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PROGRESS IN BRAIN RESEARCH

Music, Neurology, and Neuroscience:

Evolution, the Musical Brain, Medical Conditions, and Therapies

EDITED BY

Eckart Altenmüller

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Contents

Preface

This tome is the second volume of three paired volumes dealing with the arts and neurology and the basic neurosciences. It was preceded by two volumes on the fine arts and two on literature, and one on music dealing with the history of the neurosciences, the neurological and psychiatric disorders of famous composers and musicians, and opera as a window for viewing such disorders in historical perspective.

This volume explores exciting new developments and insights related to music and the brain, along with some more history, "especially when dealing with music therapies," to put some of these advances in a richer context. In recent years, there have been quite a few books on neuroscience and music, including a series of conference reports on "Neurosciences and Music" published in the *Annals of the New York Academy of Sciences*. These volumes, however, were dedicated to specific research projects and ongoing experimental studies, and not more comprehensive, integrative reviews that dealt with broader changes in the rapidly developing fields of the basic and applied neurosciences.

Needless to say, we were not able to summarize all facets of these new developments, since many are progressing very rapidly, and because the field of neuroscience of music has become an important part of neuroscience in general. This explosion of activity reflects the fact that music processing and music making in healthy and diseased individuals provides an exciting paradigm for a wide range of highly refined sensory, motor, memory, and emotional activities. Furthermore, music is rewarding, motivating, and one of the most valued of all human cultural accomplishments. Hence, we can only offer a sampling of the different ways in which music and neuroscience could be brought together, both when contributing to what we know about the human brain and when being considered for therapeutic purposes.

This volume starts with some pertinent history, namely the ideas of Spencer and Darwin and their controversy over the evolutionary role and significance of music. In this opening section, our authors also look at more contemporary research about the origins of music, a topic that clearly is still generating considerable discussion. As will be seen, researchers are now able to compare emotional signaling in primates and other mammals to specific features of music. Indeed, one of the roots of our love of music may well be founded in an ancient emotional communication behavior.

In our second section, we explore the role of music in driving beneficial brain plasticity. Here, our authors review some of the many adaptations of brain function and structure that have been beautifully documented in both budding musicians and highly accomplished virtuosos.

In the following sections, we change directions and focus on neurologic disorders associated with musicians and music, a topic also addressed in the first of these two volumes, although there largely by looking at back at specific, famous individuals and their disorders, and at specific types of music (e.g., from the glass armonica). What our authors now show is that there really is a dark side to the increasing specialization of professional musicians: namely the deterioration and loss of skilled motor behavior. Focal dystonia is one of these conditions, and it has now been associated with changes in the subtle balance of inhibition and activation of specific brain regions. One of our authors also shows that music can be linked to seizure disorders, including a condition now called musicogenic epilepsy, although such cases are rare. Another ailment plaguing musicians (and other performers) is anxiety and stage fright, and its prevention and treatment are also addressed in this section.

Music's therapeutic potential in helping people with neurological, psychiatric, and associated disorders is the theme of the final section of this volume. As will be seen, there is a long history of the mutual relationship between mental states and music, one with documentation dating back to ancient times. Attempting to mix the old with the new in this section, our authors first look at some of the literature from the Greco-Roman era, and then at an enlightened eighteenth-century physician, Richard Brocklesby, who wrote one of the first books on music therapy, which he believed might help (among others) melancholics. Dance therapy, which has been used therapeutically in older cultures and in modern societies, is also examined here. Additionally, we learn that music might be helpful in Alzheimer's disease, since musical memories are extremely stable and might be retrievable even in an advanced stage of this disorder. Today, neurologic music therapy in the narrow sense of the word is best exemplified by reports on music-supported stroke rehabilitation of fine-motor hand functions, and on a recent development called "melodic intonation therapy" in patients suffering from aphasia, both of which are also examined in this section. Many more therapeutic applications of music in neurologic diseases have, of course, been found useful. Rhythmic auditory stimulation, for example, can sustainably improve gait in Parkinson patients, and even simply listening to preferred music after a stroke or in patients with dementia could have antidepressive effects, with the potential to improve cognition, memory, arousal, and well-being.

With this as our prelude, we hope that this sampling of scholarly papers will show our readers some of the ways in which cutting-edge research in the neurosciences, neurology, and music can reveal more about brain functions in general, the origin of ideas, and the changing faces of "neurologic music therapy."

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RECOMMENDED ADDITIONAL READINGS

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PART

1

Evolutionary considerations

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CHAPTER

Darwin and Spencer on the origin of music: is music the food of love?

1

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Abstract

Finding an evolutionary explanation for the origins of music serves as a rich test of broader ideas on the emergence of mind and the evolution of mental processes. Charles Darwin and Herbert Spencer both offered evolutionary explanations for the origins of music, indicating the importance of the question for these two leading nineteenth-century students of "descent with modification." Their discussion unfolded between the publication of Spencer's "The origin and function of music" in 1857 and Darwin's commentaries on music in *The Descent of Man* in 1871 with an addendum Spencer offered to his original article in light of Darwin's views. They had conflicting views on the lines of causation, asked differing questions, and had fundamentally different approaches. Their exchange laid the foundation for the discussion among contemporary adaptationists and nonadaptationists and contributed to the thinking of those who argue for Mixed Origins of Music or that it is a Transformative Technology of Mind.

Keywords

Charles Darwin, Herbert Spencer, music, evolution, sexual selection, adaptationism

Finding an evolutionary explanation for the origins of music serves as a rich test of broader ideas on the emergence of mind and the evolution of mental processes. Charles Darwin and Herbert Spencer both offered evolutionary explanations for the origins of music, indicating the importance of the question for these two leading nineteenth-century students of "descent with modification." Their discussion unfolded between the publication of Spencer's "The origin and function of music" in 1857 and Darwin's commentaries on music in *The Descent of Man* in 1871 with an addendum Spencer offered to his original article in light of Darwin's views. They had conflicting views on the lines of causation, asked differing questions, and had fundamentally different approaches.

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Spencer sought a first cause of music as an outgrowth of the physical expression of emotion, arising from nervous excitement in animals. Vocalizations and then music itself became more advanced forms of the expression of emotion. That rudimentary function was the *origin* of music. Darwin's scope was in some ways narrower: he took vocalizations as a given. Music then evolved secondarily with sexual selection as the primary mechanism shaping its development. They largely talked past one another, as Spencer's approach was to deduce explanations from fundamental principles while Darwin carefully gathered observations as he tested his hypotheses. Thus, their dispute sheds light on how to pursue evolutionary problems that can continue to be helpful today by defining the recurring questions and enduring frameworks in understanding the matter.

When Darwin formulated his evolutionary explanation for the origin of music in 1871 in *The Descent of Man, and Selection in Relation to Sex*, he was justly renowned as the author of *On the Origin of Species* (1859) for its succinct yet encompassing explanation of "descent with modification." As he put it in his full title, such descent occurs by "means of natural selection [in] the preservation of favoured races in the struggle for life" or, as Spencer himself coined it, "the struggle for existence" (Spencer, 1864, p. 444). But, when Spencer opened the discussion in 1857, Darwin was known for his memoir of the Voyage of HMS Beagle and, much more narrowly, a monograph on barnacles. His careful development of his theory of natural selection as a mechanism for evolution would remain underground until 1858 when Alfred Russel Wallace sent him a short manuscript offering a strikingly similar explanation which was presented with some of Darwin's own writings at a meeting of the Linnean Society. Wallace spurred Darwin into action to publish *On the Origin of Species* in 1859 as an abstract of his evolutionary views.

In 1857, Spencer published "Progress: Its laws and causes," which was a formative statement of his evolutionary views which were expanded in *First Principles of a New System of Philosophy* (Spencer, 1862). He had established himself as a broad synthetic thinker on a range of topics with works such as *Social Statics* (Spencer, 1851) and *Principles of Psychology* (Spencer, 1855).

Darwin's and Spencer's two distinctively different approaches continue to define the discussion on the origin of music. Aniruddh D. Patel (2010) has helpfully identified these two approaches as adaptationist (Darwin) and nonadaptationist (Spencer) and traced their respective influences. Adaptationists seek to explain music's contribution to our species survival in terms of sexual selection, parental care, social cohesion, and the development of music as homologous to language. Sexual selection goes back to Charles Darwin himself in seeing music as one kind of courtship behavior with mate choice refining the development of song. Parental care focuses on the role of music in maternal (mostly) bonding with infants and children. Social cohesion sees music as a way that families, clans, tribes, and other units bond (Brown et al., 2000, pp. 12–13). The nonadaptationist tradition is equally rich, starting with Spencer but extending through William James and on to Steven Pinker today (Patel, 2010). In this view, music is purely a human invention with no biological function.

In returning to an examination of the Spencer/Darwin debate, we can see these two powerful perspectives in formation. They largely talked past one another with different aims and criteria for a satisfactory explanation. Yes, Darwin was the prototypical adaptationist, but he was far more pluralistic than Spencer, more willing to accept music as a spandrel, in Gould and Lewontin’s (1979) sense, a modification that comes along structurally with an adaptation subject to selection. His is a broader examination of sexual selection of which music is but one example. Spencer is the one who is compelled to explain “The origin and function of music” to the end, subjecting every detail of the phenomenon of music to his explanation. In this way, it is Spencer, paradoxically, who is closer in spirit to the ultra-adaptationists Gould and Lewontin criticize.

This summary of these historically influential perspectives on the origins of music provides a framework for deepening our contemporary efforts to understand the evolutionary role of music and, from there, to understanding the evolution of the mind and other mental processes.

1 HERBERT SPENCER: “ON THE ORIGIN AND FUNCTION OF MUSIC”

In 1857, the same year that he published his important “Progress: Its laws and causes” (Spencer, 1857), Herbert Spencer also published in October “The origin and function of music” in *Fraser’s Magazine* (Spencer, 1901). The former was a formative statement of his evolutionary views which were expanded in *First Principles of a New System of Philosophy* (Spencer, 1862). Progress from simple, undifferentiated, and homogeneous forms to complex, differentiated, and heterogeneous ones was a universal law applicable to all sciences from cosmology to the social sciences. He sought such “first principles” and “laws” from which he deduced “new systems” not just of philosophy but for most areas of human inquiry. His was an all-encompassing world view. (Francis, 2007; Hofstadter, 1955; Kivy, 1964; Weinstein, 2012).

But it and his approach were not completely convincing as others challenged his premises and methodology. His friend, Thomas Henry Huxley, for example, commented that “Spencer’s idea of a tragedy is a deduction killed by a fact” (Spencer, 1904, p. 467). Charles Darwin (1969) was less pithy and more measured, though perhaps just as pointed in an unpublished comment:

> *His deductive frame of treating every subject is wholly opposed to my own frame of mind. His conclusions never convinced me and over and over again I have said to myself, after reading his discussions, “here would be a fine subject for half-a-dozen years work.” (p. 162).*

When Spencer addressed the origin and function of music, the starting point was the simple physical, even prevocal, expressions of emotion in animals. Dogs wag their tails when happy; cats arch their backs when frightened; and people smile in reaction to pleasurable scenes. So, “All feelings, then—sensations or emotions, pleasurable or painful—have this common characteristic, that they are muscular stimuli” (Spencer, 1901, p. 403). This notion of an emotional “energy quotient” is shared in the work of such diverse thinkers as Michael Foster, Sigmund Freud, and Konrad Lorenz.

If all creatures express emotions through their bodies, then it is natural that their/our vocalizations are but a specialized response to muscular stimuli. For Spencer (1901):

> *All music is originally vocal. All vocal sounds are produced by the agency of certain muscles. These muscles, in common with those of the body at large, are excited to contraction by pleasurable and painful feelings. (p. 403).*

He continues, arguing that, "it follows that variations of voice are the physiological results of the variations of feelings" (Spencer, 1901, p. 404). Loudness correlates with strong feelings, as it takes more energy to expel more air from the lungs across the vocal cords. We speak louder when excited and we scream when grieving or in pain. Spencer (1901) asserts that vocal tone reflects different moods, noting "the ringing laugh of joy" and "the chanting tone of grief" and that "the ordinary speech of a virago [a shrill, unpleasant woman] has a piercing quality" (p. 405). Pitch, its variability, and the intervals we use are *prima facie* evidence for Spencer of particular eternal moods, even though we may just as much learn to express our emotions—complaint, joy, and grief—with particular inflections. Spencer's effects are as much causes, or at least there is an interaction between speaker and listener negotiating the meaning of the communication.

But, as Spencer writes (Spencer, 1901),

> *. . .we find all the leading vocal phenomena to have a physiological basis. They are so many manifestations of the general law that feeling is a stimulus to muscular action—a law conformed to throughout the whole economy, not of man only, but of every sensitive creature—a law, therefore, which lies deep in the nature of animal organization. (pp. 409–410)*

He has once again charted a general progression from nervous muscular expression to more specific emotions expressed vocally. His point goes even further:

> *Have not we here, then, adequate data for a theory of music? These vocal peculiarities which indicate excited feeling,* are those which especially distinguish song from ordinary speech. *Every one of the alterations of voice which we found to be a physiological result of pain or pleasure* is carried to an extreme in vocal music.
>
> **Spencer (1901, p. 410, original emphasis)**

The line from the physical expression of emotion to their vocal expression to music is direct and concrete, not metaphorical or analogous. That is the origin of music for Spencer; going back to the very root of the phenomenon.

The historical functions of music, with supposedly eternal but actually very historically contextual cultural assumptions, are also part of Spencer's argument. "Savages" chant monotonously within an interval of no more than a musical fifth; ancient Greek music was accompanied by a simple four stringed lute; "(t)hat [primitive]recitative—beyond which, by the way, the Chinese and Hindoos seem never to have advanced—grew naturally out of the modulations and cadences of strong feeling, we have indeed current evidence" (Spencer, 1901, p. 416). More sophisticated music grows out of the finer feelings of civilization and "Musical composers are men of acute sensibilities" (Spencer, 1901, p. 417), witness Mozart, Beethoven, Mendelssohn, and Chopin, in this last case we know this from the memoirs of George Sand.

This is Herbert Spencer's answer to the problem of the origins of music. From the physical expression of emotion to vocalization to primitive chanting to the highest expressions of European civilization, it is the result of the inherent progressive tendency from simple, undifferentiated, and homogeneous forms to complex, differentiated, and heterogeneous ones. No mechanism was required.

2 CHARLES DARWIN: SEXUAL SELECTION

Darwin sought the exact opposite, a mechanism for the origin of music. That mechanism was, he concluded, sexual selection. Starting from the facts that vocalizations occurred in many creatures, he sought to determine what caused them to develop toward what we recognize as music. He found an explanation in the role of courtship behavior and mate selection, as well as in the facts of sexual dimorphism in vocal structures, observations of animal behavior, and similarities both with other examples of sexual selection and behaviors in many species.

This particular behavior as well as others, such as display characteristics and sexual dimorphisms, could provide differential reproductive success and hence could be selected for. Sexual selection was different from natural selection. Organisms not only struggled for existence within their species, with other species, and against the environment as natural selection posited, but they also competed to leave more offspring. Evolution resulted from the survival primarily, but also the fecundity, of the fittest—to amend what was, after all, Spencer's phrase.

With an approach rather like the "one long argument" of *On the Origin of Species*, Darwin catalogs observations of sound-making in animals across several families, from insects to mammals. Frogs and toads sing, "but to speak of music, when applied to the discordant and overwhelming sounds emitted by male bullfrogs and some other species seems, according to our taste, a singularly inappropriate expression" (Darwin, 1977, pp. 689–690). Still some "sing in a decidedly pleasing manner" (Darwin, 1977, pp. 689–690), as he recalls from a time near Rio de Janiero during the HMS Beagle voyage (Darwin, 1989). The key points are that males tend to emit these sounds during breeding season, and there is significant sexual dimorphism in the vocal organs in this family. He cites a Mr. C.J. Maynard's report in the December 1869 issue of *The American Naturalist* that in *Rana exculenta* (edible frog) only the males have an air sac that opens into the larynx, so that "the croak of the male is thus rendered exceedingly powerful; while that of the female is only a slight groaning noise" (Darwin, 1977, pp. 689–690).

In birds, Darwin (1977) first notes that they express various emotions: "distress, fear, anger, triumph, or mere happiness" (p. 704). He further demurs that "naturalists are much divided with respect to the object of singing in birds," some suggesting that it marks a territory that females can then select while others see "the effect of rivalry and emulation," and not for the sake of "charming their mates" (Darwin, 1977, p. 705). He takes on further "difficulties on theory" as he did in the *Origin*, acknowledging that emulation and courtship are not incompatible nor does the fact that females also sing disqualify singing as a sexual characteristic that can be selected for nor, finally, that birds sing outside of the breeding season. Even sexual dimorphism related to voice is not universal, though he can cite spectacular vocal sacs in grouses and bustards and tracheal differences in swans and ducks. Courtship is significant, witness that "birds which sing well are rarely decorated with brilliant colours or other ornaments" (Darwin, 1977, p. 709).

Thus,

> *The diversity of the sounds, both vocal and instrumental, made by the males of many birds during the breeding-season . . . are highly remarkable. We thus gain a high idea of their importance for sexual purposes. . .*
>
> **Darwin (1977, p. 713)**

Darwin has also just discussed the role of feathers as noise-makers and repeats, with modifications, the sexual selection argument concerning display that he has offered before as a key example for his broader explanation.

Turning to mammals, he observes that they use their voices to signal danger, call to other members of the troop, between mother and young, and even in the nervous excitement before a fight between males. His interest though is in the differences between the sexes (Darwin, 1977, p. 840). He has examples from stags (though these seem to serve no direct purpose, either as a proxy or preparation for battle or in courtship), gorillas, and gibbons. He is especially interested in "two very curious sexual peculiarities occurring in seals." These are the male sea elephant with a nose that elongates during breeding season and the bladder nose seal with a nose that develops only in mature males. He suggests that these developments may have more to do with appearance than vocal capabilities.

Darwin's discussion of humans is not exclusively about *Homo sapiens per se*, rather it serves to summarize his general argument about music. While the "capacity and love of singing or music [is] not a sexual character in man," it must not be ignored, because in other species

> *a strong case can be made out, that the vocal organs were primarily used and perfected in relation to the propagation of the species . . .The chief and, in some cases, exclusive purpose appears to be either to call or charm the opposite sex.*
>
> **Darwin (1977, p. 875)**

Vocal organs are more developed in males and are used primarily during breeding season, yet "it is a surprising fact that we have as yet not any good evidence that these organs are used by male mammals to charm the females." (Darwin, 1977, p. 876)

His argument for sexual selection as explanation for the origin of music is not strong in itself. His purpose is instead to make the broader case that sexual selection supplements natural selection in shaping evolution in general. A sexual selection theory of music is strengthened by analogy with other better developed sexual selection explanations concerning appearance, display, and behavior.

Still, his work on the origin of music in this framework is richly suggestive, anticipating many aspects of current research. He comments on the evolution of hearing, pointing out that discrimination of musical notes was not selected for but that, simply, "an ear to be capable of discriminating noises—and the high importance of this power is admitted by every one—must be sensitive noises" (Darwin, 1977, p. 877).

He concludes this discussion by arguing that "musical sounds afforded one of the bases for the development of language" (Darwin, 1977, p. 880). As he has shown, "musical tones and rhythm were used by our half-human ancestors, during the season of courtship, when animals of all kinds are excited not only by love but by the strong passions of jealousy, rivalry, and triumph" (Darwin, 1977, p. 880). This association connects music to strong emotions, yet many animals long before we humans with our articulate speech have made noises to win mates, express emotions, and communicate with others. Hence, he argues that "it would be altogether opposed to the principle of evolution, if we were to admit that man's musical capacity has been developed from the tones used in impassioned speech" (Darwin, 1977, p. 880). Darwin's conclusion is, in fact, the exact opposite, that music contributed to the development of language.

3 SPENCER'S REJOINDER

Nearly 20 years after Darwin's remarks, Spencer added a postscript to "Origin and Function of Music" answering him (and also Edmund Gurney) and disputing the role of sexual selection on this question. He finds Darwin "swayed by his doctrine of sexual selection" (Spencer, 1901, p. 427). His critique is, as Peter Kivy (1959)[1] points out, surprisingly empirical, given both their profound methodological differences and Spencer's own usually very deductive approach. Instead, he challenges Darwin for his contention that what he attributes to "amatory feeling" is actually so specific that general emotional excitement triggers the vocal noises that develop into music: "This roundabout derivation [via sexual selection] has, I think, less probability than the direct derivation [from Spencer's own explanation]" (Spencer, 1901, p. 427).

Spencer observes that "the animals around us yield but few facts countenancing his view" of sexual selection's impact on the development of music (Spencer, 1901,

[1]Peter Kivy's "Charles Darwin on Music" was published in his 1993 collection *The Fine Art of Repetition: Essays on the Philosophy of Music*, but grew out of his MA thesis at Yale around the time of the centenary of the publication of *On the Origin of Species*. His essay is a strong summary of the conflicting views of Darwin and Spencer, so, of course, I owe much to his analysis.

p. 428). Pigeons' cooing and bird song in general *seem* to be a courtship behavior, but he is dubious about "caterwauling," dogs barking for any number of reasons, pigs' happy grunts over food, and other examples which seem to be "at variance with the view 'that the vocal organs were primarily used and perfected in relation to the propagation of the species'" (Spencer, 1901, p. 428).

It is Spencer who collects observations (birds singing out of breeding season, after the young had fledged) to suggest that such an expression "results from the overflow of energy" (Spencer, 1901, p. 430). Even if the sexual selection hypothesis were true in birds, he disputes that such a finding would necessarily be relevant in humans. Spencer believes "we are out to find vocal manifestations of the amatory feeling becoming more pronounced as we ascend along that particular line of inferior *Vertebrata* out of which Man has arisen" (Spencer, 1901, p. 432). Yet this does not appear to be true, and Spencer uses Darwin against himself, calling the following "an admission which amounts to something like a surrender:" "It is a surprising fact that we have not as yet any good evidence that these organs are used by male mammals to charm the females" (Darwin, 1977, p. 876, in Spencer, 1901, p. 432). Spencer offers more empirical counter-evidence from his series *Descriptive Sociology.*

Spencer concludes his critique of Darwin by lecturing him for not having "reduced his hypothesis to a shape admitting comparison" (with Spencer's views). "Mr. Darwin should have shown that the sounds excited by sexual emotions possess these same [musical] traits; and. . .shown that they possess these same traits in a greater degree [than those Spencer identifies as the result of emotional excitement in general]" (Spencer, 1901, p. 436). This is the nub of the debate. Spencer wants to explain the simplest, most undifferentiated, and most homogeneous form of sound that will lead to the complexity, differentiation, and heterogeneous forms of human music today. He argues that sexual selection overemphasizes the role of "vocal sounds caused by the amatory feeling only" (Spencer, 1901, p. 436).

4 ASSESSING THE OPPOSING VIEWS

They are not comparable hypotheses at all. Darwin had different aims. He takes vocalization as a given and wonders what has shaped its development, especially music. Spencer feels compelled to explain where vocalizations come from—and Darwin has little reason to dispute Spencer's framework. Indeed he remarked in *The Expression of the Emotions in Man and Animals*: "No one can listen to an eloquent orator or preacher, or to a man calling angrily to another, or to one expressing astonishment, without being struck with the truth of Mr. Spencer's remarks" (Darwin, 1965, p. 86).

Darwin's method is also more flexible. Spencer needs to explain the whole phenomenon of music, from beginning to end, and finds in nervous energy the most general, homogeneous, and undifferentiated explanation. He disputes Darwin because Darwin cannot—and does not choose to—explain the entire sweep from vocalizations in insects to the most sophisticated forms of human music in terms of sexual selection. He demands a strictly adaptationist explanation from Darwin, whereas, to use Gould and Lewontin's (1979) striking metaphor, music is more likely a spandrel. It comes along with other adaptations, just as support arches for domes create spaces that can then be decorated, to be taken as a whole rather than being specifically selected for as a separate adaptation.

Spencer specifically takes up "The Origin and Function of Music" directly and in so many words as an end in itself, whereas Darwin offers music as one small example in a much broader argument about the role of sexual selection as an evolutionary mechanism. It is that broader argument that he is making and, while the specific examples matter, it is their collective, cumulative, comprehensive, and converging character that he strives for.

There is further confirmation in avenues of research each view opens up. Spencer seems to have settled the question of the origin of music and offers this particular example as a further evidence of his basic laws of progress. Darwin instead offers sexual selection itself as a reasonably established hypothesis to be tested in numerous applications, including music.

5 CURRENT WORK ON THE ORIGIN OF MUSIC

Wallin et al. (2000) collected the papers of their fellow biomusicologists in a volume titled *The Origins of Music*. Using this volume as a window on contemporary, largely adaptationist views, one finds developed and defined research in sexual selection while, perhaps paradoxically, other contemporary hypotheses on the origin of music—social cohesion and parental care—reflect a pluralism Darwin, perhaps even more than Spencer, would appreciate. Additionally, contemporary views (see also Wallin, 1991) on the relationship of music and language seem to reject both Darwin's and Spencer's views. Further, the work of Patel and Altenmuller reflects perceptive attempts to break the adaptationist/nonadaptationist knot.

Recall that Spencer viewed language as preceding music, whereas Darwin had the opposite view. For Spencer, excited emotion gave rise to vocalizations, of which music was a specialized kind—and a later development; for Darwin, pre-human animals used vocalizations made more pleasing by sexual selection to win mates well before language as we know it developed. In *The Origin of Music* collection, Jean Molino (2000) and Bruce Richman (2000) emphasize the common foundation of imitation and rhythm to both music and language, suggesting the development of both music and language from what Steven Brown (2000) calls "musilanguage."

Brown and others "link music's adaptive role to its ability to promote coordination, cohesion, and cooperation at the level of the social group" (Brown et al., 2000, p. 11). Music's key role in rituals of work, worship, and war are offered as evidence of a long history and, in turn, a basis for humans developing music. Similarly, Ellen Dissanayke (2000) suggests that song developed in response to the most primary bond of social cohesion, that between mother and infant.

Sexual selection itself remains a robust explanation with developed research in its support. Peter Todd (2000) offers nuanced computer simulations supporting sexual selection models for the changes of songs in populations through mate choice. But it is Geoffrey Miller who makes the most extended argument for sexual selection as a "complex biological adaptation" that therefore must be explained through natural or sexual selection; in support of the latter he suggests that "Darwin's courtship hypothesis can be updated in light of contemporary evolutionary psychology, biological signaling theory, and sexual selection theory" (Miller, 2000, p. 329). Indeed this "put[s] music in the adaptationist arena where theories have to play by very strict rules" (Miller, 2000, p. 333). It has costs (expenditures of resources) yet "no identifiable survival benefits," so reproductive benefits are the probable evolutionary explanation (Miller, 2000, p. 337). He also embraces a version of Richard Dawkins' "selfish gene" model (1976) and strictly rejects group selection models, since "individuals are the units of selection, [but] genes are the units of selection and replication, and selection views individuals as transient vehicles for passing on their genes" (Miller, 2000, p. 334).

In arguing for the social cohesion hypothesis, Brown points out that music is an activity done by the group and for the group. He therefore accepts that "groups of musical hominids out-survived groups of nonmusical hominids due to a host of factors related to group-level cooperation and coordination" (Brown, 2000, p. 297). Musicality is correlated with other forms of cooperation and social cohesion has survival benefits. This view is compatible with perceiving music as a spandrel, in Gould and Lewontin's metaphor, that is, something not directly selected for or even selected for at all and thus loosed from "very strict [adaptationist] rules" (Miller, 2000, p. 333).

Aniruddh Patel and Eckhardt Altenmuller and colleagues offer synthetic views on the origin of music that are neither adaptationist nor nonadaptationist. Patel (2010) describes music as a "transformative technology of mind" while Altenmuller et al. (2013) propose "mixed origins of music." Music, in Patel's view, is a "biologically powerful" human invention with "lasting effects on nonmusical brain functions, such as language and attention, within individual lifetimes" (Patel, 2010, p. 91). Those last effects are not what music is "for," nor what the brain specializes for. It is a "spandrel," inviting great decoration, but, those "lasting effects" matter and are incorporated into who we are. Altenmuller's view is that music derives from both esthetic and strong emotions. The esthetic emotions are relatively recent, in an evolutionary sense, without strong physical correlates and, as such, this aspect of music is a "transformative technology of mind." But the strong emotions elicit such physiological responses as chills down the spine, and so "point towards an evolutionary old acoustic communication system we share with many other nonhuman animals" (Altenmuller et al., 2013, p. 320).

6 CONCLUSIONS

The Spencer/Darwin debate on the origins of music is interesting not only on its own terms, but for the light it sheds how to approach evolutionary questions. It is as much in this methodological way as through specific scientific conclusions that studying their nineteenth-century debate can help contemporary workers to begin to understand the origin of music.

Spencer sought to explain the origins of music as an outgrowth of the physical, even prevocal, expression of emotion. Vocalization is itself a subset of that physical excitement and, as animals found ways to express emotions, their vocalizations became more varied and ultimately musical, albeit with language coming first in hominids. He explained once again how a complex, differentiated, heterogeneous phenomenon such as music can grow out of the simpler, more unformed, and homogeneous expression of emotion. That is the approach he took to the "origin and function of music."

Darwin took a contrary approach, taking vocalization as a given, but then asking what shaped its development into music. He was even sympathetic to some of Spencer's basic observations and there is a pluralism in his approach that Spencer's lacks. His aim was different, since his explanation was but a subsidiary example in a broader argument for sexual selection. Given the variation at hand, sexual selection shaped songs in many species, including human ancestors and close primate relatives.

Darwin's pluralistic argument with Spencer echoes ones he had with fellow naturalist Alfred Russel Wallace, the co-discoverer of natural selection, over both sexual and natural selection. Wallace rejected the former in favor of the exclusive adaptive power of the latter. Darwin wrote at the end of the Introduction to the first edition of *On the Origin of Species*, "I am convinced that natural selection has been the main but not exclusive means of modification." (Darwin, 1964, p. 6)

Wallace was so fully committed to natural selection that everything had to be an adaptation to be selected for—there could be no spandrels. As Stephen Jay Gould (1980) writes:

> *Natural selection may build an organ "for" a specific function or group of functions. But this "purpose" need not fully specify the capacity of that organ. Objects designed for definite purposes can, as a result of their structural complexity, perform other tasks as well. . .[O]ur larynx may have arisen "for" a limited range of articulated sound needed to coordinate social life. But its physical design permits us to do more with it, from singing in the shower for all to the occasional diva. (p. 57)*

Geoffrey Miller's strict adaptationist sexual selection explanation of the origin of music in the Brown et al. (2000) volume has a similar tinge, even though he offers it in the name of Darwin's sexual selection. But it is actually more aligned with Spencer's drive to explain every detail about the origin and function of music in terms of one fundamental principle.

Darwin's pluralistic approach, even as he suggests music as an example of sexual selection, better helps us advance our current understanding of the multiple roles music has played (courtship, social cohesion, and parental care as well as shaping brain function) in human history and its complex and varied impact on human life.

Whether music is refined nervous excitement or a "transformative technology of mind," or has mixed origins or is sexually selected, that is, it "be the food of love," we human "play on" in countless glorious ways.

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CHAPTER

Music evolution and neuroscience☆

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Abstract

There have been many attempts to discuss the evolutionary origins of music. We review theories of music origins and take the perspective that music is originally derived from emotional signals. We show that music has adaptive value through emotional contagion, social cohesion, and improved well-being. We trace the roots of music through the emotional signals of other species suggesting that the emotional aspects of music have a long evolutionary history. We show how music and speech are closely interlinked with the musical aspects of speech conveying emotional information. We describe acoustic structures that communicate emotion in music and present evidence that these emotional features are widespread among humans and also function to induce emotions in animals. Similar acoustic structures are present in the emotional signals of nonhuman animals. We conclude with a discussion of music designed specifically to induce emotional states in animals.

Keywords

adaptive value, cross-species parallels, emotional signals, emotions in music, evolution of music, music and speech interactions

1 INTRODUCTION

What are the origins of music? Is music unique to humans or does it have an evolutionary history? Does music have an adaptive function and, if so, would this function have been of use to other species? What is the relationship between music and

☆This chapter is dedicated to the memory of Michael J. Owren (1955–2014) whose influential work on emotional signals in human and nonhuman species has provided an empirical and theoretical basis for our writing.

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language? Can music be related to emotional signaling in nonhuman animals? Are there emotional universals in music and in animal signals? If music can induce emotional states in listeners, can animal signals do the same? This chapter attempts to provide some answers to these questions. We take the perspective that music was derived from the emotional signals of other species and had as its initial primary function to induce emotional states in listeners. We will briefly review various theories of music origins and then provide data suggesting that music is adaptive in promoting social cohesion and has beneficial physiological effects in humans and other species. We then provide evidence that the emotional content of language is mediated by music-like structures involved both in vowel harmonics and in prosody. Prosody in human speech also influences the behavior of preverbal infants, as well as the behavior of other species, suggesting an evolutionary continuum. Next, we will consider the possibility of universals in the ways music induces emotions across cultures and look for similar universals in animal emotional signals. We will provide evidence on some experimental tests of playing music to animals and conclude with some suggestions for future directions.

2 THEORIES OF MUSIC ORIGINS

There is a variety of ideas about the evolution of music that focus on whether music is adaptive or not, ranging from the "music as cheesecake" hypothesis of Pinker (1997) that music is nice but has no adaptive function to the idea that music is sexually selected and is important in mate choice (Charlton, 2014; Darwin, 1871; Kleinman, in the first volume; Miller, 2000), to the Mixed Origins of Music hypothesis (Altenmüller et al., 2013) which maintains that the early roots of music may lie in an ancient affective signaling system that is common to many socially living mammals. However, later on music also induced aesthetic emotions and facilitated a safe practice environment for auditory learning, promotion of social cohesion, and for psychological and physiological well-being.

The origins of music have been hypothesized to be uniquely human following after the evolution of language, since music requires many of the cognitive skills associated with language (Patel, 2008) or has evolved simultaneously with language (the music language hypothesis; Brown, 2000). As an alternative to music being unique to humans, Juslin and Västfjäll (2008) and Levitin (2008) have proposed that music has evolved from emotional communication and that the musical components of speech provide honest communication about emotions. This is the view that we will support in this chapter. We agree with Altenmüller et al. (2013) that there is more to music than simply affective or emotional communication, but from a phylogenetic perspective we can focus only on observable behaviors.

In studying the evolution of a phenomenon, there are two separate questions that need to be answered. The first question has to do with adaptation or function. Can we discern obvious benefits to music that cannot be found with other types of auditory inputs such as speech or other sounds? If there is no clear adaptive function that can be detected then what we study might simply be an artifact of another evolved function. Thus, music might simply have been an incidental component to the evolution of a complex auditory system that is needed to process speech sounds. The second question has to do with time course or phylogeny. A trait might be adaptive solely for modern humans and could have evolved after branching off, or a trait may have appeared even in nonhuman mammals and may thus be ancestral and shared by other species as well.

