NIELS TRUSBAK HAUMANN

An Introduction to Cognitive Musicology

Historical-Scientific Presuppositions in the Psychology of Music

Introduction

Cognitive Musicology originates in part in an interdisciplinary tradition of studying music from the perspective of psychology.[1] This tradition was initiated in 1863 by Hermann von Helmholtz,[2] and is sometimes called psychomusicology.[3] The introduction of new, non-invasive methods for studying the brains of humans while they play or listen to music,[4] and new methods in computer modeling[5] has attracted renewed attention to this field.[6] The recently revitalized interest in interdisciplinary studies,[7] the need to test music theory empirically,[8] and a focus on new applications of music theory[9] may also have contributed to an increasing interest in Cognitive Musicology.

1 David Huron, ″Music and Mind: Foundations of Cognitive Musicology,″ Department of Music, University of California, Berkeley, http://www.music-cog.ohio-state.edu/Music220/Bloch.lectures/Bloch.lectures.html (accessed October 2, 2013).

2 Diana Deutsch et al., ″Psychology of Music,″ *Grove Music Online*, (accessed October 2, 2013); Jack Taylor, "The Evolution and Future of Cognitive Research in Music," *Arts Education Policy Review* 94, 6 (1993): 35-39. http://dx.doi.org/10.1080/10632913.1993.9936940; Marc Leman, *Music, Gestalt, and Computing: Studies in Cognitive and Systematic Musicology* (New York: Springer, 1997): 2; János Maróthy, "Cognitive Musicology, Praised and Reproved," *Studia Musicologica Academiae Scientiarum Hungaricae* 41, 1 (2000): 119-123. http://dx.doi.org/10.1556/SMus.41.2000.1-3.5.

3 Taylor, *The Evolution and Future of Cognitive Research in Music*, 35-39.

4 Mari Tervaniemi and Titia L. van Zuijen, ″Methodologies of Brain Research in Cognitive Musicology,″ *Journal of New Music Research* 28, 3 (1999), 200-208. http://dx.doi.org/10.1076/jnmr.28.3.200.3114; Ole Kühl, *Musical Semantics* (Bern: Peter Lang, 2007), 29.

5 Hendrik Purwins et al., ″Computational Models of Music Perception and Cognition I: The Perceptual and Cognitive Processing Chain,″ *Physics of Life Reviews* 5, 3 (2008a): 151-168. http://dx.doi.org/10.1016/j.plrev.2008.03.004; Hendrik Purwins et al., "Computational Models of Music Perception and Cognition II: Domain-Specific Music Processing," *Physics of Life Reviews* 5, 3 (2008b): 169-182. http://dx.doi.org/10.1016/j.plrev.2008.03.005.

6 E.g. see Benny Karpatschof and Lars Ole Bonde, *Tema: Musik Og Psykologi* (Copenhagen: Dansk Psykologisk Forlag, 2007).

7 Maróthy, ″Cognitive Musicology, Praised and Reproved.″

8 Eric F. Clarke and Nicholas Cook, *Empirical Musicology: Aims, Methods, Prospects* (New York: Oxford University Press, 2004), 5; Jukka Louhivuori, "Systematic, Cognitive and Historical Approaches in Musicology," *Lecture Notes in Computer Science* 1317 (New York: Springer, 1997), 30-41. http://dx.doi.org/10.1007/BFb0034105; Leman, *Music, Gestalt, and Computing: Studies in Cognitive and Systematic Musicology*, 1.

9 Louhivuori, *Systematic, Cognitive and Historical Approaches in Musicology*, 30-41; Leman, *Music, Gestalt, and Computing: Studies in Cognitive and Systematic Musicology*, 1.

Since Cognitive Musicology is partly based on a 150-year interdisciplinary tradition in the psychology of music, a review of the history of the ideas and discoveries within this tradition is appropriate. With this historical overview, I offer a foundation for understanding the basic ideas and terms that underlie Cognitive Musicology. I expect that the early ideas and discoveries in the psychology of music will provide an inspiring introduction to the more elaborate and detailed research that is taking place today.[10] I also hope that the historical-scientific overview and suggested solutions to recent methodological problems in Cognitive Musicology will stimulate reflection and discussions related to current research. The focus of this introduction is the presentation of basic empirical research, which is reported in the English literature. However, a few works related to applied research,[11] theories without empirical evidence, and non-English literature will be mentioned. The historical overview focuses on the early development of ideas and discoveries in the psychology of music during the late 19th century, and the first decades of the 20th century. This historical overview is primarily based on the review papers by Diserens's *Reactions to musical stimuli* (1923),[12] Mursell's *Psychology of Music* (1932),[13] and Schultz and Schultz's *A History of Modern Psychology* (2004).[14] It should also be mentioned that the Freudian psychoanalytic or psychodynamic tradition has had a critical influence on the history of psychology, and to some extent, is popular in the humanities, but it is rarely referred to in empirically-based research in cognitive psychology[15] or Cognitive Musicology, and therefore is not introduced here.

In the following sections, I intend to offer a historical overview that focuses on separate approaches. Although the ideas and methods of these approaches vary, they were developed during approximately the same time period, and therefore I do not attempt to present a single chronological, historical overview claiming that one approach is chronologically followed by the next, except for the preceding, early approaches in the 19th century (section 3) and the more recent cognitive and neuroscience approaches of the late 20th century (sections 9 and 10). First, I propose a definition of Cognitive Musicology (section 2), and subsequently present early precursors of a psychology of music in c. 1850-1870 (see section 3). Thereafter, five different approaches to the psychology of music, developed separately during the 1870s through the 1930s, are explained. The first atomistic and Gestalt approaches introduce the still-relevant discus-

10 For a briefer historical overview of the psychology of music, see Deutsch et al., "Psychology of Music".

11 For an introduction to research in music therapy see Thomas Wosch and Tony Wigram, eds., *Microanalysis in Music Therapy: Methods, Techniques and Applications for Clinicians, Researchers, Educators and Students* (London: J. Kingsley, 2007); Lars Ole Bonde, *Musik og menneske: Introduktion til musikpsykologi* (Frederiksberg: Samfundslitteratur, 2009).

12 C. M. Diserens, "Reactions to Musical Stimuli," *Psychological Bulletin* 20, 4 (1923), 173-199. http://dx.doi.org/10.1037/h0071546.

13 James L. Mursell, "Psychology of Music," *Psychological Bulletin* 29, 3 (1932), 218-241. http://dx.doi.org/10.1037/h0074849.

14 Duane P. Schultz and Sydney Ellen Schultz, *A History of Modern Psychology*, 8th ed. (Australia, Belmont, CA: Thomson/Wadsworth, 2004).

15 However, see Drew Westen, "The Scientific Legacy of Sigmund Freud: Toward a Psychodynamically Informed Psychological Science," *Psychological Bulletin* 124, 3 (1998), 333-371. http://dx.doi.org/10.1037/0033-2909.124.3.333.

sions of the definition of mental representations of music, the problems of explaining how musical structure is perceived as analytical elements, such as individual pitches, beats, and sound qualities, and the challenge of explaining how particular combinations of these pitches, beats, and sound qualities are perceived as musical patterns (sections 4-5). The following section introduces the functionalist approach, which anticipates the more recent discussions of the bio-cultural evolution of music as a human, aesthetic, art form, and presents discussions on the ecology (i.e. physical and social environments) of music (section 6). These are followed by the aptitude testing and behaviorist approaches, which address the development of objective tests and tools for measuring musical skills and reactions to music, and which are fundamental to the current methods for measuring musical structures, music perception, and musical performance (sections 7-8). Sections 9 and 10 outline the more recent cognitive and neuroscience approaches to the psychology of music, which combine and add further perspectives and methods to the preceding ones. The research methods of the humanities and the natural sciences were developed after the discoveries of the late 19th and early 20th centuries, presented here. Therefore, although the reliability of the presented results is open to discussion, they are not discussed here (see section 2 for a review of the current knowledge and methods of Cognitive Musicology). However, the final section (section 11) briefly highlights the most important historical dialectics in a discussion about the general, inherent methodological problems and possibilities that remain relevant to Cognitive Musicology today.

What is Cognitive Musicology?

Cognitive Musicology is a fairly recent subdiscipline of musicology that suggests drawing on disciplines outside traditional musicology, to study and explain musical phenomena. It finds its primary approaches to music in the interdisciplinary fields of the Cognitive Sciences.[16] The goal of the Cognitive Sciences is to study how humans apply and respond to any kind of information. In Cognitive Musicology, the basic theory is that music may be understood as a type of information that humans process. To study how humans process any information in the world in which we live, the Cognitive Sciences combine theories and research methods from the humanities and the natural sciences, such as psychology, semiotics, computer science, and neuroscience. Cognitive Musicology seeks to answer questions particularly concerned with how musical information is processed. In contrast, the music psychology and the neuroscience of music consider music an example that explains other, more general, psychological and neurological mechanisms.

According to Huron, the basic theory of Cognitive Musicology is that musical information may be understood as mental representations resulting from sensory sound impressions and thought processes.[17] These mental representations of music are mod-

16 Huron, *Music and Mind: Foundations of Cognitive Musicology.*
17 *Ibid.*

ulated by knowledge, attention, motivation, and conscious reflection. I suggest that Cognitive Musicology seeks to answer six general questions with regard to mental representations of music: How do we perceive and acquire musical information?[18] How does musical information evoke moods or emotions in the listener?[19] How do musicians and composers perform music and imagine musical information?[20] How is musical information organized in the human brain?[21] How is musical information embodied and constrained through social and physical interactions between musician, music instrument, and audience?[22] How is musical information embedded in cultural environments, and received across cultures?[23]

Within Cognitive Musicology, the questions of musical information processing are studied by applying a vast range of theoretical, quantitative empirical methods, and computer modeling methods from the Cognitive Sciences. More seldom, qualitative empirical methods have been introduced in research on music information processing. The qualitative methods are applied to study humans' immediate spoken or written impressions of specific musical phenomena, for example, the phenomenon of the "earworm," that is, a piece of music that continually repeats in a person's mind after it is no longer heard.[24]

Theoretical methods in Cognitive Musicology combine theories of musical structures with theories of how the human mind processes musical information. These interdisciplinary theories provide theoretical tools to analyze the perceptions and experiences of the tonal and rhythmic structures in music.[25] Also, theoretical methods are applied, to analyze associations of music and meanings, beyond the domains of sounds and musical structures.[26] An example of these cognitive theories is Fauconnier and Turner's Conceptual Integration Network theory, which is applied to analyze

18 E.g. Carol L. Krumhansl, "Rhythm and Pitch in Music Cognition," *Psychological Bulletin* 126, 1 (2000): 159-179. http://dx.doi.org/10.1037/0033-2909.126.1.159; Erin E. Hannon and Laurel J. Trainor, "Music Acquisition: Effects of Enculturation and Formal Training on Development," *Trends in Cognitive Sciences* 11, 11 (2007), 466-472. http://dx.doi.org/10.1016/j.tics.2007.08.008.

19 E.g. Patrik N. Juslin and Daniel Västfjäll, "Emotional Responses to Music: The Need to Consider Underlying Mechanisms," *The Behavioral and Brain Sciences* 31, 5 (2008): 559-575. http://dx.doi.org/10.1017/S0140525X08005293.

20 E.g. Caroline Palmer, "Music Performance," *Annual Review of Psychology* 48, 1 (1997): 115-138. http://dx.doi.org/10.1146/annurev.psych.48.1.115; Timothy L. Hubbard, "Auditory Imagery: Empirical Findings," *Psychological Bulletin* 136, 2 (2010): 302-329. http://dx.doi.org/10.1037/a0018436.

21 E.g. Isabelle Peretz and Robert J. Zatorre, "Brain Organization for Music Processing," *Annual Review of Psychology* 56, 1 (2005): 89-114. http://dx.doi.org/10.1146/annurev.psych.56.091103.070225; Eckart O. Altenmüller, "How Many Music Centers are in the Brain?" *Annals of the New York Academy of Sciences* 930, 1 (2001): 273-280. http://dx.doi.org/10.1111/j.1749-6632.2001.tb05738.x.

22 E.g. Marc Leman, *Embodied Music Cognition and Mediation Technology* (Cambridge, MA: MIT Press, 2007).

23 E.g. Steven J. Morrison and Steven M. Demorest, "Cultural Constraints on Music Perception and Cognition," *Progress in Brain Research* 178 (2009): 67-77. http://dx.doi.org/10.1016/S0079-6123(09)17805-6.

24 Victoria J. Williamson et al., "How do "earworms" Start? Classifying the Everyday Circumstances of Involuntary Musical Imagery," *Psychology of Music* 40, 3 (2011): 259-284. http://dx.doi.org/10.1177/0305735611418553.

25 E.g. Fred Lerdahl and Ray S. Jackendoff, *A Generative Theory of Tonal Music* (Cambridge, Mass: MIT Press, 1983); Fred Lerdahl, *Tonal Pitch Space* (New York: Oxford University Press, 2001).

