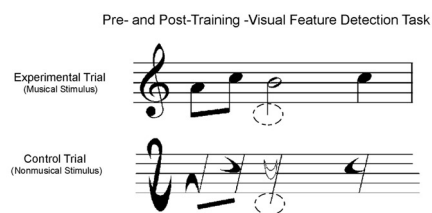


Figure 2: Implicit Music Reading Task. The task was to identify the presence of a visual target, both pre-training and post-training.

3.3. Statistical Analysis

The explicit and implicit music reading tasks were analyzed separately, for the pre-training and post-training sessions. Data were analyzed using Statistical Parametric Mapping. Population inferences were made through a two-stage procedure. In the first stage, the data were analyzed participant-by-participant. The volumes acquired during each condition were treated as a time-series. The BOLD response to the stimulus onset for the experimental and control blocks were modelled as a boxcar function convolved with a haemodynamic response function (HRF). These functions, plus six rigid body deformation parameters, derived from the realignment stage and a constant term, were used as participant-specific covariates in a general linear model (GLM). Parameter estimates for each covariate were calculated from the least mean squares fit of the model to the

time-series at each voxel. The following terms have been defined so that they can be used as a short hand for the contrasts which we refer to throughout the remainder of the paper:

Trial Effect: a voxel shows a Trial Effect if there is statistically greater activity for experimental trials versus control trials.

Training Effect: a voxel shows a Training Effect if there is a statistically greater Trial Effect, post-training versus pre-training (i.e. an interaction between control/experimental trials and pre/post-training).

Planned contrasts across covariates were performed for each participant, generating a contrast image of the Trial Effect for each participant. These contrast images were used in the second, random-effects analysis. Contrast images for each participant were compared between scanning sessions (post-training - pre-training) using a paired t-test and treating participants as a random variable in order to derive statistical parametric maps (SPM's) of the Z statistic (thresholded at $p < 0.001$ uncorrected), relating to the Training Effect. Inclusive masking of SPMs revealed commonalities in the Trial Effect across pre-training and post-training sessions. Each SPM was thresholded at $p < .01$ to give a combined $p < .0001$. To look at commonalities in the Training Effect across the two tasks, contrast images relating to the Training Effect were produced for each participant. Inclusive masking of the SPMs revealed commonalities in the Training Effect across the two tasks, using a combined threshold of $p < .0001$.

4. RESULTS

4.1. Behavioural Data During Scanning

Reaction times and errors for each participant were calculated, pre- and post-training, for both music reading tasks. For the explicit music reading task, the cumulative response time (total time taken to make all five keypresses across a single trial) was calculated for trials in which all keypresses were correct. Participants were faster to produce a sequence of keypresses on control (ramp) trials compared to experimental (non-ramp) trials, both for reading by numbers (pre-training) and reading by notes (post-training) (both $p < .01$). Analysis of variance (ANOVA) revealed that this control/experimental difference in reaction time was significantly greater for reading by notes ($p < .01$), owing to an increase in reaction time for experimental trials based on notation. Participants were also more accurate in their production of a sequence of keypresses on control trials compared to experimental trials, both for reading by numbers ($p < .001$) and reading by notation ($p < .01$) but there was no interaction.

For the implicit music reading task, simple reaction time and error percentages were calculated for each trial type. There was no difference in reaction time or percentage error between experimental trials and control trials. Similarly, there was no effect of training on either reaction time or error percentage and no interaction. As might be expected, given the relative simplicity of the feature detection task, the acquisition of music reading skill had no measurable behavioural effect on performance.

4.2. fMRI Data

4.2.1. Learning to Play a Melody: Explicit Music Reading

Inclusive masking revealed a common Trial Effect, pre-training and post-training, in bilateral cerebellum, parietal cortex, caudate nucleus and middle frontal gyrus. A Training Effect (greater Trial Effect, post-training minus pre-training) was seen in superior parietal cortex, including the intraparietal sulci, bilaterally, as well as an area in left fusiform gyrus (figure 3). An examination of the mean percentage signal change for the maxima of these regions revealed a Trial Effect which, though significant pre-training, was even greater post-training.

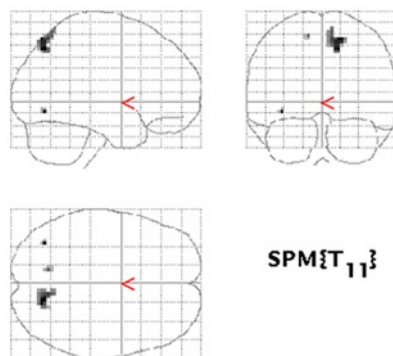


Figure 3: Glass brain statistical parametric map (SPM) relating to the Training Effect (reading by notes, post-training, minus reading by numbers, pre-training).

4.2.2. Exposure to Musical Notation: Implicit Music Reading

Inclusive masking revealed no common Trial Effect, pre-training and post-training. A Training Effect was seen in left supramarginal gyrus, left inferior frontal sulcus and right frontal pole. An examination of the mean percentage signal change for the maxima of these regions (figure 4) revealed that all voxels exhibited the same relative pattern: a Trial Effect that was restricted to the post-training session.

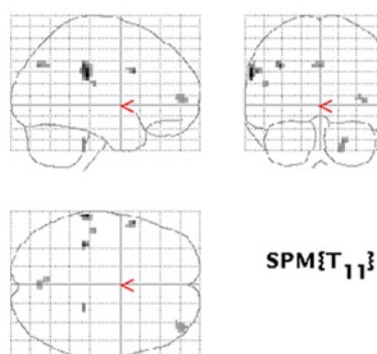


Figure 4: Glass brain statistical parametric map (SPM) relating to the Training Effect (target detection within notes post-training, minus target within notes pre-training).