There are two models of phylogeny-divergent and convergent evolution. Most people are familiar with divergent evolution: that traits studied in one species might be shared with a common ancestor. Thus, for humans, apes and monkeys are our closest relatives and traits shared among several species suggest a common ancestor dating back to when the lines diverged. Less well known is the concept of converging evolution: that species with similar problems to solve may have developed similar adaptations regardless of phylogenetic closeness. Thus, many have argued that songbirds are good models for human speech and music, since vocal signals appear to play a much more important role for humans and songbirds than for our closest relatives. We need to evaluate both adaptation and phylogeny to understand the origins of music.

3 MUSIC IS ADAPTIVE

We first need to demonstrate how music can be adaptive. One of the best known putative adaptive advantages has been music as a sexually selected trait that allows males to compete for females. This idea was initially suggested by Darwin (1871) and subsequently advocated by Miller (2000). Haselton and Miller (2006) found increased attractiveness of men expressing creative intelligence as short-term sexual partners at the time of ovulation in women. Charlton (2014) has reported that periovulatory women show significant short-term mating preferences for men who are attributed as composers of complex music. The "complex" music used by Charlton (2014) is still relatively simple compared with most composed music, which may make these short-term mate preferences even stronger with most music.

As articulated by Owren and Rendall (2001) for animal signals, emotional signals can induce emotional states in others that can lead to social cohesion with shared emotions and increased cooperation within a group. Mithen (2005) has suggested this social cohesion function of music for our prehistoric ancestors. Emotional signals can also influence cognition and have effects on the physiology and neuroendocrine systems of listeners.

One contemporary study provides evidence for the social cohesion function of music. Kirschner and Tomasello (2010) studied two groups of 4-year-old children. In one condition, pairs of children marched around an artificial pond containing toy frogs, while singing a song to musical accompaniment and picking up the frogs in time to the song to wake them up. In the other group, pairs of children engaged in the same actions but without singing. The children were then tested on a task that involved cooperation with the other child and on a task where one child could choose to help the other child. In the joint singing condition, children were significantly more likely to cooperate with and to help one another than in the condition without music.

Several cognitive and physiological effects of music have been demonstrated in human and in nonhuman animals. When neuroanatomical terms are presented in the form of a song, college students learned the terms more rapidly and retained more of the terms when tested up to 10 days later (Panksepp and Bernatzky, 2002). Adding speech to music (as in a song) may lead to greater memory. Weiss et al. (2012) measured recognition memory for old versus new melodies using piano, banjo, marimba, and voice, with greater recognition occurring for sung melodies. Emotional mood induction by music (happy or sad) can influence whether happy or sad memories can be recalled (Parrott and Sabini, 1990).

Music has also been used in therapeutic situations with reports suggesting music reduces anxiety and improves mood for medical and surgical patients (Kemper and Danhauer, 2005), with specific effects on pain reduction and pain distress in the early postoperative days in patients undergoing abdominal surgery (Vaajoki et al., 2011), and with soothing music increasing oxytocin levels after open heart surgery (Nilsson, 2009). Music also reduces anxiety and depression, and blood volume pulse amplitude in caregivers of cancer patients (Lai et al., 2011). Although music could not have evolved initially to alleviate stress in patients, the more general conclusions are that soothing music can influence physiological process that bring about enhanced physical and mental well-being, and these could have had important adaptive functions.

Listening to music has been shown to modulate activity in a network of structures associated with reward and pleasure in the brain. Using functional magnetic resonance imaging (fMRI) and functional and effective connectivity analyses in human participants, Menon and Levitin (2005) demonstrated activation of the nucleus accumbens and ventral tegmental area with subsequent connections to the hypothalamus, insula, and orbitofrontal cortex. Salimpoor et al. (2013) used similar methods with people listening to a piece of music for the first time and found that the aesthetic rewards of music correlated with the interaction of the nucleus accumbens with the auditory cortex, amygdala, and ventromedial prefrontal cortex. These results help explain why listening to music is highly pleasurable.

Studies in nonhuman animals provide similar findings to those in humans, suggesting some sort of continuity across species. Thus, music reduces the distress vocalizations produced by newborn chicks in isolation (Panksepp, 1998) similar to the effects of injecting the social hormones, prolactin, or oxytocin into the brain (Panksepp, 1996). Music also increases levels of dopamine and norepinephrine in the brain, both of which are involved in processes of arousal and attention and lead to rewarding effects (Panksepp and Bernatzky, 2002). Music has been shown to have several other effects. For example, dogs in shelters were calmer after listening to classical music and barked more after listening to heavy metal (Wells et al., 2002). However, music by Mozart (*Symphony #40*) decreased heart rate in hypertensive rats, whereas music by Ligetti (*String Quartet #2*) increased blood pressure in hypertensive rats (Lemmer, 2008), suggesting that classical music should not be treated as a unitary genre. Playing of Mozart's Adagio (from *Divertimento #7, K. 205*) reduced blood pressure and stimulated dopamine synthesis in hypertensive rats

(Akiyama and Sutoo, 2011), but only music in the range of rat vocalizations (4–16 kHz) was effective, illustrating that the type of music played should be related to the auditory system of the species being studied (see below). Prenatal exposure to Mozart's *Piano Sonata (K. 443)* led rats when adults to learn maze tasks more quickly (Chikahisa et al., 2006). Ames and Arehart (1972) exposed lambs to music of Montovani or to white noise and found decreased heart rate and decreased heart rate variability in music-exposed lambs.

One would not normally expect fish to be responsive to music, but several studies in fish have reported effects on growth rate and physiology. Gilthead seabream showed increased growth rate and weight gain, but decreased dopamine levels when exposed to Mozart's *Eine Kleine Nachtmusik (K. 525)* (Papoutsoglou et al., 2008), similar to results in common carp (Papoutsoglou et al., 2007).

In summary, taken together these human and animal studies suggest a role for music in emotional induction and coordination of behavior, increased cognitive skills, in beneficial physiological effects, and positive neurochemical changes. However, it is not clear what aspects of music have positive physiological and cognitive effects in humans and animals. In many cases, the precise music being used is not specified, and in other cases music by Mozart is used ostensibly to mimic the now discredited "Mozart effect" on human cognition (Steele et al., 1999). It is likely that different aspects of music—tempo, harmony versus dissonance, major versus minor keys, note duration, and familiarity—may all have an influence on these processes. Future work should examine with greater precision which aspects of music have specific effects on both humans and animals. With nonhuman animals, researchers should consider the range of auditory sensitivity in the tested species, as well as typical tempos in animal vocalizations when testing with music, since the literature also reports many studies where music has no effect on animal development, physiology, or behavior.

4 MUSIC AND PHYLOGENY

The second evolutionary issue concerns whether music or music-like phenomena are seen in other species. If we do see aspects of music in other species, then the origins of music may predate our own species. There already have been several reviews on this by Altenmüller et al. (2013), Fitch (2006), Hauser and McDermott (2003), and Patel (2008, 2010), each reaching different conclusions. Hauser and McDermott (2003) assert that any features of music perception found in nonhuman animals must be related to similar perceptual systems and not to music, since they assume that music is not to be found in animals. Fitch (2006) is more open-minded and considers that learned song in birds, whales, and other species might represent convergence to music in humans whereas drumming by apes might represent a potential homology. Patel (2010) argues in partial agreement with Hauser and McDermott that any aspects of music cognition that are based on brain functions were developed for other purposes and cannot be part of the natural selective processes for music. However, like Fitch he thinks that species with vocal learning might be able to display with humans the ability to synchronize behavior to the changing of tempi in music, and that this may represent a phylogenetic origin of the ability to keep time with a beat. Indeed, Patel et al. (2009) have shown that a cockatoo is able to synchronize to a changing beat. Here, we adapt the view of Altenmüller et al. (2013) of two emotional systems, with "strong" emotions having close parallels with emotional communication in other species and "aesthetic" emotions being derived in humans.

We will detail support for this view in later sections but first address some other data from animals. Patel and others have argued that vocal learning is a prerequisite for beat synchronization and a study of rhesus macaques (which do not learn vocalizations) found that the macaques could detect rhythmic groupings but not the beat (Honing et al., 2012). However, a recent study on one sea lion (Cook et al., 2013) demonstrated the ability to entrain movement to rhythmic auditory stimuli. Thus, vocal learning may not be a prerequisite for keeping the beat.

Many studies have demonstrated absolute pitch in nonhuman animals (Hulse and Page, 1988), but only one study (in rhesus macaques) has demonstrated octave generalization, the ability to recognize melodies when transposed one octave higher or lower (Wright et al., 2000). Interestingly, the macaques could generalize only when melodies were taken from the diatonic scale; when they were tested with atonal melodies, octave generalization disappeared. Most studies have used atonal melodies and the success of generalization with the diatonic scale suggests that the diatonic scale may have some fundamental perceptual features that can be found even in distantly related animals. It is interesting to note that research on bird songs (most commonly suggested as analogous to human music) has failed to find evidence of harmonic intervals that match the chromatic, major diatonic, or major pentatonic scales (Arala-Salas, 2012; Dobson and Lemon, 1977). Thus bird song is not really musical. This suggests that, even if one used a diatonic scale, one would not find octave generalizations or relative pitch in songbirds.

Several researchers have examined whether animals can discriminate between different types of music and whether they show preferences. Porter and Neuringer (1984) found that pigeons slowly learned to discriminate between music by Bach and Stravinsky, but the pigeons showed rapid generalization to novel pieces by Buxtehude and Scarlatti with Bach, and to pieces by Carter and Piston with Stravinsky. Human subjects showed similar generalization ability. Watanabe and Nemoto (1998) found half of Java sparrows tested preferred Bach to Schönberg and subsequently generalized to Vivaldi versus Carter. Watanabe and Sato (1999) reported that five of seven Java sparrows discriminated between Bach and Schönberg and generalized to novel examples from the same composers, as well as to music by Vivaldi (for Bach) and Carter (for Schönberg). Otsuko et al. (2009) trained rats to discriminate between music by Bach and by Stravinsky and found that rats could generalize to novel examples, but they also found that, although rats could discriminate between composers, they did not exhibit any preferences. Since the auditory range of rat vocalizations (unlike pigeons and sparrows) is much higher than that of human music, and because rats have subsequently been found to react only to the high-frequency components of music (Akiyama and Sutoo, 2011), it is difficult to interpret the lack of preference for human music by rats. We address this general issue in greater detail later in this chapter.

There have been contradictory findings with respect to whether animals have a preference for consonant over dissonant music. Sugimoto et al. (2010) found that one infant chimpanzee showed a preference for consonant over dissonant music, whereas Koda et al. (2013) reported that Campbell's monkeys did not show any preference for consonance. However, Chiandetto and Vallortigara (2011) found that chickens did prefer consonant music. It is hard to make sense of this pattern of results in terms of phylogeny.

In summary, there is considerable controversy about the degree to which music-like phenomena are found in nonhuman animals, and results from different species do not suggest consistent phylogenetic homologies or a consistent pattern of convergent analogies. We think that the data are much clearer with respect to emotional signals. In the next section, we shall consider musico-emotional effects in human language and emotional communication and then shall seek parallels in animal signals.

5 MUSIC AND EMOTION IN HUMAN SPEECH AND PARALLELS IN OTHER SPECIES

Human vowel sounds are based on the chromatic scale. In a series of studies, Purves and collaborators have shown that the statistical structure of human speech shows a probability distribution with peaks at frequency ratios that match the chromatic scale. This appears to be a direct result of the resonances of the human vocal tract, and suggests that music and speech are closely linked. Peaks in the distribution were especially prominent at the octave, the fifth, the fourth, the major third, and the major sixth forming the intervals of the pentatonic scale and most of the intervals on a diatonic scale (Schwartz et al., 2003). The authors sampled not only English speakers but speakers of Tamil, Farsi, and Mandarin and found similar relationships within each language. Han et al. (2011) examined music and speech from three tonal languages and three nontonal languages and found that changes in pitch direction occurred more frequently and had larger changes in pitch direction in tonal languages, and that the music typical of the cultures with tonal language also showed similar frequent and large changes in pitch direction, suggesting a coevolution of music and language. Gill and Purves (2009) showed that the most widely used scales across time and across cultures are those that are similar to harmonic series. The authors suggest that humans prefer tone combinations that reflect the spectral relationships of human vocalizations. Bowling et al. (2010) sampled speech spectra from excited versus subdued speech and found that the spectral distribution of excited speech showed similarities to the distribution of major intervals, whereas the spectral distribution of subdued speech matched the spectral pattern of minor intervals. This was particularly noteworthy with respect to major and minor thirds. Thus, the harmonic structure of speech closely parallels that of music across cultures, and affective changes in emotion are evident in different harmonic structures of speech just as they are in music.

A second source of music in language is prosody—the intonation contours of speech. It seems quite likely that we detect emotional signals more clearly through pitch and intonation contours than we do through actual words. A clear test of this is in studies of communication between human parents and preverbal infants, where specific prosodic (musical) features have been identified that can influence the behavioral state of the infant (Fernald, 1992). Several short, upwardly rising staccato calls lead to increased arousal. Long descending intonation contours have a calming effect, and behavior can be stopped with a single short plosive note. These patterns were observed across speakers of several different languages. Interestingly, similar features appear in the calls and whistles used by humans to control the behavior of working animals (dogs and horses) (McConnell, 1990, 1991). The convergence of signal structure that humans use to communicate with both preverbal infants and nonhuman animals suggests that these signals are effective across species. The communication of affect through voice is not unique to humans, and the acoustic structures involved must have similar effects on the nervous system of both human infant and animal recipients.

Prosody can be used to induce behavioral changes in others. In the case of humans who are attempting to manage the behavior of infants and animals, the speakers need not be directly experiencing the emotion they are trying to induce. Rather, they are using specific signal types to induce a form of emotional contagion in their listeners. We know very little about the effects of natural animal signals on inducing emotions in other animals, a point we will try to address below.

Juslin and Laukka (2003) examined a large number of studies that evaluated how emotions were conveyed in spoken language and in music performance, and they found notable similarities between the two modes in the accuracy with which listeners could identify discrete emotions and the specific types of acoustical cues used to convey discrete emotions in both music and speech. There is indeed a very close relationship between emotional communication in speech and language.

Given that nonhuman animals respond behaviorally to the same affective signals that human infants do, we must next ask whether humans have the ability to distinguish affective states in the calls of other species. Belin et al. (2008) presented humans with positive and negative affective vocalizations from humans, cats, and monkeys, and they found that humans were adept at discriminating human affective calls, but were at chance level with the cat and monkey vocalizations. However, when the same participants were presented with the same stimuli while undergoing fMRI of their brains, they found that the animal vocalizations activated the same areas that human vocalizations with similar valence activated. Specifically bilateral regions of the auditory cortex were activated more by negative vocalizations from all three species; bilateral regions of the lateral inferior prefrontal cortex were activated more by positive vocalizations of all three species; and the right orbital frontal cortex responded more to negative vocalizations of all species.

Thus, although the human participants did not display conscious recognition of different animal calls of different emotional valences, their nervous systems distinguished between these calls.

In another study of cat calls, Nicastro and Owren (2003) found a modest ability of humans to discriminate between positive and negative calls, and also found that participants who owned cats or interacted frequently with cats were more adept at discrimination. Similarly, Scheumann et al. (2014) tested human ability to discriminate between agonistic and affiliative calls of humans, dogs, chimpanzees, and tree shrews and found that whereas discrimination of human calls was easy for everyone, there was a clear effect of familiarity with a species and with the contexts of agonism or affiliation, leading to more accurate discrimination. Thus, although human brains appear responsive to affiliation and agonistic calls of other species, conscious discrimination of these calls appears to require significant familiarity with the species.

In summary, music and speech appear to be closely linked, and the linkage is clearest at the level of emotional expression. Both the prosody of speech and the spectral distribution of speech sounds can convey emotional meaning. These same characteristics are effective in altering the behavior of nonverbal human infants and of working animals (e.g., horses, herding dogs), suggesting that these emotional signals are effective across species. The brain areas in humans involved in distinguishing between positive and negative emotions in human and animal calls appear to be the same and can be activated even if the human is unable to make a conscious discrimination between the affective calls of another species. However, with experience, humans can make accurate discriminations. Let us now turn to the question of whether there exist emotional universals in human music, and then consider whether similar universals are present in animal calls.

6 ARE THERE EMOTIONAL UNIVERSALS IN HUMAN MUSIC?

Emotions can be expressed in music and there have been several attempts to describe the structures that convey emotions. Scherer (1995) suggested that sadness is conveyed by slow tempos, a narrow frequency range, decreases in pitch, and a slow rate of articulation. (This is similar to the intonation contours that lead to calming in preverbal infants and nonhuman animals.) Joy is conveyed by fast tempos, increasing pitches that are highly variable, and by increased rates of articulation. (This is similar to the intonation contours that lead to increased activity and arousal in preverbal infants and nonhuman animals.) Anger is conveyed by an increase in fundamental frequency and by higher intensity (amplitude), and fear is shown with an increase in fundamental frequency, many high-frequency components, and a faster rate of articulation.

Snowdon and Teie (2013) hypothesized that harmonic structures and pure tones would be associated with positive states, whereas dissonant (or noisy) structures would be associated with aggression, fear, and defense. Staccato calls would be arousing, whereas legato notes would be calming. Regular rhythms should be associated with positive states or events, whereas irregular rhythms would be associated with negative states or events.

In a review of several studies on how emotions were expressed in both speech and in music, Juslin and Laukka (2003) reported that the structural patterns matched very closely the predictions made by Scherer (1995). Bresin and Friberg (2011) experimentally tested the validity of Scherer's classification by having 20 trained musical performers manipulate seven different variables (i.e., tempo, sound level, articulation, phrasing, register, timbre, and attack speed) to communicate five emotions (i.e., neutral, happy, sad, fear, and calm). Happiness was communicated by a fast tempo, staccato articulation, high register, high intensity, and fast attack. Fear was communicated by a fast tempo, staccato articulation, moderate intensity, low register, and slow attack rate. Sadness was communicated by a slow tempo, very low intensity, legato articulation, mid-range register, and slow attack speeds. Calmness was communicated by a slow tempo, low intensity, legato articulation, high register, and slow attack rate. Thus, when musicians were asked to express different emotions in the same piece of music, they explicitly used the same acoustic variables that Scherer hypothesized to be involved in emotional expression.

Gomez and Danuser (2007) studied the relationship between the emotional aspects of music and psychophysiological response to music. Participants evaluated the degree of pleasantness and arousal of different types of music, while simultaneous measurements were made of skin conductance, heart rate, and respiration. There was a close connection between self-reported emotional evaluation and the physiological responses with mode, harmonic complexity and rhythmic articulation differentiating between negative and positive valences and tempo, acceleration and rhythmic articulation discriminating between high and low arousal. Thus, participants not only evaluated the music appropriately, but the music actually induced emotional responses.

However, all of these studies have been done using Western listeners and musicians as well as with Western music. Does emotional communication generalize to music of different cultures, and are listeners who are unfamiliar with music from another culture still able to distinguish emotions? Balkwell and Thompson (1999) presented Western listeners with no prior experience with Indian ragas with excerpts from ragas recorded in the field in northern India. Each excerpt was intended to convey one of four emotions (i.e., joy, sadness, anger, and peace), and Western participants were able to identify the ragas associated with joy, sadness, and anger, although peace was confused with sadness. Among the key features for discrimination were rising notes and a fast tempo for joy, and falling notes and a slow tempo for sadness—again reflecting the prosodic features used by humans with preverbal children and with animals to arouse or calm them, respectively. Despite the great differences between Indian and Western music, the same structural features appear to encode the strong emotions of joy, fear, and anger.

In summary, one can find acoustic structures in music that reliably communicate different emotions. Experienced musicians can manipulate these structures when asked to communicate a specific emotion, and naive listeners can identify emotions even within musical genres that are unfamiliar to them. There appear to be some emotional universals in music.

7 ARE THERE EMOTIONAL UNIVERSALS IN ANIMAL CALLS?

Based on the results on how music communicates and induces emotions in humans, we can now ask if similar structures are found in the calls of other species. If we can find similar acoustic variables influencing emotional calls in nonhuman species, then it seems likely that the "strong" emotions (see Altenmüller et al., 2013) could have served as precursors for human music. The best known model of affective signals in animals is the motivational-structural model of Morton (1977). Morton evaluated call structures in fear and aggressive contexts in a variety of bird and mammal species and suggested that high-pitched, narrow-band, legato calls were used in fear contexts and that low-pitched, broad band (or noisy) calls signaled aggression.

Snowdon and Teie (2013) applied their framework of emotional structures in music to the calls of cotton-top tamarins. Recordings of spontaneous calls were presented to musicians, who evaluated the timbre, tempo, rate of articulation, and pitch of calls without knowing the context in which the calls were given. Five different clusters of calls were found and subsequently associated with the actual contexts in which they were given: calls used for affiliation had harmonic structure, legato articulation with ascending pitch, and narrow bandwidth; calls used for high arousal and threat were characterized by broadband staccato calls with clear harmonic intervals; calls used in fear contexts were characterized by noisy, dissonant, staccato sounds; and calls signifying confident threats were characterized by legato, harmonic sounds with rising pitches; the approach context was characterized by calls in triple meter with moderately long notes displaying harmonic structure but with both rising and falling intonations. The acoustic properties hypothesized for human emotional expression and music also appear to have parallels in the vocal repertoire of tamarins.

Research on several other species provides supporting evidence for some of these acoustic structures being involved in emotional communication. Yang et al. (2013) removed estrus females from male mice and found an increase in ascending components of ultrasonic vocalizations (indicating arousal) and a return to flat frequency calls (indicating calm) when reunited with females. In contrast, Brudzynski (2013) found alarm and threat calls (initiated by release of acetylcholine) in both rats and cats were characterized by low frequency, constant pitch, and long notes, whereas positive appetitive vocalizations (initiated by release of dopamine) were higher in pitch with frequency modulation and short notes (equivalent to the prosodic features that lead to arousal in preverbal infants and working animals). Soltis (2013) reported that dominance interactions in African elephants were associated with increased amplitude and duration of calls, whereas social agitation was associated with increased and more variable fundamental frequency and shorter duration notes. Aggression and mating were also characterized by high-frequency vocalizations.

In nonhuman primates, Zimmermann (2009) showed that gray mouse lemur calls increased in pitch and in duration during conditions of high arousal. A startled lemur produces loud, noisy, and plosive grunts, and females rejecting male mating approaches also produce short, frequency-modulated calls. Males courting females, however, use long, frequency-modulated or broadband calls. Infant mouse lemurs gave short frequency-modulated calls in threats, longer and less modulated calls when isolated, and low-pitched purrs while being groomed. Lemasson et al. (2012) studied three species of arboreal Old World primates under two conditions of affect intensity. As seen with mouse lemurs, each of these species produced higher pitched calls of longer duration when in the high-intensity condition. Thus, it appears that increased arousal in these species is communicated with longer calls, rather than the short, frequency-modulated prosodic variables that humans use to induce arousal. However, in cats Scheumann et al. (2012) reported intensity was coded by longer duration calls with shorter intercall intervals but decreased fundamental frequency.

In a comprehensive review of 39 studies across the mammalian order, Zimmermann et al. (2013) found increases in call rate were associated with alarm/disturbance and agonistic contexts and to some extent with affiliation as well. Call duration was longer with both affiliative and agonistic contexts, and increased fundamental frequency was seen with both alarm and agonistic contexts. However, there was also much variation between species, with call rate showing the most consistent correlation with arousal.

All socially living animals have to discriminate between individuals as well as context, and several studies have looked at whether different acoustic parameters are used for individual recognition or contextual information. In general, the results suggest that source and filter-related variables (e.g., fundament frequency, peak frequency, bandwidth) code for individual recognition whereas temporal (e.g., call duration, intercall interval), source-related, and tonal (e.g., voicing, harmonic to noise ratio) parameters code arousal (for cats, see Scheumann et al., 2012; for baboons, see Rendall, 2003). In addition, different types of affective calls differ in the likelihood of coding individual features. Thus, mother baboons could easily discriminate the contact calls of their own infants, but not their distress screams (Rendall et al., 2009). There may be adaptive value in structuring a distress scream for an immediate response without taking additional time and resources to encode individuality.

Emotional contagion is frequently seen when animals vocalize. Singing birds, duetting titi monkeys and gibbons, pant-hooting chimpanzees, howling wolves, and many other species show emotional contagion. When one animal or pair begins to call, others of the same species join in, until many members of one group or pair are calling to members of other groups and pairs. The contagious calling serves to reinforce social relationships within a pair or group, and serves to keep others away from the pair or group, just as music was hypothesized to promote social cohesion in our human ancestors.

In summary, there are many parallels between the structures of signals used to communicate specific emotional states across animal species, just as there are among humans. This is especially clear with respect to arousal and less clear with respect to states such as fear, aggression, or affiliation. Emotional contagion is common in many animal species and serves to promote social cohesion among group members and to keep others away.

8 HOW DO ANIMALS RESPOND TO SPECIES-RELEVANT MUSIC?

Although there are some similarities in emotional signaling, there are also species differences that must be considered. This becomes most obvious in the case of playing human music to nonhuman animals. Akiyama and Sutoo (2011), in an effort to see if playing Mozart would have any effect on blood pressure in hypertensive rats, found that, if they filtered the music, the components above 4 kHz were as effective as playing the unfiltered music. Given that rats use frequencies into the human ultrasound range for communication and are sensitive to a higher frequency range than humans, this makes sense. However, many other studies have failed to consider the ecological relevance of human music to other species.

McDermott and Hauser (2007) tested common marmosets and cotton-top tamarins for preferences for Mozart versus heavy metal and found a preference for Mozart. But when they tested Mozart against silence, they found the monkeys preferred silence, and they concluded that monkeys are indifferent to music. However, the monkeys they tested have small bodies and communicate in a frequency range three octaves above human speech and at a tempo at least twice as fast. It seems premature to conclude that monkeys are indifferent to music.

Playbacks of animal sounds are often used as the gold standard for evaluating the functional significance of animal signals, but Owren and Rendall (1997) have proposed an affect-conditioning model of primate affective signals. If affective responses are conditioned to calls, then it becomes difficult to find naive subjects to evaluate emotional responses. One solution to this problem is to create species-relevant music in the frequency range and with the tempos appropriate to the species being tested, and then to build features into the compositions that are hypothesized to be of affective significance. Using this strategy, Snowdon and Teie (2010) presented cotton-top tamarins with music composed in their frequency range and tempos, and compared their responses with music composed for humans having similar features. Tamarins responded to "tamarin music" with arousing features with increased activity and increased signs of anxiety, and sought increased social interactions with group mates. In contrast, they responded to "tamarin music" with calming features by reducing activity, increasing foraging, and decreasing social contact. Thus, different emotional states could be induced in monkeys with appropriate species-specific music. However, music composed to induce similar affective responses in humans had no effect on the tamarins (similar to results of McDermott and Hauser, 2007).

Recently, Snowdon et al. (in review) have used music designed to be relevant to cats (higher pitched than human music with tempos similar to purring or sucking) and found that cats preferred this music to calming music composed for humans. Furthermore, cat music led to a significant increase in calm behavior in the cats. The use of species-relevant music may have many practical effects on behavior of animals in laboratories, zoos, and shelters, but to date most facilities use human music—generally the genres preferred by the caretakers—and the results evaluating the effects of music have been inconsistent.

In summary, there is much contradictory literature about the effects of human-based music on nonhuman species with some authors claiming other species have no appreciation for music. However, there has been little effort to consider the effects of specific types of music and even less effort to make music ecologically relevant to other species. When music is composed that takes into account the ecological differences between humans and another species, music has been shown to be effective in inducing emotional responses.

9 SUMMARY AND CONCLUSIONS

In this chapter, we have argued that music has adaptive functions for humans including increasing cooperation and helping, and modulating physiological responses. It may also have value in mate selection, but in our view, this would be a more recently evolved effect. Musical structures are found in the distribution of harmonics in speech and in the prosodic features of speech that communicate emotions. Prosodic features are also used by humans to manipulate the activities and emotional states of preverbal infants and working animals. Although humans find it difficult to consciously identify the emotional valence in the calls of other species without direct exposure and experience with those species, there is some evidence of unconscious discrimination of affective state in animal calls using brain imaging.

Emotions in music can be differentiated by both musicians and nonmusicians, and Western listeners unfamiliar with Hindu ragas can nonetheless discriminate the emotional intent of the composers of the ragas. Many of the acoustic features seen in how emotions are presented in music are also seen in similar emotional signals in many mammalian species ranging from rodents to primates. This consistency in the acoustic structures underlying different affective states supports our notion that music has emerged in humans based on strong emotional signals and consequently has early phylogenetic origins.

However, there is still critical research to be done. Are the differences in affective signals in some species real or due to different paradigms and different definitions of behavioral contexts? Can researchers manipulate the affective states of animals through music that is species relevant? Music is frequently used as psychological enrichment in shelters, laboratories, and zoos, but rarely does the selection of music relate to the specific goals of enrichment (does one want more active or calmer animals?), nor are species-relevant aspects considered. More work needs to be done on the intriguing possibility that human brains might be capable of analyzing animal sounds at a subconscious level. Finally, the music we enjoy listening to is not just about strong emotions. Our species has developed a complexly structured corpus of music that affects us emotionally but also affects us aesthetically (Altenmüller et al., 2013). How and why this development occurred is the central question in the evolution of music, and we are still some distance away from understanding this occurrence.

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PART

The musical brain

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CHAPTER

Musicians and music making as a model for the study of brain plasticity

3

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Abstract

Playing a musical instrument is an intense, multisensory, and motor experience that usually commences at an early age and requires the acquisition and maintenance of a range of sensory and motor skills over the course of a musician's lifetime. Thus, musicians offer an excellent human model for studying behavioral-cognitive as well as brain effects of acquiring, practicing, and maintaining these specialized skills. Research has shown that repeatedly practicing the association of motor actions with specific sound and visual patterns (musical notation), while receiving continuous multisensory feedback will strengthen connections between auditory and motor regions (e.g., arcuate fasciculus) as well as multimodal integration regions. Plasticity in this network may explain some of the sensorimotor and cognitive enhancements that have been associated with music training. Furthermore, the plasticity of this system as a result of long term and intense interventions suggest the potential for music making activities (e.g., forms of singing) as an intervention for neurological and developmental disorders to learn and relearn associations between auditory and motor functions such as vocal motor functions.

Keywords

brain plasticity, diffusion tensor imaging, morphometry, motor, auditory, Melodic Intonation Therapy, Auditory–Motor Mapping Training (AMMT)

1 INTRODUCTION

Musicians with extensive music training and playing experience provide an excellent model for studying plasticity of the human brain. The demands placed on the nervous system by music making are unique and provide a uniquely rich multisensory and motor experience to the player. As confirmed by neuroimaging studies, playing

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music depends on a strong coupling of perception and action mediated by sensory, motor, and multimodal integration regions distributed throughout the brain (e.g., Schlaug et al., 2010a; Zatorre et al., 2007). A violinist, for example, must execute a myriad of complex skills which includes translating visual analysis of musical notation into motor movements, coordinating multisensory information with bimanual motor activity, developing fine-motor skills mostly of their nondominant hand coupled with metric precision, and monitoring auditory feedback to fine-tune a performance in progress.

This chapter summarizes research on the effects of musical training on brain organization. Musical training usually commences at an early age, and requires the acquisition and maintenance of a range of skills over the course of a musician's lifetime. In the past, much research has focused on how musical training shapes the healthy brain, more recent studies provide evidence that music making activities induces brain plasticity to help overcome neurological impairments. Both neurodevelopmental disorders (e.g., stuttering, speech-motor acquired brain injuries; e.g., stroke patients with motor and communication deficits, patients with Parkinson's disease) and neurodevelopmental disorders (e.g., stuttering, speech difficulties in individuals with autism) and acquired brain injuries (e.g., stroke patients with motor and communication deficits, patients with Parkinson's disease) are examples of such impairments.

2 BEHAVIORAL STUDIES: THE EFFECTS OF MUSICAL TRAINING ON COGNITIVE PERFORMANCE

Over the past 20 years, a large plethora of research has referenced the beneficial effects of musical training on cognitive development in children. Cross-sectional studies have shown that musically trained children are better than musically untrained children on a range of auditory and motor abilities, such as pitch and rhythmic discrimination (Forgeard et al., 2008), melodic contour perception (Morrongiello and Roes, 1990), and finger sequencing (Forgeard et al., 2008).

Many studies have examined whether or not musical training leads to enhancement of other cognitive skills. For example, similarities between music and language suggest that musical training may lead to enhanced language abilities. Studies with children showed a positive association between pitch perception and reading abilities (Anvari et al., 2002), and years of musical training predicted increased verbal recall (Jakobson et al., 2003) and reading skills (Butzlaff, 2000). Additionally, musically trained children showed superior auditory, finger tapping, and vocabulary skills when compared to their musically untrained counterparts (Schlaug et al., 2005), who were matched on age, handedness, and socioeconomic status. Improvements in mathematical and spatial skills have also been implicated, although their relationship with musical training remains unclear (e.g., Forgeard et al., 2008; Hetland, 2000; Vaughn, 2000). Recently, Kraus et al. (2014) showed that having a group of children engage in a music enrichment program for 2 years improved their neurophysiological processing of speech sounds which was not seen in a wait-list control group or after only 1 year of music classes.

It is not unexpected that musical training induces domain-specific adaptations in terms of improved sensorimotor and auditory abilities. However, what remains to be determined is whether or not training in the musical domain might enhance function in an untrained domain. In one study, for example, the level of engagement in musical practice during childhood predicted academic performance at university level (Schellenberg, 2006). These differences in performance persisted even when variables such as socioeconomic status and parent education were controlled. One potential mechanism for this association is the effects of musical practice on general executive function (Schellenberg and Peretz, 2008), although recent research has not provided support for this hypothesis (Schellenberg, 2011). Another hypothesis is that of cross-modal transfer of plasticity: long-term musical training leads to changes in polymodal integration regions (e.g., regions surrounding the intraparietal sulcus), which may alter task performance in other domains (Wan and Schlaug, 2010). Playing music, for example, leads to changes in the intraparietal sulcus, and this region is implicated in numerical representation and operations (Cohen Kadosh et al., 2007; Dehaene et al., 1998; Piazza et al., 2007; Pinel et al., 2004). Accordingly, adaptations in brain regions that are involved in musical tasks may have an effect on mathematical performance because of shared neural resources involved in the mental manipulation of symbolic representation. Further research examining the mechanisms underlying the associations between musical training and cognitive skills is clearly warranted.