26 E.g. Lawrence Michael Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis* (New York: Oxford University Press, 2002); Kühl, *Musical Semantics*.

how tonal and rhythmic structures in Franz Schubert's music for the song, *Trockne Blumen*, enhances the changing lyrics about dying flowers versus blooming flowers, and the main character's alternating emotional state.[27] Furthermore, Marshall and Cohen's Congruence-Associationist model is used to explain how matching features of musical and dynamic visual structures strengthen interpretations of movies.[28]

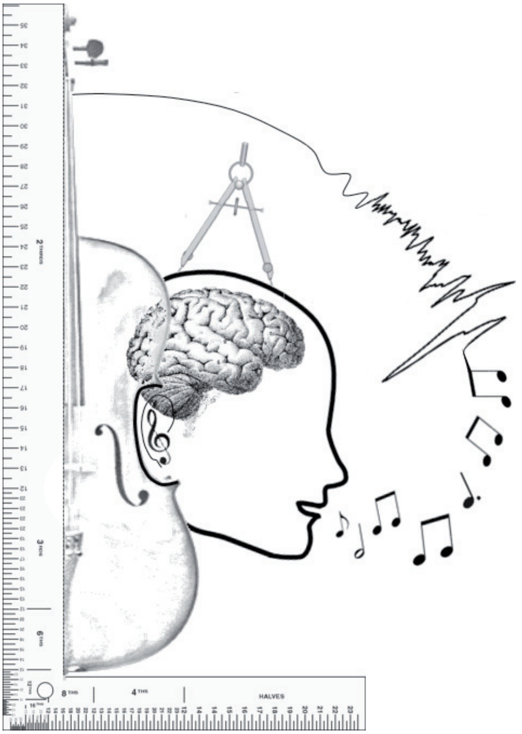


Figure 1: Art work illustrating empirical methods in Cognitive Musicology.[32]

If a theory has not been tested empirically, the reliability of the theory is uncertain. Specific hypotheses, or testable claims, may be derived from theories, and these hypotheses may be tested with quantitative empirical methods. One type of empirical method is quantitative music analysis. This method is based on measuring the number of occurrences of a specific musical structure in musical information from notated music or recorded improvisations,[29] or the intensity of certain sound parameters in recorded musical information as sound media, for example.[30] Quantitative music analysis may be applied to empirically test hypotheses regarding musical structures or sounds of specific music genres, styles, historical periods, or music of specific world cultures.[31]

27 Lawrence M. Zbikowski, "The Blossoms of 'Trockne Blumen': Music and Text in the Early Nineteenth Century," *Music Analysis* 18, 3 (1999): 307-345. http://dx.doi.org/10.1111/1468-2249.00098.

28 Sandra K. Marshall and Annabel J. Cohen, "Effects of Musical Soundtracks on Attitudes Toward Animated Geometric Figures," *Music Perception* 6, 1 (1988): 95-112; also see Annabel J. Cohen, "Music as a Source of Emotion in Film," in *Handbook of Music and Emotion: Theory, Research, Applications*, eds. Patrik N. Juslin and John A. Sloboda (Oxford, New York: Oxford University Press, 2010), 879-908.

29 E.g. "Center for Computer Assisted Research in the Humanities at Stanford University." http://www.ccarh.org/ (accessed October 2, 2013); Jaakko Erkkilä, "Music Therapy Toolbox (MTTB) – an Improvisation Analysis Tool for Clinicians and Researchers," in *Microanalysis in Music Therapy*, eds. Thomas Wigram and Tony Wheeler (London: Jessica Kingsley Publishers, 2007), 134-148.

30 Olivier Lartillot, Petri Toiviainen and Tuomas Eerola, "MIRtoolbox," Finnish Centre of Excellence in Interdisciplinary Music Research, https://www.jyu.fi/hum/laitokset/musiikki/en/research/coe/materials/mirtoolbox (accessed October 2, 2013); Olivier Lartillot and Petri Toiviainen, "A Matlab Toolbox for Musical Feature Extraction from Audio" 2007).

31 For an introduction, see Clarke and Cook, *Empirical Musicology: Aims, Methods, Prospects*.

32 Adapted from Cognitive and Systematic Musicology Laboratory, Ohio State University, http://musiccog.ohio-state.edu/home/index.php/Home

Another empirical method is the quantitative psychological method, which may involve measurements based on questionnaires exploring subjective ratings on a specific, adjective numerical scale.[33] For example, a questionnaire on emotional impressions of certain music could contain the following question: "Is the music 1: slightly pleasant, 2: pleasant, or 3: very pleasant?" Other, more objective, quantitative psychological measures that are applied to the study of musical phenomena are measurements of the speed of people's responses, the number of correct responses to a specific musical task, and measurements of people's physical movements, for example, studying whether a certain type of music motivates a person to move or dance in particular ways.

A third type of quantitative method comprises neurophysiological methods, which provide measurements of brain activity as people listen to, or play music.[34] Brain activity may be measured with various neuroimaging methods. These neuroimaging methods are based on more advanced technologies, which require a more elaborate introduction, when compared to the other methods introduced here. One of these methods is structural Magnetic Resonance Imaging (structural MRI), which requires the subject to lie in a Magnetic Resonance (MR) scanner tube. Structural MRI scans are assumed to indirectly yield measurements of the sizes of specific regions of the brain, which may be compared with levels of musical expertise. The functional MRI (fMRI) method provides indirect measurements of changes in the level of oxygen in the blood going to specific regions of the brain, which is believed to be an indication of musical information processes in these brain regions. However, the MR scanner produces a high level of noise during the fMRI measurements, which could disturb the listening experience. Electroencephalography (EEG) is another neuroimaging method, which measures electrical activity in the brain via electrodes in a cap worn by the subject. The related method of magnetoencephalography (MEG) can measure the magnetic fields generated by electrical activity in the brain through Superconducting Quantum Interference Device (SQUID) sensors in a scanner, with a helmet positioned around and above the subject's head. The EEG and MEG methods are assumed to indicate strong, synchronous, electrical potentials from a large group of neurons in the brain, related to specific types of music information processes. For example, the processing of a deviating tone in a musical scale or a deviating beat in a rhythm may generate certain measurable electrical potentials and magnetic fields in the brain. The positron emission tomography (PET) method is also applied to the study of music-information processing in the brain. PET may indirectly measure specific changes in the levels of chemical substances in the brain, for example, changes in the levels of pleasure-related dopamine hormones secreted by regions of the brain, while a person plays or listens to specific music. However, the experimental situation with neuroimaging measures is often rather different from the everyday experience of playing and listening to music, and most methods involve a tradeoff between

33 Darren Langdridge, *Introduction to Research Methods and Data Analysis in Psychology* (Harlow: Prentice Hall, 2004), 74f.

34 E.g. Tervaniemi and van Zuijen, *Methodologies of Brain Research in Cognitive Musicology*, 200-208; Karl J. Friston et al., *Statistical Parametric Mapping: The Analysis of Functional Brain Images* (Amsterdam, Boston: Elsevier/Academic Press, 2007).

the precision of the measured timescale, which is important in music, particularly for rhythms, and the precision in locating the measured brain region.[35] Another problem with the quantitative methods in general is that it is difficult, and often impossible to measure realistic and complex musical information processes, but generally, they may be used to provide evidence of a smaller part of a musical information process.

In Cognitive Musicology, computer modeling methods are also applied to simulate the processing of musical information from the low level of the cochlea in the ears, to higher levels of music perception and cognition in the brain.[36] Furthermore, computer models that can simulate emotional experiences of music have been developed.[37] However, because an endless number of computer models, with varying levels of detail, can simulate the same musical information processes, and because the behavior of the computer models becomes more difficult to analyze as they become more complex, these computer models may be considered illustrative and practical tools for the automated classification of musical characteristics, genres, moods, or for automated music composition, and their scientific reliability should be evaluated with regard to their internal logic, as well as their empirical support.

Research in Cognitive Musicology studies how the human mind processes information related to music, while playing or listening to music. These studies apply a range of interdisciplinary theories from musicology and the cognitive sciences, quantitative psychological and neurophysiological measures, and also, to a lesser extent, qualitative methods. The following sections explain how these cognitive theories and methods for studying music originate partly in basic ideas and discoveries presented during the historical development of a psychology of music.

Emergence of a Psychology of Music

Functions, meanings, and emotions in music have been considered for thousands of years. In ancient Greece, music with specific emotional associations was suggested for certain occasions, for example, for wars, religious rituals, or relaxation.[38] During the Middle Ages and the Renaissance, music composers suggested relations between meanings of song lyrics and figures of musical structures, for example, a movement to-

35 Kühl, *Musical Semantics*, 94.

36 E.g. Purwins et al., "Computational Models of Music Perception and Cognition I: The Perceptual and Cognitive Processing Chain"; Purwins et al., "Computational Models of Music Perception and Cognition II: Domain-Specific Music Processing"; DeLiang Wang and Guy J. Brown, eds., *Computational Auditory Scene Analysis: Principles, Algorithms, and Applications* (Hoboken, New Jersey: John Wiley & Sons, Inc, 2006); Barbara Tillmann, Jamshed J. Bharucha and Emmanuel Bigand, "Implicit Learning of Tonality," *Psychological Review* 107, 4 (2000): 885-913. http://dx.doi.org/10.1037/0033-295X.107.4.885; Harold E. Fiske, *Connectionist Models of Musical Thinking* (Lewiston, N.Y.: Edwin Mellen Press, 2004).

37 E.g. Youngmoo E. Kim, Erik M. Schmidt and Lloyd Emelle, "MoodSwings: A Collaborative Game for Music Mood Label Collection"; Eduardo Coutinho and Angelo Cangelosi, "The use of Spatio-Temporal Connectionist Models in Psychological Studies of Musical Emotions," *Music Perception* 27, 1 (2009): 1-15.

38 Walter Freeman, "A Neurobiological Role of Music in Social Bonding," in *Origins of Music*, eds. Nils Wallin, Björn Merker and Steven Brown (Cambridge, Massachusetts: MIT Press, 2000), 417.

ward heaven symbolized by an ascending melodic contour.[39] In the late 15th century, there was an increase in theories regarding music's influence on the affective states of an audience, for example, how specific types of music elicit feelings of sadness, anger, or joy.[40] Later, in 1767, Jean-Jacques Rousseau suggested that sounds and music could act as a kind of memory; for example, deployed Swiss soldiers reported feelings of sadness and a desire to defect when they heard the sound of cowbells, or a particular song from their native country.[41] However, it was not until the 19th century that researchers began to ask the questions, "What are the psychological mechanisms underlying music, and how can these be studied with scientific methods?"

In Germany, during the 19th century, there was an increased interest in the application of scientific methods from the natural sciences to the study of subjects concerning the human mind and behavior.[42] In 1850, the physicists Ernst Weber and Gustav Theodor Fechner made a discovery about the perception of the intensity of sounds and music. They found that ratio differences in physical stimulation were perceived as linear differences in intensity.[43] Fechner explained that the result of adding the sound of one bell either to the sound of another bell or to the sound of 10 chiming bells is the same with regard to the difference in physical power. However, our minds seem to perceive physical differences in ratios. Thus, the result of adding the sound of one bell to the sound of another bell would be perceived as a doubling of the sound volume, whereas the result of adding the sound of one bell to the sound of 10 bells would be perceived only as a smaller difference in sound volume of one to 10. This discovery led to the invention of the decibel scale of sound volume used today.

In 1863, the physician Hermann von Helmholtz introduced a new combination of music theory and scientific research on acoustics and the physiology of the ear in his book, *On the Sensations of Tone*. Helmholtz explained that each musical tone consists of multiple partial tones, originating in subdivisions of the vibrations in the instrument that produces the tone, which determines the quality, or timbre, of the musical instrument.[44] Helmholtz suggested that music is perceived as more consonant if the physical sound waves of the partial vibrations of the tones in scales, melodies, and chords overlap in the ear.[45] In contrast, if the combined partial tones in music have slightly different frequencies, slow difference tones, also called "beating tones," are created in the ear, and these beating tones make us perceive the music as more dissonant.[46] Thus, Helmholtz suggested that tones in scales and chords with major thirds overlap and do not result in beating tones. In contrast, the partial tones of minor

39 George J. Buelow, "Figures, Theory of Musical," Grove Music Online, (accessed October 2, 2013).

40 George J. Buelow, "Affects, Theory of The," Grove Music Online, (accessed October 2, 2013).

41 Charlotte Rørdam Larsen, "Husker du? Nutidig genlyd af fortid: Om reklamefilms brug af musik og lyd som nostalgi og kulturel erindring," *Danish Musicology Online* (2012): 50-74.

42 Schultz and Schultz, *A History of Modern Psychology*, 71.

43 *Ibid.*, 77, 79.

44 Hermann L. F. von Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, 2. English ed. (New York: Dover, 1863/1954), 65f.

45 *Ibid.*, 204.

46 *Ibid.*

thirds do not perfectly overlap, and these create rough tones in the ear. This lack or presence of rough or beating tones in the ear provided a physical explanation for why music in a major key is perceived as more consonant than music in a minor key.[47] The difference between the major and minor scales is still being debated and investigated in Cognitive Musicology,[48] and studied by means of neurophysiological methods.