4.3.3. Activations Common to Both Explicit and Implicit Music Reading

Inclusive masking revealed common Training Effects across the explicit and implicit music reading tasks. Only two cerebellar regions in the left hemisphere survived the extent threshold of 5 voxels, however, the striking bilaterality of some of the subthreshold activations caused us to relax the extent threshold to the single voxel level, revealing a common Training Effect in bilateral superior parietal cortex, medial superior parietal cortex and left postcentral gyrus. The medial superior parietal region also survived $p < 0.001$ (uncorrected) in both the implicit and explicit tasks, separately.

5. CONCLUSIONS

5.1. Learning to Play a Melody

When our learners used their newly acquired skill of sight-reading, they showed activation in bilateral superior parietal cortex. Why is this part of cortex recruited in our aspiring pianists? In the introduction, we argue that music reading is essentially visuospatial. The dorsal visual processing stream, within which superior parietal cortex resides, is known to be important for coding of spatial, as opposed to the featural aspects of visual stimuli (the “what”/“where” distinction”) (Damasio and Benton, 1979; Gross, 1973; Maunsell and Newsome, 1989; Mishkin and Ungerleider, 1982; Pohl, 1973). A distinction has also been made between the visual perception of objects versus the control of action toward those objects (the “what”/“how” dichotomy) (Goodale and Milner, 1992)). Whether the distinction made is one of “what versus where or “what versus how”, sight-reading for keyboard performance falls within the class of behaviours that the dorsal stream is known to subservise. First, the information relevant for performance is contained in the position of the note on the staff (“where”); second, musical performance relies on the use of this positional information to guide selection of the appropriate keypress (“how”).

An activation similar to one found in the present study, in right superior parietal cortex, was also seen in a PET study of musical sight-reading (Sergent et al., 1992). Performance of the main task (sight reading, playing and listening) by professional pianists activated right superior parietal cortex, but this region was not activated in the reading alone or listening alone condition. The replication of this finding in our study, using fMRI as opposed to PET and novice pianists as opposed to professionals, suggests that the common activation across the two studies is likely to reflect the specifically visuospatial translational element of music reading, and, furthermore, that such activation may be independent of skill-level.

5.2. Exposure to Musical Notation

Since the implicit music reading task did not involve, or require sight-reading, differences in activation, related to the presence of task-irrelevant musical notation, after-training, must reflect an effect of learning at an implicit level. Such differences were obtained in the left supramarginal gyrus, left inferior frontal sulcus and right frontal pole. Unlike the explicit music reading

task, in which the Training Effect was characterized by a relative increase in the Trial Effect across the two scanning sessions, the Training Effect observed in the implicit music reading task was characterized by a Trial Effect that was present only after training. The training effect was independent of any behavioural change in the performance of the feature detection task.

An explanation of the activation change in supramarginal gyrus rests on the following argument. During the course of training, participants learned to make specific keypresses in response to particular musical notes. We suggest that the visual appearance of musical notes, post-training, may be automatically and unconsciously interpreted as an instruction to act. For the purposes of performing the feature detection task (up/down discrimination of a visual target), preparation of the learned musical response would be inappropriate and would be overridden by the preparation and execution of the task-relevant motor response. While the preparation and execution of the task-relevant response was common across both the pre- and the post-training sessions, the implicit preparation of a music-specific motor response would have only occurred post-training.

The supramarginal gyrus, especially on the left, is thought to be important in processes related to "motor intention". While a network of areas including the posterior parietal cortex of the right hemisphere have been demonstrated to subserve visual attentional processes (Corbetta, 1993; Corbetta et al., 1993; Corbetta, 1998), imaging and TMS studies have highlighted the importance of more anterior parietal cortex of the left hemisphere for motor orienting (Godschalk and Lemon, 1989; Rushworth et al., 2001a; Rushworth et al., 2001b; Rushworth et al., 2001c), a hypothesis that is supported by observations that patients with damage to left inferior parietal cortex have difficulty in performing a number of different movements one after another (Harrington and Haaland, 1992; Kimura, 1993; Rushworth et al., 1997), as well as having problems in the representation and awareness of movements (Sirigu et al., 1999).

5.3. Commonalities in the Training Effect

In the introduction, we argued that a common Training Effect (a post-training/pre-training activation change in the same brain region across both explicit and implicit tasks) could be confidently interpreted to be specifically learning-related. In the present study, specific learning effects were seen in several areas, including bilateral superior parietal cortices. The presence of a Training Effect in superior parietal cortex is of particular interest. We have suggested that the Training Effect shown by this area in the explicit task reflects a visuospatial sensorimotor translation between the notes on the staff and the appropriate keypresses. The fact that this region also showed a Training Effect in the implicit task leads us to conclude that the mere presence of musical notation may result in a similar translation even when such translation does not result in motor execution.

In summary, the activation in superior parietal cortex seen in the explicit music reading task, after training, supports the hypothesis that music reading involves a sensorimotor translation in which the spatial characteristics of musical notation are used to guide selection of the appropriate keypress. The activation of left supramarginal gyrus in the implicit music reading task,

in conjunction with the Stroop interference seen after training, suggests that after fifteen weeks, musical notation is automatically processed. The common activation of superior parietal cortex across the two tasks reflects an effect which is specific to the acquisition of music reading skill and is independent of the particular tasks used. The study serves to illustrate the power that culture has in shaping brain function and illustrates one approach by which neuroimaging can be used to capture and delineate such changes.

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