**Consciousness, Embodiment and Music Listening:
An overview according to the findings of Gerald Edelman, Antonio Damasio and Daniel Stern**

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Chapter 6.
Subcortical and Cortical Processing of Sound and Music in the Brain

Introduction
The specific regions of the brain are integrated in extended functional systems. Two neuroscience scholars, Gerald Edelman and Antonio Damasio, have proposed comprehensive theoretical accounts of these brain systems. Their ideas contribute to a global understanding of the interaction of sensory and motor systems, emotion, memory and consciousness. Gerald Edelman, in collaboration with his younger colleague Giulio Tononi, has summed up his ideas in *A Universe of Consciousness. How Matter Becomes Imagination* (2000).[1] Antonio Damasio has gathered his neuroscientific insight in *Self Comes to Mind. Constructing the Conscious Brain* (2010).[2]

6.1 Gerald Edelman & Giulio Tononi: A Universe of Consciousness

Integration and differentiation are fundamental concepts in Edelman & Tononi's understanding of the brain. Billions of neurons with differentiated functions are integrated in large-scale dynamic networks. The authors point out three fundamental types of anatomical connections in the brain; reentrant connectivity, parallel loops, and diffuse projections.

Reentrant connectivity
The first anatomical arrangement is the thalamocortical system, a large, three-dimensional network of millions of neuronal groups linked in circuits, which connect most parts of the cortex with the thalamus, and different parts of the cortex with each other. The thalamus consists of two egg-shaped structures situated above the brainstem. They function as a relay stations which forward most kinds of sensory information to the cortex. The crucial quality of the thalamocortical system is reentry, which is a continuous process of signaling back and forth between the connected groups of neurons (pp. 42-45, 70-75). The reentry process implies that any change in one part of the network may elicit rapid responses everywhere else in the network. Roughly, the back of the network is engaged in perception, and the front engaged in action and planning (p. 42).

The authors argue that conscious processes are typically based on these highly differentiated neural patterns in the thalamocortical system, characterized by ”the rapid integration of the activity of distributed brain regions” (p. 70). They add that the conscious processes are dependent on an activating system in the brain stem (p. 54).

Parallel loops
The second anatomical system consists of long parallel loops which leave the cortex, enter one of the cortical appendages, and go back to the cortex. The cortical appendages are the cerebellum, the basal ganglia, and the hippocampus, three structures which subserve the cortex in the performance of specific functions.

The cerebellum consists of two lobes connected with the brain stem. An important function of the cerebellum is to modulate the activity of the motor cortex, in order to ensure smooth and accurate performance of movements. The cerebellum contributes to emotional and cognitive functions as

1 Edelman and Tononi's *A Universe of Consciousness* (2000) is preceded by several publications by Edelman, notably *Neural Darwinism* (1987), *The Remembered Present* (1990), and *Bright Air, Brilliant Fire* (1992). In a more recent overview of the neurology of consciousness, Laureys and Tononi (2009:375-412) recapitulate the main ideas of the 2000 publication, emphasizing the importance of the thalamocortical system and the widely distributed reentrant neural networks, and downplaying the role of brain stem areas as generators of consciousness.
2 Damasio's *Self Comes to Mind* is preceded by three books, *Descartes' Error* (1994), *The Feeling of What Happens* (1999), and *Looking for Spinoza* (2003). Damasio indicates that *Self Comes to Mind* presents an updated account of his ideas (2010:185, 322).

well. A loop passes from the cortex through the brain stem to the cerebellum, and projects back to the cortex via the thalamus.

The basal ganglia encompass a group of large nuclei situated close to the thalamus. They are connected with different cortex areas by different loops, and assist these areas in their specific tasks. One loop is involved in motor control, another loop in regulation of mood and emotion. The loops are organized in parallel, and do not interact with each other. A loop arises in one cortex area, arrives in an area of the basal ganglia, and projects via the thalamus back to the same cortex area.[3]

The hippocampus is an arch-shaped continuation of the temporal cortex. The hippocampus and nearby areas constitute the hippocampal formation, which is connected by loops to cortical and subcortical areas, in particular association areas of the cortex. An important function of the hippocampal formation is the consolidation of memory traces in relevant distributed parts of the cortex. The loops permit a continuous interchange of information between the hippocampus and cortex areas.

The authors underscore that the loop architecture is radically different from the reentrant thalamocortical network. In the loops, information travels in one direction, and the function of the loop is to execute a subservice to the cortex with speed and precision (pp. 45-46, 184).

Diffuse projections

The third kind of anatomical arrangement is a diffuse set of connections which originate in the brain stem and hypothalamus and spread to most parts of the brain. The function of these widespread connections is to distribute neurotransmitters, which modulate the activity of the neurons.

Neurotransmitters are produced by specific nuclei in the brain stem, basal forebrain, and hypothalamus. Significant neurotransmitters are dopamine, serotonin, norepinephrine, acetylcholine, and histamine. The authors denominate the diffuse projections of neurotransmitters *value systems*, because they can transmit information about the state and well-being of the whole organism, as well as emotional responses to occurring events, such as novel and unpleasant stimuli.

One example is norepinephrine (also named noradrenaline), which is produced in a small group of approximately 15.000 neurons in the brain stem, called the locus coeruleus. These neurons receive sensory information and respond by distributing norepinephrine to virtually all parts of the central nervous system, including the cortex, cerebellum, basal ganglia, hippocampus, and hypothalamus. Neurons in the locus coeruleus respond to novel and exciting stimuli, and an effect of norepinephrine is to influence arousal and shifts of behavior. Edelman and Tononi underscore the potential impact of the value systems on conscious experience, cognition, learning, and memory (pp. 43-48, 88-92).

Reentry and mapping

According to the authors, reentry is the unique feature of higher brains in animals and humans. Reentry is an ongoing interchange of signals between widely dispersed, reciprocally connected areas of the brain, ”an interchange that continually coordinates the activites of these areas' maps to each other in space and time” (p. 48). Reentry is not feedback, but interchange of information across multiple simultaneous paths. Reentry leads to rapid synchronization and desynchronization of groups of functionally specialized neurons, permitting the integration of perceptual and motor processes and the activity of local and global mappings. A global mapping is a dynamic structure, which integrates multiple reentrant motor and sensory processes, and permits continuous adjustment of brain functions and the body's activity. The authors argue that perception is closely connected to action, continuously influenced and altered by motor activity and rehearsal (pp. 85-86, 95-96).

Memory is not a representation, but a result of the interaction of numerous brain systems, which have been modified by signals from the world, the body, and the brain itself. ”The dynamic changes linking one set of circuits to another within the enormously varied neuroanatomical repertoires of the brain allow it to *create* a memory” (p. 98). The consolidation of the changes in neural connections that support memory is influenced by the value systems.

3 Brodal (2010:332-333) describes four different loops between the basal ganglia and the cortex.

Perception and memory

Perception is not merely a reflection of input from the world and the sensory organs. Perception of the environment is a result of the interaction between signals from the outside and intrinsic signals in the activated connections of neurons. Sensory information interacts with memory in the form of neural structures that have been influenced and stabilized by previous experience. To a certain degree, perception involves construction in the brain and comparison with memory (pp. 137-138, 160).[4]

Functional clusters and dynamic cores

Edelman and Tononi propose the existence of functional clusters, which are integrated subsets of neural elements which interact strongly among themselves by means of reentrant connections, but less strongly with other structures in the brain. A functional cluster is supposed to be temporarily integrated and active in a cognitive task over a period of hundreds of milliseconds. The authors suggest that the rapid synchronization of large populations of neurons, which can be measured by EEG and MEG, indicates the creation of functional clusters. However, they are aware that more research in this field is needed (pp. 120-124).[5]

In order to contribute to conscious experience, it is essential that the integrated functional cluster is highly complex and differentiated, corresponding to "a conscious state selected out of billions of possible states" (p. 125). The authors denominate such an integrated and differentiated cluster "a dynamic core". A dynamic core is not localized in a single place in the brain. It is a process of spatially distributed interactions which may change its composition rapidly. These reentrant interactions occur primarily in the thalamocortical system, but they may involve other brain regions (pp. 139-144).

Primary consciousness and higher-order consciousness

The authors sum up their hypothesis that "the neural processes underlying conscious experience constitute a large and changing functional cluster, the dynamic core, which includes a large number of distributed neuronal groups and has high complexity" (p. 164). They distinguish between primary and higher-order consciousness.

Primary consciousness is the ability to generate a unified mental scene for the purpose of guiding present behavior. It occurs in human brains and in animals with similar brain structures, and is based on reentrant processes. Primary consciousness requires perceptual categorization, concepts, memory, and value responses. Concepts are not words, but mappings of recognizable activities, for example forward motion. Positive and negative values are added to perception and memory by the diffusely projecting value systems, which distribute neurotransmitters to many brain regions. An integrated mental scene depends on the interaction between perception of sensory stimuly and memory of previous experience. Consequently, the authors characterize primary consciousness as "remembered present." Primary consciousness is supported by functions on three levels in the brain; the value systems in the brain stem, the value-related limbic system, which forms a circle around the brain stem, and the thalamocortical circuits characterized by reentrant connectivity (pp. 78, 102-109).