Although cross-sectional studies provide information about the potential benefits of musical training on cognitive functions, longitudinal studies allow stronger inferences to be made within a group of individuals. The reason is that longitudinal studies minimize the possible influence of preexisting factors such as socioeconomic status, home support, and available resources, which be responsible for some of the differences between musicians and nonmusicians. Longitudinal studies have also provided evidence that musical training has positive implications for cognitive functioning. For example, children who received 1 year of instrumental musical training showed superior verbal memory skills compared to children who had discontinued training (Ho et al., 2003). Considering that this study was done in Hong Kong, one might speculate that superior verbal memory skills could be due to an enhancement in memory for the pitches of lexical tones. However, another study showed an increase in IQ comparing children who participated in a 36-week music program to children who received drama lessons (Schellenberg, 2004). Interestingly, children who practiced singing during the music program had greater increase in IQ compared to those who played the keyboard. In two other longitudinal studies, children who received music lessons were compared to children who received painting lessons. After 8 weeks of training, there were clear differences in electrophysiology between the two groups (reduction of late positive component to strong pitch incongruities in the music group), despite no differences in their ability to perform a language perception task (Moreno and Besson, 2006). In a subsequent study, children allocated to the music and painting groups were tested before and after 6 months of training

(Moreno et al., 2009). For children who received music lessons, there were improvements in reading and language perception abilities, while no such improvement was observed in children who received painting lessons. These behavioral enhancements in the musically trained children were accompanied by changes in the amplitudes of specific event-related potential components associated with music and speech. A recent study also reported that a specialized weekly instrumental program in a socioeconomically disadvantaged school led to significantly improved learning and immediate recall for verbal information after 1 year of instruction, but no such benefits were observed in children who underwent a standard classroom music program and those who underwent juggling training for a year (Rickard et al., 2010). However, when a standard classroom music program in a non-disadvantaged school was compared with standard drama and art programs, there were no significant benefits of music instruction on cognitive abilities over other instructions (Rickard et al., 2011). The absence of cognitive effects in this latter study could be due to the class-based nature of the program, which made it less likely to adapt instruction for the wide range abilities in the students and be equally engaging for all. Furthermore, classroom-based studies are often difficult to conduct because it is challenging to find an appropriate "control" instruction program, to randomly allocate students into the experimental conditions, and to match students on preexisting abilities.

3 IMAGING STUDIES: THE EFFECTS OF MUSICAL TRAINING ON BRAIN ORGANIZATION

Musical training in childhood has profound effects on both the structural and functional organization of the brain. The first study that examined structural differences between musicians and nonmusicians reported larger anterior corpus callosum in musicians (Schlaug et al., 1995a), a finding that has since been replicated by different research groups using different methodological approaches (Hyde et al., 2009; Lee et al., 2003; Oztürk et al., 2002). Specifically, musicians who began training at an early age ($\leq$7 years) had a significantly larger corpus callosum compared to musicians who commenced training later. When cortical motor regions were examined, a similar finding was observed. In particular, the depth of the central sulcus, often used as a marker of primary motor cortex size, was larger on both hemispheres, but more pronounced on the right hemisphere for musicians compared to nonmusicians, possibly due to years of manual motor practice emphasizing the nondominant hand, while the dominant hand undergoes some form of fine-motor training in every adult writing with the right hand and using the right hand for skilled sensorimotor tasks (Amunts et al., 1997; Schlaug, 2001). As was observed for the corpus callosum, there was a positive correlation between the size of the primary motor cortex and the onset of instrumental musical training (used as a surrogate for intensity and duration of training).

Structural brain differences have been reported in musicians who play different instruments (Bangert et al., 2006). For keyboard players, the omega sign of the precentral gyrus, which is associated with hand and finger movement representation, was found to be more prominent on the left hemisphere for keyboard players, but was more prominent on the right hemisphere for string players. This structural difference is likely to reflect an adaptation to the specific demands of different musical instruments. One brain region that differentiates musical experts from novices is the planum temporale, or secondary auditory cortex, which occupies the posterior plane of the superior temporal gyrus (Schlaug, 2001; Schlaug et al., 1995a,b; Zatorre et al., 1998). A pronounced leftward asymmetry of the planum temporale was linked to the ability to perceive absolute pitch. More recently, it was also demonstrated that in musicians with absolute pitch, the posterior superior temporal gyrus is connected to a region within the middle temporal gyrus which has been associated with categorical perception (Loui et al., 2010). Thus, the connections between the posterior superior temporal gyrus and the middle temporal gyrus may play a role in determining whether or not someone develops absolute pitch in addition to early exposure to music. Other areas showing structural differences between musicians and nonmusicians include the Heschl's gyrus, or primary auditory cortex (Schneider et al., 2005a), Broca's area, and the inferior frontal gyrus in general (Gaser and Schlaug, 2003a,b; Sluming et al., 2002), as well as the cerebellum (Hutchinson et al., 2003), and areas in the superior parietal lobule (Gaser and Schlaug, 2003a). These structural differences appear to be more pronounced in those musicians who began training early in life (Elbert et al., 1995; Schlaug et al., 1995b) and who practiced with greater intensity (Gaser and Schlaug, 2003b; Schneider et al., 2005b).

In addition to structural alterations, intensive musical training has also been associated with an expansion of the functional representation of finger or hand maps, as demonstrated in magnetoencephalography studies. For example, the somatosensory representations of the playing fingers of string players were found to be larger than those of nonmusicians (Pantev et al., 2001). This effect was more pronounced for the fifth digit, which was rarely used in the nonmusician group. Musicians who had begun training early in life (<13 years) demonstrated larger cortical representation of their left fifth digit compared to those who started to play their instruments later, who, in turn, had larger representations than nonmusicians. In addition to these enhanced somatosensory representations, musicians have larger representations for tones than do nonmusicians. In one study, musicians who had started playing at a young age demonstrated the largest cortical representations (Pantev et al., 1998), and this enlargement was evident for piano tones but not for pure tones. In contrast, a study by Schneider et al. (2002) reported increased representation for pure tones, up to twice as large in professional musicians compared to nonmusicians. In that study, amateur musicians showed an intermediate increase over nonmusicians, but only for tones less than 1000 Hz. In a longitudinal study, violin students showed a larger cortical response to violin sounds compared to other sounds after only 1 year of training, whereas this difference was not observed in musically untrained children (Fujioka et al., 2006).

A large body of research has used functional magnetic resonance imaging (fMRI) to compare musicians and nonmusicians. Differences in activity have been observed across many brain regions when individuals were asked to perform musical tasks involving discrimination (e.g., Foster and Zatorre, 2010; Koelsch et al., 2005), working memory (e.g., Gaab and Schlaug, 2003; Gaab et al., 2006), or production (Bangert et al., 2006; Kleber et al., 2010). Despite the heterogeneity of the tasks used, an area that was commonly activated in many of these studies was the posterior superior temporal gyrus, which is important for spectrotemporal processing as well as auditory–motor transformations (Warren et al., 2005). Indeed, a recent study identified the left superior temporal gyrus as the region that is linked with musical training, in terms of cumulative practice hours (Ellis et al., 2013).

A relatively new technique that can be used to study brain differences between musicians and nonmusicians is diffusion tensor imaging (DTI). This technique provides information about white matter microstructures (i.e., orientation and direction of axons and their degree of myelination) by measuring diffusion properties of water molecules. Some studies reported lower fractional anisotropy (FA, a measure of the directionality of water diffusion) in the internal capsule (Schmithorst and Wilke, 2002), corticospinal tract (Imfeld et al., 2009), and a portion of the arcuate fasciculus (Halwani et al., 2011) of musicians compared to nonmusicians. In contrast, higher FA in the internal capsules has also been observed. For example, Bengtsson et al. (2005) have reported that the number of practice hours during childhood is positively correlated with increased FA values, not only in the internal capsule but also in the corpus callosum and the superior longitudinal fasciculus.

Rüber et al. (2013) recently assessed diffusivity measures of different corticospinal motor tracts of 10 keyboard players, 10 string players, and 10 nonmusicians. When compared with nonmusicians, FA values of right-hemispheric motor tracts were significantly higher in both musician groups, whereas left-hemispheric motor tracts showed significantly higher FA values only in the keyboard players. Voxel-wise FA analysis found a group effect in white matter underlying the right motor cortex. Diffusivity measures of fibers originating in the primary motor cortex correlated with the maximal tapping rate of the contralateral index finger across all groups. It was argued that the observed between-group diffusivity differences might represent an adaptation to the specific motor demands of the respective musical instrument. The discrepancy in published studies between higher and lower FA values of known tracts in response to intense training may reflect the different mechanisms by which different brain regions and brain systems can remodel. Variations in FA across and within individuals over time can be influenced by factors such as fiber density, axon diameter, myelination, axon collateral sprouting, cell membrane density, and fiber coherence. Higher FA values has been thought to reflect more aligned fibers in a particular tract, while lower FA values does not only indicate less alignment of fibers, but could also mean more axonal sprouting and more branching of axons the closer the tract is to the cortical target region (see Wan et al., 2014). Future developments in DTI methodologies are likely to generate

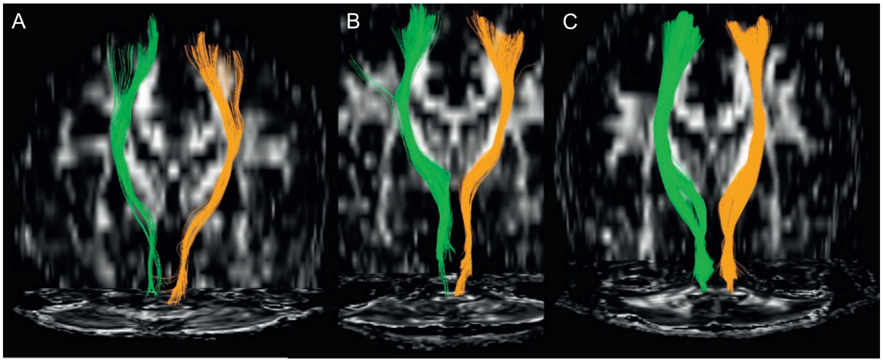

FIGURE 1

Corticospinal tracts of both hemispheres (green; dark gray in the print version = left) show a child nonmusician (A), an adult nonmusician (B), and an adult musician (C). A comparison of A and B shows the maturational changes that the corticospinal tract undergoes from childhood to adulthood. A comparison of A/B to C shows the additional adaptation of this important motor tract in an adult keyboard player whose requirements are to make fast, precise, and coordinated fine finger movements.

further interest in the music neuroscience community to utilize this technique (see also Fig. 1).

4 AUDITORY–MOTOR INTERACTIONS UNDERLIE MUSIC AND LANGUAGE LEARNING

Playing a musical instrument is a complex sensorimotor activity that simultaneously engages multiple brain regions. The interactions between auditory and motor brain regions are in particular important for both music learning and speech learning. Whether one is learning how a note is played or how a word is pronounced, both tasks involve the association of sounds with articulatory actions associated with auditory feedback. Several studies have shown that merely listening to a melody that one has learned to play on a keyboard (i.e., where a sound-motor map has been established) can activate a motor network, which includes the inferior frontal gyrus, in addition to auditory brain regions. However, listening to a melody that one has not learned to play (i.e., where a sound-motor map has not been established) does not activate the inferior frontal gyrus (e.g., Lahav et al., 2007; Meister et al., 2004) (see also Fig. 2). A more recent study showed that modulation of activity in premotor cortex is associated with increased performance when novices learned to play a melody on a keyboard (Chen et al., 2012). Presumably, the reduced activity in the dorsal auditory action stream is related to increase processing efficiency as individuals acquire auditory–motor associations.

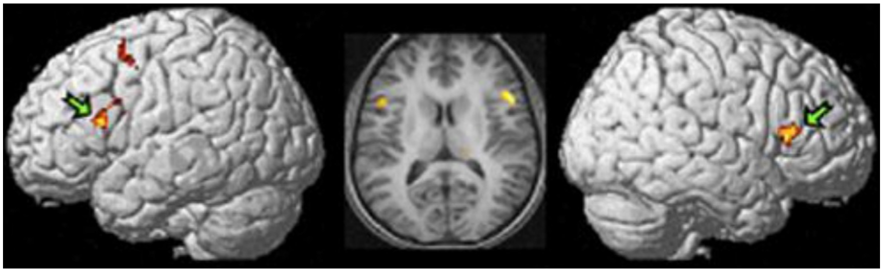

FIGURE 2

Mapping of sounds to finger actions. Activation spots show significant brain actions when subjects listened to short melodies that they had learned to play on a keyboard subtracted from a condition that had subjects listen to short melodies that were equally familiar, but were never mapped to keyboard actions. It was concluded that the posterior inferior frontal region (Broca's region on the left and Broca's homologue on the right) plays a critical role in the mapping of sounds to actions.

Figure is adapted from Lahav et al. (2007).

5 MUSIC-BASED TREATMENTS TO MODULATE BRAIN PLASTICITY: MELODIC INTONATION THERAPY AND AUDITORY–MOTOR MAPPING TRAINING

As described, intensive musical training can lead to modifications in brain structure and function. Recent research has demonstrated that training-induced plasticity is not restricted to the developing brain, but that intensive skill learning in adulthood can also lead to plastic changes. Even for older adults, skill learning appears to preserve gray and white matter structures during the normal ageing process when the brain generally undergoes substance loss (e.g., Boyke et al., 2008; Sluming et al., 2002).

The malleability of the human brain across the lifespan has important implications for the development of rehabilitation techniques, particularly for overcoming impairments associated with neurological disorders. Here, we describe the ongoing research in our laboratory that tests the therapeutic potential of music-based interventions in facilitating speech output in chronic stroke patients with aphasia and in completely nonverbal children with autism. Both disorders are characterized by marked impairments in speech production, and the utility of these interventions (Melodic Intonation Therapy (MIT) for stroke patients, and Auditory–Motor Mapping Training (AMMT) for children with autism) may lie in our understanding of how music and language are processed in the brain.

A large body of neuroimaging research has demonstrated that music and language share brain networks (e.g., Koelsch, 2005; Koelsch et al., 2002; Ozdemir et al., 2006; Patel et al., 1998; Schon et al., 2004) and that active and intensive training with music may assist language recovery and acquisition. In particular, fMRI studies have reported activation of Broca's area (a classical language area in the brain including the posterior inferior frontal gyrus) during music perception tasks (e.g., Koelsch et al., 2002; Tillmann et al., 2003), active music tasks such as singing (e.g., Ozdemir et al., 2006), and imagining playing an instrument (e.g., Baumann et al., 2007; Meister et al., 2004). Moreover, a common network appears to support the sensorimotor components for both speaking and singing (e.g., Kleber et al., 2010; Ozdemir et al., 2006; Pulvermuller, 2005) (see also Fig. 3).

Understanding the extent to which the neural substrates of speaking and singing are distinct depends on an understanding of the lateralization of speech function in the brain. Specifically, speech can be decomposed according to time scale. For example, formant transitions, and consonant-vowel (CV) transitions, are regarded as the fast components of speech (tens of milliseconds), whereas processing syllables and the prosody are regarded as the slow components of speech (hundreds of milliseconds) (Abrams et al., 2008; Poeppel, 2003). Considering a delay of more than 25 ms for interhemispheric transfer in humans, this necessitates a localization of functions involving the resolution of very fine and rapid temporal changes in the signal to one hemisphere (Aboitiz et al., 1992; Ringo et al., 1994). Tasks that involve short temporal integration windows (tens of milliseconds) would preferentially recruit the left hemisphere (Poeppel, 2003), whereas tasks involving temporal integration windows on the order of hundreds of milliseconds may recruit homologous structures in the right hemisphere (Abrams et al., 2008; Poeppel, 2003). Consistent

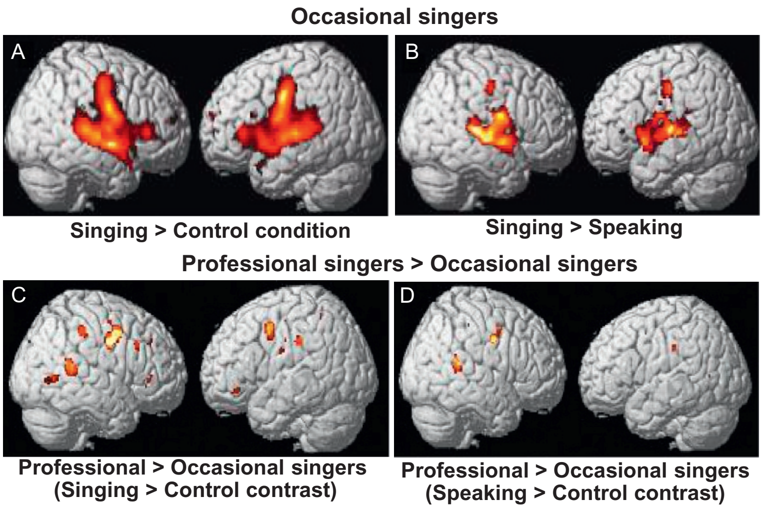

FIGURE 3

Activation pattern of an overt singing and speaking task contrasting occasional singers with professional singers. Professional singers showed additional activations in temporal, parietal, sensorimotor, and inferior frontal regions on both sides of the brain (right more than left), which was not only seen in the highly controlled singing task but also transferred to the speaking control task (for details on the fMRI task and data analysis, see Ozdemir et al., 2006).

with this functional localization, neuroimaging studies have shown that tasks involving the rapid articulation of phonemes (such as CV transitions) and the modulation of prosody are correlated with fronto-temporal activation patterns that show a right more than left lateralization (Meyer et al., 2002).

5.1 MELODIC INTONATION THERAPY

The ability to sing in humans is evident from infancy and does not depend on formal vocal training, although it can be enhanced by training (Dalla Bella et al., 2007; Halwani et al., 2011; Kleber et al., 2010; Siupsinskiene and Lycke, 2011; Zarate and Zatorre, 2008). Given the behavioral similarities between singing and speaking, as well as the shared and distinct neural correlates of both, researchers have begun to examine whether forms of singing can be used to treat speech-motor impairments associated with acquired and congenital neurological disorders (Wan et al., 2010b).

The most obvious neurological condition that could benefit from a singing-type intervention is aphasia. Aphasia is a common and devastating complication of stroke or traumatic brain injury that results in the loss of ability to produce and/or comprehend language. It has been estimated that between 24% and 52% of acute stroke patients have some form of aphasia if tested within 7 days of their stroke; 12% of survivors still have significant aphasia at 6 months after stroke (Wade et al., 1986). The nature and severity of language dysfunction depends on the location and extent of the brain lesion. Accordingly, aphasia can be classified broadly into fluent or nonfluent. Fluent aphasia often results from a lesion involving the posterior superior temporal lobe known as Wernicke's area. Patients who are fluent exhibit articulated speech with relatively normal utterance length. However, their speech may be completely meaningless to the listener with errors in syntax and grammar. These patients typically also have severe speech comprehension deficits. In contrast, nonfluent aphasia results most commonly from a lesion in the left frontal lobe, involving the left posterior inferior frontal region known as Broca's area. Patients who are nonfluent tend to have relatively intact comprehension for conversational speech, but have marked impairments in articulation and speech production. It has been observed for more than 100 years that patients with severe nonfluent aphasia can often sing phrases that they cannot speak (Gerstman, 1964; Geschwind, 1971; Keith and Aronson, 1975). This clinical observation formed the basis for developing an intervention which has been referred to as MIT.

It is now understood that there can be two routes to recovery from aphasia. In patients with small lesions in the left hemisphere, there tend to be recruitment of both left-hemispheric, perilesional cortex, and only variable involvement of right-hemispheric homologous regions during the recovery process (Heiss and Thiel, 2006; Heiss et al., 1999; Hillis, 2007; Rosen et al., 2000). In contrast, for patients with large left-hemispheric lesions involving language-related regions of the fronto-temporal lobes, their only path to recovery may be through recruitment of homologous language and speech-motor regions in the right hemisphere (Rosen et al., 2000; Schlaug et al., 2008). For these patients, therapies that specifically stimulate the homologous right-hemispheric regions have the potential to facilitate the language recovery process beyond the limitations of natural recovery (Rosen et al., 2000; Schlaug et al., 2008, 2009). It has been argued that MIT, which emphasizes melody and contour, engages a sensorimotor network on the unaffected hemisphere (Albert et al., 1973b; Schlaug et al., 2010b; Sparks and Holland, 1976). The two unique components of MIT are the (1) intonation of words and simple phrases using a melodic contour that follows the prosody of speech and the (2) rhythmic tapping of the left-hand tapping which accompanies the production of each syllable and serves as a catalyst for fluency.

The intonation component of MIT was intended to engage the right hemisphere, which has a dominant role in processing spectral information (Albert et al., 1973a; Meyer et al., 2002; Schlaug et al., 2010b; Zatorre and Belin, 2001) and is more sensitive than the left hemisphere to the slow temporal features in acoustic signals (Abrams et al., 2008; Zatorre and Gandour, 2008). The fronto-temporal cortices of both hemispheres can be involved in both singing and speaking, although singing tends to show stronger right-hemisphere activations compared to speaking (Bohland and Guenther, 2006; Ozdemir et al., 2006). Thus, the slower rate of articulation associated with intonation enhancing the prosodic and contour aspects of the stimulus may increase the involvement of the right hemisphere. The left-hand tapping component of MIT not only serves as a metronome but can also facilitate auditory–motor mapping (Lahav et al., 2007) and engages a sensorimotor network that controls both hand and articulatory movements (Meister et al., 2009).

To date, a few studies using MIT have produced positive outcomes in patients with nonfluent aphasia. These outcomes range from improvements on the Boston Diagnostic Aphasia Examination (Goodglass and Kaplan, 1983; see also Bonakdarpour et al., 2000), to improvements in articulation and phrase production (Wilson et al., 2006) after treatment. The effectiveness of this intervention is further demonstrated in a recent study that examined transfer of language skills to untrained contexts. Schlaug et al. (2008) compared the effects of MIT with a control intervention (speech repetition) on picture naming performance and measures of propositional speech. After 40 daily sessions, both therapy techniques resulted in significant improvement on all outcome measures, but the extent of this improvement was far greater for the patient who underwent MIT compared to the one who underwent the control therapy.

The therapeutic effect of MIT is evident in several neuroimaging studies showing reorganization of brain functions. Not only did MIT result in increased activation in a right-hemisphere network involving the premotor, inferior frontal, and temporal lobes (Schlaug et al., 2008), but also the white matter structure that connects these regions, the arcuate fasciculus, underwent noticeable microstructural remodeling (Schlaug et al., 2009). This remodeling is most prominent in the white matter underlying the posterior inferior frontal gyrus, which further highlights the potential role of the Broca homologue in the right hemisphere for the relearning of mapping sounds to actions and the selection of motor plans through reciprocal connections with premotor and motor areas (Schlaug et al., 2009; Zheng et al., 2011).

5.2 AUDITORY–MOTOR MAPPING TRAINING

AMMT is an intonation-based speech therapy that has been developed in our laboratory specifically for nonverbal children with Autism Spectrum Disorder (ASD). ASD is a developmental condition that affects 1 in 110 children, and one of the core diagnostic features relates to impairments in language and communication. In fact, up to 25% of the individuals with ASD lack the ability to communicate with others using speech sounds, and many of them have limited vocabulary in any modality including sign language (Koegel, 2000; Turner et al., 2006). Although the ability to communicate verbally is considered to be a positive prognostic indicator for children with ASD (Luyster et al., 2007), there are extremely few techniques that can reliably produce improvements in speech output in nonverbal children with ASD.

AMMT is a therapy technique that aims to facilitate speech output and vocal production in nonverbal children with ASD (Wan et al., 2010a). Briefly, AMMT involves two main components: (1) intonation of words/phases and (2) motor activities. Intonation (or singing) is known to engage a bilateral network between frontal and temporal regions, which overlaps with components of the putative mirror neuron system (Meister et al., 2003, 2004; Ozdemir et al., 2006). It has been argued that a dysfunctional mirror neuron system underlies some of the language deficits in autism (Iacoboni and Dapretto, 2006). The presumed mirror neuron system consists of, among others, the posterior inferior frontal regions, which also play a critical role in auditory–motor mapping. Our preliminary imaging findings suggest that the arcuate fasciculus may show a reversed pattern of asymmetry in completely nonverbal children with ASD compared to typically developing children (Wan et al., 2012). Motor activity (through bimanual tapping tuned drums) not only captures the child's interest but also engages or primes the sensorimotor network that controls orofacial and articulatory movements in speech (e.g., Bangert et al., 2006; Dambeck et al., 2006; Meister et al., 2003, 2006a,b). The sound produced by the tuned drums may also facilitate the auditory–motor mapping that is critical for meaningful vocal communication.

A recent proof-of-concept study showed that AMMT had a significant therapeutic effect on the speech output of six completely nonverbal children (Wan et al., 2011). In that study, each child was enrolled into an intensive 40-session program over an 8-week period. Using a single-subject multiple-baseline design, the speech (CV) production of each child before treatment was compared to that observed during treatment and also to the immediate posttreatment assessment. Follow-up assessments enabled us to establish that the effects were lasting beyond the cessation of the daily AMMT treatments. After therapy, all children showed significant improvements in their ability to articulate words and phrases, and this ability even generalized to items that were not practiced during therapy sessions. Most importantly, these skills were maintained during the 8-week follow-up assessment. A larger-scale clinical trial is currently underway to examine whether AMMT produces superior results compared to non-intonation speech therapy.

6 CONCLUDING REMARKS

Emerging research over the last 20 years has shown that long-term music training and the associated sensorimotor skill learning can be a strong stimulus for neuroplastic changes. These changes can occur in both the developing and the adult brain, and affect both white and gray matter, as well as cortical and subcortical structures. Active musical activities lead to a strong coupling of perception and action mediated by sensory, motor, and multimodal brain regions and affect important sound relay stations in the brainstem and thalamus. Active musical activities make rehabilitation and restorative neurotherapies more enjoyable and can remediate impaired neural processes or neural connections by engaging and linking brain regions with each other.

Although music-based interventions have intuitive appeal, it is critical that developments are grounded on a neurobiological understanding of how particular brain systems can be engaged by music listening and music making activities and what music offers beyond the traditional approaches. The efficacy of these experimental interventions should be assessed quantitatively and objectively, as one would require from any other experimental intervention. A strong neuroscientific basis, combined with compelling data from randomized clinical trials, are important steps in establishing effective music therapies that will enhance brain recovery processes and ameliorate the effects of neurological disorders.

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CHAPTER

Expert music performance: cognitive, neural, and developmental bases

4

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Abstract

In this chapter, we explore what happens in the brain of an expert musician during performance. Understanding expert music performance is interesting to cognitive neuroscientists not only because it tests the limits of human memory and movement, but also because studying expert musicianship can help us understand skilled human behavior in general. In this chapter, we outline important facets of our current understanding of the cognitive and neural basis for music performance, and developmental factors that may underlie musical ability. We address three main questions. (1) What is expert performance? (2) How do musicians achieve expert-level performance? (3) How does expert performance come about? We address the first question by describing musicians' ability to remember, plan, execute, and monitor their performances in order to perform music accurately and expressively. We address the second question by reviewing evidence for possible cognitive and neural mechanisms that may underlie or contribute to expert music performance, including the integration of sound and movement, feedforward and feedback motor control processes, expectancy, and imagery. We further discuss how neural circuits in auditory, motor, parietal, subcortical, and frontal cortex all contribute to different facets of musical expertise. Finally, we address the third question by reviewing evidence for the heritability of musical expertise and for how expertise develops through training and practice. We end by discussing outlooks for future work.

Keywords

long-term and working memory, motor control, feedback monitoring, auditory–motor integration, premotor cortex, parietal cortex, basal ganglia, cerebellum, early training, heritability

1 INTRODUCTION

A performance by a highly skilled musician is a captivating experience. One such virtuoso performer who entertained millions over the past few decades was the late jazz pianist Dave Brubeck. When he performed his standard "The Duke" in a

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televised or live performance, he was demonstrating one of the most demanding cognitive and motor behaviors of which humans are capable. Audiences marveled at his ability to perform a long and complex piece of music entirely from memory. Listeners were also astounded by his ability to bring the piece to life by embellishing, improvising, and continuously changing the expressive nuances of his performance. Audiences were equally amazed at the speed, dexterity, and precision of his movements on the piano. These memory and motor control capabilities make expert music performance a useful domain in which to study the human brain.

Dave Brubeck likely had two main goals in mind when he sat down at the piano. His first goal was to perform the music accurately by making sure that every note in the music occurred in the right place at the right time. He ensured that the pitch sequencing and the temporal sequencing, or rhythm, were correct by hitting each key and each temporal interval between keys in the correct serial order (Gabrielsson, 2003; Palmer, 1997, 2006; Zatorre et al., 2007). His second and perhaps foremost goal was to express or interpret the music. He used small but noticeable variations in tempo, force, and phrasing throughout the music in order to heighten or exaggerate the contrast between different pitches and temporal intervals. He would have used expressive devices such as these to communicate hierarchical structures of the music, or groupings of musical events at various timescales. For instance, he would have emphasized important events among consecutive pitches or among simultaneous pitches or harmonies (e.g., Krumhansl & Shepard, 1979) by playing those events louder or longer (Goebl, 2001; Palmer, 1996; Repp, 1996a). He also would have emphasized the meter of the music, which refers to the grouping of rhythmic patterns into larger temporal intervals (Essens and Povel, 1985; Lerdahl and Jackendoff, 1983; Povel and Essens, 1985). Metrical grouping often creates the sense of an underlying pulse or beat in a musical rhythm. Musicians often emphasize the meter by playing pitches louder and longer when they occur on the downbeat, or the beginning of each metrical group (Repp, 1992; Sloboda, 1983, 1985). Finally, music is often comprised of segments or musical phrases that sound complete because they have a noticeable beginning, middle, and end. Musical phrases combine to form melodies, which in turn combine to form movements such as a verse or chorus. Musicians often emphasize musical phrase boundaries by slowing down at the end of a musical phrase (Johnson, 2000; Repp, 1992, 1998a) Importantly, experts such as Dave Brubeck also cultivate their own expressive styles either to give a particular song a unique color and mood or to distinguish their performances from those of other expert musicians (Repp, 1995, 1997).

A virtuoso performance is perhaps easy to appreciate, but much harder to explain. Cognitive neuroscientists have approached this problem empirically, by examining the component facets of music performance independently (e.g., pitch and rhythm production and finger movements) and testing hypotheses derived from theories of general human cognition, such as memory and motor control (Palmer, 1997; Zatorre et al., 2007). This approach is powerful because it can explain expertise in music and in many domains of human behavior. Cognitive neuroscientists examine the cognitive and neural bases for music performance by linking patterns of behavior and brain response. Behaviors such as patterns of pitch-sequencing errors (Palmer and van de Sande, 1993, 1995) or variations in speed and loudness (Nakamura, 1987; Repp, 1998a, 1999a) can reveal how musicians remember music and control their movements. Linking such musical behaviors to features of brain anatomy using structural magnetic resonance imaging (MRI) or to changes in blood oxygen levels in the brain using functional MRI can reveal which brain structures may contribute to a particular behavior. In addition, linking behaviors to rapid changes in cortical electrical signals using electroencephalography or magnetoencephalography (MEG) can reveal the brain's sensitivity to transient features or events in music performance. In addition to behavioral and neural measurements, cognitive neuroscientists perform experiments to compare musicians' behavior and brain responses under different carefully controlled conditions that are designed to isolate factors believed to be important for music performance.

2 WHAT IS EXPERT PERFORMANCE?

Performing music requires experts to retrieve musical information from long-term memory and continuously plan their ongoing performance in their working memory system. Performing music also requires experts to initiate and control complex movements and to monitor outcomes or feedback from those movements to make adjustments if needed. Here, we review the demands of music performance on memory retrieval and motor control.

2.1 MEMORY

Expert musicians have been aptly referred to as expert "memorists" (Chaffin and Logan, 2006, p. 113) because they can retrieve complex musical works consisting of thousands of bits of information fluently from memory (Palmer, 2006). Moreover, expert musicians must be familiar with hundreds of pieces and are often required to play from memory. At least two different types of memory are crucially involved: long-term memory refers to the ability to store information and working memory refers to the ability to retrieve, maintain, and manipulate previously learned information.

2.1.1 Long-Term Memory

To successfully remember music during performance, expert musicians may rely to some extent on general knowledge of harmonic, metrical, and hierarchical structure of music (Chaffin and Logan, 2006). Experts' performance accuracy and expression are influenced by musical conventions. For instance, experts usually make pitch errors that fit the structural context of the music and thus sound correct (Palmer and van de Sande, 1993; Repp, 1996b). Paralleling memory feats of other experts, such as chess masters (De Groot, 1965), musicians recall musical information much better when it is correctly structured than when it is random, whereas nonexperts do not show this advantage (Halpern and Bower, 1982). Experts also emphasize musical events that are typically important, such as downbeats or notes in the primary melody (Gabrielsson, 2003; Goebl, 2001; Palmer, 1996; Repp, 1996a; Sloboda, 1983, 1985). In addition, musicians are better able to perceive, remember, and reproduce expressive variations in music that are typical for the given musical structure as opposed to atypical (Clarke, 1993; Clarke and Baker-Short, 1987; Repp, 2000). These findings suggest that musicians use "cognitive schemas" (Repp, 2000) or generalized knowledge of musical structure and expression as a framework for memorizing and retrieving particular pieces of music during performance (Chaffin and Logan, 2006).

To perform from memory, musicians also seem to rely on their individual interpretations of particular musical works. Expert musicians express particular pieces of music in a consistent manner yet very differently from other performers (Gabrielsson, 1999; Repp, 1997, 1998a; Sloboda, 1985). Expert musicians' interpretations of music likely reflect conscious decisions made during rehearsal (Chaffin and Logan, 2006; Chaffin et al., 2010). When experts are asked to interpret a particular musical line as the primary melody, they perform the pitches in that line earlier and more accurately than those in other lines (Palmer and van de Sande, 1993; Repp, 1996a,b). In addition, musicians' expressive intentions influence how they change the loudness of their performances (Nakamura, 1987), and musicians' intended phrase structure influences error patterns (Palmer and van de Sande, 1995) and the degree to which they intend to slow down at the end of the phrase (Palmer, 1989). How do musicians remember their interpretations? Case studies of professional musicians suggest that experts develop "mental maps" of music during rehearsal that consist of key points of subjective importance in the music. Musicians then use the expressive features at these points (speed/loudness changes) as cues that can be retrieved automatically and guide performance (Chaffin and Logan, 2006; Chaffin et al., 2010). Thus, expert musicians seem to rely on their individual expressive interpretations of music to perform accurately and to make their performance stand out as unique.