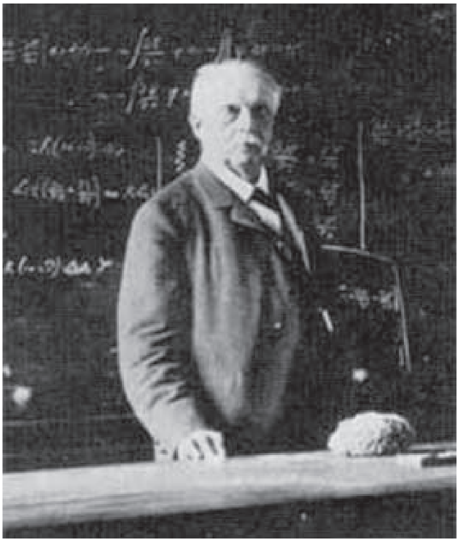


Figure 2: Hermann von Helmholtz.[49]

According to Helmholtz, both physics and culture are important to our experience of music. Helmholtz argued that "the system of scales, modes, and harmonic tissues does not rest solely upon inalterable natural laws, but is also, at least partly, the result of aesthetic principles, which have already changed, and will still further change."[50] Consequently, Helmholtz suggested that the threshold for when a person experiences rough or beating tones as having a particularly dissonant quality is dependent on taste and habit.[51]

Another contribution to the early development of psychomusicology was made by Charles Darwin. In 1871, 12 years after he had published his book, *On the Origin of Species*, Darwin considered how the ability to sing and play music might be explained as a biological adaptation.[52] Darwin suggested that musical abilities may

47 *Ibid.*, 215f.
48 E.g. Lise Gagnon and Isabelle Peretz, "Mode and Tempo Relative Contributions to "Happy-Sad" Judgements in Equitone Melodies," *Cognition & Emotion* 17, 1 (2003): 25-40. http://dx.doi.org/10.1080/02699930302279.
49 Helmholtz Institute, Utrecht University, http://www.fss.uu.nl/psn/Helmholtz/mainsite/Research/Background.html
50 Helmholtz, *On the Sensations of Tone as a Physiological Basis for the Theory of Music*, 235.
51 *Ibid.*
52 Nils Wallin, Björn Merker and Steven Brown, *The Origins of Music* (Cambridge, Massachusetts: MIT Press, 2000), 8.

have offered an advantage in courtship among our human ancestors. Also, he suggested that musical sound expressions were likely related to, and preceded the development of speech. These ideas regarding the evolution of music led to the later discussions of the functions music might serve (see section 6), and whether the same cognitive mechanisms and functional regions in the human brain are reserved for music and language.[53]

In 1882, approximately 10 years after Darwin's considerations about music and evolutionary theory was presented, the explicit idea of a psychology of music was introduced by the psychologist Edmund Gurney. Soon after, in 1883 and 1890, the psychologist Carl Stumpf published the two-volume text on music psychology, called *Psychology of Tone*, which introduces a scientific focus on the physical aspects of music.[54] These early anticipations of a psychology of music were based on theories that combined different disciplines of the 19th century, detailed physical measurements, and mathematical formulas explaining relations between physical sound waves and impressions of sounds and music.

The Earliest Psychological Studies on Elements of Music

In 1875, Wilhelm Wundt established a laboratory at the University of Leipzig, and developed the first experimental methods in psychology.[55] Wundt applied the method of analytical introspection, that is, the observation of one's own mental state.[56] These self-observations were performed by trained psychologists called "observers." The first psychological experiments on emotions concerned emotional impressions of music.[57] Wundt played simple, regular, metronome-click rhythms, and observed how certain rhythms were pleasant and agreeable to him, whereas others were perceived as less pleasant. Also, he discovered that, in anticipation of the next beat, he reacted with more or less tension or relaxation when the next beat was heard. Furthermore, if he made the metronome play the beats faster, he felt more excited, whereas he became more depressed if he played the beats more slowly. Interestingly, the simple idea of playing a regular pattern of beats is still used in 21st-century systematic studies of more complex, rhythmical expectation mechanisms,[58] and neural substrates of rhythmical expectation mechanisms.[59]

53 E.g. Isabelle Peretz and José Morais, "Music and Modularity," *Contemporary Music Review* 4, 1 (1989): 279-293. http://dx.doi.org/10.1080/07494468900640361; Nobuo Masataka, "The Origins of Language and the Evolution of Music: A Comparative Perspective," *Physics of Life Reviews* 6, 1 (2009): 11-22. http://dx.doi.org/10.1016/j.plrev.2008.08.003.

54 Schultz and Schultz, *A History of Modern Psychology*, 111.

55 *Ibid.*, 90.

56 *Ibid.*, 95.

57 *Ibid.*, 97.

58 E.g. Mari Riess Jones et al., "Temporal Aspects of Stimulus-Driven Attending in Dynamic Arrays," *Psychological Science* 13, 4 (2002): 313-319. http://dx.doi.org/10.1111/1467-9280.00458.

59 E.g. Renaud Brochard et al., "The "Ticktock" of our Internal Clock: Direct Brain Evidence of Subjective Accents in Isochronous Sequences," *Psychological Science* 14, 4 (2003): 362-366. http://dx.doi.org/10.1111/1467-9280.24441.

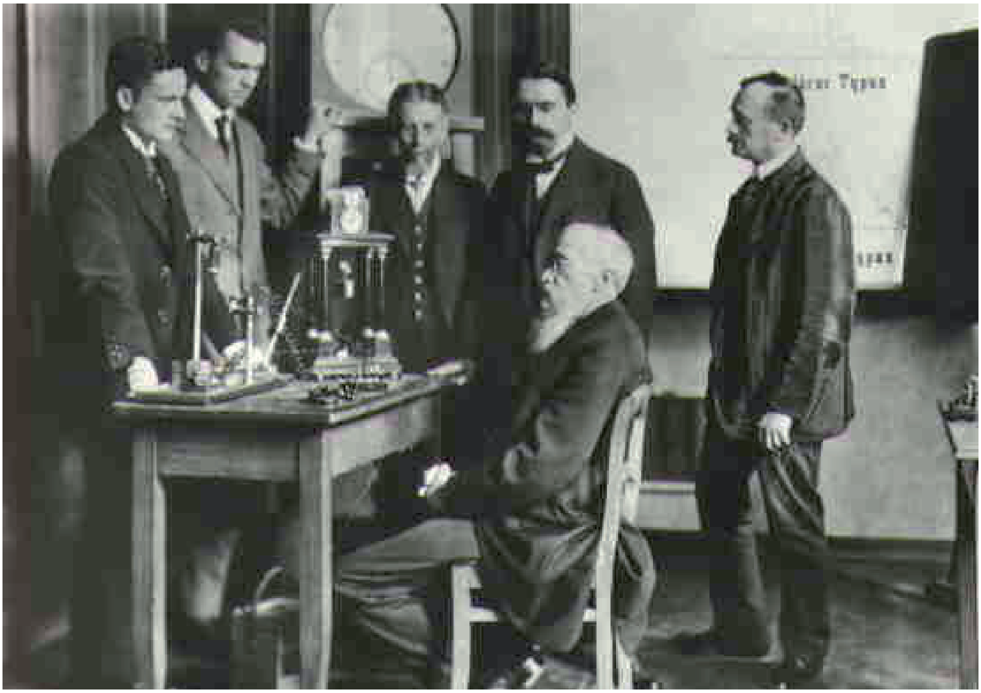


Figure 3: Wilhelm Wundt and his research group.[60]

Inspired by the methods of the natural sciences, including chemistry, Wundt wanted to create a "periodic table" covering the basic "atoms" of the mind.[61] He suggested that these elements could be combined to explain more complex mental structures. In keeping with this line of thinking, Carl Emil Seashore pioneered the psychology of music. Many of the experiments he and his colleagues conducted focused on basic elements of music. These were considered to be pitch, loudness, time, and timbre.[62] They claimed that from these elements, more complex structures, such as harmonies, dynamics, rhythms, and tone qualities, could be formed, as well as musically-derived thoughts, feelings, actions, memories, and imaginings.

In the study of music in psychology, researchers attempted to define music as based on certain basic sound "atoms," and this made it possible to systematically describe the theoretical concepts defined by musicologists. However, Wundt had already realized that "a compound clang is more in its ideational and affective attributes than merely a sum of single tones."[63] Recently, similar criticism of the reduction of music to basic sound "atoms" was put forward in Cognitive Musicology. For example, researchers were criticized for narrowing down the music used in most experiments to test only a few theoretical concepts.[64] Also, it was argued that music is characterized

60 Wikipedia.org
61 Schultz and Schultz, *A History of Modern Psychology*, 94f.
62 Carl Emil Seashore, *Psychology of Music* (New York: McGraw-Hill, 1938), 29.
63 Wilhelm Wundt, *Outline of Psychology* (Leipzig: Engelmann, 1896), 321.
64 Maróthy, "Cognitive Musicology, Praised and Reproved."

by a series of phrases, not by isolated fragments of sound.[65] Studies in which music was reduced to single sounds might be more relevant for investigating the single sounds, than explaining an aspect of music. The subsequent Gestalt approach to psychology suggested inverting the problem. Rather than studying how the parts of music are combined into whole structures, the idea was to study how whole structures of music organize the parts.

The First Psychological Studies of Whole Structures of Music

To solve the problems in Wundt's atomistic approach, Gestalt psychologists Max Wertheimer, Kurt Koffka, and Wolfgang Köhler demonstrated that sensory elements are formed in patterns, also called Gestalts.[66] They attempted to describe the principles of these Gestalts. Different musicologists had already defined principles of relationships among musical elements, prior to the development of Gestalt psychology. In 1838, the musicologist Adolf Bernhard Marx argued that music is composed of forms that are combined into larger compound forms by following specific principles of organization.[67] Also, in 1895, the musicologist Hugo Riemann introduced his theory of harmonic functions, in which he defined principles of appropriate relations between series of chords.[68]

The first ideas in Gestalt psychology were also related to music.[69] Thus, in 1885, Ernst Mach explained that a melody emerges when you compile a group of musical notes, but the melody is independent of the particular, individual tones.[70] Christian von Ehrenfeldts demonstrated that a melody has a form quality that may also be recognized if the melody is played in a higher or lower key; it consists of a pattern of different tones. The Gestalt psychologists termed this ability to perceive a pattern as the same, even if its elements are shifted as a group, as the phenomenon of perceptual constancy.[71]

Gestalt psychology discovered several principles of perceptual organization, but these principles were not fully applied to sounds and music until the 1970s through the 1990s, by the psychologist Albert Bregman.[72] According to these Gestalt principles, a series of tones are perceived as a coherent melody when they follow one another at a *close distance* or are in close *proximity* in onset time, tone height, and loudness, when there is

65 Taylor, "The Evolution and Future of Cognitive Research in Music."
66 Schultz and Schultz, *A History of Modern Psychology*, 358, 362.
67 Adolf Bernhard Marx, *Die Lehre Von Der Musikalischen Komposition, Praktisch Theoretisch: I-IV.* (Leipzig: Breitkopf & Härtel, 1871-1879), II, 5-7.
68 Brian Hyer and Alexander Rehding, "Riemann, Hugo," *Grove Music Online* (accessed October 2, 2013).
69 Purwins et al., "Computational Models of Music Perception and Cognition I: The Perceptual and Cognitive Processing Chain."
70 Schultz and Schultz, *A History of Modern Psychology*, 360.
71 *Ibid.*
72 Albert S. Bregman, *Auditory Scene Analysis: The Perceptual Organization of Sound* (Cambridge, MA: MIT Press, 1990); David Huron, "Tone and Voice: A Derivation of the Rules of Voice-Leading from Perceptual Principles," *Music Perception* 19, 1 (2001): 1-64. http://dx.doi.org/10.1525/mp.2001.19.1.1; Schultz and Schultz, *A History of Modern Psychology*, 372; Purwins et al., "Computational Models of Music Perception and Cognition I: The Perceptual and Cognitive Processing Chain."

continuity in the change of tone heights and volume in the sequence of tones, and when they have *similar* sound qualities that are produced by the musical instrument. Moreover, if the melody is briefly interrupted by a break or masked by noise, the perception principles still ensure a *closure* of this gap or *good form* that unites the perception of the melody. Furthermore, increased attention to the rhythm, for example, may enhance a rhythmic *figure* in the melody, and draw the tonal patterns into the *background*.

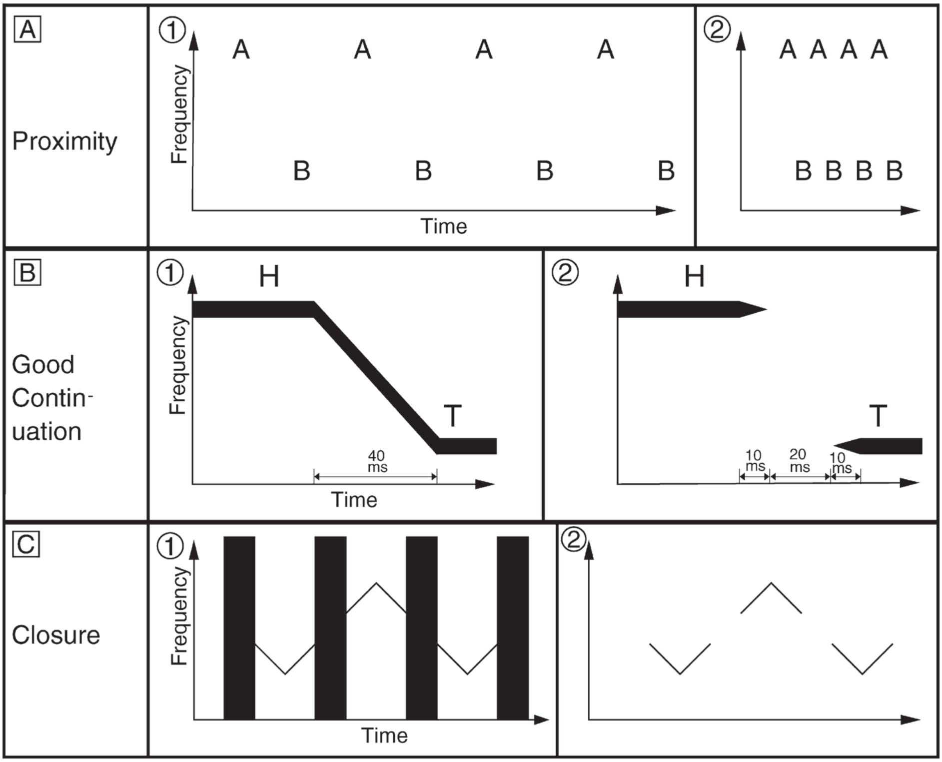


Figure 4: Illustrations of Gestalt grouping principles in sound perception, based on proximity, continuity, and closure, with respect to time (horizontal axis) and frequency or tone (vertical axis). From Purwins et al. (2000).[73]

The Gestalt approach also inspired the early development of new approaches to research on music and the education of musicians. Between the 1910s and 1920s, it was suggested that the structure[74] and the formation of meaningful patterns[75] affect the ability to learn new melodies, and professional musicianship could be regarded as a unitary

73 Figure 1 from Hendrik Purwins, Benjamin Blankertz and Klaus Obermayer, "Computing auditory perception", *Organised Sound* 5, 3 (Cambridge University Press, 2000): 159-171. The figure is shown with permission from the authors and publisher. http://dx.doi.org/10.1017/S1355771800005069.

