How Many Music Centers Are in the Brain?

ECKART O. ALTENMÜLLER

Institut für Musikphysiologie und Musiker-Medizin der Hochschule für Musik und Theater Hannover, 30175 Hannover, Germany

ABSTRACT: When reviewing the literature on brain substrates of music processing, a puzzling variety of findings can be stated. The traditional view of a left–right dichotomy of brain organization—assuming that in contrast to language, music is primarily processed in the right hemisphere—was challenged 20 years ago, when the influence of music education on brain lateralization was demonstrated. Modern concepts emphasize the modular organization of music cognition. According to this viewpoint, different aspects of music are processed in different, although partly overlapping neuronal networks of both hemispheres. However, even when isolating a single "module," such as, for example, the perception of contours, the interindividual variance of brain substrates is enormous. To clarify the factors contributing to this variability, we conducted a longitudinal experiment comparing the effects of procedural versus explicit music teaching on brain networks. We demonstrated that cortical activation during music processing reflects the auditory "learning biography," the personal experiences accumulated over time. Listening to music, learning to play an instrument, formal instruction, and professional training result in multiple, in many instances multisensory, representations of music, which seem to be partly interchangeable and rapidly adaptive. In summary, as soon as we consider "real music" apart from laboratory experiments, we have to expect individually formed and quickly adaptive brain substrates, including widely distributed neuronal networks in both hemispheres.

KEY WORDS: Music; Brain; Neuromusicology; Music centers

CHANGING CONCEPTS IN NEUROMUSICOLOGY

During the past two decades, the concepts of brain substrates underlying music processing have changed. Although never unequivocally supported by classical lesion studies,[1,2] traditional theories proposed a simple right-versus-left–hemisphere dichotomy, with music being processed in the right brain, language in the left. This simple viewpoint—still represented in many textbooks—could not be held any longer, when in 1974 Bever and Chiarello[3] were able to demonstrate the influence of professional training on hemispheric lateralization during music processing, nonmusicians exhibiting right, professionals left hemispheric preponderance. In the following years, results of several brain imaging studies supported this idea. In our

Address for correspondence: Prof. Dr. med. Eckart Altenmüller, MD, MA, Institut für Musikphysiologie und Musiker-Medizin der Hochschule für Musik und Theater Hannover, Plathnerstr. 35, 30175 Hannover, Germany. Voice: +49 (0) 511 3100 552; fax: +49 (0) 511 3100 557.
altenmueller@hmt-hannover.de

laboratory, for example, brain activation patterns were investigated during demanding harmonic and melodic discrimination tasks in a large group of nonmusicians, amateurs, and professional musicians. Professional musicians processed these tasks primarily in the left frontotemporal lobes, whereas amateurs as well as nonmusicians bilaterally activated the frontal lobes and the right temporal lobe.[4] It was assumed that professional musicians had access to different cognitive strategies ascompared to amateurs and nonmusicians. The left hemisphere activation in professionals was attributed to covert inner speech, since trained musicians—as a consequence of hundreds of lessons of ear-training and solfège—reported that they named the intervals and harmonies more or less automatically during processing of the task. In other words and speaking more generally, access to "auxiliary" representations of music acquired during training was discussed as accounting in part for the variability in brain activation patterns during music listening. Consequently, brain substrates of music processing were supposed to reflect the *way of listening and processing* rather than more-or-less fixed "music centers."

