An investigation of neurological processes in music using quantitative electroencephalography and topographic brain mapping

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It would seem reasonable to expect that musical stimuli activate unique neurological processes, however such processes have yet to be demonstrated conclusively. Whether it is possible, using current technology, to measure and interpret neurological processes in response to musical tasks and conditions is a tantalising question. While there is an established literature on brain function and music, the findings have not yet provided a substantial basis upon which to extend the understanding of learning processes in music performance and music comprehension. One of the reasons for engaging in this research is to determine whether objective measures of brain electrical activity can provide new data on which to base a review of current principles and practice in music education.

Some music educators draw upon research into brain processing of musical activities and stimuli with much attention given to information pertaining to the dominance of the right hemisphere associated with musical tasks. Kohut suggests that the two hemispheres represent two separate modes of consciousness and that music educators should focus their training on the right brain.[1] Blakeslee argues that results from dichotic listening tests indicate that music education courses change music listening from a right-brain activity to a left-brain activity.[2] Such suggestions about brain activity in response to musical stimuli are based on an extensive and diverse literature. However, recent developments in neuro-imaging technologies which examine brain activation using a variety of objective measures are providing new data which call for a re-evaluation of our understanding of brain function.

The use of objective measures to inform teaching and learning processes in music presents particular problems. Aesthetic endeavours, crowded as they are with variables of an apparently highly subjective nature, are elusive when it comes to quantification because technology is yet to provide the means by which the intricate processes in aesthetic thinking can be definitively traced and interpreted.

Quantitative electroencephalography (QEEG) is an objective method of recording brain electrical activity in subjects. Electrical impulses are taken from the skull of subjects via electrodes placed according to standardised locations, amplified and then stored as data. The data is then analysed and displayed both statistically and as topographic brain maps.

QEEG technology was pioneered by Hans Berger who, after thirty years of research, published results in 1929.[3] Berger demonstrated that brain electrical activity recorded from the skull was a reliable representation of mental events, not mere 'noise' as argued by his contemporaries. Developments in recent decades, particularly the application of computer technologies, have resulted in QEEG being eminently suitable to this research undertaking as it is non-invasive and relatively inexpensive.It has been used extensively in the investigation of dysfunctional brain conditions, including those associated with epilepsy and brain trauma. In recent years, researchers have been applying QEEG to the diagnosis of dementia and Altzheimers disease.[4]

EEG has been used to investigate neurological processing of music by a number of researchers. Findings have been various and a strong body of information is yet to be established on which disciplines such as music education can draw for the development of new procedures. Methods of data collection and analysis vary substantially so normative data is not available to researchers in musical processing. Much of the research involving musical stimuli has been in the context of dysfunctional states, and the understanding of musical processing has been peripheral rather than central to the research paradigm.

Different EEG responses to different musical conditions have been shown by a number of studies. Likewise, differences between the responses of groups of trained musicians and groups of non-musicians have been suggested, not only in response to musical stimuli, but also at rest.[5] Breitling produced results with non-musician subjects in which monotone and musical scale stimuli evoked a predominant left hemisphere activation and melody conditions resulted in more widespread right hemisphere activation.[6] This activation does not indicate a strong right hemisphere dominance, rather, it suggests an apparently more general distribution in contrast to the left hemispheric predominance in the monotone and scale conditions. Of the three conditions (monotone, scale and melody), only the melody condition can be regarded as a musical construct resulting from a compositional process. Katayama has demonstrated augmented frontal midline theta (Fm0)[7] in subjects engaged in playing works from the piano repertoire and in the same subjects while listening to the same works performed by other pianists.[8] Fm0 is associated with concentration on mental tasks, and appears more frequently under those conditions than under non-task conditions.

It is clear that research and analysis methods vary and this limits the extent to which findings from different studies can be compared. However, there is a substantial amount of information which serves to guide future projects.

The aims of our research are first to determine whether QEEG provides an objective and reliable means of recording and analysing brain electrical activity under the conditions defined by the proposed paradigm. Second, the research aims to determine whether different brain electrical responses to musical conditions occur with trained musicians in comparison to non-musicians. Third, the research aims to determine whether changes occur in brain electrical response when comparing subjects in a resting state with subjects listening to music, and when comparing subjects listening to different musical conditions. Finally, the research aims to determine whether lateralisation of brain electrical activity (hemisphere dominance) can be demonstrated using QEEG.