74 Christian Paul Heinlein, "A Brief Discussion of the Nature and Function of Melodic Configuration in Tonal Memory, with Critical Reference to the Seashore Tonal Memory Test," *Pedagogical Seminary and Journal of Genetic Psychology* 35 (1928): 45-61. http://dx.doi.org/10.1080/08856559.1928.10532135.

75 Kate Gordon, "Some Tests on the Memorizing of Musical Themes," *Journal of Experimental Psychology* 2, 2 (1917): 93-99. http://dx.doi.org/10.1037/h0073224.

set of skills, rather than consisting of various subskills.[76] A combined approach was also suggested in 1928, as A. W. Brown discussed how a musician learning to play the piano might benefit differently when focusing on the parts or the whole of the music.[77] Thus, the atomistic and Gestalt approaches introduced, respectively, 1) a bottom-up perspective to music that focuses on how different lower level elements of music combine into a coherent, higher level experience, 2) a top-down approach that considers how higher level musical wholes determine the lower level structure of musical parts, and 3) an alternation between these perspectives. These theoretical considerations later became important for the development of the cognitive approach to music (see section 9).

With the increasing complexity of the Gestalt approach, it also became increasingly difficult to distinguish between the elements that were measured in the psychological experiments. Another general problem with the approaches introduced so far is the exclusive focus on sounds and musical structures. The functional approach to the psychology of music also emphasized questions of why music evolved as an art form, which functions music might serve, and how functions of music might evolve in physical and social environments.

Emergence of Studies of Musical Functions and Environments

Various researchers have emphasized that the mind does not exist in isolation. It is connected to biologically evolved body and brain functions, and is shaped by the physical and social environments with which we interact. Around 1900, a new approach to psychology, called "functional psychology," was established in the United States.[78] The functional approach was introduced between 1860 and 1897 by Herbert Spencer, who argued that the human mind exists in its present form as the result of continuous adaptation to its environment.[79] In 1890, William James claimed that the body and the brain are involved in shaping our immediate experiences.[80] In 1904, James Rowland Angell argued that it is more relevant to study mental operations, rather than mental elements, because mental operations serve specific functions.[81] In line with these ideas, it was discovered that the human brain contains functional regions that seem to implement mental operations, and if these regions of the brain are damaged or lost, the ability to understand sounds and music is also damaged or lost. By 1874, Carl Wernicke discovered that the so-called Wernicke's area in the temporal lobe of the brain is involved in the ability to understand sounds in spoken languages.[82] Also, in 1922, Quensel and Pfeiffer discovered a patient with more specific brain damage, who was able to understand language, but could not recognize melo-

76 Geza Révécz, "Prufung Der Musikalitat," *Zsch.F.Psychol* 85 (1920): 163-209.

77 A. W. Brown, "The Reliability and Validity of the Seashore Tests of Musical Talent," *Journal of Applied Psychology* 12, 5 (1928): 468-476. http://dx.doi.org/10.1037/h0072753.

78 Schultz and Schultz, *A History of Modern Psychology*, 171.

79 *Ibid.*, 174.

80 *Ibid.*, 182.

81 *Ibid.*, 197.

82 Tervaniemi and van Zuijen, "Methodologies of Brain Research in Cognitive Musicology."

dies.[83] These early lesion studies precede the contemporary research on the functional regions of music in the brain.[84]

The emotional roles of music were increasingly discussed and investigated. In 1916, Margaret Floy Washburn speculated that emotional responses to music may have developed from ancient social adaptations.[85] However, more concrete explanations were also discussed. Following the musicological ideal of so-called "absolute music," or music regarded as pure sound structures, in 1928 Max Schoen stated that music did not have a representational nature.[86] In line with this idea in the 1920s Carl Emil Seashore, Sophie Belaiew-Exemplarsky, and Boleslaus Jaworsky suggested that emotional responses to music are related to certain mechanisms that involves "artistic fluctuations from regularity."[87] More specifically, if a part of the musical structure deviates from a normally expected structure, then it might elicit an emotion in the listener. This mechanism was later investigated in 1956 by Leonard Meyer,[88] and more recently elaborated by David Huron.[89] On the other hand, in 1912, by following the musicological idea of program music, Henry Porter Weld argued that emotional responses to music are related to mechanisms of association and imagery in various modalities.[90] Thus, music could also be associated with specific emotions that are not inherent in the musical structure itself. Moreover, the way in which the enjoyment of music differs among types and ages of listeners, attitudes in listening to music, and depends on repetitive exposure and familiarity with a piece of music were also studied.[91] Consequently, in 1926, on the basis of studies of the relation between music and emotions, Charles Diserens discussed the possible applications of music as a type of psychological therapy, anticipating the more recent developments in music therapy.[92] Interesting-

83 Simone Dalla Bella and Isabelle Peretz, "Music Agnosias: Selective Impairments of Music Recognition after Brain Damage," *Journal of New Music Research* 28, 3 (1999): 209-216. http://dx.doi.org/10.1076/jnmr.28.3.209.3108.

84 E.g. see Peretz and Zatorre, "Brain Organization for Music Processing"; Altenmüller, "How Many Music Centers are in the Brain?"

85 Margaret Floy Washburn, "Psychology of Aesthetic Experience in Music," *N. E. E. Proc.* (1916): 600-606.

86 Max Schoen, "The Aesthetic Attitude in Music," *Psychological Monographs* 39, 2 (1928): 162-183. http://dx.doi.org/10.1037/h0093345.

87 Mursell, *op. cit.*: 224; Carl Emil Seashore, "Measurements on the Expression of Emotion in Music," *Proceedings of the National Academy of Sciences of the United States of America* 9, 9 (1923): 323-325. http://dx.doi.org/10.1073/pnas.9.9.323; Carl Emil Seashore, "A Base for the Approach to Quantitative Studies in the Aesthetics of Music," *The American Journal of Psychology* 39 (1927): 141-144; Sophie Belaiew-Exemplarsky and Boleslaus Jaworsky, "Die Wirkung Des Tonkomplexes Bei Melodischer Gestaltung," *Archiv Fur Die Gesamte Psychologie* 57 (1926): 489-522.

88 Leonard B. Meyer, *Emotion and Meaning in Music* (Chicago: The University of Chicago Press, 1956).

89 David Brian Huron, *Sweet Anticipation: Music and the Psychology of Expectation* (Cambridge, Mass.: MIT Press, 2006), 2.

90 Harry Porter Weld, "An Experimental Study of Musical Enjoyment," *The American Journal of Psychology* 23, 2 (1912): 245-308.

91 *Ibid.*; Max Schoen, ed., *The Effects of Music* (San Diego, California: Harcourt, Brace and Company, 1927); Sophie Belaiew-Exemplarsky, "Das Musikalische Empfinden Im Vorschulalter," *Zeitschrift Für Angewandte Psychologie* 27 (1926): 177-216.

92 Charles Murdock Diserens, *The Influence of Music on Behavior* (Princeton: Princeton University Press, 1926).

ly, the suggested basic mechanisms involved in the effects of music on the emotions have been found to be relevant, and are still studied today; however, additional emotional mechanisms have been added since the early discussions.[93]

Figure 5: The functionalist approach might introduce discussions of how music evolved in physical and social environments, and which purposes music might serve. For example, in some cases, a musician might play music to create emotional states.[94]

The functional approach introduced ideas concerning the evolution of music perception and performance in physical and social environments. In 1896, John Dewey suggested thinking of the relationship between an organism and the environment in which it functions as circular.[95] Dewey rejected the idea that we sense something in an environment, and only react to this sensation (as suggested by the behaviorist approach, see section 8). Instead, Dewey argued that we perform whole, coordinated acts, which involve continuous, circular relations between actions and sensations. Dewey's proposed circular relationship of coordinated actions and sensations was supported by a 1925 study by R. M. Mosher. Mosher discovered that the more accurately people could transcribe music (notate music they heard), the better they could read other music and sing it aloud, and vice versa.[96] Thus, the concept of notated music could be regarded as a result of a coordinated act, which involves a circular relationship between the organism, who knows how to read music and sing it aloud in the environment (of physical and social objects), and the organism, who hears music in the environment and knows how to write it down, and vice versa. Also, coordinated relations between actions and sensations may explain how specific musical concepts

93 See Juslin and Västfjäll, "Emotional Responses to Music: The Need to Consider Underlying Mechanisms."

94 Louis Gallait's *Power of Music*, c. 1852. Wikimedia.org

95 John Dewey, "The Reflex Arc Concept in Psychology," *Psychological Review* 3, 4 (1896): 357-370. http://dx.doi.org/10.1037/h0070405.

96 Raymond M. Mosher, "A Study of the Group Method of Measurement of Sight Singing," *Contributions to Education* 194 (1925).

have evolved. Thus, in 1896 Karl Buecher argued that the concept of rhythm in music develops in relation to simple work activities.[97] The idea of rhythm in music originating in timed movements of work activities could explain why abstract rhythms in music may be associated with body movements and changes in attention.[98] These early ideas anticipated the more recent embodied mind and ecological approaches that define how music is developed and shaped by physical actions, and through interactions with objects in physical and social environments.[99]

With the ideas of the functionalist approach,[100] it became apparent that music could also serve specific functions, for example, in rituals such as weddings and funerals, and thus, music could serve as a means for developing practical tools for solving everyday problems, for example, helping an infant fall asleep by singing a lullaby. However, there was a need to develop specific tests to investigate the different levels of musical ability, for example, to distinguish among non-musicians, amateur musicians, and professional musicians.

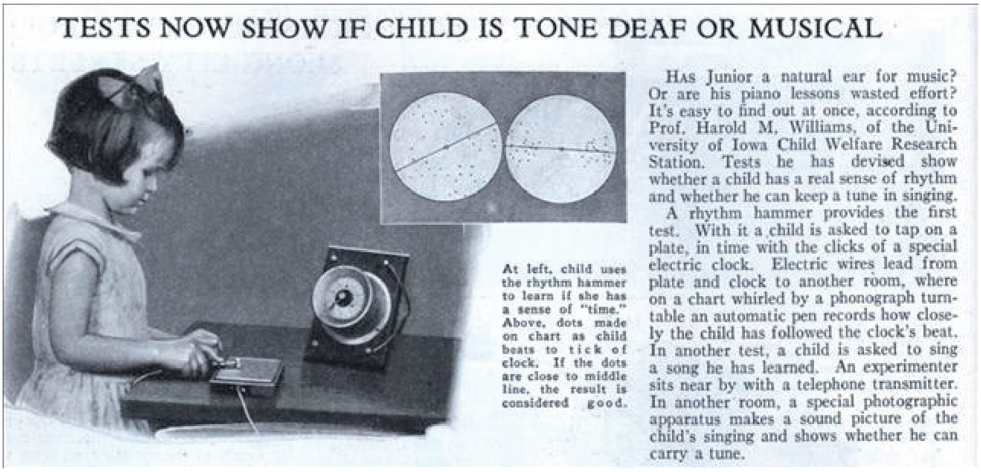
The Invention of Musical Competence Tests

In functional psychology, specific tools were invented for testing mental skills, which also influenced the psychology of music. In 1890, James McKeen Cattell published an article on mental tests,[101] and in 1884, Francis Galton established a laboratory for conducting mental tests.[102] Cattell and Galton developed and applied specific measures to collect data on the performance of animals' and people's senses and physical behaviors. They measured how quickly people could respond to sounds or specific tones. Later, the self-taught French psychologist, Alfred Binet, invented a test with tasks that also required specific memory, attention, imagination, and comprehension skills.[103] In 1916, Lewis M. Terman further developed Binet's test in a new version, which was called the intelligence quotient (IQ) test. This test compares a person's mental competence score with the average scores of people of the same age.