LISTENING TO MUSIC: CONCEPTS OF PERCEPTIVE MODULES AND HIERARCHIES

Before considering brain substrates of music processing, we have to clarify what we term "music" in this context. To our understanding, music is not a mere acoustic structure in time, or a stimulus created in a laboratory to fit a well-controlled experimental design, but a phenomenon of subjective human experience. Such an experience is not based on a uniform mental capacity but on a complex set of perceptive and cognitive operations represented in the central nervous system. These operations act interdependently in some parts, independently in others. They are integrated in time and linked to previous experiences with the aid of memory systems, thus enabling us to perceive, or better, to "feel" a sort of meaning while listening. Neuromusicology has been profoundly influenced by the idea of the *modularity of musical functions*.[5,6] According to Fodor,[5] a module corresponds to a specialized computational device that is devoted to the execution of some biologically important function. Applied to music, this concept has been put forward by the groups of Isabelle Peretz and Robert Zatorre, demonstrating convincingly the neuropsychological fractionation of different musical subfunctions in patients following brain lesions.[7–12] Taking together the results of these studies, we see that a complex pattern of distinct dissociation syndromes with isolated loss of cognitive subunits of music processing following a lesion emerges. For example, there is evidence that separate modules are processing time or pitch structures of complex musical stimuli. Generally speaking, time structures seem to be processed to a greater extent in the left temporal lobe, whereas pitch structures may be processed primarily in right temporal lobe networks. According to recent results, a predominance of the posterior portions of the right supratemporal lobe for processing of pitch structures may exist.[13]

Such a modular organization concerning processing of segregated physical (temporal or pitch) properties of musical structures could account for the involvement of separated, in part, overlapping, neuronal substrates. However, the situation becomes more complex when one considers that perception of music may occur on different hierarchical levels. With respect to temporal structures, for example, two levels of organization may be distinguished: meter and rhythm. Rhythm is defined as the serial relation of durations between different acoustical events in a train of sounds—that is, rhythm represents a serial durational pattern—whereas meter involves a temporal invariance in terms of the regular recurrence of pulses or beats marking off equal durational units, which can be organized as measures. Meter therefore represents a more complex acoustical "gestalt," since its perception and production require information on sound intensity (accented and unaccented events) and on periodicity of rhythmical events, the latter based on integration of information over longer time periods. Again, by means of neuropsychological fractionation of perceptive subfunctions in patients with brain lesions, it was possible to isolate neuronal networks processing meter and rhythm, demonstrating spared metric judgment but disrupted rhythmic discrimination.[7] It is beyond the scope of the present contribution to discuss the complex issue of local versus global gestalt processing in the auditory domain. Whereas in the visual modality, a dissociation of neuronal substrates concerned with local (left parietal) or global (right parietal) processing can clearly be demonstrated,[14] in the auditory modality such a clear-cut neuroanatomical distinction is still under debate. This may be related to the methodological problem of fractionating time structures in appropriate perceptive units allowing for a clear and interindividually consistent discrimination between local or global processing units. In fact, most experimental designs have not been very convincing in excluding variable time fractionation based on rapidly changing individual auditory habits.

"MUSIC CENTERS" IN THE BRAIN REFLECTING THE AUDITORY BIOGRAPHY

Although lesion studies conducted in larger groups of patients suffering from well-defined lesions support the idea of modularity and hierarchy and yield relatively clear results, it still remains a scientific challenge to further clarify the nature and function of these hypothesized modules and hierarchies and to delineate their degree of autonomy and specificity to music. Another, in our opinion, even more urgent problem arises when taking a look at the individual data. In a recently published study,[15] where procedures were performed on patients suffering from small unilateral ischemic lesions of the temporal, parietal, or frontal lobe, respectively, a surprising heterogeneity of the patterns of impairment with respect to modular subfunctions of auditory processing emerged. Whereas none of the patients had a deficit in basic auditory perception as, for example, in pitch discrimination, in some individuals right hemispheric lesions produced deficits in more complex temporal or pitch organization tasks, including in all instances, however, a combined deficit of local as well as global processing stages. Following left hemispheric stroke, surprisingly dissociated impairments of rhythm, meter, interval, or contour processing occurred, irrespective of whether the lesion was localized anterior or posterior to the central sulcus. In summary, it emerged that individually variable varieties of brain regions were necessary to ensure complex auditory functions, including parts of the posterior parietal lobes and the frontal lobes. It therefore becomes evident that not only the temporal lobes, as suggested in the comprehensive study of Liégois-Chauvel and coworkers,[13] but widespread and individually developed neuronal networks may underlie music processing. Without going into methodological details, it should be mentioned in this context that our patients were investigated relatively early—7 to 14 days following the ischemic stroke—before profound plastic changes compensating for impaired functions had reached their full extent. The discrepancies with earlier studies applying similar test batteries can in part be explained by the early timing of the investigation.