Higher-order consciousness is a characteristic of humans. It presupposes the existence of primary consciousness and is accompanied by a sense of self and the ability to assemble past and future scenes (p. 102). The self is constructed from social and affective relationships, entailing the development of a self-conscious agent. The concepts of past and future emerge from semantic capabilities.

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4 In *The Embodied Mind* (1991), Varela, Thompson and Rosch propose a related view concerning the pathway of visual perception from the eye via the thalamus to the cortex. They state that merely 20% of the information transmitted through the thalamus to the visual cortex comes from the eye, while 80% comes "not from the retina but from the dense interconnectedness of other regions of the brain" (1991:95). Similarly, Brodal indicates that considerable selection and suppression of signals take place in the sensory pathways (2010:164).

5 Brodal confirms that "each cortical area establishes association connections with many other areas; (…) Together, the many areas of the cortex are extensively connected, forming complex networks specialized for specific tasks" (2010:497-498).

Higher-order consciousness is based on semantic capability, the ability to refer to objects and express feelings by symbolic means. The authors propose that in evolution, semantics developed before language in the form of gestures and sounds conveying meaning. Subsequently, verbal syntax may have emerged from a ”protosyntax” related to gestures and pointing actions. The evolutionary development of symbolic gestures and speech has served expressive functions as well as referential functions, and is closely linked to value systems. Fully developed higher-order consciousness is strongly dependent on language and memory systems mediated by language (pp. 193-197).

6.2 Antonio Damasio: Self Comes to Mind. Constructing the Conscious Brain

Similar to Edelman and Tononi, Damasio proposes a model of the working brain and its connections on the cortical and subcortical levels. He characterizes his project as a framework of hypotheses. Damasio’s understanding of conscious experience displays similarities with Edelman and Tononi’s model, but also an important difference. Damasio includes the brain stem as an integrated basis of consciousness. He proposes that the key brain structures crucial for consciousness are sectors of the upper brain stem, nuclei in the thalamus, and widespread regions of the cortex.

Mapping

It is a fundamental concept in Damasio’s framework that the brain maps the surrounding world as well as is own activity. Maps are momentary neural patterns which represent objects and events in the external world and the body, or represent other patterns processed in the brain. These momentary patterns are experienced as images in the mind. In Damasio’s terminology, an experienced image may be auditory, tactile or visceral as well as visual (p. 18, 70-71).

The construction of maps of the outside world is closely connected to interaction with objects in the world. Similar to Edelman and Tononi, Damasio underscores the connection between perception and action, and states that perception involves both information from the senses and active contributions from inside the brain (pp. 63-65).

Contributions of the thalamus and the cortex to consciousness

Damasio agrees with Edelman and Tononi that reentrant connectivity between the thalamus and regions of the cortex is a requirement for the processing of images in the conscious mind. He refers to reentry as massive recursive cross-signalling amplified by corticothalamic interlocking. Furthermore, he points out the cooperation between the primary sensory cortices, nuclei in the thalamus, and large areas of associative cortices. Ensembles of neurons that work together appear to synchronize their activity momentarily. This synchronization can be measured by EEG as oscillations in the gamma range, approximately 40 Hz (pp. 75, 86-88, 248).

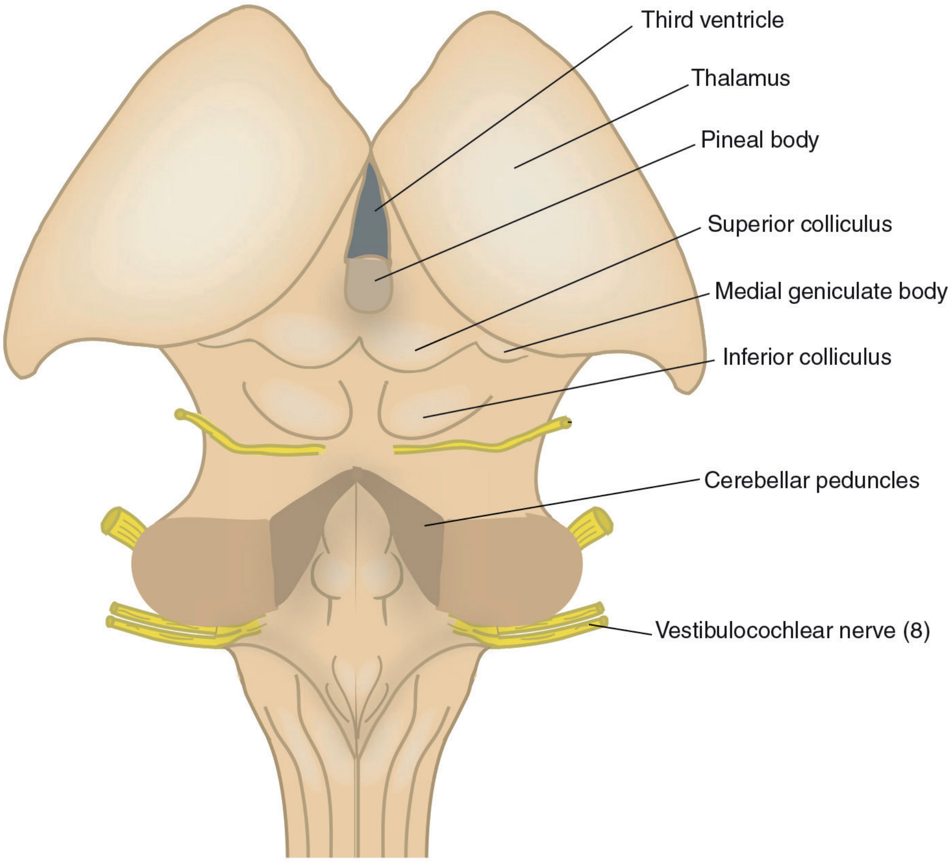

Figure 6.1. The brain stem.

The Inferior colliculus and the Superior colliculus are located in the upper part of the brain stem, close to the Medial geniculate body in the lower part of the Thalamus. The vestibulocochlear nerve connects the brain stem with the ear. The figure also shows other cranial nerves (yellow).

The pineal body is a gland.[6] The third ventricle is a fluid-filled cavity. The cerebellar peduncles connect the brain stem with the cerebellum, which is cut off in the figure.

(Brodal 2010:86)

Contributions of the brain stem to consciousness

Damasio argues that ”brains begin building conscious minds not at the level of the cerebral cortex but rather at the level of the brain stem” (p. 22). He finds evidence that subcortical structures can create coarse maps, in particular the geniculate bodies in the lower thalamus and the neighboring superior colliculus in the upper brain stem. Deep layers of the superior colliculus create maps related to visual, auditory and somatic information, and the superior colliculus displays gamma-range oscillations, similar to oscillations ascribed to synchronization in the cortex (pp. 68, 83-86, 326).

A special kind of evidence for the contribution of the brain stem to the conscious mind comes from the study of children born without the cerebal cortex as consequence of a trauma during the pregnancy period. This deficit is known as hydranencephaly. Such a child possesses an intact brain

6 The pineal gland produces the hormone melatonin, related to the regulation of sleep.

stem and hypothalamus, but its skull is filled with fluid in the place of the cortex. These children can survive if provided sufficient care, they can orient head and eyes, they respond to light, sound, music and human voices, and they display expressions of emotions.[7] Damasio concludes from these findings that functions in the brain stem support a modest kind of conscious mind. Related findings indicate that patients with damage to the visual cortices retain a vague visual orientation supported by the superior colliculus, known as blindsight (pp. 80-85).

Emotion and Feeling

Damasio distinguishes between emotions and feelings. Emotions are complex programs of actions carried out in the body. Feelings of emotions are perceptions of emotions mapped in the brain. Damasio states that all feelings of emotions can be considered variations of the primordial feelings which arise in the brain stem.

Primordial feelings arise continuously and spontaneously, reflecting the internal state of the body as variations of pleasure and pain or relaxation and tension. Particular nuclei in the brain stem respond to the body signals and transmit them to the thalamus and insular cortex (pp. 78-80, 97-98, 109-111).[8] Further structures that produce emotional responses are the amygdala, the ventromedial prefrontal cortex, and nuclei in the basal forebrain (p. 255). Damasio points out that the insular cortex and a closely connected area, the anterior cingulate cortex, are the important cortical regions involved in the processing of feelings (pp. 117-118). He briefly refers to the neurotransmitters and their relations to value, pain and pleasure, reward and punishment (pp. 47, 193, 209).[9]

Memory

Damasio agrees with Edelman and Tononi's view of the brain functions underlying memory. Memories are not stored as representations, but as dispositions, which are procedures for reactivating and assembling aspects of past perception (p. 141). These procedures require the synchronized activation of distributed brain regions. Damasio proposes that the interaction of two fundamentally different types of brain systems is necessary. He denominates one type ”the image space”, consisting of the areas which can map sensory and motor information: the visual cortex, the auditory cortex, the sensorimotor cortices, and nuclei in the upper brain stem.