2.1.2 Working Memory

In addition to long-term memory, working memory is necessary during performance in order for musicians to retrieve, hold, and manipulate musical segments and continuously update them according to where they are in the music. How do experts maintain and update music in working memory during performance? Evidence suggests that experts plan ahead and in segments. When expert musicians make pitch errors, they tend to mistakenly produce pitches that occur later than the correct pitch, rather than before (Drake and Palmer, 2000; Palmer and Drake, 1997; Palmer and van de Sande, 1993). Expert pianists also demonstrate finger motion toward an upcoming key press prior to the actual key press, and this anticipatory motion occurs sooner when pianists play faster (Goebl and Palmer, 2006). In addition, pianists demonstrate hand and finger kinematic changes that anticipate forthcoming changes in a musical piece (Engel et al., 1997). Further evidence suggests that expert performers plan music in segments or groups of events, rather than one event at a time. For instance, when musicians make pitch errors, they are more likely to mistakenly replace a correct pitch with an "intruder" pitch from within the same phrase rather than across different phrases (Palmer and van de Sande, 1995). The distance between incorrectly swapped pitches increases as phrase length increases (Palmer and van de Sande, 1995). Expert musicians thus seem to plan ahead and segment-by-segment. This behavior may reflect musicians' ability to group or "chunk" music into meaningful units, similar to how other experts perceptually group information (Chase and Simon, 1973; Egan and Schwartz, 1979; Simon and Gilmartin, 1973). Musicians' ability to chunk music may be enabled by their schematic knowledge of typical musical patterns (Repp, 2000). This manner of planning may allow experts' working memory to keep pace with the high speeds of real-time music performance.

2.2 EXECUTION

2.2.1 Motor Skill

In addition to highly trained memory, expert performance requires highly trained motor skills. As described earlier, expert musicians can quickly and precisely reproduce the pitch and temporal sequences in music entirely from memory. Expert pianists, for example, can reach up to 20 notes per second (Lashley, 1951) while maintaining less than 3% errors (Palmer, 1997, 2006) and millisecond-level precision in timing (Repp, 1992, 1998a) with high consistency (Sloboda et al., 1998). This feat stands in stark contrast to many everyday movements, which tend to be slower when the need for precision increases (Keele, 1968). Highly skilled musicians sometimes choose biomechanically difficult movements, even when simpler movements are possible (Parncutt et al., 1997; Sloboda et al., 1998). The complexity and precision of expert movement may be enabled in part by greater independence and economy of individual limb movements. For instance, expert pianists are capable of controlling their hands and individual fingers more independently of one another than less-skilled pianists (Aoki et al., 2005; Furuya et al., 2011; Shaffer, 1981). In addition, expert pianists organize their upper-limb movements during performance such that they minimize muscle effort relative to less-skilled pianists (Furuya and Kinoshita, 2007, 2008). Movement control and complexity may additionally be influenced by musical features. For instance, pianists display greater movement complexity and accuracy with the right than with the left hand, regardless of handedness (MacKenzie and Van Eerd, 1990; Parncutt et al., 1999; Shaffer, 1981). This may be because pianists usually play the primary melody in most Western music with the right hand.

2.2.2 Feedback Monitoring

In addition to skilled execution, expert performers may to some extent monitor their ongoing performances to ensure that they are accurate and have the desired expressive quality. Music performance results in various types of sensations resulting from movements, or sensory feedback. Performers receive visual, tactile, proprioceptive, and sometimes vestibular feedback during performance, in addition to the auditory feedback (Gabrielsson, 2003). Performers do not always need to monitor their auditory or other types of sensory feedback. Experts are able to perform well-learned music accurately in the absence of sound (Finney and Palmer, 2003), and musicians can perform expressively without auditory feedback (Repp, 1999b,c). These findings suggest that experts can rely largely on their long-term memory of the music and practiced movements to perform accurately and with expressive nuance. However, feedback seems to sometimes help experts achieve optimal expressive performance. For instance, pianists are better able to control variations in sound quality using footpedaling when auditory feedback is present (Repp, 1999b). In addition, pianists and clarinetists display greater temporal accuracy when their finger movements accelerate toward the keys faster, generating greater tactile feedback (Dalla Bella and Palmer, 2011; Palmer et al., 2009). Case studies of professional musicians further suggest that experts monitor the expressive quality of their auditory outcomes in order to maintain conscious control over their performances, thus preventing themselves from relying exclusively on automatic actions (Chaffin and Logan, 2006). An interesting question for further research is whether musicians who play different instruments weight different types of feedback differently. For instance, singers may rely more on proprioceptive feedback since they cannot see their instrument (Kleber et al., 2010, 2013), while pianists may rely more on vision and touch.

3 HOW IS EXPERT PERFORMANCE ACHIEVED?

How do expert musicians coordinate remembering and executing music during performance? One of the primary mechanisms thought to underlie musical expertise is a strong link between sound perception and movement production, or auditory–motor integration (Zatorre et al., 2007). This link may enable expert performers to simultaneously remember and produce music during a performance. Auditory–motor integration may play a role in how musicians initiate and adjust their actions during performance, how they predict what will come next during performance, and how they remember and imagine music.

3.1 AUDITORY–MOTOR INTEGRATION

Expert musicians have a strong tendency to associate the sounds from their instrument with the movements that produce those sounds, and vice versa. This sound–action association likely results from learning the contingencies between sounds and movements over years of training (Chen et al., 2012; Elsner and Hommel, 2001; Lahav et al., 2007). When musicians hear sounds from their instrument, this perception facilitates or primes the corresponding actions, even when those sounds are irrelevant to the task (Drost et al., 2005a,b). Musicians are also highly sensitive to the way in which actions and sounds are paired in motor tasks. For instance, musicians are faster to initiate patterns of key presses when keys are paired with tones in a spatially compatible fashion (top, middle, and bottom keys produce high, middle, and low tones, respectively) as opposed to a random fashion (Keller and Koch, 2008). In addition, musicians' actions can influence their sound perception. The direction of pianists' key presses on a piano influenced whether they heard tone sequences as ascending or descending (Repp and Knoblich, 2007). Thus, for musicians, hearing musical sounds can trigger or facilitate corresponding actions, and performing movements can alter sound perception.

3.1.1 Motor Control

Expert performance requires initiating, controlling, and, if needed, adjusting difficult sequences of actions. Some views propose that skilled performers rely mainly on motor memory to control their actions. Well-learned actions may be stored in memory as sets of motor commands that can be carried out without feedback (Keele, 1968) but are also flexible enough to adapt to different performance contexts (Schmidt, 1975). Skilled performers may store motor commands as abstract or generalizable rules for how certain movement patterns can be applied to meet certain goals across a variety of movement contexts; parameters such as speed and force can be adjusted to the specific movement context before execution, with no external feedback needed (Schmidt, 1975). These views of motor control are supported by evidence that musicians can perform well-learned music accurately with absent or even random auditory feedback (Finney & Palmer, 2003; Pfordresher, 2005). Musicians can produce actions more quickly than the central nervous system can perceive sounds or other external sources of feedback (e.g., vision, touch; Keele, 1968; Lashley, 1951; Schmidt, 1975). In addition, when musicians make mistakes during performance, they show brain responses up to 100 ms *before* incorrect actions (see Fig. 1A), and incorrect actions tend to be slower than correct actions (Maidhof et al., 2009a; Ruiz et al., 2009). Taken together, this evidence suggests that fast and fluent actions typically produced by expert musicians are controlled by feedforward mechanisms whereby already-learned motor commands are selected and prepared before execution (Ruiz et al., 2009; Schmidt, 1975).

Some views of skilled motor control additionally suggest that musicians use their associations between movements and sound to initiate actions. For instance, it has been proposed that musicians initiate movements by anticipating the sounds they would expect to hear from those movements, even when auditory feedback is not available (Elsner and Hommel, 2001; Hommel et al., 2001; Prinz, 1997). This view holds that performers' auditory and motor memory for music are unified, allowing auditory retrieval to engage the motor commands that carry out the necessary movements. The idea that anticipating the correct or intended sounds can select and initiate the correct actions can help explain why musicians can easily adapt or generalize their movements to different contexts. For instance, skilled pianists can fluently perform a previously learned melody with an unpracticed set of finger movements; however, they are slower to perform a new melody with the same set of finger movements they had previously practiced (Palmer and Meyer, 2000). The above evidence suggests that musical expertise is not instantiated as a set of fixed action sequences, but rather as generalizable motor skill (Schmidt, 1975) in which movements are closely linked to intended sound.

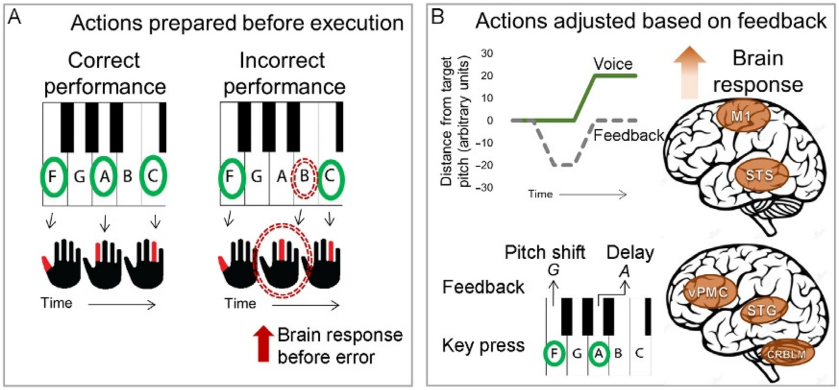

FIGURE 1

Motor control in musicians. (A) Example of motor control during performance whereby actions are thought to be selected and planned before execution, given that brain responses to errors occur before the error occurs (Maidhof et al., 2009a; Ruiz et al., 2009). (B) Examples of motor control during performance whereby actions are influenced by altered auditory feedback. Singers engage auditory and motor brain cortex when adjusting their vocal output to compensate for pitch-shifted feedback (Zarate and Zatorre, 2008, top panel). Pianists engage premotor cortex when adjusting their actions to delayed auditory feedback and auditory cortex and cerebellum when adjusting to pitch-shifted feedback (Pfordresher et al., 2014). M1, primary motor cortex; STS, superior temporal sulcus; vPMC, ventral premotor cortex; STG, superior temporal gyrus.

Musicians may also adjust their actions during performance based on the discrepancies between perceived and expected auditory feedback (Adams, 1968; Greenwald, 1970). This view is supported by musicians' responses to alterations in auditory feedback (Pfordresher, 2006; see Fig. 1B). For instance, pianists change their key-stroke timing when auditory feedback from the key strokes is delayed, and they tend to play erroneous pitches when pitch feedback is altered (Furuya and Soechting, 2010; Pfordresher, 2003, 2005). Musicians' tendency to adapt their pitch and temporal sequencing to feedback changes may help explain why the presence of auditory feedback can help musicians perform more expressively in certain contexts (Repp, 1999b). Trained singers are able to compensate well for unexpected perturbations of pitch feedback (see Fig. 1B); but unlike nonsingers, they can also ignore such modulations (Zarate et al., 2010) indicating flexibility in the degree to which feedback versus feedforward mechanisms can be used.

3.1.2 Expectancy

One possible mechanism by which musicians may link sounds to movements during performance is expectancy. Expectancy refers to predicting a future sensory or motor event, based on the previous exposure to regular occurrences of those events.

Plentiful evidence suggests that expert musicians have strong expectancies for how music should sound in both the pitch and temporal dimensions (Besson and Frederique, 1995; Herholz et al., 2008; Pearce and Wiggins, 2012; Repp, 1998b; Vuust et al., 2005, 2009) and for how actions should be performed (Repp, 2000; Sammler et al., 2013). Evidence suggests that musicians' production of music enhances their expectancies for pitch events in the music. For instance, when sounds were altered while musicians performed or listened to music, cortical electrical responses were elicited about 200 ms after the alterations (Maidhof et al., 2009b), around the time at which brain responses are elicited by unexpected or rule-violating events in an auditory sequence (Koelsch et al., 2001, 2002). Brain responses to incorrect pitches were greater during performance than during listening alone (Maidhof et al., 2009b) and also greater for melodies pianists had previously produced than for those they had only heard (Mathias et al., 2014). Musicians' expectancies for sounds may therefore be influenced by their expectancies for movements, and vice versa. Such auditory–motor expectancies may help performers anticipate or prepare thoughts and actions for expected events (Hommel et al., 2001; Prinz, 1997) and adapt to unexpected events in music (Furuya and Soechting, 2010; Pfordresher, 2006). Auditory–motor expectancies may thus help expert musicians' retrieve music from long-term memory, plan ahead, control actions, and adapt to auditory feedback during a performance.

3.1.3 Musical Imagery

Finally, musicians' auditory–motor associations may contribute to their ability to experience music that is not physically present. Musicians are skilled at imagining musical sounds (Aleman et al., 2000; Brodsky et al., 2003; Herholz et al., 2008; Yumoto et al., 2005) and movements (Coffman, 1990; Langheim et al., 2002; Lotze et al., 2003; Meister et al., 2004) accurately and vividly in the absence of auditory perception or physical performance. This skill may be due to their experience listening to and performing music, or associating sounds and movements (Baumann et al., 2007). For instance, when musicians imagine musical sounds, they appear to engage subtle motor responses such as subvocalizations (Brodsky et al., 2003, 2008) and they engage motor circuits in the brain (Baumann et al., 2007). Musical imagery abilities may therefore be closely related to auditory–motor integration in music performance. Experts' ability to imagine music may also be related to their long-term and working memory. Auditory and motor imagery tasks often require musicians to actively retrieve music from long-term memory, such as familiar melodies, and maintain that information in working memory (Halpern and Zatorre, 1999; Herholz et al., 2008). Individual differences in mental imagery have also been associated with working memory capacity (Baddeley and Andrade, 2000) and with the ability to suppress interference from another task while performing music (Brown and Palmer, 2013). For an expert musician, musical imagery may be closely related to the ability to remember music and the ability to link the sounds with the actions for that music.

3.2 NEURAL BASES FOR EXPERT PERFORMANCE

3.2.1 Auditory–Motor Integration: Auditory, Motor/Premotor, and Parietal Cortex

As indicated earlier, the actions of a performer and the consequent sounds produced form a continuous sensory-motor loop. The neural bases of this integration are becoming more well understood thanks to brain imaging and related studies in musicians. First, it is important to point out that musical training has now been clearly established to influence the auditory system as well as the motor system separately. That is, clear evidence exists for changes in both structure and function in musically trained individuals compared to untrained persons that reflect adaptations or plasticity to the exigencies of musical performance and/or musical perception (for review, see Herholz and Zatorre, 2012). For example, musically trained individuals have enhanced brainstem representation of musical sound waveforms (Wong et al., 2007), while at the cortical level they can also show stronger responses to such stimuli (Pantev et al., 1998; Schneider et al., 2002; Shahin and Bosnyak, 2003). Similarly, there is evidence of enhancement in the response of the somatosensory/motor system as a function of musical training, which is related to the instrument used: fingers of the left hand for string players (Elbert et al., 1995) or larynx for singers (Kleber et al., 2010). These functional adaptations are accompanied by anatomical changes in auditory cortex (Bermudez et al., 2009; Gaser and Schlaug, 2003; Schneider et al., 2005), and in motor and premotor regions, including their underlying white-matter pathways (Bengtsson et al., 2005), as well as portions of the corpus callosum that interconnect motor regions (Schlaug et al., 1995; Steele et al., 2013). Both anatomical and functional changes have been shown to be causally linked to musical training in longitudinal studies with children (Fujioka et al., 2006; Hyde et al., 2009); however, predisposing factors may also exist that modulate the effects of training (Zatorre, 2013).

Not only are auditory and motor systems independently related to musical training, but also there is direct evidence that their interactions are enhanced in musicians. For example, auditory and premotor cortices are coactivated when pianists play music without auditory feedback or listen to music without playing (Bangert et al., 2006; Baumann et al., 2007; see Fig. 2). Similarly, MEG shows motor cortical responses in musicians to sound only (Haueisen and Knösche, 2001), while increased motor cortical excitability (elicited via transcranial magnetic stimulation) was observed when pianists listened to a piano melody that they knew how to play, as opposed to a flute melody (D’Ausilio et al., 2006). A causal link between training and auditory–motor integration has been shown by findings of enhanced premotor recruitment to tonal patterns after specific training on the production of those tonal patterns (Lahav et al., 2007) although the nature and amount of training necessary for such effects remains to be determined. These training-related effects are complemented by findings that premotor cortices show modulated responses to metrically organized rhythm patterns even in nonmusicians (Chen et al., 2008a,b), indicating that auditory–motor coupling may be a basic feature of neural organization, even if

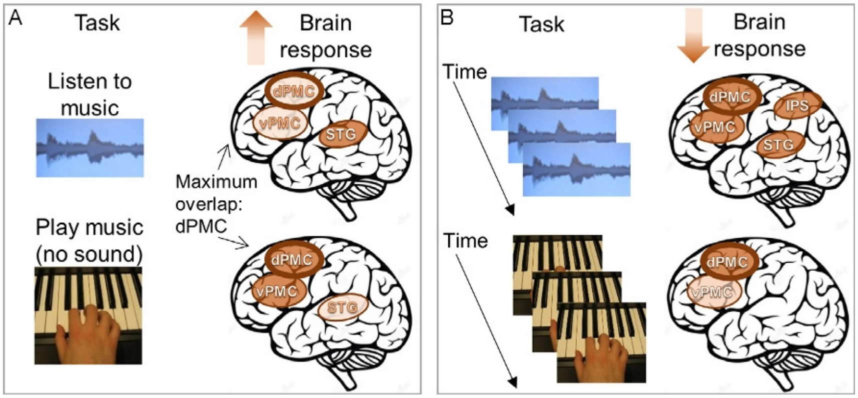

FIGURE 2

Perception and production of music in musicians. (A) Musicians engage premotor and auditory cortex when either listening to music without performing (top panel) or performing music silently (bottom panel), suggesting that premotor and auditory regions link sound with action (Bangert et al., 2006; Baumann et al., 2007). (B) Musicians also demonstrate adaptation or decreased response in premotor cortex to both repeated listening and repeated performance of music (Brown et al., 2013), further supporting a role for premotor cortex in integrating sound and action. dPMC, dorsal premotor cortex; STG, superior temporal gyrus; vPMC, ventral premotor cortex; IPS, intraparietal sulcus.

training enhances it (Grahn and Rowe, 2009; see Fig. 3). Finally, evidence that auditory–motor pathways are anatomically enhanced in musicians (Halwani et al., 2011) also supports the conclusion that these interactions are important for musical execution.

The auditory–motor interactions just described rely on general-purpose auditory pathways that go along dorsal and ventral routes (Hickok and Poeppel, 2007; Rauschecker and Scott, 2009). The more ventral component has been shown to be important for the representation of melodic features such as contour (Lee et al., 2011) or musical intervals (Klein and Zatorre, 2014), whereas the dorsal pathway appears to be the most relevant for performance. Thus, musical experts engage dorsal parietal and premotor circuits when transforming a sound pattern into a motor pattern (Brown et al., 2013; see Fig. 2B); the dorsal premotor cortex (dPMC) along with frontal areas is also recruited during improvisation (Bengtsson et al., 2007; Berkowitz and Ansari, 2008) with a greater connectivity between these areas for expert improvisors (Pinho et al., 2014). This dorsal pathway is likely involved in a number of different types of transforms across modalities, of which sound to action is only one (Culham and Kanwisher, 2001). Thus, the intraparietal region, a component of the dorsal stream, has been shown to be engaged in purely cognitive tasks, such as transposing a melody mentally from one key to another (Foster and Zatorre, 2010a,b), or during mental "rotation" of a musical theme in time, as in retrograde transformations (Foster et al., 2013; Zatorre et al., 2010). The parietal

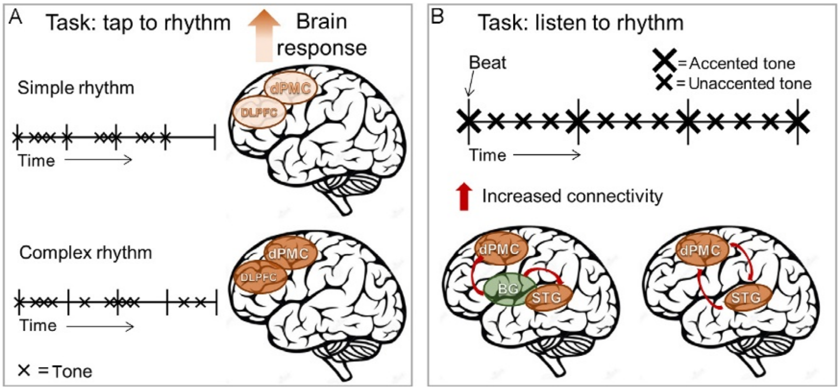

FIGURE 3

Perception and production of rhythm and beat in musicians. (A) Responses in dorsal premotor cortex and dorsolateral prefrontal cortex are modulated by rhythmic complexity when tapping along with auditory rhythms, and musicians engaged prefrontal cortex more than nonmusicians (Chen et al., 2008a). (B) Listening to a rhythm with a strong beat increases interactions between the basal ganglia and premotor and auditory brain regions. Listening to a strong beat also increases interactions between auditory and premotor cortex, more so for musicians than for nonmusicians (Grahn and Rowe, 2009). dPMC, dorsal premotor cortex; DLPFC, dorsolateral prefrontal cortex; BG, basal ganglia; STG, superior temporal gyrus.

cortex may provide coordinate transformations that enable expert musicians to flexibly link sound with action.

3.2.2 Temporal and Pitch Sequencing: Basal Ganglia, Cerebellum, and Supplementary Motor Area

Other important systems required for expert performance are those involved in sequencing, or performing pitch and temporal events in the correct order. Several motor regions are thought to be central to these processes, including the basal ganglia (BG), cerebellum, and the supplementary motor area (SMA). The BG and the cerebellum are subcortical structures that are known to be involved in control and optimization of movement, as well as learning (Doya, 2000; Doyon and Benali, 2005; Middleton and Strick, 2000). The SMA is a cortical region that is considered an interface between the frontal cortex, where movement goals are initiated, and the motor cortex, where they are implemented (Hikosaka and Nakamura, 2002). How do these regions work together?

The BG are hypothesized to play a role in both perceiving temporal sequences and controlling the temporal sequencing of movement (Ivry and Spencer, 2004; Lewis et al., 2004; Meck et al., 2008; Rao et al., 2001; Teki et al., 2011). This region is commonly engaged when people listen to sounds that contain a strong or predictable beat (Fujioka et al., 2010; Grahn and Brett, 2007; Grahn and Rowe, 2009), when they have attended to a rhythm long enough to hear an underlying beat (Chapin et al., 2010), or when they judge temporal intervals based on a previous beat (Teki et al., 2011). It has been hypothesized that the BG are most engaged in perceptual or motor timing tasks in the context of highly regular temporal spacing of events (Chapin et al., 2010; Fujioka et al., 2010; Grahn and Brett, 2007, 2009; Grahn and Rowe, 2009; see Fig. 3B). In addition, the interaction between BG and frontal cortex activity during beat synchronization is influenced by metrical complexity (Kung et al., 2013), illustrating one way in which the BG may work closely with frontal neural circuits. The BG may also play a role in processing pitch sequences in music (Janata et al., 2002), though this has been less studied than BG's role in timing in the context of music, and presents an avenue for further research.

In contrast, the cerebellum may be more engaged when timing is absolute or unpredictable (Teki et al., 2011). It has been proposed that the cerebellum has a general role in the timing of perception and action (Ivry and Spencer, 2004). People commonly engage the cerebellum when listening to and tapping along with auditory rhythms (Chen et al., 2008a; Grahn and Rowe, 2009; Grube et al., 2010; Kung et al., 2013; Sakai and Hikosaka, 1999; Teki et al., 2011). Patients with damage to the lateral cerebellar hemispheres also show poorer perceptual and tapping performance (Ivry and Keele, 1989; Ivry et al., 1988), and the volume of cerebellar lobule VIIIa has been linked to timing variability (Baer et al., in press). Importantly, patients with cerebellar degeneration are impaired on tasks requiring absolute interval timing, whereas patients with BG damage are impaired in beat-based timing (Cope et al., 2014; Grube et al., 2010). Taken together, the findings show that the BG may play a critical role for timing which is beat-based, well-learned, or predictable, whereas the cerebellar engagement in timing may be related to its involvement in learning and error correction (described in Section 3.2.3), both of which are more relevant for absolute or less-predictable timing. The cerebellum may also play a role in pitch sequencing; musicians engage the cerebellum when listening to music with complex pitch structure (Janata et al., 2002), suggesting that the cerebellum may play a role in both pitch and temporal sequencing.

Finally, the SMA may also be important for both rhythm and pitch processing because of its role in sequencing and hierarchical organization of movement (Hikosaka and Nakamura, 2002). Skilled musicians and nonmusicians engage the SMA when either performing music or when imagining listening to or performing music (Baumann et al., 2007; de Manzano and Ullén, 2012a,b; Herholz et al., 2012), suggesting that the SMA may be crucial for experts' ability to plan music segment-by-segment during performance. Importantly, this region seems to be engaged for both rhythm and melody sequencing (de Manzano and Ullén, 2012a).

Expert musicians make use of all of these systems during performance, but they may differ from novices in the degree to which each region is engaged and in the ways they interact. For example, in the studies of rhythm perception and synchronization, musicians showed greater engagement of the cerebellum compared to nonmusicians and performed better on the tasks (Chen et al., 2008a; Grahn and Brett, 2007). Further, during rhythm perception experts may show stronger interactions between auditory and motor regions (Chen et al., 2008a), likely because the rhythmic sequences are more strongly linked to movement in the musicians (Grahn and Rowe, 2009; see Fig. 3B). In addition, musicians show stronger engagement of SMA than nonmusicians when performing or imagining music (Baumann et al., 2007), possibly because musicians are better able to "chunk" musical sequences. However, when temporal or pitch sequencing tasks are easy, experts may also show reduced engagement of auditory and motor regions due to greater efficiency (Jäncke et al., 2000; Koeneke et al., 2004; Lotze et al., 2003; Meister et al., 2005).

3.2.3 Error Correction/Optimization/Learning: Cerebellum

The cerebellum is thought to play a role in optimizing movement and correcting errors. It is also known to be strongly engaged in learning of new skills, and it has been hypothesized to be a part of a network including parietal and motor cortex that encodes internal models of these skills. The cerebellum is connected to almost all regions of the brain, including those important for memory and higher cognitive functions. Based on this, it has been hypothesized that the cerebellum serves as a universal control system that contributes to learning and optimizing a range of functions across the brain (Ramnani, 2014).

There are two unique features of the anatomical organization of the cerebellum that may underlie its specialized role in learning and optimization of movements and other skills. First, the cerebellum is cell-dense, with many more neurons than the rest of the brain packed into a structure less than one-tenth the size (Balsters et al., 2010). Second, in all regions of the cerebellum neurons are organized into identical local circuits; unlike the cerebral cortex, where each region is made up of different cell types with different local organization. Thus, cerebellar regions are differentiated only by the cortical areas to which they connect—medial regions to sensory and motor cortices, and lateral regions to the frontal, parietal, and temporal lobes.

The local circuits in the cerebellum receive both sensory and motor information and studies of music processing have shown that it is active during both listening to, producing, and even imagining music (Brown et al., 2013; Chen et al., 2008a; Herholz and Zatorre, 2012; Herholz et al., 2012). Because the cerebellum integrates sensory and motor information (Bower, 1996; Manto et al., 2012), it allows actions or percepts and their outcomes to be compared. Through repetition, these comparisons contribute to the optimization of a movement or skill and also yield a stable internal model both of the motor commands to make a particular movement and of the sensory consequences of that movement (Bastian, 2006; Diedrichsen et al., 2010; Miall and King, 2008; Wolpert et al., 1998). The development of internal models is the basis of learning and also allows us to detect and correct movement errors. Evidence for this conceptualization of cerebellar function comes from studies in which people learn new skills (Doyon and Benali, 2005; Penhune and Steele, 2012; Shadmehr and Krakauer, 2008). In the context of music, expert pianists showed greater cerebellar activity early in the course of learning novel melodies when timing and accuracy were poorer (Brown et al., 2013). Further, cerebellar activity is evoked when musicians make and correct errors when playing (Pfordresher et al., 2014; see Fig. 1B).

Conversely, musicians showed greater cerebellar engagement during performance of complex rhythms compared to nonmusicians, even though they performed more accurately (Chen et al., 2008a). There are two possible interpretations for this finding. First, greater activity may be related to an enhanced internal model for the performance of the rhythm task in musicians. Specific increases in cerebellar activity with learning are thought to be related to development of an internal model for the particular skills (Imamizu et al., 2007; Steele and Penhune, 2010). The second is that greater cerebellar activity may be related to stronger interactions with the frontal cortex related to working memory mechanisms relevant for the task (Marvel and Desmond, 2010; Ramnani, 2014).

3.2.4 Long-Term Memory Retrieval and Working Memory

As described earlier in this chapter, a central ability for musical performance is memory. Long-term memory, or the ability to store information, is associated with the hippocampus and other medial temporal lobe structures. Working memory, or the ability to retrieve and manipulate previously learned information, is associated with frontal lobe networks.

Numerous studies in patients with surgical excisions of the hippocampus have shown that this structure is important in memory for musical pitch, timbre, melody, and rhythm (Alonso et al., 2014; Ehrlé et al., 2001; Samson and Zatorre, 1991, 1992, 1994). However, evidence for expertise-related changes in the hippocampal memory systems is relatively scarce. One recent study found that musicians showed greater hippocampal activity than nonmusicians during a melody recognition task (Groussard et al., 2010) and another found that musicians showed greater engagement of the hippocampus for novel temporal sequences (Herdener et al., 2010).

There is greater evidence that musical experience affects the structure and function of the frontal lobe memory systems, including the dorsolateral prefrontal cortex (DLPFC) and ventrolateral prefrontal cortex (VLPFC). Frontal lobe systems are engaged when we must actively retrieve and/or manipulate information, for example, when a musician plays a piece from memory.

On the basis of work in both humans and monkeys, it has been proposed that VLPFC interacts with sensory regions during active memory retrieval that requires control that is effortful and attention-demanding, or selection among options (Badre et al., 2005; Cadoret and Petrides, 2007; Kostopoulos and Petrides, 2003, 2008; Kostopoulos et al., 2007). The results of experiments requiring active memory retrieval in a musical context are consistent with this interpretation. VLPFC has been shown to be engaged when musicians hold rhythmic or pitch sequences in memory (Brown et al., 2013; Konoike et al., 2012; Schulze et al., 2011; Vuust et al., 2006) and during complex auditory imagery tasks (Leaver et al., 2009; Zatorre et al., 2010). A recent study of beat synchronization performance showed that activity in VLPFC was correlated with activity in the BG, particularly for more complex meters (Kung et al., 2013). This suggests that subcortical and frontal structures may work together to optimize retrieval and implementation of music.

The DLPFC is hypothesized to be important for manipulating information in working memory and in guiding attention to specific aspects of information (Curtis and D'Esposito, 2003). For example, DLPFC is engaged when musicians improvise (deManzano and Ullen) and the interaction between this region and the dPMC is greater for those with more experience improvising (Pinho et al., 2014). This makes sense, because musical improvisation requires retrieving a known melody and then manipulating it to create novel forms. The DLPFC is also engaged during synchronization with complex as compared to simple rhythms, and musicians show greater activity in this region than nonmusicians (Chen et al., 2008a; see Fig. 3A). This may be because musicians have more experience with complex rhythms and musical forms in general, and therefore can use previous knowledge of musical conventions or "schemas" to guide attention during performance.

4 HOW DOES EXPERT PERFORMANCE COME ABOUT?

4.1 PREDISPOSITION/TALENT

One of the most persistent debates in musical performance is that pitting predisposition or talent against experience or practice. On the one hand, Shinichi Suzuki held that "there is no inborn talent for music" whereas C.E. Seashore stated that "the gift of music [is] inborn." Retrospective reports describing child prodigies like Mozart and Itzhak Perlman emphasize their ability to play after little training and to perform at a level unattainable for other children. In contrast, others have emphasized the importance of experience for the development of expertise (Ericsson et al., 1993; Krampe and Ericsson, 1996; Sloboda et al., 1996). This idea has been popularized through the notion that more than 10,000 h of targeted practice is required for professional level performance (Gladwell, 2008). However, this literature tends to focus on retrospective evidence based on those who have already achieved expertise, as opposed to prospective evidence of those who undergo training. Common observation suggests that outcomes will not be identical for all individuals even if the amount of training is the same. Evidence supporting the contribution of preexisting individual differences comes from twin studies showing that the propensity to practice is partially heritable (Mosing et al., 2014). In a series of studies, Schellenberg and colleagues have investigated the contribution of cognitive and personality variables to music training, showing that those who engage in music perform better on cognitive tasks, have better educated parents, and describe themselves as more "open to experience" on personality scales (Corrigall et al., 2013). Neuroscience findings are also beginning to accumulate in both music and other domains, such as speech, indicating that learning outcomes can be predicted in part based on the preexisting structural or functional brain features (Zatorre, 2013). Other predisposing factors that have not been explored are low-level motor or perceptual abilities, and parental support and children's motivation for music.

On the other hand, training is clearly necessary for musical expertise, with a large number of studies finding that the length of musical experience is strongly correlated with performance on a range of musical tasks, as well as with brain structure and function (Amunts et al., 1997; Bengtsson et al., 2005; Bermudez and Zatorre, 2005; Chen et al., 2008a; Foster and Zatorre, 2010b; Oechslin et al., 2009). Taken together, it seems reasonable to suppose that both predispositions and experience contribute to musical expertise, and the relative balance between the two factors may depend on specific aspects of skill. For example, “perfect” or “absolute” pitch is strongly linked to early musical experience (Baharloo et al., 1998; Miyazaki, 1988; Sergeant, 1968) but is also more common in certain populations and may run in families (Baharloo et al., 2000; Gregersen et al., 2001).

4.2 EARLY TRAINING

Skilled musicians often begin training early in life. Review of the biographies of famous keyboard players (Lehmann, 1997) and interviews with professional (Manturzewska, 1990) and conservatory musicians (Jørgensen, 2001) found that many top players began lessons before the age of six. Such observations have led to the hypothesis that there might be a “sensitive period” for musical training—a concept defined by neuroscientists as a time during maturation when specific experience can have long-lasting effects on behavior (Knudsen, 2004). Evidence for a sensitive period for musical training comes partly from studies showing that musicians who began lessons before age seven had structural differences in the corpus callosum and sensorimotor cortex compared to those who began later (Amunts et al., 1997; Schlaug et al., 1995). More recent work has further addressed this question by controlling for any inherent differences in the length of training between musicians who begin training earlier than those who begin later. A series of behavioral and brain imaging studies compared early-trained (before age seven; ET) and late-trained (after age seven; LT) musicians who were matched for years of musical experience, years of formal training, and hours of current practice. These studies show that ET musicians perform better on rhythm synchronization and melody discrimination tasks (Bailey and Penhune, 2010, 2012, 2013; Watanabe et al., 2007) and have enhancements in gray- and white-matter structures in motor regions of the brain (Bailey et al., 2014; Steele et al., 2013; see Fig. 4). Other recent work has shown that musical training sharpens the response of the brainstem to auditory stimuli and that this is more significant for children than adults (Skoe and Kraus, 2013). Taken together, it has been proposed that early training creates a behavioral and brain scaffold on which later practice can build (Penhune, 2011; Skoe and Kraus, 2013).