Carl Emil Seashore speculated about whether it would be possible to create a musical intelligence quotient (MIQ).[104] Hence, in 1919, Seashore presented a battery of tests to measure musical talent. The tests investigated people's abilities to discriminate among tones, intensities, consonance, time, rhythms, and tonal memory.[105] Although Seashore's test measured abilities related to musical perception only, and not musical performance, between 1928 and 1929, Hazel M. Stanton demonstrated that, to some

97 Karl Buecher, *Arbeit Und Rhythmus* (Leipzig: Veit, 1896).
98 Christian A. Ruckmick, "Rhythm and its Musical Implications," *Music Teachers' National Association* 19 (1924): 53-62.
99 E.g. see Leman, *Embodied Music Cognition and Mediation Technology*.
100 Cf. Schultz and Schultz, *A History of Modern Psychology*, 207.
101 *Ibid.*, 222.
102 *Ibid.*, 158f.
103 *Ibid.*, 224-226.
104 Seashore, *Psychology of Music*, 8.
105 *Ibid.*, 317; John McLeish, *The Factor of Musical Cognition in Wing's and Seashore's Tests* (London: Novello, 1968).

extent, the test scores could predict which music school students would continue their studies and receive high grades.[106] Also, tests were developed for measuring the abilities to recognize transposed melodies, tonal sequences, tonal cadences, phrases, and variations on musical themes.[107] In the period between 1926 and 1938, people of different ages, and with different levels of musical training were tested.[108] These tests confirmed the intuitive knowledge that people's musical ability increased over time, and with musical training.[109]



TESTS NOW SHOW IF CHILD IS TONE DEAF OR MUSICAL

At left, child uses the rhythm hammer to learn if she has a sense of "time." Above, dots made on chart as child beats to tick of clock. If the dots are close to middle line, the result is considered good.

Has Junior a natural ear for music? Or are his piano lessons wasted effort? It's easy to find out at once, according to Prof. Harold M. Williams, of the University of Iowa Child Welfare Research Station. Tests he has devised show whether a child has a real sense of rhythm and whether he can keep a tune in singing.

A rhythm hammer provides the first test. With it a child is asked to tap on a plate, in time with the clicks of a special electric clock. Electric wires lead from plate and clock to another room, where on a chart whirled by a phonograph turntable an automatic pen records how closely the child has followed the clock's beat. In another test, a child is asked to sing a song he has learned. An experimenter sits near by with a telephone transmitter. In another room, a special photographic apparatus makes a sound picture of the child's singing and shows whether he can carry a tune.

Figure 6: Technical equipment for testing musical talent in children, in 1931 at the University of Iowa Child Welfare Research Station.[110]

The invention of musical competence tests offered new tools for testing the level of a person's musical competence. However, it was found that certain measures were more relevant to the study of specific musical skills than others, and the measurements also depended on some interpretation of the data.[111] New competence tests have been developed recently, but because some tests were too easy or too difficult for certain types of people,[112] separate tests were more specifically tailored to measure the mu-

106 Hazel Martha Stanton, "Seashore Measures of Musical Talent," *Psychological Monographs* 39, 2 (1928): 135-144; Hazel Martha Stanton, *Prognosis of Musical Achievement: A Study of the Predictive Value of Tests in the Selection of Degree and Certificate Students for the Eastman School of Music* (Rochester, New York: Eastman School of Music, the University of Rochester, 1929).

107 Mursell, *Psychology of Music*, 218-241.

108 William Stern, Clara Stern and Anna Barwell, *The Psychology of Early Childhood Up to the Sixth Year of Age* (New York: Henry Holt and Company, 1926); H. König, "Über Das Musikalische Gedächtnis," *Zsch. F. Psychol* 108 (1928): 398-420; Hazel Martha Stanton, "Measurement of Musical Talent: The Eastman Experiment." *University of Iowa Studies in the Psychology of Music* (1935).

109 Seashore, *Psychology of Music*, 318.

110 http://blog.modernmechanix.com/tests-now-show-if-child-is-tone-deaf-or-musical/#more

111 McLeish, *The Factor of Musical Cognition in Wing's and Seashore's Tests*.

112 (A too easy test results in so-called ceiling effects. This means that test scores could be higher, but the test has a ceiling that constrains the upper limit of the scores. Conversely, the scores from a too difficult test would have a floor effect that prevents the scores from reaching lower levels.)

sical skills of non-musicians, and musicians with low, intermediate, or high professional levels of musical ability.[113] The behaviorist approach, which is introduced in the following section, is also based on measurements, but behaviorism focuses exclusively on objective measurements and minimizing interpretation of the data collected in the experiments.

Early Experiments on Reactions to Music

With the invention of musical tests, it became possible to provide a measure of a person's musical skills and to relate these measures to other factors, and thereby investigate possible effects of musical training, for example. So far, the various approaches to the psychology of music often involved some form of introspection. The ideal of the approach to psychology called "behaviorist psychology" was the avoidance of subjective evaluations of oneself or others, and the collection of the most accurate and objective measurements possible.

After Darwin published *On the Origin of Species*, in which he claimed that humans were evolutionarily related to animal species, there was an increased interest in comparing humans and other animal species.[114] It was not possible to ask animals what they thought or felt, but it was possible to observe animals' and humans' behaviors. In 1902, Ivan Petrovich Pavlov was studying digestive functions, and measured the amount of saliva from the mouths of dogs who received food.[115] Accidentally, he found that the dogs salivated even before they received food, prompted by the mere sound of foot steps, or the sight of the person who usually fed them. Pavlov suggested that it was a conditioned reflex. He discovered that the dogs in the experiment would eventually respond with salivation to a specific stimulus, such as specific sounds or tones, if he had previously repeatedly given the specific stimulus to the dogs immediately before they received the food. Thus, the specific stimulus and food became associated with each other, even in the absence of food. Pavlov's simpler, passive, one-way stimulus-response association differs from Dewey's more complex, circular relation between sensations and actions (see section 6), because Pavlov's theory of the conditioned reflex does not consider that an action of a subject can be followed by a sensation that becomes conditioned on this action, which is possible with operant conditioning. In the case of operant conditioning, we might choose to listen to or play certain music, because we learn that it will be associated with a certain reward.

113 E.g. see I. Peretz, A. S. Champod and K. Hyde, "Varieties of Musical Disorders. The Montreal Battery of Evaluation of Amusia," *Annals of the New York Academy of Sciences* 999 (Nov, 2003): 58-75; Daniel Müllensiefen et al., "The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population," *PloS One* 9, 2 (2014); Mikkel Wallentin et al., "The Musical Ear Test, a New Reliable Test for Measuring Musical Competence," *Learning and Individual Differences* 20, 3 (2010): 188-196. http://dx.doi.org/10.1016/j.lindif.2010.02.004.

114 Schultz and Schultz, *A History of Modern Psychology*, 260.

115 *Ibid.*, 276.

Figure 7: Illustration of a dog's conditioned reflex to the sound of a bell.[116]

In 1913, John B. Watson acknowledged the objective methods for measuring conditioned reflexes. Watson further considered interesting possibilities of the new method, for controlling and predicting the behavior of animals.[117] Also, Watson emphasized that Pavlov measured observable behavior only, and thus avoided any personal observations or reports of his own mental states or emotions, and that Pavlov began to separate the observer and the subject by using a box to avoid the possible disturbance of external factors on the measured behavior.[118] Furthermore, with regard to the theory of conditioned reflexes, Watson believed that specific human behaviors, which may appear to be biologically inherited instincts, might actually be socially conditioned responses, learnt in particular physical and social environments.[119] Interestingly, in 1927 George Humphrey also demonstrated that it was possible to condition humans to respond reflexively to melodies.[120]

According to Watson, behavioral psychological experiments were based on objective observations, tests, or measurements of responses, for example, physiological changes, with the use of instruments.[121] In keeping with this line of thinking, experiments were made to test animals' and humans' physiological responses to music, and some of these experiments had already been conducted in the 1870s, 1880s, and 1890s, prior to Watson's general definition of the behaviorist approach. As early as 1874, it was shown

116 http://voiceofthemonkey.com/does-the-name-pavlov-ring-a-bell-2/
117 Schultz and Schultz, *A History of Modern Psychology*, 300.
118 *Ibid.*, 301f.
119 *Ibid.*, 304.
120 George Humphrey, "The Effect of Sequences of Indifferent Stimuli on a Reaction of the Conditioned Response Type," *The Journal of Abnormal and Social Psychology* 22, 2 (1927), 194-212. http://dx.doi.org/10.1037/h0070766.
121 Schultz and Schultz, *A History of Modern Psychology*, 301f.

that a sudden sound resulted in an acceleration of the pulse in dogs,[122] and in 1895, it was found that the sudden sound of a gong was followed by a decrease in blood pressure in human subjects.[123] In 1887, while W. P. Lombard was measuring involuntary knee jerks, by coincidence, several bands passed on the street outside the laboratory, and as the bands passed, Lombard observed an increase in the average movement of the knee, followed by a decrease.[124] Also, in 1890, J. Tarchanoff discovered that the electric conductance of the skin of the human hand changes in response to music.[125] Furthermore, in 1896 M. L. Patrizi helped a 13-year-old boy recover from an accident with an axe. In a remarkable experiment, Patrizi discovered that by playing music and placing measurement equipment into an open hole in the boy's skull, he could detect that the top of the cerebral cortex of the brain responded to music with slight movements caused by blood flow.[126] Thus, the behaviorist approach introduced physiological measurements of the human response to music, which anticipated the more recent neurophysiological methods for measuring brain activity while people play or listen to music.

In part, the functionalist approach to the psychology of music (see section 6) intended to investigate the practical applications of music in people's everyday lives. In this regard, the objective methods of the behaviorist approach made it possible to measure the effects of specific music on people's behavior in everyday situations. Interestingly, studies between 1891 and 1904 showed that groups of people seemed to behave differently, depending on the tonal mode and dissonance or consonance of the music to which they listened. In 1891, a study demonstrated that a group of people reacted more quickly to minor chords than to major chords,[127] and in another study, reported in 1904, it was found that the ability to lift a weight with the middle finger increased in response to consonant or ascending tone intervals, and decreased in response to dissonant or descending tone intervals, but as they became fatigued, the effect of dissonance and consonance was reversed.[128] In the 1910s through the 1920s researchers also considered whether listening to music might improve the performance of various professional tasks. It was reported that athletes competing in a bicycle race seemed to pedal faster when they heard music, compared to when they rode without music,[129] workers

122 L. Couty and A. Charpentier, "Effets Cardio-Vasculaires Des Excitations Des Sons," *Arch, De Physiol* 4 (1874): 525-583.

123 Alfred Binet and J. Courtier, "Circulation Capillaire Dans Ses Rapports Avec La Respiration Et Les Phénomènes Psychiques," *L'Année Psychologique* 2, 1 (1895): 87-167. http://dx.doi.org/10.3406/psy.1895.1532. http://www.persee.fr/web/revues/home/prescript/article/psy_0003-5033_1895_num_2_1_1532.

124 Warren Plympton Lombard, "The Variations of the Normal Knee-Jerk, and their Relation to the Activity of the Central Nervous System," *The American Journal of Psychology* 1, 1 (1887): 2-71.

125 J. Tarchanoff, "Ueber Den Galvanischen Erscheinungen in Der Haut Des Menschen Bei Reizungen Der Sinnesorgane Und Bei Verschiedenen Formen Der Psychischen Tätigkeit," *Pflügers Archiv* 46 (1890): 46-55.

126 M. L. Patrizi, "Primi Esperimenti Intorno all'Influenza Della Musica Sulla Circolazione Del Sangue Nel Cervello Umano," *Rivista Musicale Ital.* 3 (1896): 390-406.

127 E. Tanzi, "Cenni Ed Esperimenti Sulla Psicologia Dell'Udito," *Riv.Di Filos.Scient* (1891).

128 Charles S. Féré, *Travail Et Plaisir* (Paris: F. Alcan, 1904), 127-159.

129 Leonard P. Ayres, "The Influence of Music on Speed in the Six Day Bicycle Race," *American Physical Education Review* 16, 5 (1911): 321-324.

in an architectural drafting room seemed to be more productive when they listened to music,[130] and people's typewriting and handwriting apparently became faster, when they listened to music, but listening to music also reduced typing accuracy.[131] Thus, it was shown that to some extent, specific music could be applied to manipulate human behavior, which anticipates studies on commercial applications of music or muzak.

The behaviorist approach introduced more precise and reliable methods for observing and measuring musical behavior, compared to the previously-mentioned introspective methods. The behaviorist approach assumed that the relation between stimuli and responses could be measured in terms of simple relations between sensations and actions, but in 1929, Karl Lashley discovered that it was not possible to find any simple point-to-point connections between the brain regions involved in sensations and actions. Instead, the neural circuits of the brain were more complex, which did not support the idea of a simple relation between a sensation and an action.[132] In that same year, William McDougall criticized the behaviorist ideas, and argued that an observation, for example, the applause of the audience at a concert, did not indicate people's thoughts, attention to the music, or pleasure in listening to the music.[133] Therefore, accurate explanations were needed for what was actually happening inside the human mind and brain when people play or listen to music. The following section introduces the cognitive approach to music, which considers the mental operations involved in making and listening to music.

Development of a Cognitive Psychology of the Musical Mind

Whereas the behaviorist approach introduced in the previous section regarded the human mind as an impossible and unsuitable subject for study, the main focus of the cognitive approach to psychology was to develop a new psychology of the human mind, which was, however, more precise than the atomistic, Gestalt, and functionalist approaches. The invention of the electronic computer was important for the development of cognitive psychology. During World War II, the American military engaged human employees called "computers", who calculated the aim direction of cannons to moving targets, but in 1943, the first electronic computer was invented to address this task.[134] The electronic computer became a metaphor for explaining the calculations and other mental operations performed in the human mind.[135] It is generally acknowledged that humans and electronic computers are rather different. However, during the initial development of cognitive psychology, the computer metaphor was applied to the human mind, to draw comparisons between the logic of manipulating, storing, and retrieving data by electronic computers, to the characteristics of human information processing and

130 E. L. Gatewood, "An Experiment in the use of Music in an Architectural Drafting Room," *Journal of Applied Psychology* 5, 4 (1921), 350-358. http://dx.doi.org/10.1037/h0070493.