When considering individual factors as possible sources of variability in brain substrates of music processing, the next step is to further delineate the nature of these factors. In order to clarify whether the *way of learning music* plays an important role, we investigated the impact of music education on brain activation patterns in a group of 13- to 15-year-old students[16] in close cooperation with the music educator Wilfried Gruhn. The hypotheses were that (1) learning music and acquiring a new mental representation of music changes brain activation patterns while listening to music, and that (2) different ways of music learning may cause various mental representations that are reflected in different cortical activation patterns.

The task was to judge formal aspects of symmetrically structured phrases, so-called musical periods that consist of corresponding parts, "antecedent" and "consequent." Students had to distinguish between correct and incorrect (balanced or unbalanced) phrases. Whereas the antecedent phrase ends in a weak cadence on the dominant, suspending the expected tonic (half cadence), the consequent phrase leads to a stable ending on the tonic (perfect cadence). This different quality of cadences and the balance of the two melodic parts can easily be recognized merely by an internal feeling of musical balance and the tension of the cadence. For training, subjects were divided into three subgroups: (1) a "declarative" learner group that received traditional instructions about the antecedent and consequent and their tonal relationship with respect to the closing on a complete or incomplete cadence (the instructions included verbal explanations, visual aids, notations, verbal rules, and some musical examples that were played for the subjects, but never sung or performed); (2) a "procedural" learner group that participated in musical experiences for establishing genuine musical representations by singing and playing, improvising with corresponding rhythmic and tonal elements, or performing examples from the music literature; and (3) a control group of nonlearners who did not receive any instruction about or in music. Low-frequency DC shifts of the electroencephalogram (EEG) were measured prior to learning and after a five-week training period.

In FIGURE 1, the main results of the study are summarized. After learning, in the verbally trained "declarative" group, music processing produced an increased activation of the left frontotemporal brain regions, which probably reflects inner speech and analytical, step-by-step processing. By contrast, the musically trained "procedural" group showed increased activation of the right frontal and of bilateral parietooccipital lobes, which may be ascribed to a more global way of processing and to visuospatial associations. These results demonstrate for the first time directly that musical expertise influences auditory brain activation patterns and that changes in these activation patterns depend on the teaching strategies applied. In other words, *brain substrates of music processing reflect the auditory learning "biography," the personal experiences accumulated over time.* Listening to music, learning to play an instrument, formal instruction, and professional training result in multiple, in many instances multisensory, representations of music, which seem to be partly interchangeable and rapidly adaptive.