4.3 PRACTICE

Although predispositions almost certainly exist, it is also clear that musical expertise is related to large amounts of accumulated practice (Ericsson et al., 1993; Sloboda et al., 1996). In addition, sustained and deliberate practice may be crucial for building

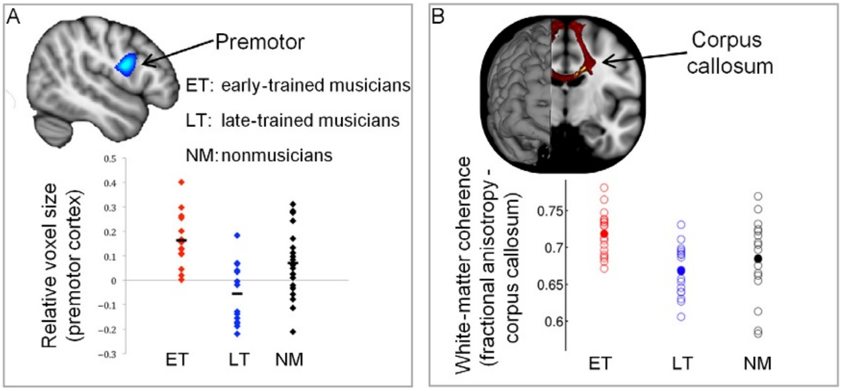

FIGURE 4

Early music training influences brain structure. (A) Early-trained musicians compared to late-trained or nonmusicians showed increased gray matter in premotor cortex (Bailey et al., 2014). (B) Early-trained musicians, compared to late-trained or nonmusicians, also showed greater white-matter coherence (as indexed by fractional anisotropy) in the corpus callosum, a white-matter tract that connects the two brain hemispheres (Steele et al., 2013).

and maintaining musical skill. Adult pianists who spend more hours per week practicing perform music from memory more accurately than those who practice less frequently (Palmer and Drake, 1997). Music performance students who achieve high levels of proficiency tend to be consistent and disciplined in their practice activities (Sloboda et al., 1996). While practice that is deliberate and formal may be critical for technical proficiency (Ericsson et al., 1993), it has been suggested that informal practice that is aimed at enjoyment may contribute to expressivity in performance (Sloboda, 2000).

In addition to building and maintaining skill, extensive rehearsal is needed for specific performances. Professional soloists spend months to years memorizing and perfecting particular musical works for public performances (Chaffin and Logan, 2006; Chaffin et al., 2010; Sloboda, 2000). Experts appear to use certain strategies consistently when rehearsing a musical work. First, they deconstruct the work by practicing individual sections repeatedly, and later putting those sections back together (Chaffin et al., 2010; Miklaszewski, 1989). Experts also appear to progress through stages during which they focus on different features of the music (Chaffin and Logan, 2006). For instance, professional soloists tended to focus first on the musical structure, second on the technical aspects and interpretation, and finally on the expressive qualities they wanted to achieve (Chaffin and Logan, 2006; Chaffin et al., 2010). These strategies are thought to help experts to automatize their performance of the work, while simultaneously allowing expressive spontaneity (Chaffin and Logan, 2006). In addition, performing musicians commonly report using mental imagery during practice (Gregg et al., 2008; Zatorre and Halpern, 2005), which has been shown to help musicians improve their performances (Coffman, 1990) and may help musicians learn new music (Brown and Palmer, 2012, 2013). Using mental rather than physical practice may reduce muscle strain and may help musicians develop an ideal performance or goal to work toward in rehearsal (Gregg et al., 2008).

5 OUTLOOK

The last few decades or so have seen rapid advances in our knowledge of expert performance and its neural and cognitive basis. The issues described in this chapter continue to be examined, along with how musical ability relates to other cognitive and motor abilities such as speech and general intelligence, how musicians perform from musical notation, and how musicians perform in a duet or group. Many questions remain, including what the nature and structure of auditory memories and motor skills are, how the two are integrated from the neural to the systems level, and how somatosensory feedback impacts performance. Neurological research aims to further understand how the structures engaged in music performance interact with one another and how these interactions change during real-time performance, and over time with experience. Importantly, the link between brain function and behavior in expert music performance will likely become clearer with these advancements.

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PART

3

New perspectives on neurological and mental disorders

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CHAPTER

5

Apollo's curse: neurological causes of motor impairments in musicians

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Abstract

Performing music at a professional level is probably one of the most complex human accomplishments. Extremely fast and complex, temporo-spatially predefined movement patterns have to be learned, memorized, and retrieved with high reliability in order to meet the expectations of listeners. Performing music requires not only the integration of multimodal sensory and motor information, and its precise monitoring via auditory and kinesthetic feedback, but also emotional communicative skills, which provide a "speaking" rendition of a musical masterpiece. To acquire these specialized auditory-sensory-motor and emotional skills, musicians must undergo extensive training periods over many years, which start in early childhood and continue on through stages of increasing physical and strategic complexities. Performance anxiety, linked to high societal pressures such as the fear of failure and heightened self-demands, frequently accompanies these learning processes.

Motor disturbances in musicians are common and include mild forms, such as temporary motor fatigue with short-term reduction of motor skills, painful overuse injuries following prolonged practice, anxiety-related motor failures during performances (choking under pressure), as well as more persistent losses of motor control, here termed "dynamic stereotypes" (DSs). Musician's dystonia (MD), which is characterized by the permanent loss of control of highly skilled movements when playing a musical instrument, is the gravest manifestation of dysfunctional motor programs, frequently linked to a genetic susceptibility to develop such motor disturbances.

In this review chapter, we focus on different types of motor failures in musicians. We argue that motor failures in musicians develop along a continuum, starting with subtle transient degradations due to fatigue, overuse, or performance stress, which transform by and by into more permanent, still fluctuating motor degradations, the DSs, until a more irreversible condition, MD manifests. We will review the epidemiology and the principles of medical treatment of MD and discuss prevention strategies.

Keywords

dynamic stereotype, motor control, musician's dystonia, prevention of dystonia, treatment of dystonia

1 BECOMING A HOROWITZ: CHALLENGES IN ACQUIRING SUPERIOR MOTOR SKILLS IN MUSICAL PERFORMANCE

Performing music at a professional level is one of the most complex human accomplishments. Playing an instrument requires the integration of multimodal sensory and motor information, the generation of appropriate action plans, the selection and retrieval of highly refined movement patterns from procedural motor memory, and the initiation of movement. In most instances, these movements are highly overlearned, and they depend on feed-forward programming of the anticipated—mostly audible—results and on real-time feedback.

Auditory and kinesthetic feedback is needed to improve, fine-tune and perfect the performance. Music making therefore relies primarily on a highly developed auditory-sensory-motor integration capacity, which has been conceptualized theoretically in the "common-coding" model by Prinz (1984). Simply put, in this model movements are represented as sound patterns, and sound patterns as movements (see for a review Zatorre et al., 2007). Subtle perturbations of this auditory feedback have a major impact on motor control. For example, playing on a keyboard with slightly delayed sound production affects the regularity of scale playing even in highly accomplished pianists (Cheng et al., 2013). Furthermore, the kinesthetic senses constitute another basis of high-level performance. They allow for the control and feedback of muscle- and tendon-tension as well as joint positions, enabling the continuous monitoring of finger-, hand-, or lip-position in the frames of body and instrument coordinates (e.g., the keyboard, the mouthpiece). Again, subtle changes in kinesthetic feedback result in an alteration of the motor program, and in some individuals long-term loss causes severe disturbances of the motor program and even focal dystonia (for a theoretical account and review on this topic, see Konczak and Abbruzzese, 2013).

In order to acquire these specialized sensory-motor skills, musicians must undergo extensive training periods over many years, starting in early childhood and passing through stages of increasing physical and strategic complexities. This process of practicing involves assembling, storing, and constantly improving sensory-motor programs through prolonged and repeated execution of motor patterns under the controlled monitoring of auditory and kinesthetic senses. To attain a professional level, as a rule of thumb, musicians have 10,000 h in 10 years of deliberate practice (Ericsson et al., 1993). Of course, time invested into the acquisition of motor skills alone is not sufficient for becoming an outstanding artist. Quality of practice as well as communication skills and expressive gesturing, rendering a speaking performance, are equally important in the process of artistic perfection of publicly acclaimed and valued interpreters (Hallam, 2014).

In music, learning through experience and training is accompanied by remarkable plastic adaptations of the central nervous system, which are not only reflected in modifications of the brain's neuronal networks as a result of a strengthening of neuronal connections, but also in its overall gross structure. It is known, for example, that music practice enhances myelination, gray matter growth, and fiber formation of brain structures involved in the specific musical task (for a review, see Chapter "Apollo's Gift: New Aspects of Neurologic Music Therapy" by Altenmüller and Schlaug; Münte et al., 2002; Wan and Schlaug, 2010). Gaser and Schlaug (2003) could demonstrate enhancement of gray matter density in cortical sensory-motor regions, auditory regions, the left dorsolateral prefrontal cortex, and in the cerebellum in professional instrumentalists as compared to nonmusicians and amateurs. Interestingly, these plastic adaptations depend on critical age periods: musicians who start playing their instruments before the age of seven do not display these structural adaptations of the brain, at least in the sensory-motor cortices and the callosal fibers; however, they seem to have an "early optimized network," which allows superior performance of motor tasks without enlarged anatomical structures (Steele et al., 2013; Vaquero et al., 2014). In contrast, those who start after the age of seven do show the above-mentioned structural adaptations accounting for the effects observed in many morphological brain imaging studies (e.g., Bangert and Schlaug, 2006; Gärtner et al., 2013).

When discussing skilled motor behavior in music performance and its deterioration or even loss, it is first necessary to emphasize what is unique to making music and what renders it particularly challenging and fragile in terms of motor control:

1. Musical training usually starts very early, sometimes before age six, when the adaptability of the central nervous system is the highest. This feature is not unique to music, as other skilled activities, for example, classical ballet, also require an early start.
2. Making music is linked to sound production. As in speech, the auditory system provides a very precise feedback of the movement effects, with a temporal resolution superior to kinesthetic and visual feedback. Furthermore, in the frame of classical music, which is notated and available as sheet music, the target parameters, namely temporal accurateness (correct tempo, accuracy of rhythm, swing, beat, pulse, etc.), and spatial accurateness (correct key—or finger position on fingerboard, correct sound quality) are predefined. Therefore, a highly reliable reproduction of movements meeting these targets is required. This feature is unique to music: in classical ballet, for example, visual feedback is less critical in terms of temporo-spatial precision.
3. Most musicians work at the upper limit of their sensory-motor capabilities and strive to push their limits even further ahead in order to be faster, louder, and more expressive. Given the complexity of music, the demands of composers, especially in the last 100 years, and the role of outstanding peers as models—for example, the Chinese pianist Lang Lang, or the "record braking" violinist David Garrett—the theoretical limit of movement accuracy and speed is the temporal and spatial resolution of the auditory system. As musicians say, "there is always a colleague, who plays this piece faster, louder and more beautiful." This is in part also true for sports, but in music, fine motor skills predominate. Therefore, musicians are frequently denoted colloquially as "small muscles' athletes."
4. The societal pressure and expectancies concerning the quality of musical performances have definitely grown over the last centuries: this is due, on the one

hand, to the ubiquitous availability of music recorded in the media, such as YouTube and CDs, but on the other hand, to collective learning processes leading to higher standards of music appreciation. This process augments anxiety, tension, and competition among musicians, making their lives increasingly stressful. Frequently even outstanding soloists have to cope with severe performance anxiety (Wilson, 1997).

5. Nevertheless, making music is frequently linked to highly positive emotions, to feelings of joy, satisfaction and even to strong emotional reactions, known as "chill responses" (Altenmüller et al., 2013). These qualities are known to enhance plastic adaptations of the brain and can even lead to a sort of addictive behavior, causing younger musicians to over-practice and ignoring their bodily limits, which are indicated by fatigue and musculoskeletal pain.

2 APOLLO'S CURSE: LOSS OF MOTOR CONTROL IN MUSICIANS

According to our new classification of motor control disturbances in musicians, we can distinguish five different types of deterioration of motor control in musicians (Altenmüller et al., 2014). The criteria for this new classification are (1) duration and development of the problem, (2) triggering mechanisms, (3) psychological profiles, (4) response to treatment, (5) accompanying symptoms, and (6) genetics.

2.1 MOTOR FATIGUE

Most musicians experience at some point a loss of motor control when playing their instrument. Frequently this phenomenon is short-term and bound to either lack of practice or overuse. It is accompanied by mental or bodily fatigue and obviously linked to reduced attention and insufficient movement monitoring. Usually, these deteriorations of movement coordination are short term: they disappear overnight and do not compromise overall performance. Although these incidents seem to be frequent, there is almost no scientific data available. A recent questionnaire study on German orchestral brass instrumentalists identified temporary crises of embouchure coordination in a percentage as high as 30% (Steinmetz et al., 2013). In clinical practice, the symptoms are lack of regularity in scales, trills, and other fast repetitive movements, and the wind-players complain of loss of sound quality and occasionally early fatigue. Pain is not usually reported. There is no information available as to whether any medical intervention other than rest is useful to treat this condition.

2.2 OVERUSE INJURY

In contrast to the former condition, overuse in the narrow sense of the word should only be diagnosed when pain is a dominating symptom and a history of either prolonged or unaccustomed practice exists. In this case, local inflammation of over-strained tissues, the release of pain-mediators, and spinal reflexes with increased or occasionally lowered muscle tone may lead to a deterioration of motor control, mostly accompanied by relieving movements (Szeto and Lin, 2011). This condition may last a couple of days and, if the patient rests, subsides after a few weeks at the latest.

2.3 CHOKING UNDER PRESSURE

Another condition leading to a deterioration of motor control is "choking under pressure" (CuP). CuP figures widely in sports' psychology literature but has not yet been adopted by experts in musician's medicine and performing arts' psychologists. In sports, the current definition characterizes CuP as an acute performance failure due to a perceived mismatch between the individual resources of an athlete and the demands of the situation (Hill et al., 2009). CuP describes the situation in which the individual perceives a subjectively unmanageable situation that is accompanied by fear of failure, anxiety, and increased arousal, leading to reduced motor control and worse performance outcome. In musicians, CuP is a relatively frequent experience, especially among performing novices, and is usually subsumed under the term "performance anxiety." According to questionnaires, between 15% and 60% of performing musicians occasionally suffer from this condition (Brugués, 2011a; Steptoe and Fidler, 1987). It may lead to loss of agility, heightened muscular stiffness accompanied by increased cocontraction of antagonist muscles, and, as a consequence, reduction of temporo-spatial precision of movements and sound quality. This has been impressively demonstrated in pianists (Yoshie et al., 2009). In brass players, the so-called tongue stopper prior to an important cue is a typical manifestation.

2.4 DYNAMIC STEREOTYPE IN MUSICIANS

If motor incoordination and lack of motor control persist for more than 4 weeks, despite the patient's resting and careful rehabilitation under the guidance of a therapist or teacher has been attempted, one can assume that there is a graver alteration of sensory-motor networks leading to a deterioration of motor programs in the central nervous system. We have called this condition "dynamic stereotype" (DS), a term borrowed from the eminent Russian physiologist Pavlov (1951) (for a critical review, see Windholz, 1996). Originally, this condition can be understood as a reflection of fatal compensation strategies, which became automated. In the words of the exponents of Russian behaviorism, DSs are defined as a type of integral activity performed by the cerebrum of higher animals and man and manifested by a fixed, or stereotyped, succession of conditioned reflexes. The DS is influenced by external factors that are repeated in a certain order. Accordingly, the DS is the most vivid manifestation of the extremely subtle analyzing and synthesizing activity of the cerebral cortex and is the product of very complex interactions between the areas of the cortex. It can at least partly be conceptualized as a consequence of long-term CuP when these dysfunctional movements are stored in procedural memory traces, possibly as a consequence of conditioned reactions to the previous choking experiences and procedural memory formation under stress (Klämpfl et al., 2013; Lobinger et al., 2014).

In many aspects, the phenomenology of DS resembles focal, task-specific dystonia (see below). However, in contrast to the latter, it seems to be more modifiable and more fluctuating, especially during stressful performances. Sometimes they experience sudden improvement and complete motor control occurs – but only for hours or a few days. DS responds occasionally to sensory trick maneuvers, such as alterations of either tactile input from the body parts affected by dystonia or alterations of auditory input, for example, by delay of the produced sound. We could demonstrate that the improvement in motor control when the patient plays with a latex glove is related to a better outcome of retraining and behavioral therapies (Paulig et al., 2014). It should be mentioned, however, that responses to sensory tricks and objective improvement are rare and highly variable (Cheng et al., 2013). Therfore, we prefer to consider this phenomenon a "soft-sign" with respect to the classification of motor control problems.

2.5 FOCAL DYSTONIA IN MUSICIANS

The most severe movement disorder among instrumental performers is task-specific musician's dystonia (MD) (Altenmüller, 2003), also known as musician's cramp. Commonly, two major forms are distinguished: focal hand dystonia (FHD) and embouchure dystonia (ED). This movement disorder is characterized by persistent muscular incoordination or loss of voluntary motor control during task-specific highly trained movements, such as playing a musical instrument (Altenmüller, 2003; Jankovic & Ashoori, 2008). In most cases, pain does not accompany the disorder; occasionally, some muscular strain can occur when patients attempt to compensate for the dystonic movement by overactivating the antagonist muscles; however, lack of pain distinguishes it from the above-mentioned overuse injury. It is important to make this distinction while bearing in mind that prolonged pain syndromes may lead to symptomatic dystonia. MD frequently terminates professional careers and is highly disabling among musicians (Altenmüller, 2003; Altenmüller & Jabusch, 2010; Brandfonbrener and Robson, 2004; Lederman, 1991).

Various symptoms can mark the beginning of the disorder: subtle loss of control in fast passages; finger curling (cf. Fig. 1); among woodwind players, a lack of precision in forked fingerings; irregularity of trills; fingers sticking to the keys; among string players, an involuntary flexion of the bowing thumb; and among woodwind and brass players, the loss of control of the embouchure in certain registers. At this stage, most musicians believe that the reduced precision of their movements is due to a technical problem or lack of practice. As a consequence, they intensify their efforts, but this reaction often exacerbates the problem. The loss of muscular coordination is frequently accompanied by a cocontraction of antagonist muscle groups. For example in pianist's cramp, the coactivation of wrist flexor and wrist extensor muscles is frequently observed, and we have documented a case of a task-specific dystonia in

FIGURE 1

Typical patterns of dystonic postures in a pianist, a violinist, a flutist, and a trombonist suffering from musician's dystonia.

the leg of a bass-drummer, leading to pronounced coactivation of ankle flexor and extensor muscles (Lee and Altenmüller, 2014).

There are special cases of task-specific loss of motor control in musicians, which should be mentioned here, as they are strongly related to MD or even constitute subgroups: dystonic tremor is characterized by task-specific tremulous movements of the supporting arm in woodwinds or in the bowing arm of string players (Lee et al., 2013, 2014). A very rare condition is a task-specific inability to recruit motor programs required for a specific overlearned movement, termed "negative dystonia" (Mezaki, 2007).

According to the recent estimates, 1% of all professional musicians are affected (Altenmüller and Jabusch, 2010). In contrast, in the general population, the prevalence of focal dystonias, including writer's cramp, blepharospasm, and cervical dystonia, is estimated as 29.5 per 100,000 in the United States and 6.1 per 100,000 in Japan (Nakashima et al., 1995; Nutt et al., 1988). In comparison to other activities producing dystonic movements, such as writing, playing golf (the "yips"), or playing darts (dartism), classical musicians have the highest risk of developing focal dystonia (Frucht, 2009).

Demographic data demonstrate a preponderance of male musicians with a male/female ratio of about 4:1 (Lim and Altenmüller, 2003). Hereditary factors play a role in the etiology of MD, as a positive family history of dystonia exists in up to 36% of affected musicians (Schmidt et al., 2009). According to the epidemiological data, the probability of developing MD depends on the instrument played: guitar players, pianists, and brass instrument players have the highest risk of developing dystonia

(Altenmüller and Jabusch, 2010). Repetitive use, controllability of motor actions, temporo-spatial demands, and extrainstrumental fine motor burdens, such as writing, are triggering factors (Altenmüller et al., 2012; Baur et al., 2011). Furthermore, those musicians who start practicing after age 10 are at a much higher risk of developing MD (Schmidt et al., 2013).

While there is probably a certain overlap between MD and the above-described DS, each of these disorders is distinct from the other. Generally, focal dystonia is more severe, and the dysfunctional movements are more obvious and more resistant to any attempt to correct them voluntarily. Furthermore, movements respond to a lesser degree to the above-mentioned sensory tricks. Sudden spontaneous improvements are rare exceptions, and psychological stressors do not influence the loss of motor control to a major degree. Finally, in contrast to DS, MD has a tendency to spread from the specific movement when playing the instrument to general, daily-life movements. For example, MD may first show only in the ring and little finger of the pianist when playing scales, as depicted in Fig. 1, but later extends to typing on a computer keyboard and to buttoning up a shirt, and in the end may lead to permanent cramping of the hand. In neurology, this condition is termed "dystonic cramp" and it seems to affect about 35% of musicians suffering primarily task-specific dystonia (Rosset-Llobet et al., 2007). Along the same line, loss of motor control may progress from the forearm to the upper arm, leading in rare cases to segmental dystonia. When dystonia spreads from one hand to the other, which is the case in about 3% of the musicians suffering from FHD, a bifocal dystonia has to be assumed (Rosset-Llobet et al., 2007).

2.6 SYMPTOMATIC TASK-SPECIFIC DYSTONIAS IN MUSICIANS

Symptomatic task-specific dystonias in musicians form a rare heterogeneous group of dystonias. Per definition, the leading symptom is isolated deterioration and loss of motor control when playing a musical instrument. In contrast to the above-mentioned "idiopathic" focal dystonias, the disorder is caused by an underlying neurological or psychological pathology. For example, in rare cases it may mark the beginning of Parkinson's disease, albeit we have to acknowledge that we have only seen two MD patients who later developed Parkinson's disease. When taking our present group of 850 MD patients into account, this incidence rate of Parkinson's corresponds to that in the general population of Germany. Furthermore, in neurological textbooks, Morbus Wilson, Huntington's Chorea, and other neurodegenerative diseases have been mentioned as causes of symptomatic dystonia; however, to our knowledge an isolated task-specific loss of motor control in these conditions, specifically when playing the instrument, has not yet been described.

MD is sometimes triggered by bodily trauma. Here, it is unclear whether the lesioning of peripheral nerves and the concomitant sensory degradation or the trauma-induced rest or change in practice schedules, playing postures, and so on constitutes triggers. We have seen two flutist patients who suffered from inferior alveolar nerve lesion and numbness of the lower lip and who then developed ED (unpublished clinical data).

Psychogenic dystonias in musicians are extremely rare conditions. We have never suspected any musician of malingering, probably due to the rewarding nature of music and the lack of secondary benefits when loosing the ability to perform. However, fluctuating or longer lasting loss of motor control when playing an instrument may occur in some psychiatric diseases, such as schizophrenia, obsessive–compulsive disorders, and constraint and anxiety disorders. In schizophrenia, long-term consequences of antipsychotic drugs have to be considered as a cause. In obsessive–compulsive disorder, dysfunctional working behavior and, as a consequence, motor fatigue and overuse may be the underlying pathogenic mechanisms. Anxiety has frequently been found to be a risk factor in MD (see below). This might hypothetically be linked to chronic CuP, as we discussed in Section 2.4.

Finally, psychogenic MD in the narrow sense of the word is, as far as our experience goes, extremely rare. The underlying theory assumes a conversion disorder, which in turn is caused by fundamental unresolved psychological conflicts, leading to subconscious alterations of motor behavior that may express the nature of the underlying conflict in a "converse" manner. It is very difficult to diagnose and therefore frequently subsumed under the term, unexplained medical conditions (Lang and Voon, 2011). As a rule of thumb, musicians suffering from psychogenic dystonia usually have a history of previous physical or psychological trauma or disorder, show the symptoms in an exaggerated, speaking manner, seem to be more emotionally distant from the motor disorder, and display less despair than do musicians with normal MD. Sometimes a triggering event can be identified, and in the follow up, fluctuating symptoms with prolonged periods of complete remission or miracle healing are suspicious for a psychogenic cause (Czarnecki and Hallett, 2012).

3 A HEURISTIC MODEL OF MOTOR DISTURBANCES IN MUSICIANS

Summarizing the previous paragraphs, we can classify the six types of motor disorders according to the duration of motor degradation, the accompanying symptoms, the underlying neurophysiological mechanisms, and the response to treatment. In Fig. 2, we depict a heuristic model which goes from a continuous worsening of motor control from temporary subtle awkwardness to increasingly unstable motor control and finally fully developed focal dystonia. Furthermore, we have added triggering factors, identified in our previous epidemiological studies (Altenmüller, 2003; Altenmüller and Jabusch, 2010; Altenmüller et al., 2013).

In the beginning, motor fatigue may cause a temporary degradation of motor skills, or, in highly skilled experts, additional/alternative recruitment of muscles contributing to dysfunctional movements. This mechanism has been convincingly demonstrated in skilled table tennis players (Aune et al., 2008) and most likely also applies to instrumental musicians. For example, in skilled piano players, fatigue

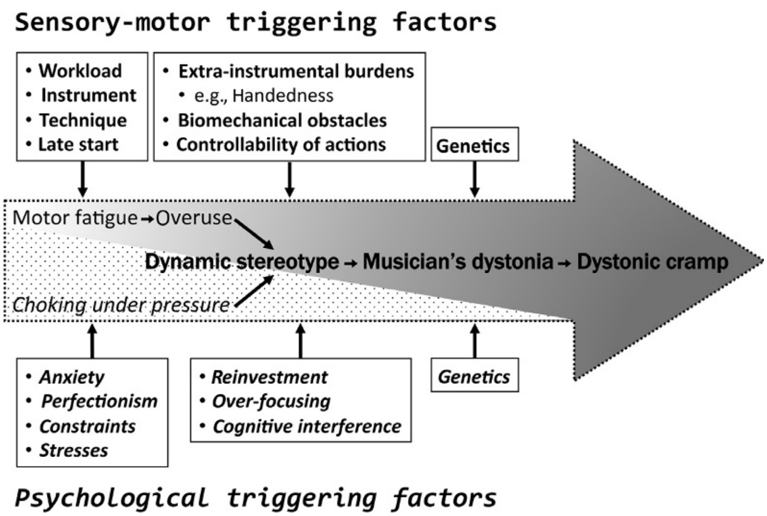

FIGURE 2

Heuristic model demonstrating the proposed interplay of sensory-motor and psychological triggering factors and their contribution to the different motor disturbances. The assumed degree of "psychological" triggering factors is displayed as the dotted space; the increasing gray shade symbolizes the increasing degree of loss of motor control.

of the long flexor muscles in the forearm may be compensated by activation of the intrinsic muscles in the hand, which in turn results in dysfunctional movements in the metacarpophalangeal (MCP)-joints with lack of fine control of touch and degraded sound quality. These changes are accompanied by central nervous adaptations due to short-term plasticity, and they result in reduced amplitude of movement-related potentials and in an alteration of the topography of motor and premotor cortex activations (Dirnberger et al., 2004). Interestingly, in a study on musicians suffering from dystonia, a fatiguing muscular contraction significantly improved motor performance. In contrast, in healthy musicians, performance consistently worsened following fatigue (Pesenti et al., 2004).

In the overuse condition, dysfunctional CNS-plasticity might play an important role in motor degradation (Byl et al., 1996, see also Flor, 2012 for a review). Although in most instances prognosis is good and quick recovery common, under conditions with heightened anxiety and other stressors, such as high professional workload, these dysfunctional motor patterns may stabilize in procedural memory. Here, psychological stress might induce the cascade of emotionally induced memory consolidation, which has been previously described for different forms of memory: consolidation mainly relies on noradrenergic activation of the basolateral amygdala (BLA) (McGaugh, 2000; Packard et al., 1994). The primary motor cortex, which is essentially involved in the storage of motor memories (Karni et al., 1998), receives a basolateral amygdala projection (Sripanidkulchai et al., 1984). Thus, it may be assumed that consolidation of these dys-coordinated movements as dysfunctional motor programs is a BLA-mediated process in the primary motor cortex (Jabusch and Altenmüller, 2004). This may also be the link to conditions, which we discuss in Sections 2.3 and 2.4.

CuP is common in sports and has been investigated in golfers suffering from the yips. This condition is defined as involuntary movements during the execution of putting strokes, resulting in a serious decrease in the success rate in putting. It has been classified by some authors as a task-specific focal dystonia (Adler et al., 2005); however, many authors believe that the yips are more related to CuP (Lobinger et al., 2014). The following are arguments against the classification as a focal dystonia:

1. The yips occurs not only in professionally trained golfers but also in golfing beginners. This renders a pathophysiological mechanism similar to that of MD very unlikely. In musicians, we could demonstrate that dysfunctional brain plasticity induced by prolonged practice leads to distorted topographies of receptive fields in the somatosensory cortex, which in turn leads to the observed degradation in motor control due to abnormal somatosensory feedback (Elbert et al., 1998).
2. The yips look more like a sudden jerk, or an anticipating tremor prior to hitting the ball. In MD, reduced inhibition in the motor output is another proven cause of dysfunctional movements, leading to prolonged coactivation, and typical dystonic postures—for example, the curling of fingers in Fig. 1.
3. The Yips are relatively frequent in the golfing community with the rate of prevalence between 16% and 24% (Klämpfl et al., 2013). This is unusual for any kind of dystonia. As of now, the most common task-specific dystonia is MD, which affects 1–2% of professional musicians.

In music, the term CuP, has not been applied, but the phenomenon clearly exists. The above-mentioned tongue stopper in brass players, or the short-action bowing tremor in violin-players, playing soft notes with the tip of the bows, is good example. Here, most probably anxiety-induced "reinvestment" leads to cognitive interference, resulting in dysfunctional movements due to the attempt to prevent or even correct feared errors. In an EEG-study on highly trained professional pianists, we could demonstrate that their brain anticipates errors of motor execution, and that these "pre-error"-related brain waves arise about 50 ms prior to the wrong key-stroke (Herrojo-Ruiz et al., 2009). Such a rapid error-anticipating mechanism cannot be cognitively controlled; rather it is highly susceptible to disturbances via cognitive control. Therefore, it is plausible that reinvestment and CuP may lead to a deterioration of motor control.

DS is characterized by a more permanent reduction of motor control. As outlined earlier, it differs from focal dystonia only gradually, but is more likely linked to psychological triggering factors than to underlying genetic causes (Ioannou and Altenmüller, 2014). In terms of underlying neurophysiological mechanisms, we speculate that these musicians have a deficit in the so-called limbic loops of the basal ganglia, linking movements, and motor control to emotions. However, this question remains to be addressed in future investigations in a patient population, which is correctly classified a priori (Ioannou and Altenmüller, 2014).

MD can be distinguished from the former by the more pronounced worsening of motor control, the lack of "islands" of wellbeing, and the tendency to progress to dystonic cramps. The pathophysiological basis of MD can only briefly be summarized. For more details, we refer to a review by Altenmüller and Jabusch (2010). Numerous studies have revealed abnormalities in three main areas: (a) reduced inhibition in the sensory-motor system, (b) altered sensory perception, and (c) impaired sensorimotor integration. In recent years, an increasing number of brain imaging studies among musicians—and other focal dystonias—have demonstrated that these alterations are probably not task-specific. Functional connectivity (Moore et al., 2012), cortical activation patterns (Haslinger et al., 2010), and basal ganglia anatomy (Walter et al., 2012) have proven to be abnormal, although behavioral tests are more in favor of task-specificity when testing musicians in other skilled motor tasks (Rosset-Llobet et al., 2007). We argue that musician's focal dystonia is the product of a hereditary susceptibility, probably related to a general lack of central nervous inhibition and the above-mentioned triggering factors. This leads not only to task-specific functional alterations of CNS-networks—as we predict in patients suffering from a DS—but also to structural alterations found in the above-mentioned studies.

In the previous publications, we have emphasized psychological conditions as an underlying triggering factor. In several questionnaire studies, we found elevated anxiety and extreme perfectionism in MD patients (Altenmüller and Jabusch, 2009; Enders et al., 2012). According to Jabusch et al. (2004), these psychological characteristics had already been present before the onset of dystonia according to personal recall. We now argue that musicians with a major psychological burden can most likely be subsumed under the classification of a DS. We are presently conducting a study, which addresses the impact of stress and anxiety on motor performance in musicians suffering from loss of motor control who show signs of either high or low psychological burdens. Subsequently, we will apply specific interventions aiming at improving psychological conditions and preventing dysfunctional reinvestment in order to improve motor control in those musicians who suffer from DSs.

4 CURING APOLLO'S CURSE: TREATMENT OF MOTOR DISTURBANCES IN MUSICIANS

What do psychological and neurophysiological findings imply for the differential treatment of motor disturbances in musicians? We have already mentioned that motor fatigue is best treated with rest, although no scientific data are available to verify the results. For the treatment of overuse injuries, besides rest, pain medication, muscle relaxants, and physiotherapy with gentle stretching exercises have proven to be useful (for a review, see Helliwell and Taylor, 2004). For these pain syndromes, a prompt intervention is required to avoid dysfunctional plastic adaptations of the central nervous system seen in chronic pain conditions (Jensen et al., 2013). CuP in musicians is probably best prevented by mental training and specific cognitive strategies which are already being applied in sports psychology (e.g., "hemispheric priming" Beckmann et al., 2013). Efficient treatment probably includes cognitive behavioral therapy, mindfulness-training, and various breathing and relaxation techniques (for a review, see Brugués, 2011b). As medications, beta-adrenergic receptor blockers (such as propanolol) and benzodiazepines are potentially helpful. Both drugs prevent dysfunctional motor memory formation (Soeter and Kindt, 2013).

As far as the treatment of DS is concerned, we predict that psychological techniques, such as the prevention of dysfunctional reinvestment and cognitive interference, will be helpful. The latter, for example, could be influenced by guiding attention from an internal (body-related) to an external (sound-related) focus. These techniques have been shown to be efficient in complex motor studies with normal and patient groups (Wulf, 2007, for an overview). Furthermore, psychotherapeutic techniques reducing anxiety and perfectionism will probably improve the condition. Specific interventions are learning-based sensorimotor training, based on re-defining spatial and temporal processing capacities in the sensory and motor cortices in order to restore task-specific skills (Byl and McKenzie, 2002). Prolonged pedagogical retraining has been successfully applied to pianists suffering from loss of motor control (van Vugt et al., 2014). Useful medications include selective serotonin-reuptake inhibitants (e.g., escitalopram) to overcome reinvestment, overfocussing, and depression; anticholinergic drugs to reduce dysfunctional motor memories; and finally, as a symptomatic treatment, local injections of botulinum toxin into the cramping muscles (Schuele et al., 2005). These medications are also applied in MD.