131 Diserens, *Reactions to Musical Stimuli*, 173-199.

132 Schultz and Schultz, *A History of Modern Psychology*, 313f.

133 *Ibid.*, 315.

134 *Ibid.*, 489.

135 *Ibid.*, 488.

accessing of memories. In 1956, George Miller published an article inspired by the new ideas of a computer-based model of the human mind, entitled "The Magical Number Seven, Plus or Minus Two: Some Limits of our Capacity for Processing Information."[136]

In 1967, Ulrich Neisser published the first book to introduce the new approach of cognitive psychology.[137] Cognitive psychology combined the ideas of the organizational principles of the Gestalt approach (see section 5), the evolved mental functions and interactions with environments of the functionalist approach (see section 6), and the methods of observing behaviors of the behaviorist approach (see section 8). With the new cognitive approach, there was a focus on mental, or cognitive, processes and the mental representations of objects and events in the surrounding physical and social environments, the organization of experience according to meaningful wholes, and the suggestion that individuals actively acquire and apply "knowledge" by choosing to attend to certain objects and events, while ignoring others.[138]

In cognitive psychology, any kind of processed information and information stored as a memory is called "knowledge", and therefore the term had many meanings. It could be "knowledge" on a phenomenon in the world,[139] such as music (called "declarative knowledge" or "semantic knowledge"). It could be knowledge that structures our behaviors,[140] for example, what we do with our fingers or voice when we play music or sing (called "procedural knowledge"). Also, knowledge may explain our experiences and behaviors to ourselves or to others (called "explicit knowledge").[141] In contrast, another type of knowledge may structure our experiences and behaviors, although we are unable to explain how or why they happen; for example, specific musical structures may cause us to experience certain music in a specific way, or structure our finger movements while playing an instrument, but without explaining how or why (called "implicit knowledge").[142] These knowledge structures are also called "schemas," "cognitive schemas," or "schemata," and they enable us to understand certain situations, and to predict what would probably happen while listening to music, for example.[143] Schemas for structuring our behavior in certain situations, for example, when singing or playing specific music (called "procedural knowledge"), are also sometimes called "scripts."[144] Studying the acquisition and application of these different types of knowledge, or cognitive schemas, raised questions regarding *how* the knowledge was acquired and applied, and *what* the specific knowledge was. Therefore, it seemed necessary to expand cognitive psychology into the fields of the neurosciences, computer sciences, and humanities.[145] Together, these broad, interdiscipli-

136 *Ibid.*, 485.
137 *Ibid.*, 487.
138 *Ibid.*, 492.
139 Margaret W. Matlin, "Cognition," sixth edition (John Wiley & Sons, 2005), 264, 129.
140 *Ibid.*, 129.
141 *Ibid.*, 145f.
142 *Ibid.*, 145f.
143 *Ibid.*, 274f.
144 *Ibid.*, 275.
145 Schultz and Schultz, *A History of Modern Psychology*, 497.

nary fields became called the Cognitive Sciences. The role of the humanities, and in particular, musicology in Cognitive Musicology, was to define *what* the acquired and applied knowledge was. Psychology, neuroscience, and computer science could investigate *how* this knowledge was acquired and applied.

Figure 8: Illustration of music as information processed in the mind and brain.[146]

In 1968, John McLeish suggested that musical talent involved "a factor of musical cognition" that "may be defined as the ability to recognize and understand the nature of changes in musical or quasi-musical materials."[147] This description of "recognition" and "understanding" of musical material implied the presence of mental operations. Later, through a series of empirical, psychological studies, it was discovered that certain people seemed to apply specific musical information, which had been previously observed by music theorists, as they perceived, processed, and responded to musical scales,[148] chords,[149] rhythms, and meters.[150] In 1983, Fred Lerdahl and Ray Jackendoff published a book called *A Generative Theory of Tonal Music*,[151] intended to develop a framework for analyzing music based on a limited set of theoretical principles that could

146 http://grfia.dlsi.ua.es/cm/projects/drims/index.php
147 McLeish, *The Factor of Musical Cognition in Wing's and Seashore's Tests*.
148 Carol L. Krumhansl and Roger N. Shepard, "Quantification of the Hierarchy of Tonal Functions within a Diatonic Context," *Journal of Experimental Psychology: Human Perception and Performance* 5, 4 (1979): 579-594. http://dx.doi.org/10.1037/0096-1523.5.4.579.
149 Carol L. Krumhansl, Jamshed J. Bharucha and Edward J. Kessler, "Perceived Harmonic Structure of Chords in Three Related Musical Keys," *Journal of Experimental Psychology: Human Perception and Performance* 8, 1 (1982): 24-36. http://dx.doi.org/10.1037/0096-1523.8.1.24.
150 Caroline Palmer and Carol L. Krumhansl, "Mental Representations for Musical Meter," *Journal of Experimental Psychology. Human Perception and Performance* 16, 4 (1990): 728-741. http://dx.doi.org/10.1037/0096-1523.16.4.728.
151 Lerdahl and Jackendoff, *A Generative Theory of Tonal Music*.

define how the human mind processes music[152] (a more developed, empirically supported, and more readable version of the theory was later presented in Lerdahl's *Tonal Pitch Space*[153]). With the increasing availability and speed of computers, it also became possible to create dynamic computer models of musical cognition. In 1973, Otto E. Laske presented a computer-based approach to analyzing symbolic representations of music in music scores,[154] and in 1994, a Center for Computer Assisted Research in the Humanities was established at Stanford University, which also offered computer programs for analyzing symbolic representations of music.[155] Also, the neural networks of the human brain provided a biological model for the cognitive processes, and the acquisition and application of "knowledge,"[156] and in 1987, an artificial neural network model was suggested, which could simulate the mental processing of tonal structures in music.[157] Various computational methods for simulating the acquisition and application of information (called machine learning methods) have also been introduced, which, apart from the biologically inspired artificial neural networks, have also been used to model the acquisition and application of musical information.[158]

The first ideas of cognitive psychology were based on the computer metaphor of information processing. Later, other aspects of functional psychology were gradually integrated into cognitive psychology and the cognitive psychology of music. For example, in 1973, a series of studies on musical rhythms anticipated a renewed focus on the listeners' experiences of musical metaphors related to movements and emotions.[159] James's idea from 1890 that the body partly shapes our experiences (see section 6), was further elaborated in 1987 by Mark Johnson, who suggested that certain image schemas constitute recurring ways of perceiving the physical environment through the body.[160] For example, some listeners have a tendency to think in terms

152 Fred Lerdahl, "Genesis and Architecture of the GTTM Project," *Music Perception* 26, 3 (2009): 187-194.

153 Lerdahl, *Tonal Pitch Space*.

154 Otto Ernst Laske, *Introduction to a Generative Theory of Music* (Utrecht: Institute of Sonology, Utrecht State University, 1973).

155 "Center for Computer Assisted Research in the Humanities at Stanford University." Software can be downloaded at www.ccarh.org

156 David E. Rumelhart, James L. McClelland and PDP Research Group, *Parallel Distributed Processing: Explorations in the Microstructure of Cognition* (Cambridge, Mass.: MIT Press, 1986); Software can be downloaded from Brad Aisa, Brian Mingus and Randall C. O'Reilly, "Emergent Neural Network Simulation System," Department of Psychology and Neuroscience, University of Colorado Boulder, http://grey.colorado.edu/emergent/index.php/Main_Page (accessed October 2, 2013).

157 Jamshed J. Bharucha, "Music Cognition and Perceptual Facilitation: A Connectionist Framework," *Music Perception* 5, 1 (1987): 1-30.

158 For an overview, see Purwins et al., "Computational Models of Music Perception and Cognition I: The Perceptual and Cognitive Processing Chain"; Purwins et al., "Computational Models of Music Perception and Cognition II: Domain-Specific Music Processing".

159 A. Gabrielsson, "Similarity Ratings and Dimension Analyses of Auditory Rhythm Patterns. I," *Scandinavian Journal of Psychology* 14, 2 (1973a): 138-160; A. Gabrielsson, "Similarity Ratings and Dimension Analyses of Auditory Rhythm Patterns. II," *Scandinavian Journal of Psychology* 14, 3 (1973b): 161-176; A. Gabrielsson, "Adjective Ratings and Dimension Analyses of Auditory Rhythm Patterns," *Scandinavian Journal of Psychology* 14, 4 (1973c): 244-260.

160 Mark Johnson, *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason* (Chicago, Ill.: University of Chicago Press, 1987).

of upward or downward physical movements, in relation to changes in pitch height in melodies, and some listeners may experience movements in relation to sound objects, in which the distance is expanded or narrowed, as indicated by a decrease or increase in sound volume, as in diminuendi and crescendi.[161] These ideas led to the introduction of an embodied mind approach to music cognition,[162] an approach that considered both the evolution of music through interaction with physical environments,[163] and the creation of diverse cultural music traditions through interaction with social environments.[164] Thus, although certain universal psychological mechanisms may be involved in experiencing and creating music, it is important to avoid ethnocentric claims of universal principles of music. In the cognitive psychology of music, certain tonal schemas, for example, represent musical knowledge for a specific cultural environment.[165]

A renewed interest in the mechanisms underlying emotional experiences and responses to music also departed from the initial computer-based metaphor of music cognition. Considerations related to physical, mental and aesthetic mechanisms of emotional responses to music,[166] strong emotional experiences,[167] and the role of mood and personality in perceiving emotions in music[168] were introduced within the cognitive psychology of music. Additional studies investigated both embodiment schemas and emotional mechanisms related to music cognition. For example, a motion-capture technique[169] demonstrated that both musical genre features and personality traits partly determined people's dance movements,[170] and the effectiveness of

161 Eric Clarke, ″Meaning and the Specification of Motion in Music,″ *Musicae Scientiae* 5, 2 (2001): 213-234.

162 See Leman, *Embodied Music Cognition and Mediation Technology*.

163 Also see the biomusicology approach in Wallin, Merker and Brown, *The Origins of Music*, 13.

164 For an overview of cultural studies on music cognition see, e.g., Morrison and Demorest, "Cultural Constraints on Music Perception and Cognition.″

165 Leman, *Music, Gestalt, and Computing: Studies in Cognitive and Systematic Musicology*, 20; Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis*, 75.

166 Juslin and Västfjäll, "Emotional Responses to Music: The Need to Consider Underlying Mechanisms"; Patrik N. Juslin, ″From Everyday Emotions to Aesthetic Emotions: Towards a Unified Theory of Musical Emotions,″ *Physics of Life Reviews* 10, 3 (2013): 235-266. http://dx.doi.org/10.1016/j.plrev.2013.05.008; Patrik N. Juslin and John A. Sloboda, *Handbook of Music and Emotion: Theory, Research, and Applications* (Oxford: Oxford University Press, 2010); Elvira Brattico and Marcus Pearce, ″The Neuroaesthetics of Music,″ *Psychology of Aesthetics, Creativity, and the Arts* 7, 1 (2013): 48-61. http://dx.doi.org/10.1037/a0031624; Elvira Brattico, Brigitte Bogert and Thomas Jacobsen, "Toward a Neural Chronometry for the Aesthetic Experience of Music,″ *Frontiers in Psychology* 4 (2013), 1-21. http://dx.doi.org/10.3389/fpsyg.2013.00206.

167 Alf Gabrielsson, ″Strong Experiences with Music,″ in *Handbook of Music and Emotion: Theory, Research, Applications*, eds. P. N. Juslin and J. A. Sloboda (Oxford, New York: Oxford University Press, 2010), 547-574.

168 Jonna K. Vuoskoski and Tuomas Eerola, ″The Role of Mood and Personality in the Perception of Emotions Represented by Music,″ *Cortex* 47, 9 (2011): 1099-1106. http://dx.doi.org/10.1016/j.cortex.2011.04.011.

169 Birgitta Burger and Petri Toiviainen, *MoCap Toolbox – A Matlab Toolbox for Computational Analysis of Movement Data* (Berlin: Logos Verlag Berlin, 2013). https://jyx.jyu.fi/dspace/handle/123456789/42837.

170 G. Luck et al., ″Effects of the Big Five and Musical Genre on Music-Induced Movement,″ *Journal of Research in Personality* 44, 6 (2010): 714-720. http://dx.doi.org/10.1016/j.jrp.2010.10.001.

Guided Imaging and Music (GIM) therapy sessions seemed to depend on the relation of certain musical structures to body-based metaphors.[171]

The increasing research on music cognition lead to the introduction of journals specifically devoted to the subject of music cognition, such as *Psychomusicology: Music, Mind and Brain*, in 1981, and *Music Perception*, in 1983, and the establishment of organizations such as *Society for Music Perception and Cognition*, in 1990, and *European Society for the Cognitive Sciences of Music* (ESCOM), in 1991, which, in 1992, introduced the journal, *Musicae Scientiae* (the Journal of the European Society for the Cognitive Sciences of Music). Thus, the cognitive psychology of music offered elaborate and detailed explanations of the underlying psychological mechanisms and cultural aesthetic principles that affect our experience of, and reactions to music, and the cognitive approach to music offered new explanations of the mental processes involved in music cognition. The following section will further consider how these mental processes occur in the human brain, which takes part in the constitution of the psychological mechanisms underlying the experience and creation of music.