Damasio denominates the other type of brain areas ”the dispositional space”. It encompasses most of the remaining brain, including the extensive association cortices in the temporal, parietal, and frontal lobes, as well as the thalamus and basal ganglia. It is Damasio's hypothesis that synchronized activation of circuits in the dispositional space sends signals to the image space, which reconstructs approximate maps of the original objects, events, and interactions in the areas where they were first mapped (pp. 130-153).[10]

Consciousness and Self

Damasio presents an extended framework of hypotheses concerning the nature of consciousness and the self. His basic proposition is the following:

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7 Björn Merker has published an elaborate study of consciousness without a cerebral cortex (2007:63-81).

8 Damasio explains that the Solitary Nucleus, also called Nucleus Tractus Solitarius (NTS) and the Parabrachial Nucleus (PBN) in the brain stem receive a complete range of signals from the interior of the body. These nuclei respond by regulating body functions, and transmitting signals from the body via the thalamus to the insular cortex (p. 78, 118). The NTS and PBN are closely connected to other nuclei in the brain stem, situated in the Periaqueductal Gray (PAG), which trigger numerous emotional responses, including laughter and crying, and reactions in situations of fear (p. 80).

9 In his earlier publication *The Feeling of What Happens,* Damasio discussed the production and impact of neurotransmitters (1999:246-253). Parvizi and Damasio (2001:144-147) discuss the interactions between nuclei that produce neurotransmitters and other nuclei in the brain stem and the basal forebrain. See also chapter seven.

10 Studies of auditory imagery for music are reported by Halpern & Zatorre (1999); Zatorre & Halpern (2005). Auditory imagery for music is ”the tune that runs through your head”, that is, music retrieved deliberately or involuntarily from memory. Halpern & Zatorre find that recall of memorized melodies activates the same brain areas as perception of melodies.

> ”Consciousness is *a state of mind in which there is knowledge of one’s own existence and of the exsistence of surroundings*” (p. 157, italics in the original).

Consciousness has content, it is always about something. It contains an aspect of feeling and includes a self process. The self is not a constant entity. The self is a dynamic process which is generated in the mind’s processing of images, and evokes feelings of knowing, and feelings of ownership and agency. Damasio characterizes the self not as an observer, but as an informer, an imaged protagonist of the mental events, which is constructed from moment to moment in the form of ”self pulses” (pp. 166, 181, 212-213). The idea of self pulses corresponds to the view that the self is continuously modified. The degree of presence of a self in the mind varies with the circumstances. However, Damasio insists that even if the feeling of self may be subtle, its presence is a necessary constituent of the conscious mind (p. 169-171).

Protoself, core self, and autobiographical self

The self is built in three stages, the protoself, the core self, and the autobiographical self. The simplest stage is the protoself, which consists of a collection of images that describe the ongoing state of the organism and generate primordial feelings, which are spontaneous feelings of the body. Contributors to the protoself are brain stem nuclei, the hypothalamus, the insular cortex, and the somatosensory cortices (pp. 180-181, 190-193).

Damasio characterizes the core self as ”a self in the proper sense”. It is generated in pulses, as moment-to-moment modifications of the protoself caused by the interaction between the organism and an object. ”The relation between organism and object is described in a narrative sequence of images, some of which are feelings” (p. 181). The assumed contributors to establishing the core self are the superior colliculi, which can generate integrated mappings of sensory information, the associative nuclei in the thalamus, which coordinate the activity of brain areas, the basal ganglia, the insular cortex, the primary sensory cortices, and the sensorimotor cortices (pp. 207-09).

The autobiographical self is the result of a multitude of core self pulses, produced by the interaction between the protoself and previous recordings of lived experience, or anticipations of the future (p. 181). The autobiographical self reconstructs, modifies and rearranges lived experiences, and the recalled events may adopt new emotional qualities in the process. Damasio’s hypothesis of the autobiographical self’s mechanism is the following: ”(a) past memories, individually or in sets, are retrieved and treated as singular objects (biographical objects); (b) objects are delivered to the protoself; (c) core self pulses are generated; (d) core self pulses are held transiently in a coherent pattern” (p. 213). Characteristically, Damasio maintains that the brain stem nuclei and the protoself are active participants in the creation of the autobiographical self (pp. 243-247).

The next indispensable participant is the thalamus, which coordinates cortical activity and the flow of information from the body to the cortex (pp. 215, 247-248). Finally, the brain areas in the ”image space” interact with the extended regions of association cortices in the ”dispositional space.” In his discussion of these areas, Damasio argues that the posteromedial cortices, which are situated near the midline of the brain, play a central coordinating role (pp. 215-229). In short, cooperation of the brain stem, the thalamus, and the cortex is necessary for the creation of the autobiographical self.

According to his concepts of the self, Damasio has named two kinds of consciousness, the core consciousness, which is the sense of the ”here and now”, and the extended or autobiographical consciousness, which includes personhood, the lived past and the anticipated future (pp. 168-169).

Damasio and Edelman: Similarities and differences

Damasio and Edelman & Tononi agree that the temporary reentrant connectivity of functional neuron clusters distributed over different brain areas is essential for consciousness. Moreover, they agree that values and feelings are indispensable components of consciousness; that perception is closely related to action; and that perception involves contributions from the brain as well as sensory input.

The main difference is that Edelman & Tononi apply a top-down view, while Damasio applies a bottom-up view. Moreover, Damasio acknowledges introspection as a relevant approach to understanding consciousness (p. 15), while Edelman & Tononi reject introspection (p. 217).[11]

Edelman & Tononi's primary interest is the "higher-order" consciousness, mediated by the thalamocortical connections, and its close relation to language. In Damasio's discussion of consciousness, he gives lower priority to language, and higher priority to visual, auditory and tactile images. Damasio maintains that the relations to the lived body, mediated by brain stem nuclei, are integrated in all levels of consciousness.

6.3 The auditory pathways[12]

Two pathways are simultaneously active in auditory perception and cognition. The ascending pathway conveys auditory information from the ear's cochlea to the auditory cortex. The descending pathway, which is also named the corticofugal system, projects in the opposite direction from the auditory cortex to the ear.

The functions of the ascending pathway are well-known. The studies of the descending pathway are gaining increasing interest, as these top-down connections modify the upward flow of information at all levels. The cortex sends information back to the ear, which promotes the selection of relevant sounds and the suppression of irrelevant sounds (Rees & Palmer 2010:2; He & Yu 2010: 264; Brodal 2010:250).

6.3.1.The ascending auditory pathway

(Figure 6.2, see also the illustration of the brain stem Figure 6.1)

The cochlea

The cochlea in the ear transmits auditory signals to the cochlear nucleus in the brain stem. The signals are tonotopically organized, that is, they reflect the precise ordering of frequencies in the cochlea, from high to low frequencies.

The brain stem

In the brain stem, auditory information is processed at four levels: (1) the cochlear nucleus, (2) the superior olive, (3) the lateral lemniscus, and (4) the inferior colliculus. At each of these levels, the nuclei are subdivided in several areas, which perform different functions.

(1) Division of the pathway: From the cochlear nucleus, one branch of nerve fibers projects to the lateral lemniscus. Another branch projects to the superior olive.

(2) Localization of sound: Nuclei in the superior olive compare auditory information from the two ears. Comparison of differences in sound level and timing permit the localization of sound sources.

(3) Further processing: The lateral lemniscus contains two different functional systems. One system processes temporal information with high precision. The other system is important for sound localization, and for discriminating between a direct sound and its reverberation.[13]

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11 Edelman & Tononi (2000:217) equate introspection with phenomenology. This is a badly informed view, cf. chapter 2.

12 Main references for this paragraph are Rees & Palmer (Eds. 2010) *The Oxford Handbook of Auditory Science: The Auditory Brain,* and Brodal (2010) *The Central Nervous System. Structure and Function.* The functions and interconnections of the auditory system are highly complex and differentiated. This paragraph presents a simplified overview.