Finally, treatment for MD is mostly symptomatic and depends on the type of dystonia. Psychological interventions seem to be less effective for the treatment of MD than for DS. Various oral medications have been used, and the anticholinergic drug trihexyphenidyl has proven to be the most effective agent (Jabusch et al., 2005). Occasionally, patients may benefit from baclofen or antiepileptic drugs such as phenytoin, primidone, or rivotril. Chemical denervation using botulinum toxin has been used for many forms of MD with considerable success. Botulinum toxin blocks the transmission of nerve impulses to the muscle and weakens the overactive muscles involved. Results in musician's cramp depend on the dystonic pattern, on the injection technique and on the precise localization of the dystonic muscles. In our series, injections of botulinum toxin were applied to 71 musicians suffering from hand dystonia. Fifty-seven percent patients reported long-term improvement (Schuele et al., 2005). A new promising therapy is bihemispheric transcranial direct current stimulation during the execution of functional movements at the instrument. In a double blind randomized prospective trial, we could demonstrate that stimulation with inhibition of the dysfunctional network of the "dystonic" motor cortex and the activation of the "healthy" network of the contralateral motor cortex improved performance significantly (Furuya et al., 2014).

Since successful treatment is still a challenge, preventing MD is important. On the basis of the heuristic model outlined in this chapter, which assumes a progression of increasing motor disturbances from fatigue, pain, anxiety to dysfunctional motor memories, and finally to MD with structural memory consolidation and brain adaptations, we now have the theoretical means at hand to intervene at an early stage. From the first lesson on, music educators should strive to create a friendly, supportive atmosphere, introduce reasonable practice schedules, teach proper techniques, and prevent overuse and pain by including mental practice and variations of movement patterns. By avoiding mechanical repetitions and hence frustration, teachers can help maintain students' motivation. Students should be taught to adopt healthy living habits, including warm-up and cool-down exercises, regular physical exercise, sufficient breaks, and sleep as the cornerstones of healthy musical practice.

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CHAPTER

Music and its association with epileptic disorders

6

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Abstract

The association between music and epileptic seizures is complex and intriguing. Musical processing within the human brain recruits a network which involves many cortical areas that could activate as part of a temporal lobe seizure or become hyperexcitable on musical exposure as in the case of musicogenic epilepsy. The dichotomous effect of music on seizures may be explained by modification of dopaminergic circuitry or counteractive cognitive and sensory input in ictogenesis. Research has explored the utility of music as a therapy in epilepsy and while limited studies show some evidence of an effect on seizure activity; further work is required to ascertain its clinical potential. Sodium channel-blocking antiepileptic drugs, e.g., carbamazepine and oxcarbazepine, appear to effect pitch perception particularly in native-born Japanese, a rare but important adverse effect, particularly if a professional musician. Temporal lobe surgery for right lateralizing epilepsy has the capacity to effect all facets of musical processing, although risk and correlation to resection area need further research. There is a need for the development of investigative tools of musical processing that could be utilized along the surgical pathway. Similarly, work is also required in devising a musical paradigm as part of electroencephalography to improve surveillance of musicogenic seizures. These clinical applications could aid the management of epilepsy and preservation of musical ability.

Keywords

musicogenic, epilepsy, Mozart therapy, temporal lobectomy, carbamazepine

1 INTRODUCTION

Music is an art form and for most people is a fundamental part of everyday life. Access to music has increased in the digital age with the ability to play and store large collections of music in portable form. Music has become a useful research tool in areas of cognitive neuroscience exploring auditory perception, memory, and new

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learning. Other fields exploring sensorimotor processing, brain plasticity, and mirror neuron circuitry have also exploited music in interrogating brain functioning. For most people, exposure to music can often be a pleasurable and emotive experience. However for people with the neurological condition epilepsy, the relationship with music can be much more complex.

Epilepsy is a common neurological condition affecting around 65 million people worldwide with a prevalence of 1 in 100 (Thurman et al., 2011). It is a condition named and derived from the Greek verb *epilambanem*, which means "to take hold of or to seize" and is characterized by at least two or more unprovoked seizures. Seizures may arise from a focus of brain cortex often manifesting as simple or complex focal seizures whereby patients may lose awareness, develop autonomic symptoms, or experience sensory or focal motor symptoms depending on the area of cortex involved. Around 70% of focal seizures emanate from the temporal lobe, an area critical for memory, language, auditory, and sensory processing. Seizures may occur *de novo* or as a consequence of viral infection, tumor, or cortical dysplasia. Other patients may experience seizures with a generalized onset involving both brain cortices. These seizures may manifest as brief myoclonic jerks, absences or generalized tonic clonic seizures characterized by loss of consciousness, stiffening of the limbs, and convulsive limb movements. Epilepsies characterized by generalized seizures are presumed to have a genetic cause (Berg et al., 2010). About 3 in every 100 patients with epilepsy will have photosensitivity where all or some of their seizures are triggered by exposure to flashing or flickering lights within the range of 16–25 Hz.

Seventy percent of patients with epilepsy can expect to achieve a remission in seizures with one or two trials of currently available antiepileptic drug treatment. However, around one third of patients may not achieve a clinically significant remission requiring multiple trials of drug therapy and, in some cases, surgery, neurostimulation, or ketogenic diet. People with medically refractory epilepsy are at greater risk of death, depression, anxiety, and adverse drug effects and are more likely to experience poorer quality of life (Taylor et al., 2011).

There are several specific triggers for seizures which have been described in the literature and define a group of epilepsy conditions termed reflex epilepsies. These include the common trigger of photosensitivity and more rare and unusual triggers such as reading, hot water, tooth brushing, eating, and most relevant, music.

Interest in the link between music and epilepsy has increased in the last two decades. Interests span from converting brain waves in seizure and nonseizure states into music to examine the utility of music as a potential nondrug therapy in epilepsy.

Music appears to have a divergent effect on patients with epilepsy. Some patients may gain benefit from exposure to music, but in others, music may trigger seizures leading to avoidant behavior and musicophobia.

This chapter discusses musical processing in the human brain, musicogenic epilepsy, and musical seizure phenomena. The therapeutic potential of music and the impact of epilepsy surgery and antiepileptic drug therapy on musical capability are also discussed.

2 MUSICAL PROCESSING IN THE HUMAN BRAIN

Anatomical studies conducted during the late nineteenth century in patients with brain damage due to stroke, traumatic injury, or other pathology enabled researchers to discover areas pertinent to musical processing. Knoblauch defined the term "amusia" meaning impaired musical abilities. This was subdivided into sensory (receptive) amusia whereby the patient cannot hear, read, or understand music and motor (expressive) amusia whereby the patient cannot sing, write, or play music (Knoblauch, 1888). Cases of motor amusia without aphasia and musical agnosia were reported in patients with temporal lobe lesions with most lateralizing to the right hemisphere (Brodmann, 1914; Edgren, 1895; Luria et al., 1965; Ustvedt, 1937). Head (1926) emphasized connections between musical functioning and the thalamus where he described a patient experiencing intolerable sensory symptoms when hearing hymns in church. Monrad-Krohn (1947) described the link between music and prosodic quality of speech and variations in pitch, rhythm, and stress. These publications gave some information on aspects of musical processing but relating to damaged brains where the pathology itself may have affected the results and neural plasticity may have contributed to the findings.

Advances in functional imaging technology using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have facilitated more detailed anatomic representation of musical processing. These techniques observe changes in mean synaptic firing rates and blood flow to areas of the brain involved during musical testing. Similarly, electroencephalography (EEG) and magnetoencephalography (MEG) have allowed researchers to record postsynaptic potentials while listening to music.

Musical processing involves the brains ability to perceive, recognize, and react to a musical stimulus. Auditory perception occurs within the primary auditory cortex (Heschl's gyrus) receiving information from the medical geniculate nucleus via thalamic afferents. The primary auditory cortex appears to then connect to a network of areas including the auditory association cortex in the superior temporal gyrus, the mesolimbic areas, cerebellum, and other multisensory areas. An extensive review by Stewart et al. (2006) analyzed 38 case reports and 27 case series of patients with structural defects and the associated musical deficit. The review summarized areas important in pitch processing, temporal processing, musical memory, and emotional responses using colored dots representing 50% or more of studies implicating that particular area. The review showed that most functions had right-sided predominance involving areas beyond Heschl's gyrus. Problems with speech perception appeared to coexist in 50% of the included cases (Stewart et al., 2006; Fig. 1). The right hemispheric preferences for music processing has been attributed to differing specializations of left and right auditory cortices for processing of temporal and spectral aspects of acoustic stimuli. The left hemisphere has evolved having better temporal resolution (important in speech analysis) and the right hemisphere having better frequency resolution (important for pitch processing; Tervaniemi et al., 2000).

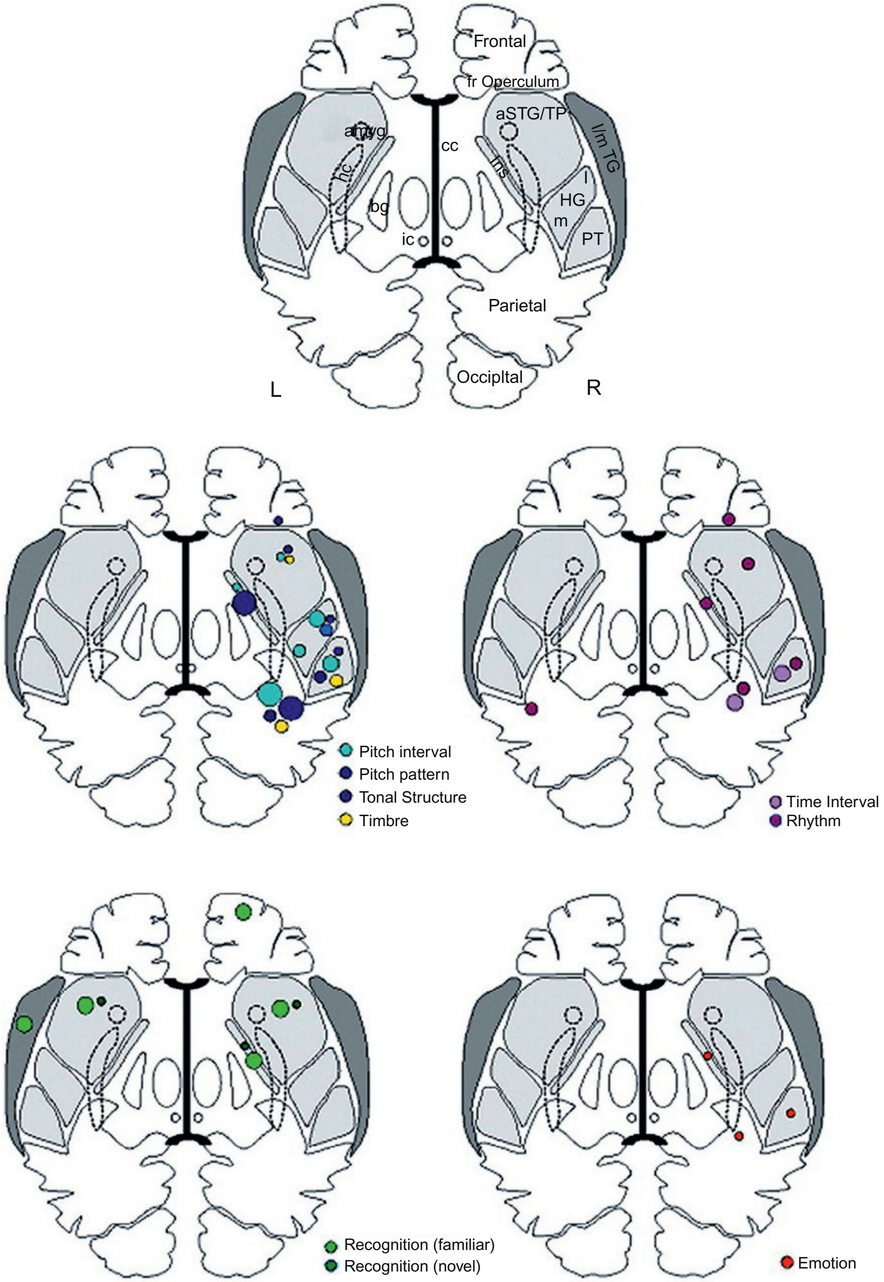

FIGURE 1

Site of brain lesions for musical listening disorders mapped for pitch processing, temporal processing, musical memory, and emotional responses to music. The colored circles represented at least 50% of studies implicate that particular region for the function. amyg, amygdala; aSTG, anterior superior temporal gyrus; bg, basal ganglia; cc, corpus callosum; fr, frontal; hc, hippocampal; HG, Heschl's gyrus; ic, inferior colliculi; i, inferior; ins, insula; l, lateral; m, medial; thal, thalamus; PT, planum temporale; TG, temporal gyrus.

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A more recent study focused on the neural correlates of music processing in neonates utilizing fMRI (Perani et al., 2010). This study ascertained that hemispheric functional asymmetry for music perception with right-sided dominance is present at birth. Gross anatomical asymmetries around the sylvian fissure have been demonstrated in fetuses from midgestation and in newborns (Chi et al., 1977).

Other studies have explored anatomical differences between the brains of musicians and nonmusicians. A key finding is a larger corpus callosum in musicians which may reflect greater cross-communication between left-sided analytical processing and right-sided spatioemotional processing (Schlaug et al., 1995).

2.1 MUSIC TRIGGERING SEIZURES

Musicogenic epilepsy is a form of reflex epilepsy where patients may experience focal onset seizures with or without altered awareness following exposure to music (Berg et al., 2010). It was first coined by Critchley (1937); however, descriptions of music-induced seizures have been reported in the literature as early as 1841 (Fujinawa et al., 1977).

It is thought to be rare with an estimated prevalence of 1:1,000,000, although given that music is not routinely used in testing seizure provocation this estimate may be inaccurate. It appears the stimulus need not be auditory in nature and that in some cases thinking or playing music and musical improvisation may trigger seizures (Le Chevalier et al., 1985; Ogunyemi and Breen, 1993; Sutherling et al., 1980). Similarly unlike many reflex forms of epilepsy, the seizure onset may be delayed, sometimes significantly by several minutes. Some patients have described a build up to a seizure with symptoms of agitation, tachycardia, and shortness of breath. Other patients however have little warning before the seizure takes hold (Poskanzer et al., 1962).

In terms of musical trigger, the reports are varied. Some patients only have seizure when listening to a certain piece of music, for example, the melody of Marseillaise (Vercelletto, 1953) or a specific Russian melody (Diekmann and Hoppner, 2014). Other patients report seizures according to music genre (Jazz, choral, electronic, classical), instrument (piano, flute, organ), or composer (Beethoven, Wagner, Beatles). Others report the quality of sound for example a husky or metallic sound due to incorrect positioning of the larynx to cause seizures (Brien and Murray, 1984).

Pittau et al. (2008) conducted a review of all cases of musicogenic epilepsy reported between 1884 and 2007. The review analyzed 110 cases, most of whom were female of high musicality with a mean age of onset of 28 years. The musical trigger varied considerably. Only a third of cases had seizures induced by music alone while the rest had additional spontaneous seizures. A quarter of cases presented with oroalimentary auras indicative of mesial temporal involvement. Sixty cases had available ictal EEG which ascertained predominant seizure activity within the right temporal lobe. Ictal SPECT in six cases again ascertained predominant involvement of the right mesial temporal structures.

There was one case utilizing fMRI during a seizure. This case report ascertained activity of acoustic areas when neutral music was played but also involvement of fronto-occipital areas when emotional melodies were played (Pittau et al., 2008).

Two other fMRI studies have demonstrated early activation of fronto-orbital areas prior to seizure activity (Diekmann and Hoppner, 2014; Mrocz et al., 2003). Both cases had a left temporal lobe focus for seizure activity.

Invasive monitoring of musicogenic seizures using subdural electrodes has been reported in three cases. These studies have ascertained activity within the right mesial temporal lobe extending to involve the lateral temporal, Heschl's gyrus, insula, and frontal lobe areas (Mehta et al., 2009; Tayah et al., 2006; Trevathan et al., 1999).

These clinical studies provide evidence of an emotive component to musicogenic seizures as shown by activation of mesial temporal structures. Some authors speculate given the relative latency period that seizures are triggered by the emotional response to music as opposed to the auditory content. Seizures stimulated by thinking of music which ultimately recruits musical memory and emotion seem to support this theory. It is possible that over time limbic connections are strengthened, thus promoting seizures on exposure (Gloor, 1990). This might explain why seizures predate the sensitivity to music in most cases.

However, what is more difficult to explain with current clinical studies is why relatively neutral music for example a specific sound might provoke seizures (Wieser et al., 1997). Similarly, musicogenic seizures have been reported in a child of 6 months, suggesting the likely epileptic nature of the seizures (Lin et al., 2003).

Musicogenic seizures can have disastrous consequences on a person's life. While a person may have identified a specific musical trigger, fear of having a seizure may ultimately lead to a complete aversion of all music. Musicophobia may subsequently lead to social isolation, depression, and impact negatively on quality of life. Antiepileptic medication is usually employed to control seizures. Over the years, a number of behavioral therapies and deconditioning techniques have be utilized in musicogenic epilepsy (Daly and Barry, 1957; Forster et al., 1965).

In summary, musicogenic seizures represent a rare reflex epilepsy. At the moment, the pathophysiology is poorly understood. What makes a facet or type of music epileptogenic is yet to be determined although it is possible that different types of music may stimulate different areas of the cortical network to varying degrees. This intriguing question is subject to ongoing research and may have clinical application in diagnostic workup for epilepsy.

2.2 MUSICAL HALLUCINATIONS AND OTHER SEIZURE PHENOMENA

Music can manifest as part of the clinical features of a seizure. This can take the form of musical hallucinations, musical craving (musicophilia), ictal singing, whistling, or humming as positive phenomena. Negative phenomena may take the form of aprosidy and amusia.

2.2.1 Musical Hallucinations

Musical hallucinations are more commonly associated with hearing loss (Berrios, 1990) but can also occur in the context of psychiatric disorders and rarely as part of temporal lobe epilepsy. In a large cohort study of 666 patients with temporal lobe epilepsy, around 16% had auditory hallucinations as part of the seizure semiology. These could be simple sounds, i.e., banging, ticking, or a specific melodic tune (Currie et al., 1971). There was a less obvious association with high musicality in these patients and the associated emotive responses varied including anger, panic, and fear. Auditory hallucinations (both musical and vocal) were associated with activation of the superior temporal gyrus with right-sided predominance.

One case report of a patient with a cerebral *de novo* arteriovenous malformation reported a vivid auditory hallucination of the Pink Floyd track "brick in the wall" prior to a tonic clonic seizure (Ozsarac et al., 2012).

Recent studies have observed neural correlates for musical hallucinations. One study in a musician with hearing loss and continuous musical hallucinations observed changes in neural activity using MEG as a function of intensity of musical hallucinations. An adapted residual inhibition paradigm was used whereby activity was observed during musical hallucinations and when an external masker stimulus was played (Bach). The study found that during musical hallucinations, four areas which lateralized to the left showed increased oscillatory activity. These were the anterior superior temporal gyrus, posterior–medial cortex, motor cortex, and orbitofrontal cortex and were less active during and following the masker stimulus. The results suggest that areas beyond the auditory cortex and important in musical imagery, memory for melody, and emotional valence of unpleasant music are recruited and sustain musical hallucinations (Griffiths, 2000; Kumar et al., 2014).

2.2.2 Musicophilia

Musical craving or musicophilia has been described in several conditions including stroke (Jacome, 1984) and frontotemporal dementia (Fletcher et al., 2013) and is a very rare but fascinating phenomena. In one particular case, a patient developed musicophilia following treatment of right temporal seizures with lamotrigine. Whereas before she had been relatively indifferent to music exposure, following treatment she developed an insatiable craving for music, listening hours at a time to classical radio stations and attending musical concerts. The patient described an intense emotional experience during musical exposure (Rohrer et al., 2006). It is proposed that longstanding seizures may have altered the emotional responses to music via reorganization of neocorticolimbic interactions. Treatment aimed at preventing seizures may have somehow restored flow in these remodeled pathways, thereby causing enhanced emotional responses. This hypothesis is similar to the "forced normalization" phenomena whereby patients may develop behavioral difficulties or psychiatric disturbance following normalization of the EEG. In this situation, it is thought that neurochemical and physiological changes involving limbic structures are responsible.

Other interesting cases of acquired musicophilia have included a person who developed musical inspiration following electrocution by lightning and another patient who developed the symptom following surgery for a right temporal oligodendroglioma (Sacks, 2008). The exact pathophysiological mechanism underpinning the musicophilia is unexplained in these cases.

2.2.3 Singing, Humming, and Whistling During a Seizure

The act of singing, humming, or whistling are complex tasks which require activation of multiple brain areas. In the case of singing, these include left superior temporal and parietal regions as well as both left and right premotor cortex, anterior superior temporal gyrus, and planum polare (Callan et al., 2006). Humming has been shown to recruit left lateral temporal and inferior frontal and parietal areas (Guedj et al., 2006). Similarly, whistling which involves coordinated articulation of lips, teeth, and tongue recruits complex neural networks involving inferior rolandic cortex, cingulate cortex, basal ganglia, amygdala, thalamus, and cerebellum (Dresel et al., 2005).

There have been nine cases of ictal singing reported in the literature (Enatsu et al., 2011). The location and laterality of seizure onset varied between cases. Some patients had frontal lobe onset seizures whereas other had temporal lobe onset. One study was able to distinguish onset according to whether the semiology were singing or humming, with humming recruiting temporal areas versus prefrontal areas for singing (Bartolomei et al., 2007). Singing may represent a form of automatism occurring as a release phenomenon or a learned motor pattern. Ictal singing may occur through activation of the network mimicking this musical action rather than a specific focus.

There have been six reported cases of ictal whistling (Burakgazi et al., 2014; Lazzarino and Valassi, 1982; Loring et al., 1994; Raghavendra et al., 2010; Tan et al., 1990). Lateralization has been inconsistent. Localization has been more consistent with five out of six reporting seizure onset within the temporal lobe. In two cases, this rare automatism was abolished with temporal lobe surgery.

2.2.4 Aprosidy and Amusia

Prosidy describes the emotional components of speech including melody, pitch, intonation, and gestures. These components may be affected during a seizure. Similarly, a loss of musical capability (amusia) can occur during a seizure. Both are considered to be negative phenomena. One study assessed aprosidy as part of a seizure in 967 focal epilepsy patients. Twenty-six patients were found to have ictal aprosidy, with most exhibiting qualitative changes in pitch and loss of melody. In 22 patients, the seizure localized to the right temporal lobe (Peters et al., 2011). Negative ictal phenomena (blindness, paralysis, and speech arrest) are poorly understood but may reflect activation of inhibitory cortical areas, loss of activity in sensory cortices, or inhibition of spinal motor neurones.

2.3 COULD MUSIC BE USED AS THERAPY FOR EPILEPSY?

The therapeutic potential of music has been largely investigated in the area of cognitive neuroscience. The K448 sonata piano duet by Mozart was reported to improve spatial temporal working memory in the short term in both humans and animal models (Aoun et al., 2005; Rauscher et al., 1993, 1998). The evidence of cognitive enhancement with Mozart K448 sonata has been met with skepticism by neuroscientists who highlight concerns over inadequate matched control groups and the difficulty in controlling for emotive responses in all groups to the musical stimulus.

The evidence of an antiepileptic effect with K448 Mozart sonata in humans with epilepsy is limited as is our understanding of how this might work. Three studies, two small short-term before and after studies and one larger randomized controlled trial (RCT), report on clinical outcomes following music therapy in epileptic patients.

The first before and after study included 58 Taiwanese children with partial epilepsy. Continuous EEG monitoring occurred before, during, and after 8 min of exposure to the Sonata. In 81% of patients, there was a reduction in interictal discharges by an average of 33%, with the greatest reduction in those patients with generalized discharges. However, around 20% showed an increase in interictal discharges by an average of 14%. No significant differences were found according to gender, IQ, or number of antiepileptic drugs and response to music. The reduction in interictal discharges was not dependent on the level of alertness or specific emotional response (Lin et al., 2010).

The second before and after study included 11 Taiwanese children aged 2–14 years old with refractory epilepsy. Two thirds had generalized seizures of symptomatic causes, and the majority (70%) had learning difficulties. Seizure frequency was observed for 6 months before music and during 6 months of Mozart K448 exposure. The study found that 73% of patients had a 50% or greater reduction in their seizure frequency, with two patients becoming seizure free during exposure to music. There were no significant differences in response status according to seizure type, IQ, etiology, or gender (Lin et al., 2011).

The third RCT study explored the effect of passive exposure to K448 Mozart sonata by randomizing 73 adults and children with neurological impairment and refractory epilepsy to overnight Mozart K448 versus no exposure during a 1-year treatment period. Patients exposed to Mozart resulted in 80% of patients having a reduction in seizure frequency with 25% seizure free. This compared to just 36% of patients having a reduction in seizures in the unexposed control group. Patients with generalized onset epilepsies appeared to respond better to treatment (Bodner et al., 2012).

Other reports have also shown that exposure to Mozart K448 reduces ictal spiking in patients with rolandic types of seizures (Turner, 2004) and also in subjects in coma and refractory nonconvulsive status (Hughes et al., 1998; Kuester et al., 2010; Lahiri and Duncan, 2007) where authors surmise that the effect is mediated via direct cortical stimulation as opposed to a response which relies on emotion or level of awareness. A recent meta-analysis of 12 studies observing the effect of Mozart's work on interictal epileptic discharges reported an overall reduction of interictal epileptic discharges in 84% of patients listening to Mozart's music. In approximately one quarter, there appeared to be a sustained carry over response. Patients with generalized discharges as part of idiopathic epilepsy and higher intelligence quotient seemed to have a greater reduction in interictal epileptic discharges to Mozart music (Dastgheib et al., 2014).

The mechanisms by which Mozart K448 music may act as an anticonvulsant are unknown. However, the effect does not appear exclusive to that particular sonata. A recent study has observed similar reductions in epileptiform discharges in children with epilepsy during exposure to Mozart K545 (Lin et al., 2012).

Neuroscientists speculate that the unique rhythmic structure and long-term coherence may explain the basis by which K448 sonata activates a wide neuronal network evoking rhythms which may possess anticonvulsant properties. Computational studies have shown that seizure-prone neural networks may be stimulated by certain periodicities while other frequencies may prevent seizure activity (Anderson et al., 2009). The K448 sonata appears to enhance spatial temporal working memory, and it is possible that the dorsofrontal activation important in working memory may exert an anticonvulsant effect on connected networks.

Mirror neuron activity is another intriguing theory by which music may behave as an anticonvulsant (Molnar-Szakacs and Overy, 2006). Listening to music may not only stimulate auditory areas but may activate mirror neurones required to produce that music, thereby providing a direct connection between auditory and motor cortices. Motor system modulation in transcranial magnetic stimulation and in behavioral studies has been observed to change during auditory stimulation (Buccino et al., 2005).

Dopamine transmission appears to have an important role in the pathophysiology of epilepsy. In autosomal dominant frontal lobe epilepsy and juvenile myoclonic epilepsy, reduced binding capacity of dopamine receptors in the basal ganglia has been hypothesized to contribute to seizures (Fedi et al., 2008; Landvogt et al., 2010). Reduced D2/D3 receptor binding in seven patients with mesial temporal lobe epilepsy was identified using FDG-PET techniques (Werhahn et al., 2006). In a study in animals, pilocarpine-induced seizures altered the binding capacity of dopaminergic receptors in striatal and hippocampal areas, and facilitated the propagation and maintenance of seizures (Mendes de Freitas et al., 2005). A musical stimulus may thus modify dopaminergic pathways within subcortical structures to influence thalamocortical projections. This may occur through dopamine flooding leading to an upregulation in D2 receptors and thereby potentially behaving in an anticonvulsant way.

In summary, the evidence of an anticonvulsant effect of music therapy is limited. Published studies focus on Mozart but without any clear understanding of the basic science underpinning the effect. More research is required into this interesting area of neuroscience to delineate which aspects of a musical stimulus are important for the anticonvulsant effect.

2.4 CURSE OR CURE: EXPLAINING THE DICHOTOMOUS EFFECT OF MUSIC ON EPILEPSY

The most intriguing aspect of music is its apparent dichotomous effect on seizures. Until we are able to fully understand the pathophysiology of this effect, the utility of music as therapy may be potentially limited. Returning to dopamine circuitry and receptors, previous studies have shown that stimulation of D2 receptors located in the forebrain appears anticonvulsant, whereas selective D1 receptor activation appears to lower the seizure threshold both clinically and in animal models (Al-Tajir and Starr, 1990; Starr, 1996). A reduction in D2 receptor binding within striatum may affect its inhibitory action on thalamocortical connections, thus promoting excitation (Deransart et al., 2000). Conversely, D2 receptor stimulation may be neuroprotective in conditions where the underpinning neuropathological process involves glutamate-induced neurodegeneration (Bozzi et al., 2000). Music exposure may result in dopamine flooding and an upregulation and activation of D2 receptors behaving as an anticonvulsant. By contrast, music may behave in a proconvulsant way as in musicogenic epilepsy through increased release of dopamine in the prefrontal cortex as a result of an emotional response, thereby suppressing limbic dopamine responses and leading to propagation of seizures (Kaneyuki et al., 1991). Similar modified dopamine pathway activity has been implicated in anxiety (Bishop, 2007).

Another interesting area of research analyzed the impact of cognitive tasks involving motor actions versus tasks of spatial construction and thinking on ictogenesis. This is relevant to music and epilepsy given the involvement of multiple cortices in musical processing. Patients EEGs were recorded during the tasks. Action tasks were particularly seizure promoting whereas spatial thinking tasks (calculations) were most inhibitory. The authors concluded that tasks involving motor pathways were more epileptogenic. Tasks that recruited parietal cortices (spatial tasks) produced an antiepileptic effect possibly via inhibition of neighboring motor cortices. Music may thus have the ability to exert an anticonvulsant effect via stimulation of cortices involved in spatial cognitive processing and a proconvulsant effect through enhanced stimulation of prefrontal cortices in anticipation of the musical stimulus (Guaranha et al., 2009).

Understanding the basic science behind the complex interaction between music and epilepsy is ongoing and will have a twofold effect. It will enable researchers to develop a new nondrug therapeutic strategy for patients with medically refractory epilepsy. The second potential use could be in devising a music paradigm by which to screen for musicogenic epilepsy during EEG monitoring, something which at the moment is not routinely performed. These two potential uses could impact on the patient's chances of achieving seizure control, thereby improving care for patients with epilepsy.

2.5 THE IMPACT OF TREATMENTS FOR EPILEPSY ON MUSICALITY

The mainstay treatment of epilepsy is antiepileptic drug therapy which can render around 70% of patients free of seizures. Patients with a brain lesion causing their epilepsy may be offered the option of epilepsy surgery. This may be either due to uncontrolled seizures or in the case of a brain tumor where there has been a transformation from a low-grade to high-grade tumor. In patients who have a temporal lobe lesion, surgery could potentially impact on that person's musical capabilities. Understanding the likely impact of surgery is therefore paramount in presurgical evaluation and the consent process.

2.5.1 Antiepileptic Drugs

There have been 27 cases reported in the literature of altered pitch perception with carbamazepine (Tateno et al., 2006) and one case with oxcarbazepine (Gur-Ozmen et al., 2013). Twenty-five of the reported cases were Japanese aged between 4 and 42 years old and most were female with high musicality. Twenty-one of 27 were prescribed carbamazepine for epilepsy. Most patients reported a lowered pitch but two cases experienced a higher pitch perception which occurred 2 days to 2 weeks into therapy. The altered pitch perception appeared to resolve following a reduction in dose or full discontinuation of treatment. The mechanism of this effect is not clear. Authors speculate a local effect on the auditory system. Reversible hearing loss and tinnitus have been reported in overdose of carbamazepine (de la Cruz and Bance, 2011); the brainstem auditory-evoked response of a patient who experienced auditory disturbance with carbamazepine was normal suggesting that the central auditory pathway was not affected. Authors posit that carbamazepine may change the mechanics of the organ of Corti (Chaloupka et al., 1994) or affect the sarcolemma of the stapedius muscle altering the tension on the tympanic membrane receiving sound.

Both carbamazepine and oxcarbazepine block voltage-dependent sodium channels which may be relevant to the pathophysiology. However in one report, a switch to another sodium channel-blocking drug lacosamide did not result in altered pitch perception (Gur-Ozmen et al., 2013). Similarly, lamotrigine, another sodium channel-blocking drug, was examined in pediatric epilepsy patients and did not exert any adverse effect on acoustic function (Yun et al., 2011). There have not been any reports of studies on other antiepileptic drugs and effect on musicality.

2.5.2 Temporal Lobe Surgery

Temporal lobe surgery for medically refractory epilepsy and the effects on a person's musicality is an important and often overlooked issue with potentially devastating consequences. An overview of available published studies examining the effect of temporal lobe surgery on musical emotion, recognition, and perception was reported in the comprehensive review by Maguire (2012). The reports involved small numbers of surgical patients, and the methods used for assessing musical processing varied considerably. In reports observing the effect on emotion, some reports observed a reduced ability to identify scary music following anteriomedial temporal resection (Gosselin et al., 2011; Khalfa et al., 2008), while another study observed no significant impact (Dellacherie et al., 2011). This inconsistency may relate to the extent of surgical resection and the different methodologies employed by the studies. Reports observing effects of surgery on recognition were broadly consistent demonstrating impaired recognition of previously presented tunes following surgery but with right-sided predominance (Samson and Zatorre, 1991, 1992; Shankweiler, 1966). The study findings imply that recognition appears bitemporally represented.

Reports observing impact on musical perception for pitch, timbre, tone, rhythm, and time interval all concluded a risk with right temporal lobectomy including Heschl's gyrus (Johnsrude et al., 2000; Kester et al., 1991; Liegeois-Chauvel et al., 1998; Milner, 1962; Samson and Zatorre, 1988, 1994; Warrier and Zatorre, 2004; Zatorre, 1985, 1988; Zatorre and Halpern, 1993; Zatorre and Samson, 1991).