Investigation of Neural Substrates for Music Cognition

Since the 1980s, the brain functions involved in music cognition have been studied using both traditional and new methods in neuroscience (Tervaniemi & Zuijen 1999).[172] Thus, in 1981, it was discovered, using electroencephalography (EEG), that the brain responds differently to a regular rhythm and an irregular rhythm,[173] and a study from 1982 applying magnetoencephalography (MEG) revealed that different parts of the human auditory cortex are activated in response to different tones.[174] Consequently, in 1989, based on further studies of patients with lesions in specific regions of the brain, it was suggested that there are different functional regions in the brain, which store and process specific types of musical information.[175] Although a functional brain region involved in the processing of music had already been observed in the 1920s, it was now possible to use non-invasive measures to see the dynamic activation of specific regions of the human brain while it processed specific musical information.

The brain's responses to increasingly complex musical structures were also investigated. Thus, in studies from 1987 and 1990, it was discovered that when people heard

171 Hallgjerd Aksnes and Even Ruud, "Body-Based Schemata in Receptive Music Therapy," *Musicae Scientiae* 12, 1 (2008): 49-74. http://dx.doi.org/10.1177/102986490801200104. http://msx.sagepub.com/content/12/1/49.abstract; Erik Christensen, "Music Listening, Music Therapy, Phenomenology and Neuroscience" (PhD thesis, Institute of Communication and Psychology, Department of Music Therapy, Aalborg University, 2012).

172 Tervaniemi and van Zuijen, "Methodologies of Brain Research in Cognitive Musicology".

173 J. M. Ford and S. A. Hillyard, "Event-Related Potentials (ERPs) to Interruptions of a Steady Rhythm," *Psychophysiology* 18, 3 (1981): 322-330. http://dx.doi.org/10.1111/j.1469-8986.1981.tb03043.x.

174 Gian Luca Romani, Samuel J. Williamson and Lloyd Kaufman, "Tonotopic Organization of the Human Auditory Cortex," *Science* 216, 4552 (1982): 1339-1340. http://dx.doi.org/10.1126/science.7079770.

175 Peretz and Morais, "Music and Modularity"; for a review of brain organization for music, see Peretz and Zatorre, "Brain Organization for Music Processing".

well-known melodies that ended on unexpected notes, which did not belong to the current musical scale, a positive deflection was measurable in the electric brainwaves, following the unexpected note.[176] With regard to brain organization, a series of functional Magnetic Resonance Imaging (fMRI) studies from 2001 to 2003 indicated that to some extent, auditory information is processed in two separate streams. A ventral stream (that goes down from around the middle toward the front of the brain) is involved in identification of what is heard in terms of increasingly complex sound structures, and a dorsal stream (that goes from around the middle, backward, and toward the upper middle part of the brain) is involved in detecting where sound sources are localized in the space around us.[177] Also, in 2011, it was discovered by using fMRI that in people who listened to an entire piece of music containing multiple musical structures, the brain activity varied in the same brain regions that was previously found to vary in response to separate musical structures, if the variations in brain activity were correlated with computer-based measurements of the separate changes in timbral, tonal, or rhythmic structures in the music.[178] Further studies also investigated possible shared brain mechanisms for the hierarchical structures of music and language,[179] and it seemed that musical training could enhance the brain's detection of acoustic changes in both music and speech.[180]

It was found that musical training and specific musical abilities, such as absolute pitch, affect both the structure of the brain[181] and the brain's way of processing musical information. In particular, musical training is related to a shift in location with regard to processing musical information; in trained musicians, the brain activity is more dominant in the left hemisphere of the frontal cortex[182] and the left hemisphere

176 M. Besson, M. Besson and F. Macar, ″An Event-Related Potential Analysis of Incongruity in Music and Other Non-Linguistic Contexts,″ *Psychophysiology* 24, 1 (1987): 14-25; R. Verleger, "P3-Evoking Wrong Notes: Unexpected, Awaited, or Arousing?″ *The International Journal of Neuroscience* 55, 2-4 (1990): 171-179. http://dx.doi.org/10.3109/00207459008985972.

177 Michela Adriani et al., ″Sound Recognition and Localization in Man: Specialized Cortical Networks and Effects of Acute Circumscribed Lesions,″ *Experimental Brain Research* 153, 4 (2003): 591-604. http://dx.doi.org/10.1007/s00221-003-1616-0.

178 Vinoo Alluri et al., ″Large-Scale Brain Networks Emerge from Dynamic Processing of Musical Timbre, Key and Rhythm,″ *NeuroImage* 59, 4 (2012): 3677-3689. http://dx.doi.org/10.1016/j.neuroimage.2011.11.019; for another multi-feature method for EEG or MEG measurements see Peter Vuust et al., "New Fast Mismatch Negativity Paradigm for Determining the Neural Prerequisites for Musical Ability,″ *Cortex* 47, 9 (2011): 1091-1098. http://dx.doi.org/10.1016/j.cortex.2011.04.026.

179 For an overview see e.g. Stefan Koelsch, ″Towards a Neural Basis of Processing Musical Semantics,″ *Physics of Life Reviews* 8, 2 (2011): 89-105. http://dx.doi.org/10.1016/j.plrev.2011.04.004; Patrick Rebuschat, *Language and Music as Cognitive Systems* (Oxford: Oxford University Press, 2012), 338; Michael A. Arbib, ed., *Language, Music, and the Brain: A Mysterious Relationship* (Cambridge, MA: The MIT Press, 2013).

180 E.g. M. Tervaniemi et al., ″Top-Down Modulation of Auditory Processing: Effects of Sound Context, Musical Expertise and Attentional Focus,″ *The European Journal of Neuroscience* 30, 8 (2009): 1636-1642. http://dx.doi.org/10.1111/j.1460-9568.2009.06955.x.

181 Gottfried Schlaug, ″The Brain of Musicians: A Model for Functional and Structural Adaptation,″ *Annals of the New York Academy of Sciences* 930, 1 (2001): 281-299. http://dx.doi.org/10.1111/j.1749-6632.2001.tb05739.x; A. Dohn et al., "Gray- and White-Matter Anatomy of Absolute Pitch Possessors,″ *Cerebral Cortex* (2013). http://dx.doi.org/10.1093/cercor/bht334.

182 Eckart Altenmüller et al., ″Music Learning Produces Changes in Brain Activation Patterns: A Longitudinal DC-EEG Study,″ *International Journal of Arts Medicine* 5, 1 (1997): 28-33.

of the auditory cortex.[183] A few studies also indicated effects on the brain, associated with learning music from different cultures. When people listened to tones of unfamiliar scales, which did not belong to the scales of familiar cultures, increased electrical signals from their brains were observed,[184] and the blood flow seemed to increase in the right medial and right inferior frontal areas, and the right angular gyrus,[185] which possibly indicated increased demands on attention and cognition while listening to the melodies of unfamiliar cultures. Also, when musicians who were trained to play specific styles of music listened to deviating tonal and rhythmic features in a melody, the musicians' brains showed characteristic responses of increased electrical signals, which seemed to depend on their accustomed musical style.[186]

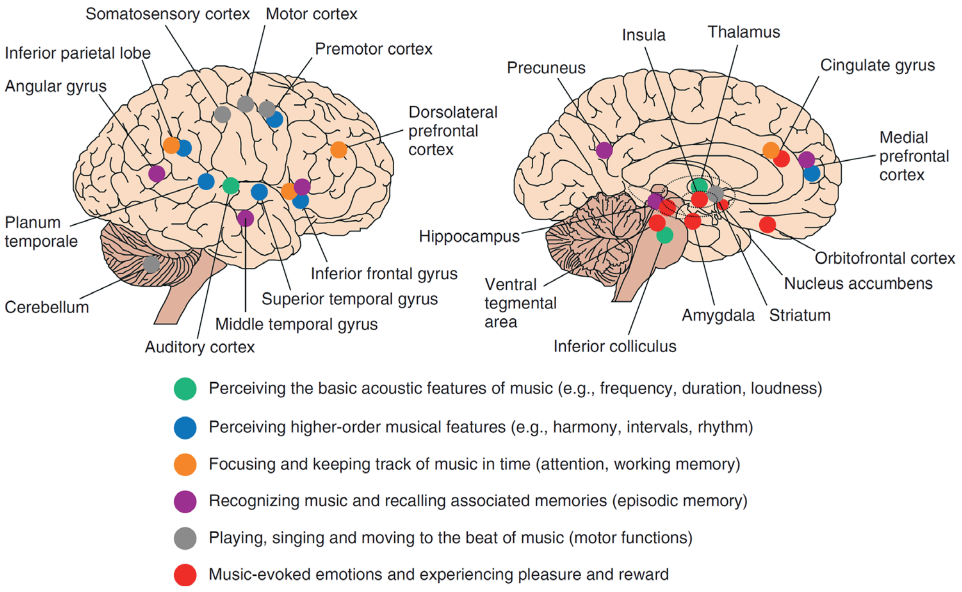


Figure 9: Locations of functional regions of the brain involved in processing musical information.[187] To the left are shown regions near the surface of the brain. To the right are shown regions deeper inside the brain. From Särkämö et al. (2013).

183 Peter Vuust et al., "To Musicians, the Message is in the Meter Pre-Attentive Neuronal Responses to Incongruent Rhythm are Left-Lateralized in Musicians," *NeuroImage* 24, 2 (2005): 560-564. http://dx.doi.org/10.1016/j.neuroimage.2004.08.039.

184 Christiane Neuhaus, "Perceiving Musical Scale Structures. A Cross-Cultural Event-Related Brain Potentials Study," *Annals of the New York Academy of Sciences* 999, 1 (2003): 184-188. http://dx.doi.org/10.1196/annals.1284.026.

185 Yun Nan et al., "Cross-Cultural Music Phrase Processing: An fMRI Study," *Human Brain Mapping* 29, 3 (2008): 312-328. http://dx.doi.org/10.1002/hbm.20390; Morrison and Demorest, "Cultural Constraints on Music Perception and Cognition".

186 Vuust et al., "New Fast Mismatch Negativity Paradigm for Determining the Neural Prerequisites for Musical Ability".

187 Illustration from Teppo Särkämö, Mari Tervaniemi and Minna Huotilainen, "Music Perception and Cognition: Development, Neural Basis, and Rehabilitative use of Music," *Wiley Interdisciplinary Reviews: Cognitive Science* 4, 4 (2013): 441-451. http://dx.doi.org/10.1002/wcs.1237.

Regions of the brain involved in emotional responses to music were also investigated. In 1999, using positron emission tomography (PET), the emotional responses to dissonance in music (see section 3) were found to brain areas that are also involved in the emotional evaluation of other stimuli.[188] Furthermore, in 2001, it was discovered that intensely pleasant emotional responses that evoke chills or goose bumps activate brain regions that are generally activated in response to highly pleasant and arousing stimuli, or the effects of chocolate, sex, or cocaine, and simultaneously decrease the activity in brain regions generally involved in the experience of negative emotions.[189] It also seemed that emotions could be induced by musical excerpts of either brief or longer duration. Brief chords,[190] short melodies,[191] and longer musical excerpts (with a duration of 45 seconds)[192] increased activity in limbic brain regions associated with either positive or negative emotional responses. More particularly, it was recently considered how the neurotransmitter, dopamine, which is partly involved in the anticipation of rewards and pleasurable sensations, might be released in certain areas of the brain in response to music.[193] That certain music could induce emotions and enhance the mood of the listeners was also suspected to play a central role in explaining why music was found to provide efficient complementary prevention and treatment of various neurological and psychological disorders, such as chronic pain, anxiety, depression, ADHD, schizophrenia, dementia, Alzheimer's disease, and the training of cochlear implant users.[194] [195] Additionally, since it was often the therapists who selected the music used in the therapy, it was also argued that music chosen by asking about the patient's preferences might have a more therapeutic effect.[196]

Recently, revolutionary neuroscience experiments involving music were conducted. One case is related to the growing interest in the possibilities of decoding the content

188 Anne J. Blood et al., "Emotional Responses to Pleasant and Unpleasant Music Correlate with Activity in Paralimbic Brain Regions," *Nature Neuroscience* 2, 4 (1999): 382-387. http://dx.doi.org/10.1038/7299.

189 Anne J. Blood and Robert J. Zatorre, "Intensely Pleasurable Responses to Music Correlate with Activity in Brain Regions Implicated in Reward and Emotion," *Proceedings of the National Academy of Sciences* 98, 20 (September 25, 2001): 11818-11823. http://dx.doi.org/10.1073/pnas.191355898.

190 Karen Johanne Pallesen et al., "Emotion Processing of Major, Minor, and Dissonant Chords: A Functional Magnetic Resonance Imaging Study," *Annals of the New York Academy of Sciences* 1060, 1 (2005): 450-453. http://dx.doi.org/10.1196/annals.1360.047.

191 Anders C. Green et al., "Music in Minor Activates Limbic Structures: A Relationship with Dissonance?" *NeuroReport* 19, 7 (2008): 711-715. http://dx.doi.org/10.1097/WNR.0b013e3282fd0dd8.

192 Wiebke Trost et al., "Mapping Aesthetic Musical Emotions in the Brain," *Cerebral Cortex* 22, 12 (2011): 2769-2783. http://dx.doi.org/10.1093/cercor/bhr353.