13 Klug & Grothe (2010:184-185)

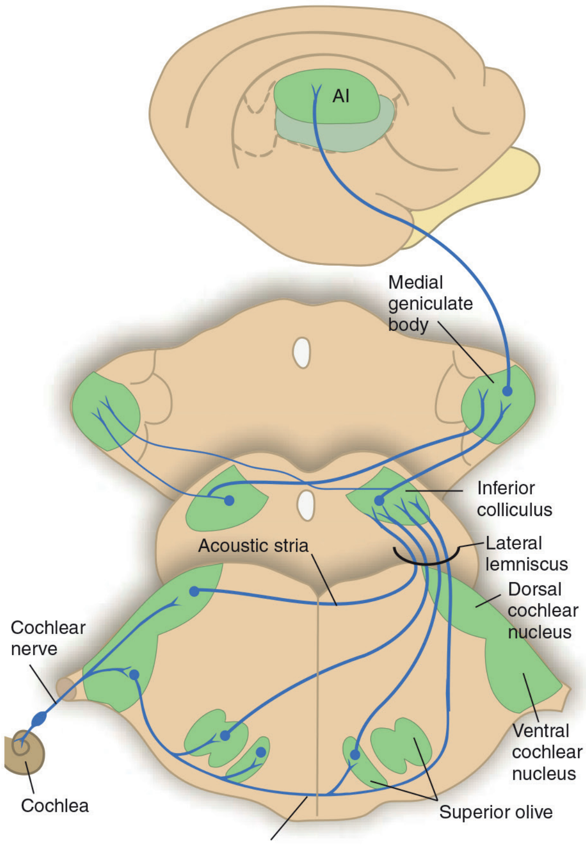

Figure 6.2. The ascending auditory pathway

The figure shows the cochlea, the cochlear nerve, and the levels of auditory processing. Levels in the brain stem: (1) the cochlear nucleus, dorsal and ventral part; (2) the superior olive; (3) the lateral lemniscus; (4) the inferior colliculus. In the thalamus: (5) the medial geniculate body. In the cortex: (6) A I, the core area of the auditory cortex. See also Figure 3.2.

(Brodal 2010:248)

(4) Integration and differentiation: The inferior colliculus (IC) collects information from all lower auditory nuclei. The IC contains several areas with different functions. It projects to the medial geniculate body (MGB) in the thalamus.

One area of the inferior colliculus displays a sharply tuned response[14] to auditory input. It projects to the MGB in a tonotopic manner, that is, the frequencies are ordered precisely from high to low frequencies. Another area of the IC displays a more broadly tuned response to auditory information. It contributes to multisensory integration. It projects to the MGB and to the superior colliculus, which integrates auditory and visual information.

Studies by Kraus et al. (NM III 2008, pp. 543-557) indicate that pitch, timbre and timing have distinct representations in the brain stem. These representations can be measured by electrodes on the scalp (p. 545).

14 Sharply tuned neurons respond to a narrow frequency range. Broadly tuned neurons respond to a wider frequency range.

Damasio points out the multisensory integration carried out by the inferior and the superior colliculi. (2010:84, 244).[15]

The thalamus

The medial geniculate body (MGB) in the thalamus conveys all auditory information from the brain stem to the cortex. It contains several nuclei. One nucelus projects tonotopically organized information to the core area of the auditory cortex. Another nucleus projects more broadly tuned information to the belt area of the auditory cortex. A third nucleus, which also projects to the belt area, is sensitive to auditory, visual and somatic stimuli.

The auditory cortex

The auditory cortex is located in the superior temporal gyrus of the temporal lobe, see Figure 3.2. It displays a complex organization, which can roughly be divided into a core area surrounded by a belt area and a parabelt area.

The core area is tonotopically organized, and responds strongly to sharply tuned sounds, such as tones.[16] The belt area responds better to spectrally complex sounds. It contributes to multisensory integration. The parabelt area adjoins the belt area. It has extended connections with other brain areas. Tramo et al. (NM II 2005, pp. 148-174) characterize the belt and parabelt areas as auditory association areas, which are integrated in a widely distributed system for music cognition.[17]

Zatorre and Belin (2001:946) have found evidence for a hemispheric specialization of the auditory cortices. The right hemisphere gives priority to spectral processing, including tones, and the left hemisphere gives priority to rapid temporal processing, including language.[18]

It appears that one route in the ascending pathway is throughout tonotopically organized, characterized by sharply tuned neurons which respond to narrow frequency information. Other routes are characterized by more broadly tuned neurons, which respond better to complex sounds.

The "what" and "where" pathways (Figure 3.2)

From the auditory belt area, functionally specialized pathways, a ventral and a dorsal stream, reach the prefrontal cortex and the parietal cortex. The ventral stream is characterized as a "what" pathway, dealing with object information, which subserves the identification and meaning of sounds. The dorsal stream is characterized as a "where" pathway, dealing with spatial information, which subserves the localization of sounds and the detection of movement (Rauschecker & Tian 2003:44-48).[19] The pathways are reciprocally connected.

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15 Damasio underscores the role of the superior colliculus for sensory integration. Malmierca & Hackett point out the role of the lateral cortex of the inferior colliculus for sensory integration (2010:27).

16 The precise location of pitch perception remains a topic for discussion. Wang & Bendor (2010:161-164) and Griffiths (NM I 2002, p. 47) propose the existence of a pitch perception area close to, but distinct from the core auditory cortex.

17 Chapter 3, p. 76.

18 A recent meta-analysis of 58 studies confirms the high speech sensitivity in the left auditory cortex, and indicates specific areas sensitive to spectral and temporal variation in both auditory cortices (Samson, Belin et al. 2011)

19 Warren et al. (2005:637-641) and Zatorre et al. (2007:549, 557) propose that the dorsal pathway serves general transformations of acoustic information into motor representations. In a recent article, Rauschecker (2012:1-4) agrees that the dorsal pathway, alongside with its role in spatial processing, also plays a more general role in sensorimotor integration and control.

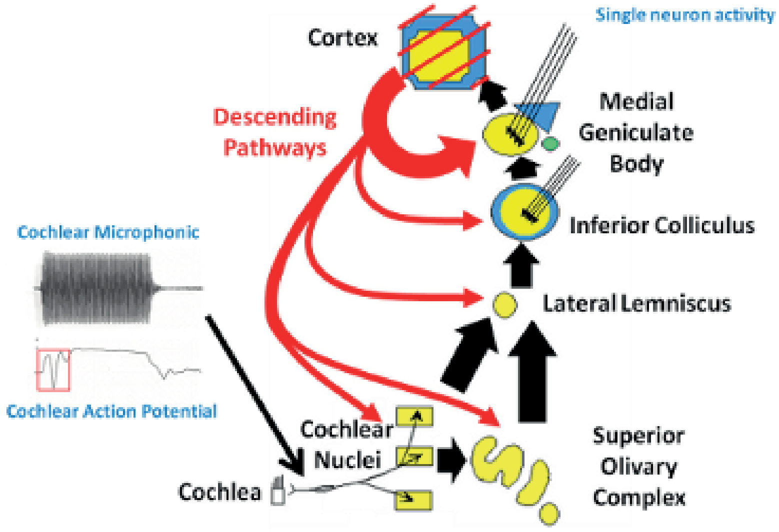

Figure 6.3. Schematic diagram of the ascending auditory pathway (black arrows) and the descending auditory pathway (red arrows).

Similar to Figure 6.2, the diagram shows the levels of auditory processing: (1) the cochlear nuclei, (2) the superior olivary complex, (3) the lateral lemniscus, (4) the inferior colliculus, (5) the medial geniculate body in the thalamus, (6) the auditory cortex.

(Courtesy of the MRC Institute of Hearing Research)

6.3.2. The descending auditory pathway

The descending pathway reaches all levels of auditory processing from the cortex to the cochlea. It performs important functions, modifying the upward flow of information and influencing the neural processing at lower levels. Direct projections descend from the auditory cortex to all levels of the auditory system (Figure 6.3). Three systems are active, a tonotopic system related to the core area, a diffuse or non-tonotopic system related to the belt area, and a multisensory system, related to widespread areas of the auditory association cortex.

The thalamus
Each area in the auditory cortex project to several nuclei in the thalamus. Some projections form reciprocal loops between the thalamus and the cortex. It is hypothesized that such loops may function as a dynamic filter for auditory attention, which permits focusing on a particular sound source or speaker (He & Yu 2010:264-265).

The inferior colliculus
The tonotopic, the diffuse, and the polysensory systems interconnect the auditory cortex with the IC. The functional roles of the three systems are not precisely understood.

The superior olive and the cochlea
The superior olive consists of many nuclei. The complex functions of this system exert impact on the hair cells in the cochleas. This impact may result in the amplification of particular frequency ranges, and contribute to the focusing on a sound source in a noisy environment.

Brief summary of the auditory functions

The overview indicates that the auditory system is integrated and highly differentiated. It processes spectral and temporal information with great precision. The processing is not linear, but mediated and modified by neural connections on several levels. The auditory system deals with tonotopically organized information as well as non-tonotopical and multisensory information, and interacts with multiple other brain systems. Important functions of the auditory system are the identification and localization of sounds, and the response to movement indicated by sound.

6.4 Music listening activates extended networks in the brain

Recent reference works and review articles report that music listening involves extended networks in the brain. [20] Altenmüller & Schlaug summarize that a typical musical experience involves attention, multisensory integration and motor preparation mediated by frontal and parietal brain areas, as well as timing and motor coordination supported by the basal ganglia and cerebellum. Simultaneously, emotional responses elicited by music are related to nuclei in the brain stem, the nucleus accumbens, hippocampus, amygdala, insula, and the cingulate gyrus. Moreover, music exerts an impact on bodily functions, such as heart rate, respiration, and perspiration (Altenmüller & Schlaug 2012:12-17). Important networks related to music concern motor planning, rhythm and regularity, and pleasure and reward.