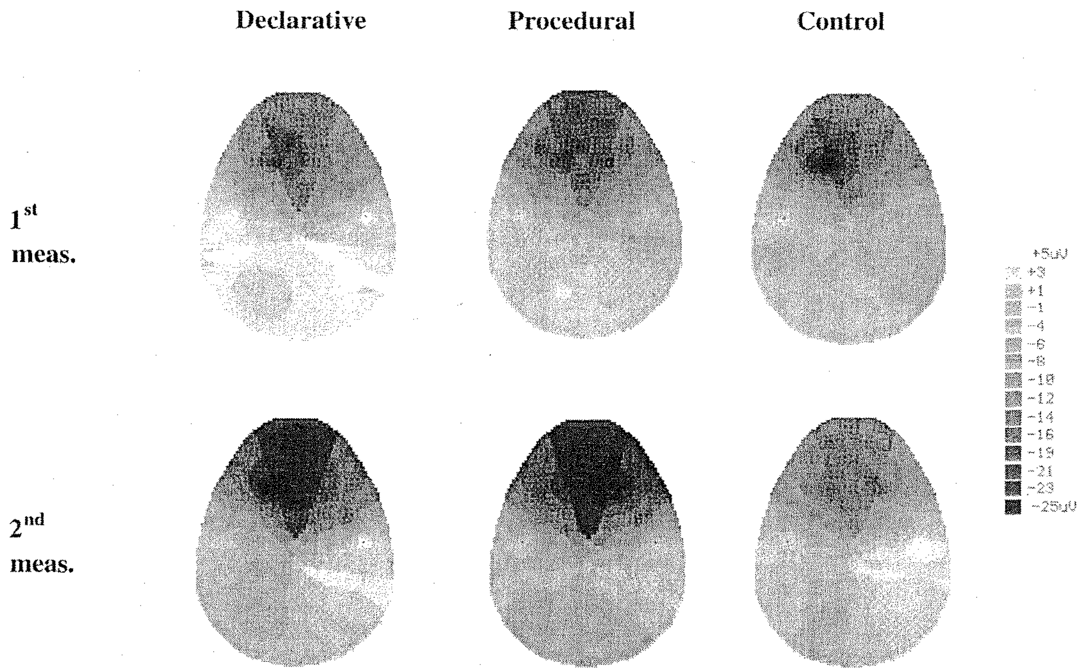

FIGURE 1. Brain maps demonstrating cortical activation patterns before (*upper row*) and after (*lower row*) learning in the "Declarative" learning group, in the "Procedural" learning group, and in the "Control" group. Group averages are displayed. Activation is *dark*, inactivation is *white* (see microvolt scale on the *right*). The brain diagrams are displayed as *top views*, frontal regions up, left hemisphere on the *left*, right hemisphere on the *right*. As can be recognized, declarative, mainly verbally mediated training leads to an increase in brain activity over the left frontal areas, whereas procedural, genuinely musical training produces an increase in activity over right frontal and bilateral parietooccipital regions. In controls, overall activity decreased slightly. (Modified from Altenmüller *et al.*[16])

A TENTATIVE MODEL ON BRAIN SUBSTRATES OF MUSIC PROCESSING

It is not a particularly fruitful approach to look at brain substrates of music processing from such a solipsistic viewpoint, stating that presently around six billion different auditory biographies may produce the same number of different "music centers" in the brain. Many aspects of auditory processing in general and music processing in particular are necessarily bound to fixed neuronal substrates common to all humans and mainly located in the superior temporal gyrus. As a sort of division of labor, hemispheric specialization may take place at a very early stage of auditory processing: the left superior temporal gyrus seems to be specialized for very rapid processes requiring high temporal resolution such as the identification of different phonemes, whereas the right superior temporal lobe is specialized for spectral analyses of sound.[17] Even at such an early stage, however, the brain substrates underlying auditory processing remain adaptive and subject to plastic changes as a consequence of conditioning or training.[18,19]

In FIGURE 2, a tentative model illustrating the interrelationship between the complexity of neuronal networks involved in music processing (y-axis) and the complexity of auditory processing (x-axis) is outlined. An additional dimension can be added on the z-axis, accounting for effects of acculturation. The complexity of neuronal networks increases with the complexity of processing demands. Training and practice add additional mental representations of music that rely on different brain substrates. Therefore, professionals presumably use larger and more complex neuronal networks during music processing than do nonprofessionals. The actual network engaged in a defined processing task is not fixed, but is subject to short- and long-term plastic changes, allowing at early processing stages for adaptations and compensations in case of damage to certain brain substrates. For example, a bilateral lesion of the primary auditory cortices with complete cortical deafness may be compensated for.[20] The vertical axis of the small cross "*P.*" (for *p*lasticity) on the left symbolizes such a reciprocal replacement of brain functions by other brain structures. The horizontal axis relates to the fact that listeners may add or reduce complexity of auditory processing by adapting their listening strategies. When entering more advanced processing stages, including many neuropsychological laboratory experiments, the learning biography, determining the multiplicity of different auditory representations may influence the actual network used for music processing. According to actual demands or as a reaction to brain lesions, processing strategies may lead to a simplified or to a more complex way to listen to the stimuli or music, respectively. Learning biography (*L.B.*) and auditory strategies are symbolized by the larger cross on the right in the diagram. For the sake of clarity, other variables influencing brain activation patterns during music processing have been omitted: guidance of attention, emotions, working memory, procedural and explicit short- and long-term memory systems, and effects of acculturation play an important role, rendering the brain substrates of music processing still more complex.