193 Line Gebauer, Morten L. Kringelbach and Peter Vuust, "Ever-Changing Cycles of Musical Pleasure," *Psychomusicology: Music, Mind, and Brain* 22, 2 (2012): 152-167. http://dx.doi.org/10.1037/a0031126.

194 I.e. a hearing prosthesis placed in the inner ear sending electric signals through auditory nerve fibers to the brain, e.g. Bjørn Petersen et al., "Singing in the Key of Life," *Psychomusicology: Music, Mind, and Brain* 22, 2 (2012): 134-151. http://dx.doi.org/10.1037/a0031140.

195 Särkämö, Tervaniemi and Huotilainen, "Music Perception and Cognition: Development, Neural Basis, and Rehabilitative use of Music.

196 Eduardo A. Garza-Villarreal et al., "Superior Analgesic Effect of an Active Distraction versus Pleasant Unfamiliar Sounds and Music: The Influence of Emotion and Cognitive Style," *PloS One* 7, 1 (2012): 1-8. http://dx.doi.org/10.1371/journal.pone.0029397; Eduardo A. Garza-Villarreal et al., "Music Reduces Pain and Increases Functional Mobility in Fibromyalgia," *Frontiers in Psychology* 5 (2014): 1-10.

of sensations and thoughts from measured brain activity, also popularly called "mind reading" methods. Thus, with functional magnetic resonance imaging (fMRI), it was discovered that the specific content of sensations for types of sound qualities,[197] for example, the sound of a guitar or a girl's voice, and tonal and rhythmical features[198] may be distinguished in the brain activity in musical pathways of particular regions in the human brain. Interestingly, it has also been shown that the brain regions involved in perceiving and imagining music overlap to some extent.[199] With this new knowledge, future developments might include interesting possibilities for recording imagined music that no one else can hear, from the brain of the person imagining the music. Although the possibilities for movement are rather constrained in a brain scanner, another controversial study applied a laminated grid for foot movements, to investigate movements in dance synchronized to music. The experimental results indicated that deeper sub-cortical brain regions, which presumably bypass conscious thinking, were active in a group of amateur dancers who were studied; the medial geniculate nucleus in the thalamus was activated while tracking the tactus of the music, and the anterior vermis in the cerebellum was involved in adjusting the dance movements to the meter of the music.[200]

In 2002, the successful new research and growing interest in the field of the cognitive neuroscience of music motivated the inauguration of a series of conferences and publications called *The Neurosciences and Music*, by the Mariani Foundation, in collaboration with the New York Academy of Sciences. However, there are also certain challenges that this field of research faces. It is neither a straightforward task to define the mental operations and representations of music, nor to explain how they are implemented in the human brain. As there have been many different music players, including gramophone players, tape players, CD players, audio file players, and various media for music recording, which have been used to store and retrieve music, there are also multiple ways to implement the processing and representation of music information in computer software and data, as well as in brains. Therefore, it is neither clear-cut which theoretical or computational model is best, nor which mental processes or brain regions are most significant for understanding a specific musical phenomenon. This makes Cognitive Musicology a highly interdisciplinary and challenging field.

197 Federico De Martino et al., "Combining Multivariate Voxel Selection and Support Vector Machines for Mapping and Classification of fMRI Spatial Patterns," *NeuroImage* 43, 1 (2008): 44-58. http://dx.doi.org/10.1016/j.neuroimage.2008.06.037.

198 Rebecca S. Schaefer et al., "Probing Neural Mechanisms of Music Perception, Cognition, and Performance using Multivariate Decoding," *Psychomusicology: Music, Mind, and Brain* 22, 2 (2012): 168-174. http://dx.doi.org/10.1037/a0031014.

199 Hubbard, "Auditory Imagery: Empirical Findings".

200 Steven Brown, Michael J. Martinez and Lawrence M. Parsons, "The Neural Basis of Human Dance," *Cerebral Cortex* 16, 8 (2006): 1157-1167. http://dx.doi.org/10.1093/cercor/bhj057; for an introduction also see Steven Brown and Lawrence M. Parsons, "The Neuroscience of Dance," *Scientific American* 299, 1 (2008): 78-83.

Discussion: Suggested Solutions to Methodological Problems

The historical-scientific development of the psychology of music as a presupposition for Cognitive Musicology introduces theoretical concepts and methods for investigating the psychological mechanisms underlying music. Thus, tonal and rhythmic structures in music, social and emotional functions of music, musical skills, reactions to music, and cognitive processes and memories involved in the perception and performance of music are investigated through scientific experiments. Consequently, Cognitive Musicology provides traditional musicology with knowledge of the psychological mechanisms underlying music perception and performance, and this knowledge is applied, for example, in relation to the analysis of music, the design of automatic computer-based tools for music analysis, music categorization, music composition, and music guidance. On the other hand, the psychology of music, the neuroscience of music, and cognitive musicology also provide psychology and neuroscience with concrete and often pleasant musical examples, which are applied in the scientific investigation of emotions, mental functions, and dysfunctions, and of both healthy and damaged brains.

The theories and findings throughout the history of the psychology of music reflect certain methodological challenges, presumably because the applied humanities-based methods of musicology and the scientific methods of the natural sciences have complementary strengths and limitations. If either a humanities-based or scientific approach alone is applied, the limitations of the approach may become a problem.[201] Therefore, I suggest that the optimal solution for Cognitive Musicology is to consistently alternate between humanities-based and scientific approaches in addressing the scope, argumentation, and relevance of the theories, research and applications. In the following discussion, pairs of humanities-based and scientific methods are presented, which may mitigate the others' limitations when they are applied jointly.

First, the scope of the scientific reductionist approach with regard to music is to analyze elements of tones and durations. This reductionist approach provides a high degree of precision, which is relevant when the aim is to test specific hypotheses empirically. In scientific experiments, it is important to isolate the tested aspect of a phenomenon, to be able to understand precisely what part has an effect in the experiment (as suggested by the atomistic and behaviorist approaches described in sections 4 and 8). For example, if you hear a piece of music that you like, you cannot be sure whether the tones, rhythms, sounds of the instruments, or lyrics cause you to like the music, unless you have tried to do an experiment in which you listen to each of these features alone. However, this reduction may also oversimplify or remove the natural context in which the observed part normally appears.[202] It might turn out that it was not the

201 For a further discussion on the combination of empiricism in the natural sciences and post-modernism in the humanities, see Huron, *Music and Mind: Foundations of Cognitive Musicology*, Lecture 3; for further historical-scientific discussions on the term "musicality", see Harald Jørgensen, *Fire Musikalitetsteorier: En Framstilling Av Fire Musikalitetsteorier, Deres Forutsetninger Og Pedagogiske Konsekvenser* (Oslo: Aschehoug, 1982), 111; Frederik Pio, "Musikalitetens Fødsel: Det Videnskabelige Menneske Og Tonalitetens Sammenbrud" (PhD, The Danish University of Education).

202 E.g. Kühl, *Musical Semantics*, 96.

tones, rhythms, sounds of the instruments, or the lyrics that made you like the music, but a combination of musical features, or the whole piece, with all its combined features (as considered in the Gestalt approach, explained in section 5). Furthermore, it might also turn out that your experience of the same music changes from day to day, and also depends partly on different listening contexts. On the other hand, a holistic humanistic approach, such as the contextually focused approach that is represented by the ideas of New Musicology,[203] which involves considering entire pieces of music, brains, bodies, and the sociocultural environments in which the music exists, may provide a more realistic explanation. A more holistic approach would be able to explain a tone in a melodic context, a melody in the context of thoughts about the melody, the thoughts about the melody in a physical context of sensations and reactions, and the thoughts, physical sensations, and reactions to a melody in a sociocultural context (as emphasized in the functionalist approach, introduced in section 6). However, this holistic approach creates a degree of complexity in which the predictive power of the reductionist method might be lost. Therefore, to increase precision, it seems appropriate to apply a reductionist approach, but also to consider a holistic approach, to avoid losing the natural context in which the studied phenomenon is situated.

Second, the argumentation in the humanities-based traditions of musicology may provide theories that define the music studied. However, some theories consist of conjectures that have no empirical basis. For example, the extent to which the proposed universal principles of Western tonality actually explain the structure observed in music from various cultures might be questioned, as might the extent to which it actually functions as a cognitive schema that structures the way persons from different cultures experience and react to certain music. However, argumentation based on scientific, empirical observations and measures may also result in data with no explanatory power. Then, music theory conjectures may be applied as a framework in which to interpret the measured data. For example, the measured, higher value in millimeters of a person's knee movements when marching bands passed by Lobard's laboratory in 1887 (see section 8) does not in itself make any sense. However, if the measured values are interpreted by applying the theories of relations between rhythms in music and physical movements, then the measurements would become more valid. Thus, it is both relevant to provide reliable measurements of the studied phenomenon, and also to be able to validate these measurements in relation to specific theoretical models which may explain the measured data.

Third, the relativist approach suggested in humanities-based cultural studies of music, which focuses on the differences between music from different cultures and different historical periods, is relevant because it provides definitions that cover the diversity of music in different cultures and time periods, such as that inherent in Helmholtz's idea of changing aesthetic principles (see section 3). However, a focus on the cultural and historical changes in music, which are relevant in today's complex, multicultural societies, results in diverse and unstable theories of music that make it diffi-

203 David Fallows, "New Musicology," *Grove Music Online*, (accessed October 2, 2013).

cult to observe, measure, and especially, to predict how a particular person will experience and respond to certain music. In this case, a more appropriate starting point may be to find more widespread and stable principles, for example, those presented by the theory of Western tonality, and to describe basic architectures and mechanisms relevant to the acquisition and application of musical information, as suggested by the more recent approaches of biomusicology and cognitive semiotics of music.[204] However, a Universalist approach should not become too rigid and try to describe certain principles as universally relevant, if they may actually vary across cultures and history. Thus, it should be considered that music may be partly based on universal, stable mechanisms with a high predictive power for explaining people's experiences and reactions to music, but at the same time, music also involves cultural, historical, and personal flexibility that make it relevant to consider how cultural, historical, and personal differences change people's experiences and reactions to music.

There are still methodological challenges for Cognitive Musicology, and that makes the most interesting questions in Cognitive Musicology those that are most difficult to answer. What distinguishes music from other sounds? Is music a universal language? To what extent is music learned or inherited? Is music a language of the emotions? Why can music be particularly powerful when it comes to communicating emotions? What is the best way to acquire musical skills, and how does one become a skilled musician? In comparison, many of the questions that may be answered currently, using the accessible and thoroughly proven methods of Cognitive Musicology, are more mundane. They relate to specific mechanisms of sound perception, mental processes involved in the understanding of music, and immediate reactions to music.[205] More methodological challenges must be solved before we can start to answer the more general questions, but future studies will presumably and gradually provide new clues to the answers.[206] The current situation of Cognitive Musicology may be compared to the early interest in combining music theory and psychology in the 19th century, which resulted in the discovery of new phenomena, and the invention of new methods in both disciplines. Similarly, the interdisciplinary research in Cognitive Musicology creates opportunities for new syntheses of theories across modern music theory, cognitive psychology, and cognitive neuroscience, as well as future solutions to methodological problems within these disciplines.

204 Zbikowski, *Conceptualizing Music: Cognitive Structure, Theory, and Analysis*, 65; Kühl, *Musical Semantics*, 30.

205 Taylor, "The Evolution and Future of Cognitive Research in Music"; Morrison and Demorest, "Cultural Constraints on Music Perception and Cognition".

206 Cf. Taylor, "The Evolution and Future of Cognitive Research in Music", 35-39; Morrison and Demorest, "Cultural Constraints on Music Perception and Cognition".

Conclusion

Cognitive Musicology is a relatively new field. However, it has a partial, 150-year historical-scientific background in the tradition of the psychology of music. The psychology of music and Cognitive Musicology combine the study of music with investigations into the psychological mechanisms underlying music perception and performance. The psychology of music emerged c. 1850 to 1870, a period in which interdisciplinary theories, scientific discoveries, and mathematical formulas for relations between physical sound waves and music perception were presented. During the period between c. the 1870s and 1930s, the psychology of music diverged into different approaches. The atomistic approach focuses on single musical parameters, such as single tones, beats, or sound qualities, whereas the Gestalt approach introduces principles for the organization of music in patterns, such as melodies and rhythms. The functionalist approach introduces considerations of evolved musical functions and mechanisms that serve specific purposes in humans' interactions with their physical and social environments, for example, mechanisms of playing musical instruments or experiencing emotions when listening to the music of a particular culture. The testing approach introduces musical tests with the purpose of measuring levels of competency, for example, to distinguish between non-musicians, amateur musicians, and professional musicians. The behaviorist approach introduces more precise and reliable methods for measuring physical changes in human behavior in response to music. The more recent cognitive approach combines the traditional branches of the psychology of music, and by using state-of-the-art computer modeling and brain scan methods, explains how cognitive processes and memories occur in human minds and brains, and how these processes and memories affect our experience and performance of music. It may be argued that Cognitive Musicology's interdisciplinary combination of methods from the humanities and natural sciences makes it possible to minimize the limitations of each individual approach. Also, interdisciplinary research creates opportunities for new syntheses of theories and solutions to methodological problems in modern music theory, cognitive psychology, and cognitive neuroscience. Therefore, I argue that Cognitive Musicology is a promising, contemporary approach to the psychology of music, with firm historical foundations.