Motor planning and preparation (See Figures 3.2 and 3.4)
A number of studies indicate that music listening activates brain areas related to motor planning and preparation, even if no motor action is carried out.

In their review of auditory-motor interactions, Zatorre, Chen and Penhune (2007:549-553) discuss the ventral and dorsal pathways, which are suggested to support object identification and spatial processing. They highlight research concerning the dorsal stream, and propose that the dorsal stream plays a role not only in spatial processing, but also a more general role, transforming acoustic information into motor representations.[21] The dorsal pathway connects reciprocally the planum temporale in the auditory cortex with the premotor cortex, motor cortex, and prefrontal areas. Furthermore, the authors report that ”hearing music in the mind” activates the supplementary motor area and premotor areas.

Bremmer et al. (2001:290-291) have found polymodal cortical areas that are activated by visual, tactile, and auditory motion stimuli. They suggest that polymodal processing involves the posterior parietal and premotor cortices.

Schönwiesner et al. (2007:2075) have studied the detection of acoustic changes by means of fMRI and EEG. They find that a pre-attentive process in the auditory system encompasses three stages: (1) initial detection in the core auditory cortex (2) detailed analysis in the posterior superior temporal gyrus and planum temporale (3) judgment of sufficient novelty for allocation of attentional resources in the mid-ventrolateral prefrontal cortex.

Chen, Penhune, and Zatorre further discuss the auditory-motor interactions in an elaborate review (NM III 2009, pp. 15-34).

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20 Useful references are review articles by Zatorre (2005), Koelsch & Siebel (2005), Zatorre et al. (2007), Warren (2008), Levitin & Tirovolas (2009). Furthermore, chapters from Hallam, Cross & Thaut (Eds. 2009) *The Oxford Handbook of Music Psychology;* Juslin & Sloboda (Eds. 2010) *Handbook of Music and Emotion;* MacDonald, Kreutz & Mitchell (Eds. 2012) *Music, Health and Wellbeing.*

21 Zatorre indicates the importance of studies by Griffiths & Warren (2002:348-352) and Warren et al. (2005:637-640).

Rhythm and regularity
Zatorre, Chen and Penhune (2007:550) indicate that listening to rhythm often involves the basal ganglia, cerebellum, the dorsal premotor cortex, and the supplementary motor area. In a subsequent study, the same authors interpret the involvement of the motor areas during passive listening as motor planning (Chen, Penhune and Zatorre 2008:2844).

Grahn (NM III 2009, pp. 35-45) has reviewed studies of the role of the basal ganglia in beat perception. She finds that the basal ganglia are strongly involved in processing a regular beat. In particular, the basal ganglia appear to be linked to internal generation of the beat.[22] Grahn proposes that rhythms with a beat involve a circuit connecting the putamen, which is part of the basal ganglia, and premotor and supplementary motor cortices.[23]

Janata and Grafton (2003) have conducted a meta-analysis of 34 PET and fMRI studies concerning sequencing and music. Their analysis indicates that a core circuit consisting of the sensorimotor cortex, the premotor cortex, the supplementary motor area, and the cerebellum underlies sequenced behaviors (2003:686). They call attention to the deviations from a strictly regular beat, which characterize an expressive musical performance, and refer to Bruno Repp, who has studied this topic in a number of experiments.

Repp (1999:529) has suggested a sensorimotor feedback mechanism that is sensitive to timing deviations. Münte et al. (NM I 2002, pp. 131-139) have found differences between drummers and nonmusicians in the pre-attentive processing of temporally deviant beats. Similarly, Vuust et al. (2005) indicate differences between jazz musicians and nonmusicians in their pre-attentive responses to incongruent rhythm.

Reward and pleasure
The classic study by Blood and Zatorre (2001), reported in chapter 3, p. 67 showed that intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. These regions include the ventral striatum in the basal ganglia (which contains the nucleus accumbens), the insula, and the orbitofrontal cortex.

Menon & Levitin (2003, 2005) have investigated responses to pleasurable music in an fMRI study based on excerpts of classical music by Bach, Beethoven, Elgar, Mozart, Rossini, Johann Strauss, and Tchaikovsky. Similar to Blood and Zatorre, they found that the experience of pleasant music activated a network which included the nucleus accumbens in the striatum, the ventral tegmental area (VTA) in the brain stem, the hypothalamus, the insula and the orbitofrontal cortex. As the VTA is a brain stem area that projects the neurotransmitter dopamine to the nucleus accumbens, they suggested that dopamine release was connected to the experience of reward and pleasure.

In continuation of these studies, Salimpoor et al. (2009, 2011) have investigated the possible relationship between dopamine release and pleasurable musical experience. They focused on chills as an indicator of strong pleasurable response, because it is possible to compare the subjective experience of chills with simultaneous objective measurements of bodily response to the music. Prominent bodily responses are changes in skin conductance response (SCR), which is related to sweat production, and changes in heart rate (HR). Both of these responses reflect arousal of the autonomous nervous system.

22 A study by Patel et al. (2009:827-830) suggests that, similar to humans, certain birds may be able to synchronize their body to a musical beat. This ability appears to be related to auditory-motor circuits in the brain, including the basal ganglia. Patel reports and discusses his study in NM III 2009, pp. 459-469.

23 Edelman & Tononi underscore that the functional connections between the basal ganglia and the cortex are one-directional loops, different from reentrant connections (2000:183-185)

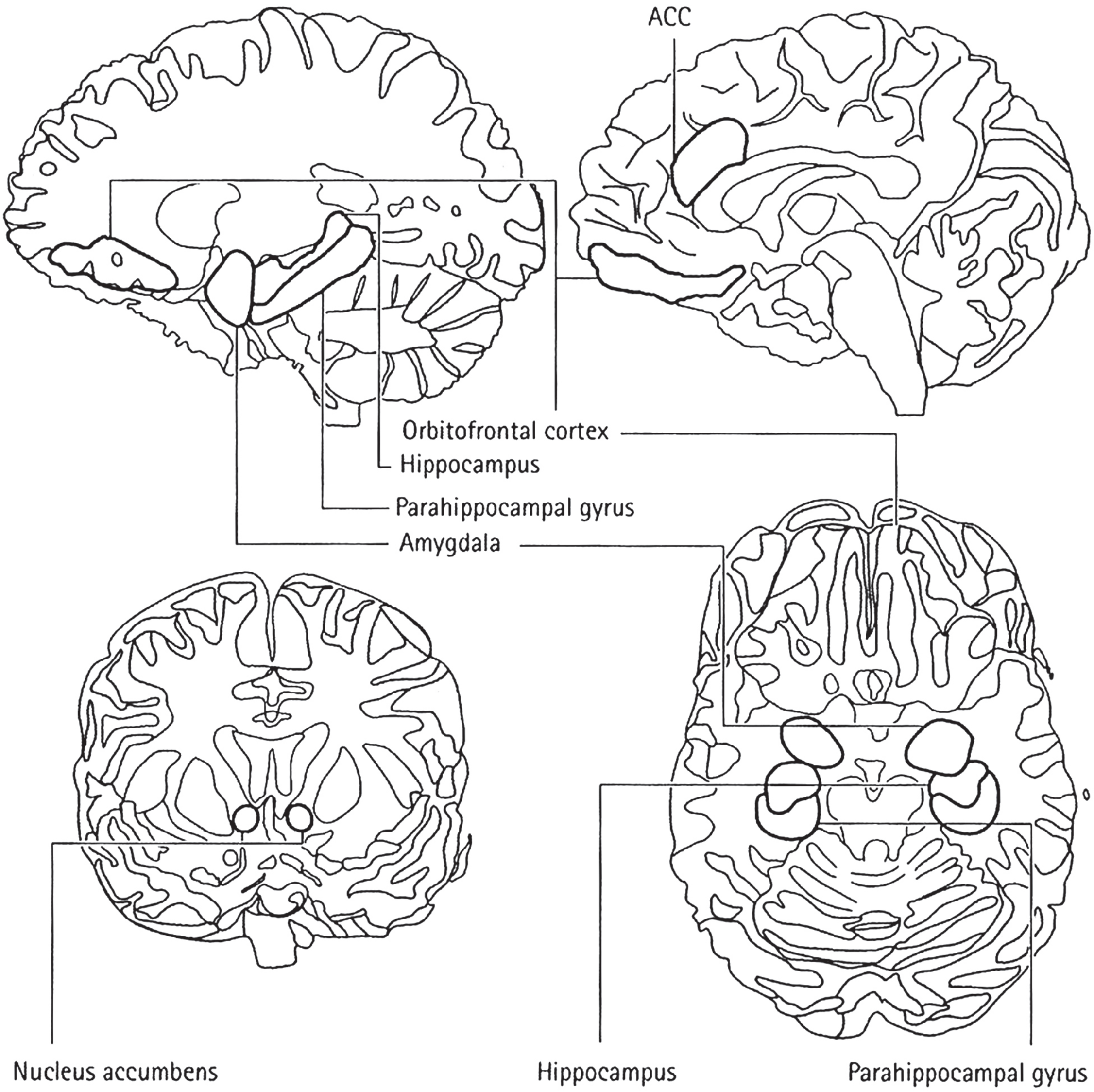

Figure 6.4. Brain areas involved in emotional processes.
The figure shows some brain structures that are involved in the generation of emotion; the amygdala, the nucleus accumbens, the anterior cinguate cortex (ACC), the hippocampus, the orbitofrontal cortex, and the parahippocampal gyrus.
Traditionally, these structures are named limbic or paralimbic. [24]