In the longer term, our research aims to use this methodology to improve theory and practice in music education.

Method

Subjects:

Six musicians (3 male, 3 female, mean age 29.3 ± 11.2 years) were recruited from the Music Division, Institute of Education, The University of Melbourne. All 6 had studied music at tertiary level for at least two years and were proficient players of at least one musical instrument.

Six non-musicians (3 male, 3 female, mean age 30.2 ± 8.9 years) were recruited from The National Ageing Research Institute (NARI). None had any formal musical training or could play a musical instrument.

All subjects were right handed and were free of any brain damage.

Materials and procedure:

All subjects were tested initially and then retested after a mean interval of 3.8 ± 1.1 months.

Testing was done at NARI, using a 23 channel Grass EEG recording system linked to an IBM compatible PC.

An audio-cassette which contained all instructions and musical stimuli conditions was played to the subjects.

There were four musical conditions of varied complexity. Each musical condition was separated by a baseline condition in which the subjects were asked to relax.

The musical stimuli conditions were:

1. A repeated note
2. A simple melody
3. The mental reconstruction of the melody
4. A complex melody—from the traditional repertoire of the Japanese shakuhachi.

All conditions lasted for one and a half minutes during which one minute of EEG data was recorded. The sequence was repeated once.

In the retest, baseline conditions were added at the start and finish of the test procedure.

QEEG analysis and topographic brain mapping:

QEEG data was reviewed by visual inspection to eliminate artefact caused by muscular activity, particularly that associated with eye movement. Such muscular activity generates electrical signals which dominate brain electrical signals in the recording process and are therefore spurious.

To facilitate the visual review, the data is displayed on screen in sections of 4 seconds in duration. These sections of data are referred to as epochs. At least ten non artefact-contaminated 4-second epochs were selected from each 60-second condition and analysed by Fast Fourier Transform (FFT). FFT is a mathematical procedure which divides the EEG spectral waveform into its component sine waves with parameters of frequency, amplitude and phase.

Four frequency bandwidths were used for brain mapping and statistical analysis:

Delta-2	(2.66 - 4 hz)	Theta	(4.33 - 7.66 hz)
Alpha	(8 - 12.66 hz)	Beta	(13 - 35 hz)

Each bandwidth had three measures:

Absolute power	total activity in a bandwidth (picowatts)
Relative power	activity in a bandwidth as a percentage of activity in all bandwidths
Mean frequency	average frequency of activity within a bandwidth

Musician and non-musician group brain maps were constructed for the measures of absolute and relative power using FERPS-2 software. The brain maps represented average activity across the repetitions of each condition and were constructed for both the test and the re-test.

Statistical analysis:

Data from 16 of the 19 scalp recording sites was combined and reduced into four lobes: frontal, parietal, occipital and temporal.

The data was also totalled as the sum of all lobes.

Reliability was calculated using Pearson's *r* correlation coefficients which show the extent to which the values on the first test relate to the values on the second test. Pearson's *r* correlation was used to calculate:

1. Test/retest reliability - the association between baseline conditions in the test and retest.
2. Within test reliability - the association between the first and last baseline conditions in the retest.
3. Within test reliability - the association between the responses to the single note conditions on first hearing and the repetition of the condition.

Results

1. Reliability

A high degree of test reliability was demonstrated in baseline and musical conditions.

The value of the correlation coefficient ranges from 0 (showing no relationship) to 1.0 (showing a perfect relationship).

In the test/retest analysis (Figure. I), overall reliability was good (r = .85). The most reliable bandwidths were Theta (.85) and Alpha (.86), and the most reliable regions were parietal (.88) and temporal (.91).

Within test reliability (r = .92) was greater than test-retest reliability (r = .85), a result which is to be expected as the subjects are not exposed to external influences during the course of the data collection session.

Some measures showed poor reliability (frontal delta and beta, occipital delta and beta) and this is attributed to regional and/or bandwidth specific artefact, factors well established in QEEG research.

	DELTA	THETA	ALPHA	BETA	TOTAL
FRONTAL	.25	.83**	.91**	.38	.77**
PARIETAL	.86**	.96**	.84**	.95**	.88**
TEMPORAL	.94**	.97**	.88**	.94**	.91**
OCCIPITAL	.22	.11	.10	.39	.32
TOTAL	.67*	.85**	.86**	.38	.85**

* p<.01 ** p<.001

Figure 1: Test-Retest Reliability (baseline condition) Combined Groups (N = 12)

The within-test overall reliability (Figure 2) was good (r = .92) with Theta (.85), Alpha (.88) and Beta (.90) bandwidths and all brain regions being reliable.