Effects on musicality following temporal lobe surgery have been specifically observed in professional musicians where self-awareness of musical ability is likely to be more sensitive. In a case series of three musicians who underwent temporal lobe surgery (two right-sided, one left-sided), a questionnaire was given before and after surgery. The questionnaire was designed to obtain the patients subjective assessment of special musical skills like melody processing, musical memory, rhythm, meter, harmony/dissonance, timbre, concentration and endurance, emotionality, and absolute pitch. In addition, more objective neuropsychological battery tests were also performed before and after surgery. In this small case series, all patients achieved seizure freedom following surgery having experienced intractable temporal seizures for at least 10 years. None of the musicians saw a deterioration in musical ability and two patients had noticed an improvement or no change to their musical ability with excellent professional recovery. Improvement in musical functional may be attributed to an absence of seizures, a reduction in antiepileptic medication, and other psychological factors (Schulz et al., 2005).

A more recent case report detailed a professional jazz guitarist who had undergone left temporal lobe surgery (70% resection) for an arteriovenous cerebral malformation. The patient suffered severe retrograde amnesia and complete loss of musical interest and ability. Over the ensuing 27 years, he gained back his virtuoso status. MRI showed extensive loss of left temporal lobe tissue with preservation of the left hippocampus. Neuropsychological testing showed only mild cognitive impairment of certain aspects of language. While there was no available preoperative cognitive assessment or functional MRI, the case highlighted considerable human brain plasticity which can occur over time (Galarza et al., 2014).

There does appear to be a strong relationship between music and plastic potential. For example, string players appear to have increased cortical representation of the digits suggesting that representation may conform to current utility and experience of individuals (Elbert et al., 1995). In the reported case of the Jazz musician, it was hypothesized that the frequent practice of improvisation which utilizes the prefrontal areas leading to widespread activation of neocortical sensorimotor areas may have acted as cognitive rehabilitation in facilitating reorganization of the functional network (Duffau, 2014).

In summary, temporal lobe surgery may impact on a patients musical abilities particularly patients undergoing right temporal resections. In professional musicians, there may be a greater capacity for modification of brain structures and functional plasticity in processes critical to musical capability. These findings have implications on the presurgical work-up of patients embarking on temporal lobe surgery, intraoperative assessment of musical skills, and postoperative cognitive rehabilitation.

2.6 ASSESSMENT OF MUSICAL FUNCTIONING THROUGHOUT THE SURGICAL PATHWAY

Studies to date highlight a potential risk to musical processing with temporal lobe surgery particularly on the right. This risk should be discussed as part of presurgical assessment with consideration of preoperative neuropsychological testing. Presurgical assessment involves the patient undergoing baseline cognitive assessments for memory and speech domains. In some centers, the utility of WADA or intracarotid propofol procedure (IPP) is employed to investigate laterality of language and memory. Functional MRI may be employed looking at brain lateralization and to assess the position of a brain lesion to eloquent cortical areas using established paradigms. Assessment utilizing the above techniques however is not routinely performed to observe musical functioning.

2.6.1 Neuropsychological Tests

Many assessment tools evaluating musical processing have been devised over the years with individual centers utilizing their own versions (Schulz et al., 2005). Two internationally recognized tools are *The Seashore Measures of Musical Talent* and *The Montreal Battery for the Evaluation of Amusia*. The Seashore tool which tests six measures: pitch, loudness, rhythm, time, timbre, and tonal memory was devised to assess musical ability in preschool children and is largely based on auditory perception rather than musical perception (Seashore et al., 1960). There have been numerous criticisms of the tool because of its lack of musical orientation and localizing value. There is also uncertainty around validity since professional musicians scored better on only three out of the six measures compared to population scores (Henson and Wyke, 1984).

The Montreal tool utilizes musical excerpts in assessing melodic and temporal processing and memory (Peretz et al., 2003). The tool assesses contour, interval, scale, meter, and memory using 30 musical phrases with high sensitivity on retesting at 4 months. The test can pinpoint specific deficiencies in components and appears easy to access and use in the presurgical setting, although further work and evaluation are required in this area.

2.6.2 WADA and IPP

There has been one study using IPP in assessing musical processing preoperatively in a right-handed professional musician with left temporal lobe epilepsy. The authors devised a series of musical tasks named "Sevilla Battery for Evaluation of Musical lateralization." This battery assessed the contributions of each brain hemisphere to music perception, recognition, learning, and cognitive processing. These tasks were used during IPP in the same order after left and right injection. There were two experimental conditions. The encoding condition during which tasks were performed under IPP explored musical semantic knowledge via melody recognition, score reading, and tempo discrimination. The retrieval condition assessed free recall and recognition of musical stimulus presented during the encoding condition, 25 min after the injection. The study ascertained that the patient's right hemisphere was involved in semantic and episodic musical memory whereas score reading and tempo processing required contributions from both hemispheres. This case report study again highlights that epilepsy and musical expertise may critically modify brain structures resulting in functional plasticity (Trujillo-Pozo et al., 2013).

2.6.3 Functional MRI

fMRI is increasingly being used to lateralize speech and memory function in presurgical patients. While there are a considerable number of fMRI studies examining musical processing and anatomic components, there are no studies to date reporting on the utility of a musical fMRI paradigm in presurgical evaluation of epilepsy patients.

2.6.4 Intraoperative Mapping of Musical Processing

There has been one study mapping intraoperative music processing using a limited three-task assessment of a right-handed amateur musician with right mesial temporal sclerosis. One task involved melody recognition, the second task involved singing a song correctly, and the third task involved identifying familiar melodies. An additional nonlinguistic acoustic test involved identifying an environmental sound (doorbell, etc.). During stimulation of the inferior-, mid-, and superior temporal gyrus, there was only one error made during melody discrimination but otherwise the tests were performed correctly. Following anterior temporal lobectomy, there were no deficits ascertained on follow-up testing at 2 months (Perrine et al., 2000).

In summary, further research is required into the neuropsychological consequences of temporal lobe surgery on musical processing. Similarly, further work is required in devising practical assessment tools which could be utilized at all stages of the surgical pathway. Neural plasticity particularly in the context of musical training may have an impact on the generalizability of cognitive associations.

3 CONCLUSIONS

Music and its association with epilepsy is intriguing and complex requiring further exploration. The dichotomous pro- and anticonvulsant effect of music remains poorly understood although dopaminergic system modulation may represent a possible mechanism. Current literature suggests the therapeutic potential of music remains uncertain. Similarly, our understanding of what makes a particular piece or facet of music pro- or anticonvulsant is currently lacking. This is crucial not only in further research of the therapeutic potential of music but also in devising a musical stimulus paradigm during EEG monitoring. Health-care professionals prescribing AEDs need to be aware of the risks of altered pitch perception with carbamazepine and oxcarbazepine and be alert to any alterations with other sodium channel-blocking AEDs. Epilepsy surgery may affect a person's musicality particularly if the resection involves the right temporal lobe. Providing accurate risk estimates however is difficult with the current literature and may vary according to the size of the resection. There is a real need for development of comprehensive preoperative and intraoperative assessment tools for examining musical processing which may better inform clinicians and patients of the risks and benefits of epilepsy surgery.

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CHAPTER

Treatment and prevention of music performance anxiety

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Abstract

Music performance anxiety (MPA) regularly occurs when musicians present themselves before an audience in performance situations, and thus, it plays an important role in the careers of professional musicians. MPA is expressed on the emotional and physical level, as well as on the levels of thinking and behavior, and extends along a continuum of varying severity. Its performance-impairing, afflicting form is considered to be a specific type of social phobia, which requires therapy. There are different psychological theories, which contribute to the understanding of the phenomenon of MPA and provide basic principles for the various treatment approaches. Current "best practice," in our clinical experience, is a personal- and problem-oriented approach within a multimodal therapy model, including the range of psychoanalytic and cognitive behavioral therapies, body-oriented methods, and mental techniques.

In order to avoid severe MPA, prevention in the field of music pedagogic is very important. Thus, the concepts of dealing positively with MPA should be implemented very early into the instrumental and vocal education of musicians.

Keywords

musicians' medicine, music performance anxiety, stage fright, treatment, multimodal treatment model, prevention

1 DEFINITION

Music performance anxiety (MPA) describes a particular state of arousal, which regularly occurs when musicians present themselves before an audience in performance situations. MPA is, thus, part of the exercise of music performance and of the career reality for professional musicians and as such an important topic in the field of Psychology and Psychosomatic Medicine in Performing Arts Medicine.

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It is known from many biographies of musicians that MPA may occur with completely different characteristics (Spahn, 2012). MPA extends along a continuum of varying severity, in which the performance may be better, worse, or even be impossible, and the person may suffer in various ways. If it is a strong, performance-impairing, afflicting form of MPA, then it is considered to be pathological and requiring therapy. When MPA is diagnosed, it is classified as belonging to the group of social phobias, according to the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2000).

2 PHENOMENOLOGY

MPA is expressed on the emotional and physical level as well as on the levels of thinking and behavior. It is characterized by typical physical symptoms such as rapid heartbeat, increased blood pressure, rapid and shallow breathing, and dry mouth, among other things. Symptoms may consist of constriction of thought—heightened alertness and concentration to fears of failure—intensified feelings between fear and exhilaration, as well as special behavior like ritualized repetitions, escapist tendencies, and general unrest.

The physical parameters of MPA have been investigated in several studies (e.g., Endo et al., 2014; Studer et al., 2014). In an investigation of our group during stage performances of solo vocalists and wind instrument players, heart rate and blood pressure reached values that were significantly above the normal physiological range (Spahn et al., 2010). The emotional component of MPA was not increased in the same direction, i.e., performers with highly elevated levels of blood pressure and heart rate reported low anxiety, whereas performers with normal physical parameters experienced intense anxiety (Spahn et al., 2010). This independence of the various levels of MPA symptoms has also been shown in other studies (e.g., Steptoe, 2005). Pathological mental symptoms such as impaired regulation of self-esteem, depressive symptoms, panic, as well as helplessness and loss of control are observed in cases of severe MPA.

3 THEORETICAL CONCEPTS

Different psychological theories contribute to understanding the phenomenon of MPA.

From the perspective of *psychoanalytic theory*, the symptoms of MPA arise from the background of the individual personal history and are an expression of internal conflicts and motifs and their related defense mechanisms (Spahn, 2012). Insights from attachment theory also play an important role in connection with these concepts (Vasey and Dadds, 2001). Thus, the development of a secure attachment in childhood has a significant importance for future mental health and, therefore, also for the development of MPA (Kenny, 2011, p. 113).

Behavioral theories of anxiety provide an important contribution for understanding MPA, particularly through the findings illuminating the development of maladaptive behaviors and cognitions. The strength of these behavioral theories lies in the general laws of learning theories—of classical and operant conditioning—while the individual quality of MPA can be differentiated by psychoanalytical theories. The question as to why persons under comparable learning conditions develop different forms of MPA may also be explained by a genetic contribution (Kenny, 2011, p. 120).

Cognitive theories focus on the importance of cognitions on behavior and physical symptoms. Here, Beck and Clark (1988) identified two cognitive distortions, which are central in particular to MPA and have led to significant therapeutic approaches: attention binding and catastrophizing. They are illustrative of the emergence of dysfunctional cognitions, restricted here to risk and failure. Osborne and Kenny (2008) investigated the value of cognitions, trait anxiety, and gender as predictors for MPA in 298 music students. The results showed that MPA was best predicted by trait anxiety and gender, but negative cognitions in the worst experience account of the students improved the prediction of MPA over trait anxiety and gender alone (Kenny, 2011, p. 127).

Kenny's *emotion-based model of MPA* presents a current concept, which takes up Barlow's previous work on a triple vulnerability model (Barlow, 2000; Kenny, 2011, pp. 157–165).

Physiological stress models can explain best the physical symptoms of MPA. Thus, the processes of control in MPA run in kind of an evolutionary ancient program developed for situations of particular threat. These physical reactions are mediated by activation of the sympathetic part of the autonomic nervous system utilizing the effector hormones adrenaline and noradrenaline. There is a series of physiological reactions, which enables a state of increased performance for fight (fight) or escape (flight) within a very short time as a response to the emotional signal of fear (fright). This is referred to as the three Fs. The fear of a threat to life in former times is replaced in civilized countries today by the fear of negative social consequences, such as exposure, failure, and losing face, among other things.

4 EPIDEMIOLOGY

According to the definition above, it is a natural reaction in performance situations in the nonpathological form of MPA, in which all performing artists are confronted with the phenomenon. In a survey of 2536 orchestra musicians in Germany, about 90% indicated that they suffer from MPA (Gembris and Heye, 2012). More interesting is the question of how frequently MPA in various forms occurs, especially as severe MPA. It is not surprising that severe MPA in orchestral musicians, for example, fluctuates between 15% and 25%, given the methodological difficulties in achieving sufficiently large sample sizes and in obtaining accurate diagnoses (Fishbein et al., 1988; James, 1997; van Kemenade et al., 1995). Approximately one-third of the performers with severe MPA have other comorbid disorders such as a generalized anxiety disorder or social anxiety (Sanderson et al., 1990).

Interactions of anxiety disorders with neurological diseases also arise among musicians. Enders et al. (2011) studied patients with musician's dystonia (MD) with regard to psychological abnormalities, including anxiety. However, it was not based on a diagnostic examination, but rather the patients were examined by the questionnaires STAI (Spielberger et al., 1958) and NEO-FFI (Borkenau and Ostendorf, 2008). It was found that the musicians with MD had higher levels of anxiety as a symptom and personality factor than the comparison groups of healthy musicians and nonmusicians. The authors report this as being consistent with the hypothesis that anxiety and MD share a common pathophysiological mechanism (Enders et al., 2011). From the perspective of clinical consultation with musicians, it is observed that coordination of movements under performance conditions decreases with increasingly pronounced MPA.

5 TREATMENT

5.1 PSYCHOANALYTIC/PSYCHODYNAMIC THERAPY

The important contribution of the psychodynamic approach in the treatment of MPA is to make both the conscious and unconscious meaning and origin of the symptoms accessible to the artist. Psychoanalytic theory assumes that resistance and defense mechanisms prevent unconscious, unpleasant thoughts and feelings from becoming conscious. Determinant is whether the respective defense mechanisms have a functional or dysfunctional character for the psychological stability and the developmental potential of a person. These manifest themselves in recurring schemes and patterns, mainly in the parents–child relationship, which date back to early-life experiences. Psychoanalytic treatment is focused on finding an emotional access to these patterns to reduce anxiety symptoms through their conscious management and thereby enhancing the freedom of action and experience.

Weisblatt (1986) identifies four recurring themes in the context of the parent–child relationship, which play a role in MPA: fear of failure with high expectations by parents; compensatory idealization of the instrumental teacher due to the lack of recognition by the parents and exaggerated fear to disappoint him; "fear of success" with unconscious competition with a parent and the fear to be better than him; and fear of losing the affection of parents, as soon as independence and autonomy arise as an artist.

Several authors point out that the performance situation, also with respect to psychological processes, represents a platform for the activation and staging of unconscious conflicts from the life story of the performers and that, therefore, considerations of unfavorable defense mechanisms should be an important part of the treatment (Nagel, 2004; Spahn, 2012). Physical complaints among musicians arise quite often by somatization of psychological issues, for example (Spahn et al., 2001).

5.2 COGNITIVE BEHAVIORAL THERAPY

Cognitive behavioral therapy (CBT) has emerged from the originally separate forms of therapy: behavior therapy and cognitive therapy. Basically, maladaptive behaviors and thinking patterns are the focus of CBT. These should be positively changed through education and information from the patient in planned learning steps. Since CBT assumes that emotions and behavior are influenced by beliefs or ideas about oneself and others, the therapeutic approach is designed to change thinking patterns through cognitive restructuring such that cognitions effect a positive impact on symptoms and behavior. The cognitive approach in the treatment of MPA is applied mainly in the forms of cognitive restructuring and in shifting the attentional focus. According to Newman and Beck (2009), there are a series of dysfunctional cognitive processes, some of which typically occur in MPA. Many artists have the inclination to overemphasize individual negative aspects of performance (selective abstraction) or generally give negative experiences greater importance (magnification and minimization). Other dysfunctional cognitions are overgeneralization with the loss of differentiated perception or "all or none" thinking. Even perfectionism is a strategy, which contributes greatly to increasing MPA (Kenny et al., 2004). More common examples are the preliminary assumption of poor performance and the imagining of mistakes—so-called catastrophizing. Performers who prioritize a high level of catastrophic thinking showed more MPA than those who had a realistic assessment of the performance (Osborne and Franklin, 2002). The ability to adopt a meta-level awareness (metacognition) and to work methodically utilizing a full repertoire of different measures (coping) is a positive resource with MPA.

The direction of attention at the performance also plays an important role and is trained in CBT using concentration techniques. MPA is lowest during a performance when the performer's concentration is directed neither on themselves (self-focus) nor on the audience (audience focus), but on the music itself (task-focus) (Wolverton and Salmon, 1991).

Behavior is explained by learning and conditioning in CBT. An important treatment approach to MPA is, therefore, the controlled exposure in selected performance situations. According to the principle of systematic desensitization, the performance conditions are gradually made more difficult with the aim to achieve and maintain a positive performance experience. Hereby, positive learning takes place and negative performance experiences are gradually erased. The variation of the performance conditions offers many starting points and can be related to the audience, the difficulty of the piece of music, the external environment (room conditions, peer pressure, etc.), and on the previous experience of the musician. Stress management techniques such as relaxation training, breathing exercises, mental techniques, and management of instrument-specific problems are taught and practiced in CBT for coping with MPA (Sadock et al., 2009).

The therapeutic approach in CBT is based on a range of measures and tasks that the patient learns in therapy and applies between sessions. The planning to the specified requirements by upcoming concerts, exams, or auditions, which the musician must fulfill, is also important in the treatment of MPA.

5.3 MULTIMODAL THERAPY

The term multimodal therapy applies to approaches, which utilize several treatment methods (multimodal treatment model of MPA; Spahn, 2011) or use results from different disciplines such as neuroscience, developmental psychology, and psychotherapy (BASE; Linford and Arden, 2009) or the broad range of affected domains in performance anxiety (BASIC ID; Lazarus and Abramovitz, 2004).

The multimodal treatment model of MPA (Spahn, 2011; Fig. 1) follows a personal and problem-oriented approach, in which the application of various psychotherapeutic methods, based on the individual needs of each patient, is carried out. It combines the psychodynamic understanding of the person with respect to their individual history with elements of CBT and exercises related to body-oriented methods and mental techniques. Practical work with instrument and voice in terms of technical and ensemble playing related questions also occupies an important place. At the beginning of the treatment is a detailed, deep psychological first interview, which is particularly focused on past performance experience, the development of stage fright during this time, and on issues of identity and self-worth. The therapist makes a picture, as to which of the unconscious conflicts in the performance situation could be effective, based on the scenic and verbal information from the patient. These psychodynamic hypotheses form the background for the further work on the topic of performance anxiety and flow into the design of a treatment planning (Spahn, 2011).

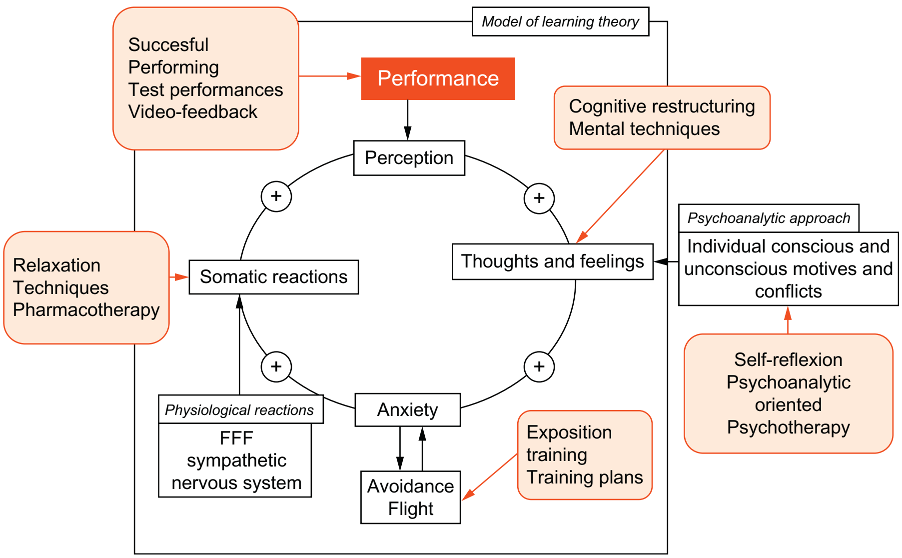

FIGURE 1

Basic elements of the multimodal treatment model of MPA (Spahn, 2011).

The problem analysis gathers and arranges the previous performance experiences and places them in relation to the current problems and needs, for which the patient has sought treatment. In particular, possible conditions perpetuating performance anxiety as well as resources for positive performance experiences are identified. Progressive goals, a practice plan for musical preparation, and therapy plan can be created and discussed with the patient based on the problem analysis. The musical arrangement also forms part of the therapy, such that musical solutions can positively influence the musical performance anxiety.

Respiratory-oriented exercises, concentration techniques, and physical exercise for obtaining a basal physical fitness form an essential basis in the performance situation and are used continuously during treatment. Exercises on stage with feedback with respect to stage presence give the patient security for the concert.

Relaxation techniques, such as autogenic training and progressive muscle relaxation, offer the possibility to regulate the autonomic tension in the weeks and days up until shortly before the performance. It is important to inform the patient about the different variations of autogenic training—duration, depth of concentrative meditation, exercise selection, etc.—and encourage him to do the exercises according to the initial situation and the targeted format.

The mental performance training follows the principles of systematic desensitization in CBT and can be performed independently by the patient. The aim here is to create the mental learning experience. It can be positive managed with support of a relaxation exercise for the performance situation, which otherwise causes aversive emotional and physical reactions. Performance routines *in vivo* with increasing levels of difficulty follow the mental training. The perception of the patient is trained from the outside and possible dysfunctional cognitions are corrected and positively changed through the use of video feedback and psychotherapeutic conversation. Biofeedback during the performance, using the parameters blood pressure, pulse rate, and respiratory rate, also allows the patient's sense of control and security over the physical symptoms of MPA.

All rehearsal measures serve the purpose of enabling the patient to experience positive performances. Specific techniques, which will be used during the performance, focus on the full concentration on the playing or singing itself. In terms of cognitive restructuring, the patient is instructed to perceive the positive aspects of the performance.

BASE (Brain, Attunement, Systems, Evidence) is an approach that seeks to transfer results from brain research directly into psychotherapeutic application. The authors deduce evidence for this from imaging studies, which show changes in certain brain structures following psychotherapy. This points out the importance of emotional processes and systemic approaches in psychotherapy (Linford and Arden, 2009). The acronym BASIC ID stands for behavior, affect, sensation, imagery, cognition, interpersonal relationships, and biological factors related to the presentation, which are addressed in this therapeutic approach (Lazarus and Abramovitz, 2004).

5.4 OTHER TREATMENT APPROACHES

In recent years, several other approaches from the field of meditation, in addition to established psychotherapy methods, have been examined—such as yoga (Khalsa et al., 2013) or interventions using guided imagery music (Martin, 2007). The results provide evidence for a reduction of MPA, but overall they are not so impressive that approaches should be derived from this therapy alone (Kenny, 2011, p. 195).

Interesting therapies come from performance research. In sports psychology, the model of "individual zones of optimal functioning" was developed (Harmison, 2006). To achieve a high performance output, an individual profile is created, as performance anxiety at high output is pronounced and accessed in accordance with the competitive situation. In sports, the relationship between goal setting and performance output has also been investigated. The best performance output was achieved when the goal was specific, challenging, realistic, acceptable, and measurable (Mahoney, 1992).

5.5 PHARMACOTHERAPY

Beta-blockers are most frequently used in the drug treatment of MPA, although overall the therapeutic use of drugs is seen as somewhat more conservative in recent years.

In the early 1980s, some authors proposed beta-blockers as the pharmacological solution to the treatment of MPA (Brantigan et al., 1982; James and Savage, 1984; Neftel et al., 1982). Already in 1990 Brandfonbrener stated in a review article that musicians seeking advice have a right to have the doctor intervene not only just to grab the prescription pad and prescribe beta-blockers but also knows the entire range of possible forms of treatment and is familiar with their application (Brandfonbrener, 1990). Lederman concluded that the use of beta-blockers should be considered as a possibility in extreme cases of MPA (Lederman, 1999). Until now there is an ongoing debate about the advantages and disadvantages of beta-blockers for musicians. Kenny points out that the performer with MPA will not benefit from treatment with beta-blockers because of the character dysfunction or primarily dysfunctional cognitions (Kenny, 2011, p. 221).

In our own clinical practice, the prescription of beta-blockers has occurred only in isolated cases and is only considered useful as a temporary measure in the treatment of MPA. The long-term regular use of beta-blockers creates the risk of unilateral fixation on the drug, since it is supposedly the most convenient way for patients and this leads to active measures being neglected. For these reasons, Birk from Harvard Medical School designated that drugs in the treatment of MPA are only occasionally useful, and in most cases are contraindicated (Birk, 2004). A number of studies show that there are effective and successful ways to treat MPA without beta-blockers (Clark and Agras, 1991; Lazarus and Abramovitz, 2004; Lehrer et al., 1990; Nagel, 2010; Powell, 2004; Salmon, 1990; Schneider and Chesky, 2011; Studer et al., 2011).

Tranquilizers administered in patients with anxiety disorders to reduce anxiety, such as benzodiazepines (Valium, Ativan, etc.), lead to a deterioration of the musician's musical output in the performance (James and Savage, 1984). In addition, these drugs result in a physical dependence, so that they are not only unsuitable for musicians, but contraindicated in most cases (Birk, 2004).

A major problem associated with drug intake in MPA is the well-known self-medication with beta-blockers, especially in orchestral musicians. In a recent study of 375 Australian orchestra musicians, 30% reported the use of beta-blockers because of MPA (Kenny, 2011, p. 219). 45.5% of these musicians cited the use of beta-blockers as the first or second leading strategy in dealing with MPA. In previous studies, similarly high numbers for self-medication were found with beta-blockers (Fishbein et al., 1988; Lockwood, 1989). An urgent need for prevention derives from these findings.

6 PREVENTION

Prevention to avoid pathological manifestations of MPA begins during the musical training in childhood and adolescence. Instrumental and singing teachers have a responsibility to provide their students with performance conditions, which promote learning. The early conveyance to music students that MPA, in its positive expression, is part of performance and that there is a repertoire of ways to deal with the excitement is one of the most important prerequisites for a positive performance career. Current results of the survey of orchestral musicians for dealing with MPA revealed few skills for dealing with MPA except for Practice and Sports (Gembris and Heye, 2012) or self-medication (Kenny, 2011). It is hoped that this will change in the coming generations of musicians. Performing Arts Medicine has evolved in the last two decades, and the field of Music Physiology has found its way into the higher education of musicians. Both future concert musicians and music educators are taught in the subjects Performance and Coping with MPA.

In the life of a musician, there are sensitive periods for development of MPA. The first significant phase is adolescence, in which exists an increased psychological vulnerability and in which the potentially negative performance experiences are stored permanently and in great detail in memory (Osborne and Kenny, 2008). Other important milestones include preludes and exams during the vocational training. This phase is particularly critical because during this time the identity as a musician crystallizes and negative or positive self-concepts are developed in terms of individual skills in the music profession. Auditions are a very special challenge for orchestra musicians and singers. They cause much suffering and exacerbation of MPA on account of their specific setting and the immensely high competition pressure (Kenny, 2011, p. 289).

Naturally uncertainties and performance constraints appear in the course of a career, which can also enhance MPA. This occurs with musicians at the beginning of their careers and among musicians with increasing age. Especially in the professional field of orchestral music, there are preventive protective factors for the development of pathological MPA, which exist in a positive communication culture with mutual esteem and social support within the orchestra. Also here there is still a lot to do before dealing with the topic of MPA is conducted openly and professionally.

In a broader sense, the socially positive perception of musical culture functions preventively, in particular the classical works. Singing and music must be maintained as a special cultural performance and honored to be experienced live, so as not to find current artists at concert performances in an inhuman situation compared with the studio productions.

7 CONCLUSION

MPA is a central phenomenon in the field of Performing Arts Medicine. In its pathological expression, severe MPA, it requires a specific and necessary treatment, as the careers and professional skills of musicians depend on it. Current "best practice" in our experience is a personal and problem-oriented approach. In the multimodal treatment model, the range of different to tried and trusted approaches from psychoanalytic and cognitive behavioral therapies, which are supplemented by additional body-oriented methods and mental techniques, should be implemented and tailored to the individual situation of the patient (Spahn, 2011).

Prevention plays an extremely important role in addition to the treatment. Thus, the concepts of dealing positively with MPA should be implemented very early into the instrumental and vocal education.

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PART

4

Music therapies then and now

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CHAPTER

Music as therapy in early history

8

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Abstract

The notion of music as therapy is based on ancient cross-cultural beliefs that music can have a "healing" effect on mind and body. Explanations for the therapeutic mechanisms in music have almost always included cultural and social science-based causalities about the uses and functions of music in society. However, it is also important to note that the view of music as "therapy" was also always strongly influenced by the view and understanding of the concepts and causes of disease. Magical/mystical concepts of illness and "rational" medicine probably lived side by side for thousands of years. Not until the late-nineteenth and early-twentieth centuries were the scientific foundations of medicine established, which allowed the foundations of music in therapy to progress from no science to soft science and most recently to actual brain science. Evidence for "early music therapy" will be discussed in four broad historical–cultural divisions: preliterate cultures; early civilizations in Mesopotamia, Egypt, Israel; Greek Antiquity; Middle Ages, Renaissance, and Baroque. In reviewing "early music therapy" practice, from mostly unknown periods of early history (using preliterate cultures as a window) to increasingly better documented times, including preserved notation samples of actual "healing" music, five theories and applications of early music therapy can be differentiated.

Keywords

music therapy, music medicine, music healing, early history

1 INTRODUCTION

The notion of music as therapy is based on ancient cross-cultural beliefs that music can have a "healing" effect on mind and body. Historical interpretations of the therapeutic mechanisms in music have almost always emphasized cultural and social science-based causalities within educational, emotional-motivational (cathartic), or spiritual and religious models of explanation and application. However, it is also

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important to note that the view of music as “therapy” was not only shaped by the role of music in a given society’s culture but was also always strongly influenced by the view and understanding of the concepts and causes of disease. Magical/mystical concepts of illness and “rational” medicine probably lived side by side for thousands of years (Davis, 2008). Not until the late-nineteenth and early-twentieth centuries were the scientific foundations of medicine to treat the body and of psychology to treat behavior established, which allowed the foundations of music in therapy to progress over the past 100-plus years from no science to soft science and most recently to actual brain science (Gaston and Gaston, 1968; Thaut, 2005).

Considering the many complex variables in culture, societal values, technology, artistic functions, spiritual beliefs, concepts of illness, and knowledge of human mind and body that have shaped the relationship between music and medicine and therapy, it comes as no surprise that a comprehensive history of music therapy has not been systematically researched and established. This chapter is trying to present evidence from uses and functions of music in therapy in four different historical categories: preliterate cultures, as evidenced from research in music anthropology and music archeology; early civilizations, with records of written communication and recorded cultural artifacts pertaining to music and “healing”; antiquity, with an emphasis on Greek writings on music and medicine; and Middle Ages, Renaissance, and Baroque, with treatises on music for therapeutic purposes.

Before presenting the specific evidence for historical uses and functions of music in therapy, a general introduction to the early history of music of the last 100,000 years—after records of artistic behavior for *Homo sapiens* appeared for the first time—will set a helpful framework for following later discussions.

2 THE ARCHEOLOGICAL EVIDENCE OF MUSIC AS A BIOLOGICAL LANGUAGE

The modern human mind—i.e., a mind with a mental architecture similar to ours—came into being perhaps sometime between 50,000 and 100,000 years ago. This evolutionary appearance was accompanied by the emergence of artifacts that have been attributed to cognitively modern minds. What might be most fascinating about these archeological records is the overwhelming evidence that these early human minds were artful minds and that artistic behavior was an integral part of human activities. Some scholars have proposed from examining the records of artistic artifacts—such as cave paintings, figurines, sculptures or statuettes—that in the arts the ancient human mind was cognitively the most advanced and most closely resembling modern standards of practice, when compared to other records of technology and culture (Ambrose, 2001; Turner, 2006).

Archeological evidence for music is harder to find than sculpted objects or paintings. The physical basis of music consists of temporal sound patterns created by vibrating objects with resonance bodies that are transmitted by vibrating air molecules to the human hearing system. One can therefore only infer from artifacts of musical instruments the existence and possible sound architecture of ancient music. The archeologically oldest confirmed musical instrument is a 45,000 year-old bone flute, discovered in an excavation site around Geissenklosterle in Southwest Germany. This flute shows five bore holes in exactly even distances, which would allow a musician to play moderns scales (Conard et al., 2009; Wallin et al., 2000). Flutes, rattles, whistles, and percussion instruments made from ivory or bones and dated as old as 30,000 years have been found. Rock engravings as old as 16,000 years depict dancers, implying the presence of music when considering the close connections between the auditory and motor system. Discoveries of musical instruments, at times numbering to the size of modern orchestras in a single excavation area and created within the last 10,000 years, have been made in many parts of the world, including Egypt, Mesopotamia, Syria, South Africa, East Africa, and China (Highham et al., 2012). An ancient set of wooden pipes has been found well preserved in Ireland, dated at about 4000 years of age—tuned in octaves, and executed with sophisticated craftsmanship beyond normal bronze-age levels. These pipes are the oldest wooden instruments ever found in Europe (O'Dwyer, 2004). The oldest still playable music instrument is a 9000-year-old flute found in China (Zhang et al., 1999).

The appearance of such highly sophisticated artworks with the emergence of modern human beings—*Homo sapiens*—suggests that artistic abilities did not evolve gradually but may have come into existence within a relatively short time span. Darwin considered the early and highly developed existence of the arts unusual and in some way a mystery, since it seemed not to follow expected evolutionary trajectories (Darwin, 1871). However, he tried to ascribe to music an evolutionary function in regard to sexual selection and courtship, emphasizing music's adaptive role in human evolution. This view falls in line with other views on the origin and function of music to contribute to survival of the human species via utilitarian functions, such as sexual selection, parental care, social cohesion and maintenance of socio-culture, intragroup cooperation, and other adaptive functions (Kleinman, 2014; Zaidel, 2013). A contrary evolutionary view on music was proposed by Spencer (1857, 1901), which considered music to be mostly as an outgrowth of the physical expression of emotion (Kleinman, 2014). In that sense it would be purely a human invention and nonadaptive for survival functions. Both views, adaptationist and nonadaptationist, continue to play an important part in the current discourse on the origin and function of music (Patel, 2008). However, for neither of these functions music, or the arts in general would have had to be highly developed. Furthermore, music's societal use has also been clearly shown disconnected from courtship and sexual selection. In regard to the proposal that music serves predominantly as a unique language of emotional expression, Berlyne (1971) in his book *Aesthetics and Psychobiology* has pointed out that the view on emotional expression as central function of music, which is widely taken for granted, is historically actually a very recent adaption and has not been firmly implanted as its prime role until the Romantic period.