(Koelsch et al. 2010:315)

24 the notion of a "limbic system" is outdated, but still in use (Brodal 2010:462)

In their first study (2009), Salimpoor et al. aimed at finding correlations between subjective experience and objective physiological responses. Out of a group af 200 volunteers, they selected 28 persons who reported repeated experience of chills when listening to music. As the experimenters were aware that emotional response to music is highly individual, they asked the participants to bring pieces of music which they knew would evoke chills. The self-selected music included classical, jazz, rock, folk, and trance music, with a majority of classical music. From these pieces, three-minute chill-evoking passages were excerpted. Additionally, according to a procedure designed by the researchers, the participants selected music that they found emotionally neutral.

In the experiments, the participants were asked to press and hold buttons while listening to the music; one button for neutral, one for low pleasure, one for high pleasure, and one for chills. Simultaneously, their physiological responses were measured.[25] Exact timing of button presses and physiological measurements permitted synchronized registration of subjective experience and objective measurements. The participants listened to chill-evoking and emotionally neutral pieces in random order.

The data showed a strong positive correlation between subjective ratings of pleasure and autonomic nervous system arousal. When participants did not experience pleasure, they showed no significant increases in emotional arousal.

On the basis of this study, the researchers designed a new experiment (Salimpoor et al. 2011:257-264). The experiment aimed at detecting release of dopamine in the brain during listening to pleasurable music. Out of the 28 participants in the first study, the researchers selected eight persons who had most reliably experienced chills during their peak pleasure responses to music. These eight persons were asked to listen to their self-selected pieces and the emotionally neutral pieces again, once during a PET scanning, and once during an fMRI scanning. During the scannings, physiological variables were measured, similarly to the first experiment.

Both kinds of scanning produce images of the brain. PET scannings permit the detection of dopamine release in particular areas of the basal ganglia after the injection of a slightly radioactive liquid in the blood.[26] However, PET scanning does not afford precise timing of the dopamine release related to the music. For this reason, the music listening was repeated during an fMRI scanning, which secured better timing.

This complicated procedure led to the desired results. The researchers found evidence for dopamine release during listening to pleasurable music in two anatomically distinct areas of the basal ganglia. The *nucleus accumbens* was more involved during the peak emotional response. The timing of the dopamine release in the *caudate* was different. The caudate was more involved during the anticipation of the peak response (2011:257, 260).

These results confirm that music listening involves brain areas related to reward and pleasure, and add considerable precision and control to the study of Blood and Zatorre (2001). The indication of different neural responses to anticipation and peak emotional experience shed light on prominent driving forces in music listening; the process of expectation and fulfilment, and the process of tension and release.

25 The measurements included five variables. Skin conductance response, skin surface temperature, heart rate, and blood volume pulse was measured at the fingertips. Respiration was measured at the chest.

26 The technical explanation is as follows: This experiment uses a synthetic radioactive molecule named [^{11}C]raclopride. The scanning investigates dopamine release in the *striatum*, which is a region of the basal ganglia. The striatum includes two areas that are of particular interest, *the nucleus accumbens*, and the *caudate*. Salimpoor et al. explain that it is possible "to estimate dopamine release specifically in the striatum on the basis of the competition between endogenous dopamine and [^{11}C]raclopride for binding to dopamine D2 receptors." (2011:257)

Real music activates large-scale brain networks

Vinoo Alluri, Petri Toiviainen and colleagues (2012:3677-3689) have launched an ambitious project. In an fMRI study, the brains of the participants were scanned while they listened to a whole 8-minute piece of music, the tango *Adiós Nonino* by Astor Piazzolla. This tango is an extraordinary piece of music. It was recorded in a live concert by Piazzolla and his tango nuevo band, which comprised two bandoneons, piano, guitar, cello, and double bass.[27] The recorded music offers a rich display of timbre, pitch, rhythm, volume, and polyphonic interplay. Remarkable are the changes from rhythmic drive to floating timing, the extreme accelerandos and ritardandos, a very large range of pitch, the use of glissando, and considerable variation in loudness, timbre contrasts, and musical expression. In order to capture the features of this complex music, the researchers have developed a novel procedure.

First, the short-term and long-term features of the music were extracted by means of the Music Information Retrieval toolbox (Lartillot & Toiviainen 2007). The short-term features encompass timbral properties of the music, including spectral centroid, spectral spread, spectral roll-off, roughness and spectral flux. The long-term feature encapsulate tonality and rhythm, and include pulse clarity, fluctuation, mode and key clarity.

Next, a principal component analysis (PCA) was performed in order to reduce the number of features, resulting in nine components; Fullness, Brightness, Timbral Complexity, Rhythmic Complexity, Key Clarity, Pulse Clarity, Event Synchronicity, Activity and Dissonance.

Third, excerpts of the Piazzolla piece that represented these nine components were presented to a group of 21 musicians. In a controlled procedure, the participants were asked to rate the musical properties of the excerpts. An analysis of the participants' ratings showed significant correlations between the rating scales of Fullness, Brightness, Timbral complexity, Key Clarity, Pulse Clarity and Activity and the respective acoustic components. These six acoustic components were used for further analysis in the fMRI study (p. 3680).

Eleven participants with formal musical training participated in the study. Five played mainly classical music, two played folk and jazz, and four played mainly pop/rock music. In the experiment, the whole-brain activity of each participant was recorded by fMRI while listening to the 8-minute piece of music. Subsequently, correlations between acoustic components and brain activity were calculated. First-level analysis showed correlations at an individual level, second-level analysis pooled the individual results to obtain group maps for each acoustic component (p. 3684).

The results of the study provided a number of new findings in comparison with previous studies. Timbral feature processing involved cognitive areas of the cerebellum and areas related to the default mode network (DMN), which is a network that constantly monitors the sensory environment. Processing of musical pulse recruited limbic and reward areas. Processing of tonality involved cognitive and emotion-related brain regions. In sum, the study "revealed the large-scale cognitive, motor and limbic brain circuitry dedicated to acoustic feature processing during listening to a naturalistic stimulus" (pp. 3677, 3685, 3687).The authors suggest that further studies may call for an expansion of the acoustic feature set.

The procedures of this experiment represent a considerable step forward in neuroimaging, permitting the investigation of neural responses to real music in controlled studies of high ecological validity. Even if the procedure and research design may be subject to further testing and refinement, this study paves the way for future investigations in neuroscience.

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27 The recording is commercially available. Astor Piazzolla: The Lausanne Concert November 4, 1989. CD Radio Suisse Romande M2-36165 R1.

Chapter 7. Embodiment

Introduction

”The body is our general medium for having a world.”
This statement in Merleau-Ponty’s *Phenomenology of Perception* (2002:169) summarizes his philosophy of embodiment. According to Merleau-Ponty, the origin of consciousness is the interaction between the body and the world;

> ”Consciousness is being-towards-the-thing through the intermediary of the body. A movement is learned when the body has understood it, that is, when it has incorporated it into its ”world”, and to move one’s body is to aim at things through it” (2002:160).

The study of embodiment is a common denominator for many fields of philosophy and science. The following presents different views of embodiment from the positions of neuroscience, receptive music therapy, cultural sociology, developmental psychology, and phenomenology.

7.1. Embodied listening

It is an everyday experience of music listeners that music induces body movement. Cross states that ”music embodies, entrains, and transposably intentionalizes time in sound and action” (2003:24). Davidson and Emberly (2012:136-149) have reviewed singing and dancing for quality of life across cultures. They highlight music’s capacity to unite people and create attachment between mother and infant, and conclude that music affords an embodied communicative experience for well-being (p. 145). Dura (2002) emphasizes the kinesthetic dimension of music listening, and states that musical meaning is a result of music’s ”intimate connection with our bodies, with which we first come to know the world” (p. 257).

Hodges (2009:125-126) reports that music is connected to physical movement in cultures all over the world, and suggests that the neural systems of our brains and bodies are ”wired” to respond to sound. He proposes that listening to music activates brain regions in a sequential order:

(1) The auditory cortex initially analyses sound;
(2) Frontal brain regions process musical structure;
(3) The mesolimbic system, involved in arousal and pleasure, is activated and produces dopamine, further activating the nucleus accumbens;
(4) The cerebellum and basal ganglia process rhythm and meter leading to physical movement.