	DELTA	THETA	ALPHA	BETA	TOTAL
FRONTAL	.35	.78**	.93**	.86**	.74**
PARIETAL	.74**	.88**	.85**	.85**	.92**
TEMPORAL	.65*	.85**	.87**	.91**	.93**
OCCIPITAL	.81**	.89**	.75**	.92**	.85**
TOTAL	.44	.85**	.88**	.90**	.92**

* p<.01 ** p<.001

Figure 2: First baseline - Last baseline (retest) Combined Groups (N = 12)

	DELTA	THETA	ALPHA	BETA	TOTAL
FRONTAL	.82**	.95**	.87**	.86**	.89**
PARIETAL	.93**	.98**	.93**	.92**	.95**
TEMPORAL	.91**	.98**	.91**	.85**	.93**
OCCIPITAL	.14	.45	.16	.75**	.42
TOTAL	.86**	.98**	.91**	.81**	.94**

** p<.001

Figure 3: Single Note Condition: correlation of first and second times (retest)
Combined Groups (N = 12)

Reliability calculated on test-retest and within test data was demonstrated using baseline conditions. The results in a single repeated note condition (Figure 3) were even better (r=.94) than those for baseline conditions. Only the occipital region showed poor correlation. The correlation was calculated on the first and second playing of the condition in Test 2, that is, a within-test correlation. It is reasonable to expect such a result, given that in the baseline condition the attention of subjects is not focused on a particular phenomenon, whereas during the music conditions attention is focused quite precisely.

2. Musician/non-musician differences

The topographic brain maps from test 2 (Figure 4 - see coloured insert), constructed on the measure Relative Alpha, show differences between the responses of the grouped musicians and the grouped non-musicians. From this it can be seen that the musician responses in the measure Relative Alpha show higher levels of brain electric activity than the non-musician responses. This applies in the baseline conditions as well as in the musical stimulus conditions.

Note: baseline conditions A and C are the first and last conditions of the test. Baseline B is the baseline condition between the melody condition and the melody reconstruction condition.

Consistent with expectations of alpha rhythm activity, the distribution shows the greatest activity for both groups in the occipital-parietal regions, somewhat less activity in the temporal regions and the least activity in the frontal regions. The measures Absolute Theta and Absolute Beta showed similar differences in the levels of activity between the two groups.

3. Changes in response to different stimuli

The topographic brain maps from test 2 (Figure 5 - see coloured insert), constructed on the measure Absolute Theta (musicians), show changes in activity in response to different stimuli and changes between the baseline conditions and musical conditions.

4. Hemisphere dominance in response to musical tasks

The topographic maps (Figures 4 & 5 - see coloured insert) do not support the hypothesis that music processing is a localised or lateralised function. The distribution of activity is more notable for its symmetry than for any clear demonstration of dominance in either left or right cerebral hemispheres. The maps shown here are typical in this regard.

Discussion

Although known for more than fifty years, the functional significance of the waveforms of the EEG are not well understood. Their generation is partly in response to neuronal activity in the cortex underlying the electrodes and partly from areas deep in the brain substance which influence patterns of activity diffusely over large areas of the cortex.

Activity in the Alpha bandwidth has been associated largely with relaxed states, a decrease in activity being evident when subjects are engaged in tasks. The Beta bandwidth is less easily associated with particular conditions and is currently regarded as multifactorial (and therefore more complex) in function. The Theta bandwidth is associated with higher cognitive functions and with emotional activity. Activity in the Delta range has been largely, to date, associated with stages of sleep and is also significant in the diagnosis of some dysfunctional states including those caused by strokes.

A surprising result shown by the production of topographic brain maps was the difference in brain electrical activation between musicians and non-musicians, even in the baseline condition (Figure 4). These differences were also evident in the measures Absolute Theta, Absolute Beta and Relative Alpha.

This result appeared to be improbable given that, while it could be anticipated in response to musical conditions, there is no apparent reason for it to pertain under conditions of rest. Screening and subsequent post-screening eliminated the possibility of heightened activity in some bandwidths resulting from one or more subjects being affected by medication.[9]

In the measures of Absolute and Relative Delta, Relative Theta, Absolute Alpha and Relative Beta no such differences were evident. This factor gives rise to the speculation that musical training may activate neuronal functions specific to certain bandwidths. The fact that the differences were not generalised and were reproduced in the second exposure to the paradigm also supports the interpretation that they are not the result of artefact or some other procedural aberration.