In summary, as soon as we consider "real music" apart from laboratory experiments, we have to expect individually formed and quickly adaptive brain substrates, including widely distributed neuronal networks in both hemispheres. In our laboratories, we are just beginning to face the enormous challenges linked to the clarification of rules determining this puzzling variety of findings, determining the

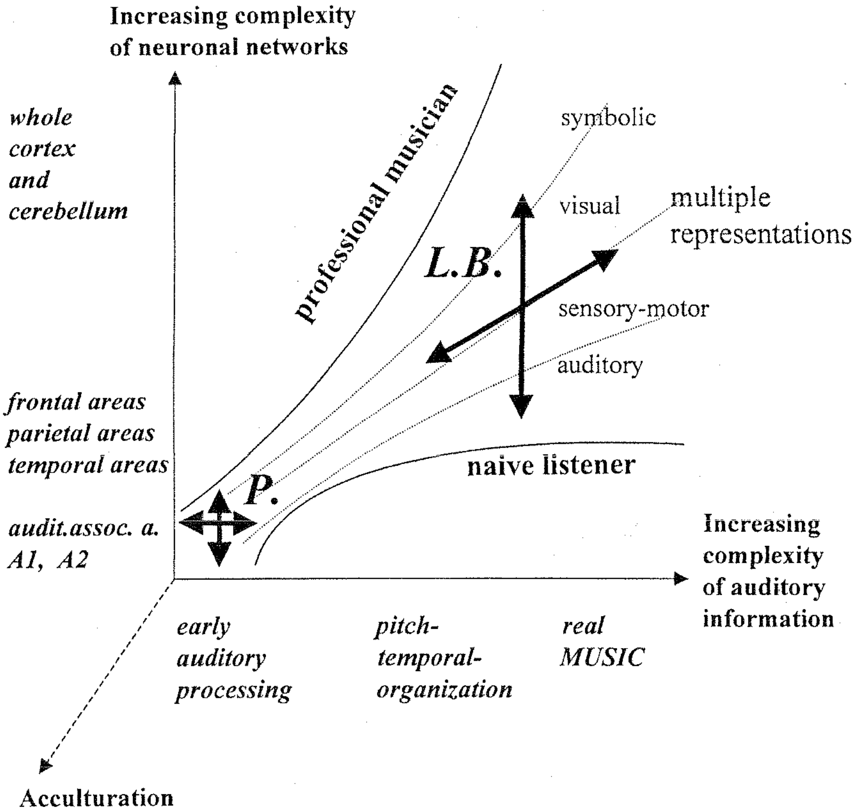

FIGURE 2. A simplified model demonstrating the interdependency between increasing complexity of auditory information processing (x-axis) and increasing complexity of neuronal networks (y-axis). *P.* = plasticity, *L.B.* = learning biography. *A1*, *A2*, and *audit. assoc. a* stand for primary auditory cortex, secondary auditory cortex, and auditory association cortices. For further explanation, see text.

complexity and transitoriness of neuronal interactions during music processing. Two hundred years ago, the German poet Johann Wolfgang von Goethe recognized and expressed this problem in a masterful way in the "scene in the laboratory:"

> *Homunculus*: That is the way that things are apt to take:
> The cosmos scarce will compass nature's kind
> But man's creations need to be confined.
>
> (Johann Wolfgang von Goethe, *Faust*, Part II, Act II. Scene in the Laboratory. Translated by Philip Wayne.)

REFERENCES

1. Henschen, S.E. 1920. Über Amusie. *In* Klinische und anatomische Beiträge zur Pathologie des Gehirns. Vol. 5: 137–213. Nordiska Bokhandeln. Stockholm.