Entrainment
Based on MEG and PET studies, Thaut et al. (NM I:364-373)[1] find that a widely distributed cortical and subcortical network subserves the motor, sensory, and cognitive aspects of rhythm processing. LaGasse & Thaut (2012:153-163) highlight the role of rhythmic entrainment in neurological rehabilitation.

In an fMRI study, Grahn (NM III:35-45) finds that the basal ganglia are strongly implicated in processing a regular beat. Zatorre et al. (2007:550) report that even when subjects only listen to rhythms, the basal ganglia, cerebellum, dorsal premotor cortex, and supplementary motor area are often activated.

1 NM = The Neurosciences and Music, cf. chapter 3.

Body listening
In the context of Guided Music and Imagery therapy, Helen Bonny (1993/2002:325-334) has described her experience of bodily impact and free body movement to well-known classical music. She employed the GIM program *Imagery,* a selection of music by Ravel, Copland, Tchaikovsky, Respighi, and Turina that she had compiled herself and knew almost by heart. She began lying on the floor in a relaxed state, and felt that the first piece induced movement and tension in her body. Subsequently, she stood up and moved freely, following the music's flowing, jerky and jumping movements with her hands, feet and facial expressions. Simultaneously, she let her body respond to the moods and feelings of the music. Bonny reported that the experience was astonishing. Even though she had known the music for fifteen years, her first attempt at moving to the music yielded an unexpected new understanding of the music's potential.

Trondalen (2004:65-66, 73-74) reports that body listening adds important dimensions to her procedure for analyzing music therapy improvisations.[2] Body listening is used in the training of GIM therapists to heighten their awarenes of inner versus outer movement and gestural qualities in the music (Bonde 2012, personal communication).

Music organizes the body
De Nora (2000:75-108) describes the use of music as a stabilizing factor for the body functions of prematurely born children, and as an organizing device of the body in rhythmic aerobic exercise.

In an intensive care unit for neonates, selected music can mask the noises of medical technologies, and regulate the disorganized body state of the infants, providing a supportive environment of stable, patterned and predictable musical sound (pp. 77-82).

In aerobic exercise, music creates the order underlying sequences of choreographed movements. Specially composed music for aerobics features high rhythmic and timbral clarity and carefully selected tempos. Timing, rhythm, melody and harmony are deliberately designed to support body conduct and coordination in the various phases of exercise. De Nora characterizes music as ”a technology of body building, a device that affords capacity, motivation, co-ordination, energy and endurance” (p. 102).

7.2. Psychophysical responses to music

Investigations of psychophysical responses provide evidence of the impact of music on bodily functions. Listening to music can exert impact on heart rate, skin conductance, blood pressure, respiration, and the release of neurochemicals (Hodges 2009, 2010).

Skin response, heart rate, and breathing
”Chills” or ”shivers down the spine” or ”gooseflesh” is a bodily response to strong experiences of music in many listeners. In a pioneering study, Panksepp (1995:171-207) investigated chills in groups of listeners on the basis of questionnaires and subjective self-reports. He found large individual differences, but also a tendency that sad songs are more likely to evoke chills than happy songs (p. 187).[3] This finding corresponds with Panksepp's hypothesis that chill responses may be related to ”distress vocalizations – the primal cry of being lost or in despair” (Panksepp 1998a:278). As stimuli that may evoke chills, he suggests a high-pitched crescendo, or a single instrument which emerges from a soft background sound. Huron (2006:36, 281-283) modifies Panksepp' s idea, suggesting that in music, chills arise when an initial negative response to a surprise is followed by a neutral or positive appraisal.

In another pioneering study, Blood and Zatorre (2001) investigated individual chill responses to self-selected music by means of PET. They found that intense chills were correlated with activity in

2 Trondalen's procedure is described in chapter 2.
3 The participant-selected examples in Panksepp's study include a variety of popular music, e.g. the groups Pink Floyd, Boston, and Air Supply (1995:179).

brain regions involved in reward, emotion, and arousal. These findings were confirmed and refined in a subsequent study by Salimpoor, Zatorre et al. (2011). [4]

Studies by Guhn et al. (2007:473) and Grewe et al. (2009:61) indicated that heart rate and skin conductance increased during music-induced chills.

All researchers agree that chill experiences are highly individual. However, musical passages that are apt to evoke chills display common characteristics. In a review of studies, Huron and Margulis (2010:594) summarize that chills are often correlated with a rapid large change of loudness, a broadening of the frequency range toward high treble or low bass, a sudden change of tempo, harmony or texture, the return of a melody, or the entry of one or more voices or instruments.

Bernardi et al. (2006:445-452) have investigated the bodily impact of raga, classical and dodecaphonic music, rap and techno. They found increase in respiration, blood pressure, and heart rate, and conclude that the music induced an arousal effect, predominantly related to tempo. A subsequent study by Bernardi et al. (2009:3171-3180) showed that the experience of crescendos in classical music by Puccini, Beethoven, and Verdi was significantly correlated with changes in heart rate, blood flow, and respiration.

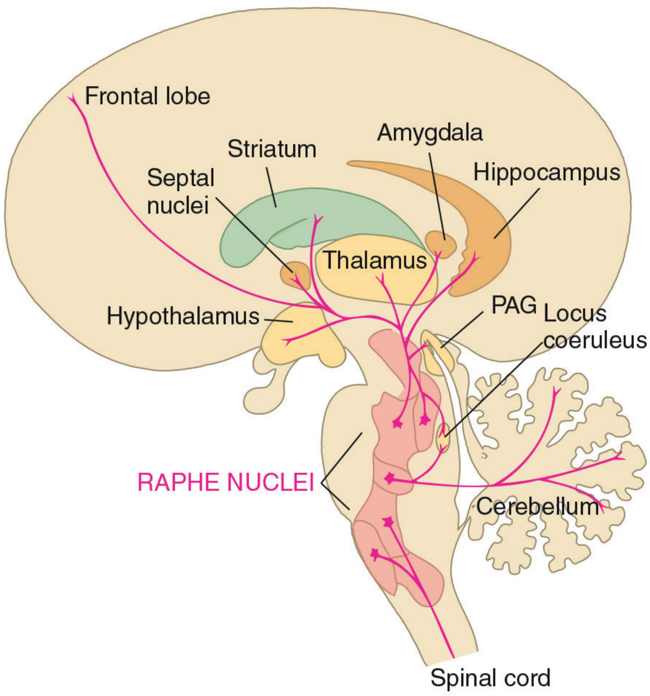

Figure 7.1 Serotonin and other neurotransmitters

Several raphe nuclei are located in the brain stem. They produce the neurotransmitter serotonin. The figure shows fibers that distribute serotonin to the frontal lobe, the striatum, the thalamus, the amygdala, the hippocampus, the cerebellum and the spinal cord.
The raphe nuclei also send fibers to the locus coeruleus, which produces norepinephrine, to the hypothalamus, which produces histamine, and the septal nuclei, which produce acetylcholine. Fibers from the raphe nuclei also project to the periaqueductal gray (PAG) , which plays a role in regulation of pain and defensive behavior.

(Brodal 2010:377)

4 Cf. chapter six.

Neurotransmitters

As indicated in chapter six, neurotransmitters play an important role in the neural processing of music. Neurotransmitters are chemicals that are produced in specific subcortical nuclei, and distributed to large areas of the brain. Edelman & Tononi have described the distribution of neurotransmitters as diffusely projecting value systems, which are capable of signaling to neurons all over the brain (2000:88). Panksepp & Trevarthen (2009:120-121) propose as a working hypothesis that the general emotional effects of music may arise from fast changes in the neurotransmitter systems, assisted by the more subtle modulating influences of related chemicals, the neuropeptides.

The manufacture and functions of neurotransmitters have been investigated by Panksepp (1998a:98-111) and Pfaff (2006:26-54). Five distinct systems work together to regulate arousal. These systems distribute the neurotransmitters Norepinephrine, Serotonin, Dopamine, Acetylcholine, and Histamine.

Norepineprhine, Serotonin, and Dopamine are produced in nuclei of the brain stem.[5]

The Norepinephrine system supports sensory alertness, in particular attention to salient and unexpected sensory stimuli. It emphasizes projections to the posterior cerebral cortex.

Serotonin is involved in regulation of emotional behavior. It has various functions, including regulation of the balance between wakefulness and sleep. The serotonin system projects preferentially to the limbic cortex and hypothalamus. Panksepp specifies that serotonin reduces the impact of incoming information (1998a:107). Some antidepressant drugs[6] raise the serotonin level in the brain by inhibiting the reuptake of serotonin in the neural synapses.

Dopamine influences motor control and mood. In studies of music, dopamine is known to induce pleasurable feelings by activating a ”reward pathway”. Pfaff indicates that dopamine seems to signal anticipation and prediction of a future rewarding event (2006:35-36).

Acetylcholine is produced in the basal nucleus and the septal nuclei of the basal forebrain. It mediates attention and arousal. Histamine is produced in nuclei of the posterior hypothalamus. It influences arousal and sleep.