In an attempt to find an explanation for these differences, individual maps for all subjects were produced to establish whether one or more subjects were skewing the results, perhaps with undetected artefact or some other individual-specific characteristic. While individual differences were, as expected, quite evident, this process failed to produce a reasonable case to suggest that the differences were spurious. The relatively small number of subjects and the unexpected result will necessitate further investigation.

In support of the hypothesis that brain electrical activation would change in response to different stimuli conditions, the measures Absolute Theta and Relative Beta, shown as topographic maps, were most revealing.

In the Absolute Theta measure for musicians, the response to the shakuhachi condition compared with that of the first and second baseline conditions shows a substantial increase in frontal-midline activity (Figure 5). This represents activity in those areas of the brain associated with higher cognitive and emotional functions. These maps from the second test demonstrate a substantial replication of the response demonstrated in the first test. Notwithstanding the differences in power between musicians and non-musicians, the same pattern of response to these two conditions was evident in the non-musicians.

Other studies using QEEG have not given unqualified support to the idea of hemisphere dominance. They suggest that the process is more complex and that musical tasks and stimuli engage the brain more broadly, in a manner that suggests that higher functions associated with music are dependent upon greater degrees of functional cooperation than some other tasks. Petsche suggests that attempts to demonstrate lateralisation are not given support by any of his experiments and that musical processing can be better investigated through focusing attention on both intrahemispheric and interhemispheric functional co-operation.[10] The topographic brain maps produced in this study would seem to support Petsche's position in this regard.

Scientific research into the field of aesthetic processes attracts criticism from a range of perspectives. As acknowledged earlier, aesthetic experience in the arts is complex and infinitely variable because of the highly subjective interaction between the art work and the audience. Music evokes responses that engage the listener on a level which goes beyond reasoning processes and activates refined sensibilities and perceptions. Little is understood of responses at this level, at least in scientific terms, and it is argued by some that science does not yet provide models of investigation with the potential to comprehend such subtle activity. Philosophical and psychological paradigms are seen to be more appropriate to research in aesthetic knowledge.

The processes of scientific exploration are seen by many as so intrusive that they interfere with subject responses to the extent that what is being observed is a process far removed from that which occurs under normal conditions. Furthermore, it is argued by some that observation of human behaviour modifies the behaviour of the subjects being observed.

On the basis of these arguments, scientific approaches tend to be regarded as inappropriate as a means of understanding musical engagement. However, the capacity to respond to music appears not to be dependent upon optimum conditions, and the suggestion that aesthetic experience or insight is undermined by unfamiliar surroundings is debatable.

QEEG has been shown to provide data which reliably reflects mental activity, that is, processes related to thinking on a range of levels and across a range of tasks. It has yet to be established whether it has the potential to identify high-order activity associated with creative or intuitive thinking.

It is the aim of our on-going research to establish whether or not QEEG can provide new information which may serve as a means of gaining better understanding of processes involved in the performance and apprehension of music. Data from this study showing different neurological activity in trained musicians when compared with non-musicians suggests that the investigation to date can at least provide a basis for further study. It is not unreasonable, however, to infer more far-reaching implications, including suggestions that music activates unique responses. If this can be established, then further research may find correlations with other high-order mental activities. If such information can be established, it would seem that music and QEEG could contribute to the broader debate concerning the nature of consciousness.

Data indicating different brain electrical responses to different musical conditions as well as distinguishing between resting and musical conditions encourages the belief that QEEG studies may provide the means to further elucidate mental functions in music.

Notes

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6 D. Breitling, W. Gunther, and P. Rondot, 'Auditory perception of music measured by brain electrical activity mapping', *Neuropsychologia* 25.5 (1987), p.765.

7 Fm0 is brain electrical activity in the frontal and midline regions of the skull.

8 S. Katayama et al., 'EEG changes during piano playing and related mental tasks', *Acta Medica Okayama* 46.1 (1992), p.23.

9 Barbiturates, tranquilizers and some stimulants are known to stimulate fast wave activity.

10 Petsche, Lindner and Rappelsberger, 'The EEG', p.133.