2. Uvstedt, H.J. 1937. The method of examination in amusia. Acta Psychiatr. Neurol. **12:** 447–455.
3. Bever, T.G. & R.I. Chiarello. 1974. Cerebral dominance in musicians and non-musicians. Science **185:** 537–540.
4. Altenmüller, E. 1989. Cortical DC-potentials as electrophysiological correlates of hemispheric dominance of higher cognitive functions. Int. J. Neurosci. **47:** 1–14.
5. Fodor, G.A. 1983. The Modularity of Mind. MIT Press. Cambridge, MA.
6. Gardner, H. 1983. Frames of Mind. The Theory of Multiple Intelligences. Basic Books. New York.
7. Peretz, I. 1990. Processing of local and global musical information by unilateral brain-damaged patients. Brain **113:** 1185–1205.
8. Peretz, I. 1993. Auditory agnosia: a functional analysis. *In* Thinking in Sound: The Cognitive Psychology of Human Audition. S. McAdams & E. Bigand, Eds.: 199–230. Clarendon Press. Oxford.
9. Peretz, I., R. Kolinsky, M. Tramo, *et al.* 1994. Functional dissociations following bilateral lesions of auditory cortex. Brain **117:** 1283–1301.
10. Peretz, I. & L. Gagnon. 1999. Dissociation between recognition and emotional judgements for melodies. Neurocase **5:** 21–30.
11. Zatorre, R.J. & S. Samson. 1991. Role of right temporal neocortex in retention of pitch in auditory short-term memory. Brain **114:** 2403–2417.
12. Zatorre, R.J., A.C. Evans & E. Meyer. 1994. Neural mechanisms underlying melodic perception and memory for pitch. J. Neurosci. **14:** 1908–1919.
13. Liégeois-Chauvel, C., I. Peretz, M. Babaï, *et al.* 1998. Contribution of different cortical areas in the temporal lobes to music processing. Brain **121:** 1853–1867.
14. Heinze, H.J., G.R. Mangun, W. Burchert, *et al.* 1994. Combined spatial and temporal imaging of brain activity during visual selective attention in humans. Nature **372:** 543–546.
15. Schuppert, M., T.F. Münte, B.M. Wieringa, *et al.* 2000. Receptive amusia: evidence for cross-hemispheric neural networks underlying music processing strategies. Brain **123:** 546–559.
16. Altenmüller, E., W. Gruhn, D. Parlitz, *et al.* 1997. Music learning produces changes in brain activation patterns: a longitudinal DC-EEG-study. Int. J. Arts Med. **5:** 28–34.
17. Zatorre, R.J. 2000. Neural specialization for tonal processing. Abstract of this conference.
18. Pantev, C., A. Wollbrink, L.E. Roberts, *et al.* 1999. Short-term plasticity of the human auditory cortex. Brain Res. **842:** 192–199.
19. Weinberger, N.M. & J.S. Bakin. 1998. Learning-induced physiological memory in adult primary auditory cortex: receptive field plasticity, model and mechanisms. Audiol. Neuro-Otol. **3:** 145–167.
20. Tramo, M.J., J.J. Bharucha & F. Musiek. 1989. Music perception and cognition following bilateral lesions of auditory cortex. J. Cognit. Neurosci. **2:** 195–212.

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Volume 930
June 2001

THE BIOLOGICAL FOUNDATIONS OF MUSIC

Editors

ROBERT J. ZATORRE AND ISABELLE PERETZ

This volume is the result of a conference entitled **The Biological Foundations of Music** held by the New York Academy of Sciences on May 20–22, 2000 at The Rockefeller University, New York, New York.

CONTENTS

Part IV. The Musical Brain

Part V. Musical Expertise/Brain Plasticity

Part VI. Music and Related Cognitive Abilities

Part VII. Poster Papers

Financial assistance was received from:

Major Funders

- THE CHARLES A. DANA FOUNDATION
- THE DAVID AND LUCILE PACKARD FOUNDATION

Supporters

- FONDAZIONE PIERFRANCO E LUISA MARIANI, PEDIATRIC NEUROLOGY, MILAN ITALY
- INTERNATIONAL FOUNDATION FOR MUSIC RESEARCH
- NATIONAL ASSOCIATION OF MUSIC MERCHANTS, INC., INTERNATIONAL MUSIC PRODUCTS ASSOCIATION
- NATIONAL INSTITUTES OF HEALTH
  - NATIONAL INSTITUTE OF CHILD HEALTH AND HUMAN DEVELOPMENT (NICHD)
  - NATIONAL INSTITUTE OF NEUROLOGICAL DISORDERS AND STROKE (NINDS)
- NATIONAL SCIENCE FOUNDATION

- Different experiences trigger activity
different parts of the brain