In addition to the five specific arousal systems, Pfaff (2006:42-48) proposes the existence of a powerful general arousal system, based on ”master cells” in the reticular formation of the brain stem. These cells use the neurotransmitter glutamate, which is the ubiquitous excitatory transmitter in the brain.

Pfaff sums up that the neuroscience of arousal investigates ”change, uncertainty, unpredictability, and surprise” (2006:144). These are characteristic features of music, together with the opposites; stability, security, predictability, and fulfilled expectation.

Vitality and arousal

In his 2010 book *Forms of Vitality,* Daniel Stern integrates his theories of developmental psychology with Donald Pfaff’s investigations of the arousal systems. In many publications, Stern has reported his observations of infants, pointing out that children possess sophisticated abilities for sensation and communication right from birth.[7] In his latest book, Stern gathers previously presented terms such as ”vitality affects” and ”vitality contours” under the englobing term ”dynamic forms of vitality” (p. 17). It is Stern’s proposition that forms of vitality are fundamental for all human activity, including sensation, motion, emotion, feeling, communication, memory, and thinking. He describes the vitality forms as ”the felt experience of force – in movement – with a temporal contour, and a sense of aliveness, of going somewhere. They do not belong to any particular content. They are more form than

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5 Norepinephrine is produced in the *locus coeruleus*, Serotonin in the *raphe nuclei*. Dopamine is produced in two areas; the *substantia nigra pars compacta*, and the *ventral tegmental area*.

6 SSRIs: selective serotonin reuptake inhibitors.

7 Important previous publications by Daniel Stern are *The Interpersonal World of the Infant* (1985) and *The Present Moment in Psychotherapy and Everyday Life* (2004).

content. They concern the ’How’, the manner, and the style, not the ’What’ or the ’Why’” (p. 8).

Stern presents a list of words which elucidate dynamic forms of vitality, including ”exploding, surging, accelerating / swelling, bursting, fading / drawn out, disappearing, fleeting / rushing, pulling, pushing / relaxing, languorous, floating / tense, gentle, halting”, and explains that a vitality form is characterized by five dynamic features; movement, time, force, space, and intention/directionality (pp. 4-7). [8] Vitality forms shape the features of musical expression, such as changes in movement, timing and tempo, intensity, accents and rhythm, flow and articulation, direction of melody, and tension of harmony.

Daniel Stern finds a possible neuroscientific basis for the vitality forms in Donald Pfaff’s investigations of the five parallel arousal systems which distribute neurotransmitters to different parts of the brain or the whole brain (Pfaff 2006). Stern considers arousal the fundamental force for all bodily and mental activity. He suggests that the combinations of the systems which distribute Norepinephrine, Serotonin, Dopamine, Acetylcholine, and Histamine can give rise to a multiplicity of rapidly changing, highly complex and finely differentiated forms of vitality (pp. 58-63).

Stern states that the influences between the brain stem and the cortex are mutual. Neurotransmitters flow ”up” from the arousal systems, and the cortex and emotion centers in the brain send regulating impulses ”down” to the subcortical nuclei. However, it is his view that dynamic experiences of vitality can arise from the arousal systems in themselves (p. 71). He briefly discusses Antonio Damasio’s ideas, and acknowledges that vitality dynamics are coextensive with Damasios ”background feelings”. However, he points out a difference. Whereas background feelings refer to the overall feel of internal states and functions in the body, vitality dynamics mainly refer to the changes in active forces during an event in motion, and can be independent of emotion and sensation (pp. 44-46).

7.3. Phenomenology and neuroscience

Perception is embodied action

In their book *The Embodied Mind* (1991) Varela, Thompson and Rosch propose the view that perception and action cannot be separated. Perception is not a passive process, which leads to a kind of representation in the mind. Perception is active investigation of the environment in order to guide potential action of the body in the world (pp. 172-175). The authors find evidence in neuroscience that the pathways in the sensorimotor system are bidirectional, ”perception and action, sensorium and motorium, are linked together as successively emergent and mutually selecting patterns” (p. 163). They find support in *The Structure of Behavior,* an early work by Merleau-Ponty, who states that,

> ”it is the organism itself - according to the proper nature of its receptors, the thresholds of its nerve centers and the movements of the organs – which chooses the stimuli in the physical world to which it will be sensitive” (Merleau-Ponty 1942/1963:13).

When we hear an unexpected sound, auditory perception guides the orientation of the head and the body towards detection of the possible sound source. This is a simple example of embodied auditory perception and action.

The investigations of current neuroscience demonstrate that the processing of auditory information is bidirectional. The ear sends auditory information to the cortex via the ascending pathway, and the cortex regulates the selective sensitivity of the ear via the descending auditory pathway.[9]

The philosopher Alva Noë elaborates on the theme of embodiment in his book *Action in Per-*

8 Stern’s theory displays similarities with the dance theorist Rudolf Laban’s movement analysis. Laban describes the dynamic categories of movement as weight, time, space, and flow (Halfyard 2003).

9 Cf. chapter 6.

ception, emphasizing that perception ”is not a process in the brain, but a kind of skillful activity on the part of the animal as a whole” (2004:2).

Neurophenomenology – the beginnings

In continuation of his philosophy of embodiment as lived experience, Francisco Varela proposed a new direction in neuroscience. He aimed at integrating the investigations intended by phenomenology and the cognitive sciences, and named this approach Neurophenomenology (1996:330-349). Varela stated that in order to bridge the gap between the first-person description of phenomenology and the third-person description of cognitive science, it would be necessary ”that both domains of phenomena have equal status in demanding a full attention and respect for their specificity” (p. 343). This implies that in a neuroscientific experiment, the researcher is obliged to integrate the test participants' first-person accounts of their experience in the validation of the experiment (p. 344).

Varela was aware that it might be a problem to convince scientists that first-person accounts represented a valid domain of investigation, and therefore proposed to gather a research community that could build a sustained tradition of phenomenological examination (p. 330, 346).

Varela passed away in 2001. He is the posthumous co-author of a paper that reports how first-person data can guide the study of brain dynamics (Lutz et al. 2002:1586-1591). In an EEG study of visual depth perception, the participants were trained to perform different perceptual tasks, and to report their experience afterwards (p. 1587). The study showed that EEG synchrony patterns depended on the task and the degree of preparation, and that the patterns were stable for several recordings. The authors found that the neural response was shaped by the preparation of the ongoing activity, as reported by the first-person data communicated by the participants (p. 1586). Similarly, Jack & Roepstorff (2002:333-339) argue that the systematic collection of introspective reports ought to be added in the protocols of brain imaging experiments.

Neurophenomenology – an unfinished project

Subsequently to the 1996 article on neurophenomenology, Francisco Varela and a group of authors published the book *Naturalizing Phenomenology* (1999). In this book, they launched the ambitious project of reconciling phenomenological philosophy with natural science. They defined naturalized phenomenology to be ”integrated into an explanatory framework where every acceptable property is made continuous with the properties admitted by the natural sciences” (Petitot, Varela, Pachoud & Roy 1999:1-2).

The interest in this project at the beginning of the 21st Century gave rise to comprehensive research programs (Lutz & Thompson 2003). Thompson sums up that,

> ”the neurophenomenological approach is to obtain detailed first-person data through careful phenomenological investigation of experience and to use these original first-person data to uncover new third-person data about the physiological processes crucial for consciousness. One central aim of experimental neurophenomenology is thus to generate new data by incorporating careful phenomenological forms of investigation into the experimental protocols of neuroscientific research on consciousness” (2007:339).

However, only a limited number of neuroscientific experiments attempted the integration of first-person and third-person data. The EEG study by Lutz et al. (2002) appears to have produced convincing results. Gallagher and Zahavi (2008:162-166) discuss neuroscientific PET studies that investigated the neural correlates of intentional action (Farrer & Frith 2002; Farrer et al. 2003). These experiments did not lead to definitive conclusions.

The early attempts were not followed by related studies. Varela's project has not found widespread adoption (Allefeld 2008:18). Varela's wish of establishing a phenomenologically oriented research community has not been fulfilled.

In a recent publication, Zahavi (2010:14-15) discusses the possibility of establishing a naturalized phenomenology. He dissociates himself from the radical definition proposed by Petitot et al. in 1999, and suggests a more modest proposal, arguing that,

> ”a naturalized phenomenology is the kind of phenomenology that engages in a meaningful and productive exchange with empirical science. Phenomenology can question and elucidate basic theoretical assumptions made by empirical science, just as it might aid in the development of new experimental paradigms. Empirical science can present phenomenology with concrete findings that it cannot simply ignore, but must be able to accomodate; evidence that might force it to refine or revise its own analyses.”

A reconciliation of phenomenology and neuroscience according to Zahavi's proposal may not be impossible. Yet, the integration of the first-person perspective of phenomenology and the third-person perspective of neuroscience remains a demanding task. It will require a considerable working effort from both parties, and an untiring willingness to reconsider established convictions and procedures in philosophy and science.

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