The evidence, however, for the early existence of highly developed artistry (on levels of sophistication, abstraction, and representation similar or close to modern art) provokes some interesting hypotheses concerning the role and nature of artistic abilities in nature, for survival of the species, and for human behavior.

The notion of the arts as "icing on the cake" of human brain development is seriously challenged by these data. Why did art evolve so early and at such high levels in human development (Fitch, 2006)?

Music anthropology is full of examples demonstrating how music expresses emotions, concepts or events in early and preliterate cultures. Joy, happiness, sadness and loss; rituals of life events such as birth, marriage and death; social and political values and norms, can all be expresses through music (Merriam, 1964). However, music can only communicate such concepts and feelings symbolically, through learned associations and extra-musical definitions and connotations. The sound patterns of music cannot depict a wedding ceremony or directly express word meanings, not even for emotions. Music *per se* is a purely abstract auditory language. Early humans might have had the ability to think "music" cognitively as an abstract esthetic "sensory" language, and then assigned expressive meaning to it. This view considers music, and the arts in general, as autonomous abstract languages of the human brain whose development was fundamental to the emergence of the cognitive ability to construct symbols that communicate meaning, a prerequisite for the development of complex cognitive abilities such as verbal and numerical languages (Arnheim, 1972; Balter, 2009; Berlyne, 1971). One of those realms of meaning appears to be in medicine or healing therapy in its broadest sense, although those concepts did not exist in the modern sense in early human history. Within such early accounts of prehistory, we may indeed consider music as a biological language of the human brain (Blacking, 1973).

From this framework of music, brain, and early human history, the chapter will proceed to discuss evidence for "early music therapy" in four broad historical–cultural divisions: preliterate cultures; early civilizations in Mesopotamia, Egypt, Israel; Greek Antiquity; Middle Ages, Renaissance, and Baroque.

3 MUSIC THERAPY IN PRELITERATE CULTURES

Preliterate cultures are characterized by the lack of systems of written communication. We can only speculate about the use of music in healing and therapy in prehistoric times, but the study of preliterate societies in existence today or in the recent past could help us to develop an impression how music was connected to therapy and "medicine" in prehistoric societies.

In general, one may conclude that music was frequently employed as part of magical rituals to control the unpredictable and unexplainable forces of nature, to calm or satisfy metaphysical forces, such as gods or demons, and to combat disease and death. In early history, as still in evidence in preliterate societies, these three realms of control of nature, control or entreaties of supernatural forces, and control of life and health, must have been highly interwoven. In this context, Nettl (1955) and Densmore (1954) refer to the importance of the physical response, in addition to the emotional response, to music by the human organism. Not only does the sound production create a physical behavior and general bodily attitude specific to the desired sound (e.g., wailing sounds to express grief), but the structures within the music could also create specific physical responses. Densmore (1954) reports that healing songs by Native Americans are characterized by irregular rhythms, which are produced by frequent changes in accent and lead to changes in measure lengths. Different classes of songs and dances are associated with different types of healing requirements for different illnesses. The connections between healing and things spiritual are further evidenced by the fact that, in certain preliterate societies, healing songs were considered originating and transmitted directly from superhuman sources to the members of society, thus becoming an intricate symbol of a society's memory of history and belief systems (Merriam, 1964).

The exact mechanism of music's use in healing appears somewhat unclear. The medicine man or woman or shaman made the decisions of treatment and possessed the repertoire of appropriate songs. However, questions remain, such as if the music were used to petition a superhuman spirit to heal, or if the healing power were in the music itself. Some strands of twentieth-century music therapy, when rediscovering and trying to reclaim the shaman tradition for modern music therapy, have emphasized the latter (Blumer and Meyer, 2007). However, music anthropology data and the ancient concepts of causes of illness would suggest the former, i.e., songs were used as a specific form of communication to intercede with spirits, who could be petitioned to exercise their "magic" healing power. Instrumental music, as well as songs and dance, were also used as a prelude or as an appropriate accompaniment to create an environment of attention and devotion to the spirits, and to give access to the magical forces prior to or during the actual healing ceremony. If preliterate societies create an accurate window into early history practices, then the fact that music was used in healing practices would be well established early on, when modern humans and their engagements in what we would now consider the arts first emerged (Boxberger, 1962).

4 MUSIC THERAPY IN EARLY CIVILIZATIONS

Historians maintain that the first civilizations, i.e., larger groups of people living in more or less permanent confined regions and settlements, and abiding by commonly shared customs and belief systems, arose in Mesopotamia 5000—6000 years ago along the rivers Euphrates and Tigris, which nowadays is in Iraq. Advances in technology, science, and medicine, growth of cities, and the development of written communication (language and numbers), as well as the first evidence for musical notation around 2500 B.C. (cuneiform tablets in the Sumerian culture of ancient Mesopotamia), characterize the advent of these early cultures.

With the rise of early civilizations, the magical, spiritual, and physical components of medicine started to separate. However, those three approaches seemingly co-existed side by side until the rise of Ancient Greek culture. Ancient Egyptian medicine during the time period of the pharaonic dynasties, starting around 3000 B.C., is among the oldest documented practices of medicine (Finger, 2000). It went largely unchanged for roughly 2500 years until the Persian invasion of Egypt in 525 B.C. (Porter, 1997). However, for its time, it appears to be highly advanced in treating fractures, wounds, and illnesses. Documented practices include noninvasive and invasive surgery—possibly developed from knowledge gained by the mummification process—anatomical observations including bones and knowledge of internal organs, setting of fractured bones, dentistry, prosthetic devices, recognition of diet and cleanliness for health, and extensive lists for preparation of compound medicinal substances (Nunn, 1996). One may consider the use of medicinal prescriptions an early attempt at pharmacology (Pain, 2007). Several important medical documents have been preserved and translated from ancient Egyptian medicine, such as the *Edwin Smith Papyrus* (c. 1600), *the Ebers Papyrus* (c. 1550 B.C.), the *Hearst Papyrus* (c. 1450 B.C.), and the *Berlin Papyrus* (c. 1200 B.C.) (Bardinet, 1995). However, modern analysis has also shown that many medicinal prescriptions found in those Papyri were actually harmful to health. Furthermore, magic and religion were intertwined with views on the causes of illness. Supernatural elements were viewed as important parts of treatment. There seemed to be no clear distinction between priests and physicians by standards of today. The *Ebers Papyrus* contains a large number of incantations to appeal to supernatural forces for healing or removing disease-causing demons (Westendorf, 1999). Music healers in ancient Egypt still practiced their craft closely related to old concepts of illness and healing. They enjoyed privileged relationships with priests and high-ranking government servants (Davis, 2008). Music was called "physic for the soul" by Egyptian priest–physicians (Feder and Feder, 1981; Merriam, 1964). In other cultures, such in Babylonian culture during their high period (c. 1850 B.C.), illness was still viewed as punishment from the gods. Music was often included in healing ceremonies to appease the gods (Davis, 2008).

One of the most famous passages documenting Hebrew uses of music to heal physical and mental disturbances comes from the *Bible (Old Testament, Book of Samuel*), where King Saul (c. 1100 B.C.) is described as being shaken by an evil spirit sent by God. David, who had joined Saul's army after slaying Goliath, plays the harp so, " whenever the evil spirit from God came, David would take the harp and play with his hand, and Saul was refreshed and was well and the evil spirit departed from him" (I. Samuel, Chapter 16, Verse 14–23). This form of "harp therapy" appeared to be a typical occurrence, maybe reflecting a common understanding at the time that music could influence positive mental states. However, the limitations of such curative power show up clearly later in Saul's case, because in chapter 19 Saul throws a spear at David trying to kill him while he was playing.

Egyptian medicine was highly influential on early Greek medicine which benefited from its advanced knowledge (Finger, 2000). However, the Greek physician Hippocrates in the fifth century B.C.—often called the "father of modern medicine"—is usually credited with the development of turning away from divine notions of medicine to using nature, and specifically observations on the body, for medical knowledge. Ancient Greeks still held beliefs that illness was a divine punishment, and healing a gift from sprits or gods. The empirical approach of the new “rational medicine,” slowly superseded these ancient concepts of medicine, although magical and mystical interpretations of illness continued to live in parallel with the new developments of rational medicine (Sigerist, 1970).

5 ANCIENT GREECE

In Greek Antique, the influence of music upon character and manners was highly accepted. Early references to this role of music start in the seventh and eighth centuries. Thaletas or Thales of Crete (seventh century, exact dates unknown)—not to be confused with the Greek philosopher and mathematician Thales of Miletus (c. 624–546 B.C.)—who had moved from Crete to Sparta and had brought with him new principles of rhythm and music to the school of music (*katastasis*) he had founded, was said to have exerted calming and pacifying influences on the various factions of the citizenry through his music. He is also purported to have used music to appease Apollo, who had unleashed a plague in Sparta. This account still reflects what had been stated about early history and preliterate accounts of music’s indirect role in healing via accessing and beseeching divine powers, which were called upon for their healing powers.

During the Golden Age of Greek antiquity, mystical views on music as therapy were being replaced with more objective accounts, influenced by a new appreciation of nature and man’s place in the cosmos. We have several transmissions of theories—although only in fragments—about music’s healing power from three of the greatest philosophers and scholars of their day: Pythagoras, Plato, and Aristotle.

Pythagoras (c. 500 B.C.) and his followers considered music as a model for the harmonic proportions of the universe. Inspired by his discoveries of the overtones in music’s physical basis of vibration patterns, he saw parallels in the harmonic overtone ratios (1:1, 2:3, 3:4, 4:5, etc.) within the positions of the planets around the earth. In other words, the physics of music reflected or paralled the physics of the universe. He proposed that, by listening to music, one could comprehend and retrace the outer “physical” harmony of the universe, which would lead to a state of inner “mental” harmony, thus reestablishing balance in the body and helping to cure mental disorders. Since he discovered the overtone ratios in music using strings, he had a marked preference for stringed instruments and warned his followers to not listen to flutes or cymbals because of their potentially unbalancing influence on the mind. He was credited in his time with curing illnesses of spirit, body and soul with specially composed music, drawing on the seven modes of the Greek modal scale system (Kahn, 2001; Thaut, 2005).

In Plato’s (c. 400 B.C.) writings about music, we find the thoughts of the Pythagoreans basically repeated. Since music is an abstract art form, Plato considered music higher than other arts, e.g., visual or theater art, which he considered mainly mimetic in nature, and therefore inferior and incompatible with the world of pure forms and essence, which for Plato formed the true reality behind the imperfect physical reality of nature. He emphasized the ethical and educational dimensions of music, which he considered important in what one may call a prophylaxis, especially for the young, to keep the soul clean and pure (Pelosi, 2010). He called for a critical role of music in educating the youth in a well-ordered society in his famous work "The Republic": "The overseers must be watchful against its insensible corruption. They must throughout be watchful against innovations in music...to counter the established order... For the modes of music are never disturbed without unsettling of the most fundamental political and social conventions" (Hamilton and Cairns, 1961, pp. 665–666).

Aristotle (fourth century B.C.), a pupil of Plato, took a very different view on music. His therapeutic concept of music was based on the notion that music can create in more modern terms emotional catharsis in mental states that need release from unhealthy inner tension or dysfunctional hyper-reactive mood states. He spoke about music's ability to communicate emotional states: "Music directly imitates passions or states of the soul...when one listens to music that imitates a certain passion, he becomes imbued with the same passion; and if over a long period of time he habitually listens to music that rouses ignoble passions, his whole character will be shaped to an ignoble form" (Grout, 1988, pp. 7–8). The function of music as evoking emotional catharsis will appear again in psychodynamic theories of music therapy. Aristotle's concept of musical catharsis finds a historical parallel in Greek history in the pre-Pythagorean *korybantic* ecstasy states induced by music and dancing. The Korybantes were armed and crested male dancers, who danced and drummed in ritual ceremonies that were symbolic of warrior victory dances and male coming-of-age initiation rites (Schwabe, 1974; Thaut, 2005).

An interesting account of music therapy with mental illness comes from Asclepiades of Bythnia (124–40 B.C.), who is recognized as the first Greek physician to establish Hellenic Medicine in Rome. He was the first physician in history who created a health and disease theory resembling what is known today as molecular medicine. He was also a pioneer in the humane treatment of patients with mental disorders, who were traditionally treated callously and harshly because they were considered cursed or possessed by evil spirits. He is reported to move patients out of dark confinements and use work therapy, healthy diet, massages, and music therapy (Yapijakis, 2009). He also referred to the special effects of Greek modal scales for healing, for example the Phrygian mode—which would correspond to the medieval and modern Dorian mode—to encourage changes from somber and melancholic states (Gonzalez, 2012). At a time when physicians were not always caring and showed sympathy toward their patients, he was famous for his admonition to treat the patients *cito, tuto, et jucunde*, meaning fast, safe, and joyful (McCallum, 2008).

One of the most famous physicians during the fifth century A.D. in the late Western Roman Empire was Caelius Aurelianus, who lived in North Africa in the Roman province of Numidia, which is located today in Algeria. He is most famous for his translations of medical works from Greek into Latin. In one of his works, *Medicinales Responsiones*, he recommends massage, bed rest, heat, dietary alterations and music against physical pain, e.g., sciatica. But he also warns against the indiscriminate use of music, since this could cause madness, another reference to music and mental illness (Davis, 2008).

6 MIDDLE AGES, RENAISSANCE, AND BAROQUE

During the Middle Ages (c. 500–1450 A.D.), Greek theories still dominated the practice of medicine and, consequently, the views on music in medicine. The theory of the four humors—black bile, yellow bile, phlegm, blood—which was originally proposed by Hippocrates still dominated medical thinking. Illnesses were thought to be caused by imbalances between those four elements.

Boethius (c. 480–524), a Roman Christian philosopher, had formulated the structure of medieval music in his book *De Institutione Musica,* which dominated thinking in Western music theory for almost 1000 years. He had subdivided the study and practice of music in three hierarchical levels. The highest level he called *musica mundana*, referring back to the ancient philosophical concepts of proportions of the celestial bodies found in the physical proportions of musical acoustics. This concept of musical science, credited to Pythagoras, considers music mostly a mathematical concept of harmony in proportions and numbers. The second level is called *musica humana*, which refers to music as a reflection of harmony of the human body and spiritual harmony. The lowest level, *musica instrumentalis*, actually refers to audible music and is performed by singers and instrumentalists, who, however, are excluded from a true understanding of musical science and are of servile rank to scholars exploring the other two levels (Chadwick, 1981). In the context of musica humana, Boethius also makes reference to the curative power of music, albeit mostly in connection with morality and character: "Music is part of us, and either ennobles' or degrades our behavior" (Schrade, 1947, p. 188).

The sixth century is also the time when music made its official entry into one of the most influential medieval treatises on education as part of the *quadrivium* (mathematics, geometry, astronomy, music), which together with the more practical disciplines of the *trivium* (grammar, rhetoric, logic) dominated classical learning for centuries. The memorable treatise was written by Cassiodorus, who followed Boethius as governor for the Ostrogothic Empire in Italy, after Boethius was executed by King Theodoric for being suspected to conspire with the East Roman Empire. By entering music into the *quadrivium* he followed faithfully the "abstract science" view of music handed down from Greek antiquity, which had been preserved by Boethius (O'Donnel, 1979).

The Middle Ages saw a gradual change in attitude towards illness inspired by the Christian Faith. Sick persons were not considered of lesser value than healthy persons. The first hospitals were established to provide humanitarian care. After the twelfth century, when European scholars had come into contact with the writings of Middle Eastern writers who had preserved many documents of medicine and science from the ancient Greeks and Romans, the foundations for an intellectual revolution were laid. Robert Grosseteste (c. 1175–1253) and Roger Bacon (c. 1214–1294), two highly educated leaders and teachers of the church as scholars, scientists, philosophers, and theologians, were among the most important figures at this time, providing the bases for the establishment of a more advanced Western science. These new efforts, to explore the world experimentally (Aristotle's lasting influence) and by methods of verification, were brilliantly reconciled with the

Christian Faith in a Creator God by philosopher–theologians Albertus Magnus (c. 1200–1280) and Thomas Aquinas (1225–1274) (Grant, 1996). However, overall the Middle Ages did not advance any radically new theories about music in medicine. Similarly, the Renaissance continued much of earlier practice of music in medicine. As many medieval church leaders had already advocated, music was thought to be able to relieve or even prevent emotional depression, melancholy, and grief and bring harmony to the soul (Boxberger, 1962).

A curious phenomenon, which could be considered negative music therapy and which swept through Europe from the fourteenth through the seventeenth century, was "Dancing Mania," also known as St. Vitus dance. It involved large groups of people—at times thousands—who would dance erratically and hypnotically for long periods of time until they collapsed (Midelfort, 2000). Sometimes musicians were brought in to control the dances with their accompaniments. However, the practice could also create the opposite effect by encouraging more and wilder dancing. The roots of this well-documented phenomenon are still unclear today. Theories range from religious cults to mass hysteria reactions against the daily dangers and burdens of life especially at a time when large epidemics like the plague swept through Europe and poverty was high (Gordon, 1959). Writings, which warn about the danger of music, continued in the eighteenth and later centuries (Kenneway, 2010). In the seventeenth and eighteenth centuries, new mechanistic models of nerve stimulation became prevalent which also referred to the effects of music on stimulating and over-stimulating the senses. For example, Benjamin Franklin's invention and use of a music instrument called "armonica" (similar to a glass harmonica) was accompanied by reports of overstimulation and overarousal due to music from this instrument, actually causing deteriorating health, even seizures, and hysteria (Finger, 2006). Kenneway (2010) has extensively reviewed historical literature of the eighteenth, nineteenth, and twentieth centuries on the negative medical effects of music. Music was frequently mentioned as a pathogenic stimulant on health, starting in the late eighteenth century and continuing during the nineteenth century. In the twentieth century, negative effects of music were less medically oriented but became a subject of moral objections to life styles, social norms, political views, and concerns about "brainwashing" the minds especially in adolescents and young adults.

New developments in theories about music's healing power had to wait until the seventeenth and eighteenth centuries. A large number of authors emerged during that period who wrote quite explicitly about theories and therapeutic methods regarding music and medicine, such as Kircher (1684), Craanen (1689), Baglivi (1696), Brendel (1706), Ettmueller (1714), Albrecht (1734), Nicolai (1745), Brocklesby and Brocklesby (1749), and Roger (1758) (Schwabe, 1974).

New developments in science had occurred during those times, which also formed the bases of some of the new ideas how music might operate therapeutically. The mostly anatomically based approach to understanding the human body during the Renaissance had been supplanted by also studying the physiological functions of the body. Descartes' theories on rational reasoning to develop the science of nature and the dualism he proposed between a mechanical body, which has material properties, and a mind that is separate and nonmaterial were highly influential in his times. His theory that mind and body can nevertheless interact via the pineal gland, which can be set into sympathetic vibrations by perceptual sensations transmitted by the nerves, had considerable influence on new theories about music as a therapeutic agent, as one sees reflected in Kircher's and Nicolai's work (Schwabe, 1974).

Kircher gave one of the most comprehensive descriptions of music in medicine in the seventeenth century. In his work *Phonurgia Nova*, he laid out the foundation for a therapeutic music style that he called in German *Iatromusik*. *Iatromusik* is supposed to bring the concepts of *musica mundana* and *musica humana* together. The therapeutic mechanism of *Iatromusik* is based on vibrations. The music sets air into vibrations. The vibrating air sets the "corpuscles" of the body into vibration. The bad humors of the body (black and yellow bile) are shaken lose by the vibrations and can escape through the pores of the skin. Kircher's highly mechanistic view on the body response to music implies that the "soul" is also purified and healed. In other words, Kircher proposed a body–mind directed connection: mechanical (vibratory) energy from the music creates a physical–physiological response in the body, which also brings psychological "mind" processes into healing harmony. Kircher gives very precise indications for which illnesses *Iatromusik* can heal and which not. Strokes, fevers, and amputations cannot be healed with music. However, what we would today consider psychological and emotional disturbances might be healed, because the prevalent view of the time was that these were caused by harmful substances in the body and needed to be released (Schwabe, 1974).

A special reference is made by Kircher to healing "Tarantism," which supposedly is caused by the bite of the Tarantula spider. Tarantula bites were considered a significant and much-feared source of illness, especially in Southern Europe—however, these Tarantula illnesses were mostly created by folk imagination. Tarantula bites are not dangerous to humans. Kircher gives very specific descriptions on what types of music and types of instruments and sounds are to be used for different types of Tarantulas and their different types of "poison." Kircher writes: "Dass aber dem einen dieses, einem andern ein anders musicalisches Instrument angenehm und tauglich ist, dass muss man der Eigenschaft, Natur, und Complexion, entweder dieser Spinnen, oder dess Menschen zuschreiben; dann die Melancholische, oder die von solchen Tarantulen gestochen, die ein gar dickes Gift fuehren, die werden mehr durch lautschallende Paucken und Trumeln.... als durch subtile Saiten beweget" (Schwabe, 1974, p. 41) ["But that different musical instruments are experienced as comforting and helpful by different people, we have to ascribe this either to the attributes, the nature, and complexity of these spiders or the persons; the persons afflicted by melancholy or those having been bitten Tarantulas carrying heavy thick poison will be stronger moved by loud sounding timpani and drums than subtle string sounds," (translation by author)].

Transmitted manuscripts of *Iatromusik* show a variety of melodic themes with figured bass—typical for the Baroque style—on which the musician should improvise, choosing different types of tempi, rhythms, dynamics, expressions, and durations for the total improvisation to match appropriately the music to specific states of illness (Russell, 1979).

Nicolai's theories on music in medicine go in the opposite direction from Kircher's. He is the first physician in the Baroque period who questioned the effects of air vibrations on the human body. Consequently, he does not use the physical–physiological basis of Kircher—shared by most *Iatromusicians* of his time—to explain the therapeutic effect of music. He emphasizes the psychological-affective effects of music on the human mind. These psychological experiences—and within those he emphasizes the emotional feeling components—will then exert physiological effects on the rest of the body. In this sense Nicolai still accepts a mind-body dualism, but he reverses the interactive directionality from Kircher's body–mind trajectory to a mind-body effect. Music, he claims, works therapeutically primarily on the psyche, which in turn will affect the physiological state of the body.

Another seventeenth century view that was much influenced by Plato and tried to reconnect music's healing properties to views from Greek antiquity was put forward by the British enlightenment author and physician Richard Brocklesby in his major treatise on music's therapeutic potential (1749). Music, by listening to the movements and proportions of its intrinsic elements of melody, harmony, and rhythm, can restore internal harmony between body and mind. Brocklesby argued strongly that music, by ordering the passions, can be an important therapeutic tool to treat mania and other acute mental disorders. He also included Plato's (and the Pythagorean and Aristotelian) appeal to the power of music to build character and moral values.

Among these different theories, Nicolai's view of music as therapy has probably survived most strongly, continuing to dominate thinking in the nineteenth century, and in many ways has even influenced the prevalent philosophies on music therapy in the twentieth century (Gaston and Gaston, 1968). Not until music became a topic of neuroscience research, did the understanding and the applications of music became entirely different. From understanding how the brain processes music and how music learning changes the brain, we finally know that music is a complex auditory language and that the elements and patterns in music could help patients to relearn and retrain motor, language, and cognitive functions in effective ways (Thaut and Hoemberg, 2014).

7 SUMMARY

Music and the arts accompany the appearance of modern humans at levels of high sophistication when compared to other artifacts of technology and culture (Mithen, 2006). We can only infer from the fragmentary bits of knowledge that music must have existed, and from studying preliterate cultures how music might have been used in medicine. The prevalent practice shows the use of music to intercede in an indirect way with the supernatural realm—spirits or gods—to petition for healing. Since illnesses were understood as being caused by divine interference as curses or punishment, or by diabolical forces, healing could only come from the divine realm. Music was used to access that realm. Shifting the understanding of music as therapy would change, but only as rational [nature-based] medicine emerged.

Some Ancient Greeks now considered music as therapeutic in more direct ways—reflecting and projecting the harmony of the cosmos onto the mind and thus creating or reestablishing inner harmony. This process was not only considered valuable as therapy, but also for educational purposes to strengthen character and virtue. The Aristotelians added a new emphasis, explicitly introducing the therapeutic function of affective "catharsis" induced by music to relieve the mind from negative emotions. We also know from the writings of the physician Asclepiades about specific "clinical" prescriptions of music therapy for treatment of mental disorders.

No radically new theories and practices of music therapy were reported during the Middle Ages and Renaissance, for a period of roughly 1500 years. In the seventeenth and eighteenth centuries, there was a flourishing of writings on music and medicine. Based on the new scientific findings at that time regarding the physiological functioning of the human body, Kircher created an entirely new theory of music's therapeutic effects, based on acoustical vibrations, which operates in a body–mind direction to heal. Nicolai in a later treatise on music and medicine reverses that direction by emphasizing the affective effect of music on the mind and soul which—still following Descartes—will influence the physical–physiological state of the body.

Finally, in reviewing the history of music therapy, from mostly unknown periods of early history (using preliterate cultures as a window) to increasingly better documented times, including even preserved notation samples of actual "healing" music (*Iatromusik*), one can differentiate five theories and applications:

1. *Music in Supernatural Petitions*: In accordance with the views on illness as caused by supernatural forces, music's healing function is indirect. It is a form of special communication with magic forces to petition for healing.
2. *Music in Early Science*: Causes of illness are not viewed in magical or religious terms. Music is viewed as a model of the physics of the universe, and by studying and listening to it can bring the order and harmony of the universe to the disturbed soul and mind. It can also strengthen education and character.
3. *Music in Rational Medicine*: Music's affective qualities can also provide for release of negative emotional states like depression or grief.
4. *Music in a Physiological Model of Healing:* Science and medicine of the Baroque provide a model of healing through the effects of the physical properties of music on the physiology of the human body and mind via vibrations.
5. *Music in a Psychological Model of Healing*: science and medicine of the Baroque still provide a basis for music therapy, but the therapeutic effect of music lies in its affective properties to stimulate appropriate feelings and emotions for healing psychological states of illness.

This review of theoretical categories for music in therapy shows that the role of music was determined and defined by two nonmusical sources of knowledge: an understanding of the causes of illness and developments in the behavioral and natural sciences. An independent understanding of intrinsic properties in music that can act as therapeutic agents did not exist. Interestingly, the most recent advances in music therapy in the late-twentieth and early-twenty-first century, e.g., as established in Neurologic Music Therapy, are still driven by these two ancient factors. The discovery, that only learning and training paradigms have shown lasting effects on changes in neuroplasticity and behavioral function in therapy and rehabilitation (Barnes and Good, 2013), has led to the development of music-based exercise models to induce changes in the injured brain. The scientific discovery that music perception and music playing can create neuroplastic changes has led to the insight that music therapy can address specific brain and behavior dysfunctions. However, it took a linkage of the neurosciences and musicology to base music in therapy more firmly in the hard sciences and bring the age-old history of music therapy to its present state (Thaut and Hoemberg, 2014).

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CHAPTER

An Enlightenment proposal for music therapy: Richard Brocklesby on music, spirit, and the passions

9

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Abstract

In 1749, the London physician Richard Brocklesby (1722–1797) published his *Reflections on Antient* [sic] *and Modern Musick*, an essay that not only sought to compare these practices in terms of their effects, but also to gather evidence supporting the use of music in treating mania and other mental diseases. As might be expected, Brocklesby's discussion of music therapy has already received attention by authors looking back to the origins of this practice, not least because he offers an account of a successful musical cure that took place in his own time (Rorke, 2001). My chapter, however, seeks to broaden the discussion of the *Reflections*, in order to show how Brocklesby's projected musical cures fit into his larger worldview, one that was influenced as much by Plato and other ancient philosophers as it was by modern thinkers such as Isaac Newton and his followers. Brocklesby's argument was essentially that music acted as a link between the mind and body and therefore could restore their intrinsic harmony, a connection that was mediated by the animal spirits, which also served as the vehicle of the passions. The movements and proportions of music could arouse or quell the passions by their effect on these (imaginary) spirits, which flowed through the nerves and brain and acted as the agent for the mind or soul. I show how his account of music in antiquity led him to reflect on the way that music was perceived and responded to in his own time, both as a stimulus to mental and bodily action, and as a source of esthetic pleasure through the cultivation of musical taste.

Keywords

Brocklesby (Richard), music therapy, passions, spirit, nerves, music, Plato

1 INTRODUCTION TO BROCKLESBY'S LIFE AND PRINCIPAL WORKS

With hindsight it is clear that the London physician Richard Brocklesby (1722–1797) was one of only a small minority of British Enlightenment authors who wrote learnedly on music (Semi, 2012). Indeed, Brocklesby's (1749) *Reflections on Antient* [sic] *and Modern Music, with the Application to the Cure of Diseases; To Which Is Subjoined, an Essay to Solve the Question Wherein Consisted the Difference of Antient Musick, from That of Modern Times* was practically the only text by an eighteenth-century English physician to take music's therapeutic potential seriously.[1] Before Brocklesby's *Reflections*, the only in-depth discussion on music's effects was the apothecary Richard Browne's (1729) *Medicina Musica: Or a Mechanical Essay on the Effects of Singing, Musick, and Dancing, on Human Bodies*, which was published exactly 20 years earlier. However, Brocklesby nowhere cites this book in his own work, and it is very likely that he was unaware of its existence. As will become clear, there is no evidence to suggest that he sang or played an instrument himself, and there is no apparent reason to explain why Brocklesby penned his *Reflections* when he did, other than his stated desire to persuade his fellow physicians to include music as part of their treatment of mania and other acute mental disorders. It is with this medical context in mind that he chose to discuss the nature of music and its effects on the mind and body, and particularly its relationship to the nervous system and to what we now call the emotions, but which in Brocklesby's time were still conceptualized as the passions (Dixon, 2006).

Although this volume is focused particularly on the history of neurology and of music therapy, Brocklesby's contribution to these fields is best understood within a broader historical and biographical framework. In this chapter, I hope to show that a close reading of the *Reflections*, coupled with an investigation into the known details of Brocklesby's life, reveals a youngish man who, in addition to promoting music's health benefits, believed that certain kinds of music should constitute part of a learned gentleman's education, and indeed should serve as a form of recreation especially in old age because of its beneficial effects on the human spirit. Early modern authors typically traced these moral values back to Aristotle and especially to Pythagoras and Plato, who were renowned for their academies in which their disciples were trained in philosophy and the liberal arts, especially music, as preparation for their future roles in society. We will see that Brocklesby approved of Plato's philosophy and cited him in the *Reflections* at several crucial points.

But there were other strong influences on this work: as a Fellow of the Royal Society of London, it is not surprising to find that Brocklesby was an advocate of the new science, which, thanks to the influence of Francis Bacon (1561–1626), was to be

[1]Another eighteenth-century physician who treated music altogether more briefly was Nicholas Robinson (1729). Also, it is worth mentioning that three Edinburgh medical dissertations (in Latin) dating from the second half of the century specifically address music's effects on the nerves. For further details, see Gouk (2014).

based on evidence derived from observation and experiment. Brocklesby himself regarded Bacon as "the prime and chief philosopher of all ages" and cites the latter's *Sylva Sylvarum* (Bacon, 1627) more than once in his *Reflections* (1749, pp. 33, 72–73). (Hereafter, all references to the *Reflections* will be limited to their page numbers.) Brocklesby clearly built up his case for the use of music in healing with references to modern instances of this practice. Yet typically for the Enlightenment, it is clear that he also looked back to more ancient philosophers as a resource for his deliberations on music, which, as the title of his book suggests, embraced not only contemporary theories and practices but also gleaned knowledge from the ancient past. In other words, Brocklesby did not reject outright ancient learning, but assumed that it contained information that had relevance for the modern age, for example, in the case of music and its role in society.

2 EDUCATION AND TRAINING

Since his parents were Quakers, Brocklesby was sent at age 12 to a Quaker school in County Kildare. (For further biographical details, see Bishop, 1947; Breathnach, 1998; Curran, 1962; Heberden, 2009; Rorke, 2001.) It was there that he began what was to become a lifelong friendship with Edmund Burke (1729/1730–1797), the later politician and writer who was also a younger pupil at this school, where they both received a rigorous academic training. We can be fairly sure, however, that Brocklesby did not practice or enjoy music either with his family as a young child or at school, because at this time Quakers were inclined to regard all music as morally suspect, including making music in private.

The opportunity for developing his musical interests first arose in 1742 when he began to study medicine at university. Like many talented nonconformists, he enrolled at the Edinburgh medical school, but fearing that anti-Jacobite feeling in London might prevent an Edinburgh graduate from practicing medicine there, transferred to Leiden, where he gained his MD in 1745 under the tutelage of Gerôme-David Gaubius (1705–1780), who was successor to Herman Boerhaave (1668–1738) as the Professor of Medicine. It was at Leiden that Brocklesby formed another important friendship, this time with the radical revolutionary John Wilkes (1725–1797), who like Burke also went on to become one of Brocklesby's London patients. These early relationships and his career trajectory might help to explain why Brocklesby came to identify himself politically as a Whig, and, as far as religion was concerned, was known for his Deist views; i.e., the belief that reason and observation of the natural world are sufficient to determine the existence of a Creator, accompanied with the rejection of revelation and authority as a source of religious knowledge (http://en.wikipedia.org/wiki/Deism; accessed 23 May 2014).

The formal curriculum at the Edinburgh and Leiden medical schools have been closely studied by medical historians, who have also commented on the creation of informal clubs and societies that were designed to foster an all-round education for university students (e.g., Lawrence, 1974). However, the role that music played in the civilizing process and as a medium for social exchange has mostly been overlooked in studies of medicine and scientific practice (see Gouk, 2005). Whether Brocklesby actually took advantage of the musical goods and services that were available to students in these university cities is unknown. Nevertheless, it is clear that both Edinburgh and Leiden offered the chance of learning to play instruments such as the violin or flute, for example, which could be played either alone in one's room as a break from study in the afternoon, or in polite company at a mixed gathering where participants listened to each other's performance. It is notable, for example, that Boerhaave, who had been a skilled lutenist himself, had encouraged his students to enjoy music in their leisure hours, and organized music meetings that took place in his own house. In short, the cultivation of the right kind of music was integral to the self-fashioning of students (not just those in medicine but also in law and philosophy) who were going on to practice their arts among the wealthiest citizens in polite society, and therefore needed to share their values and experiences. Brocklesby's *Reflections* also demonstrates how the ability to discourse *about* music and even to write learnedly on its "science" (i.e., what we now call music theory and criticism), also seems to have been valued in the circles in which he moved.[2]

Brocklesby's move to the capital around 1745 marks another phase in his development as a physician and also as a man of letters. His first medical practice was in Broad Street, Bishopsgate. Once settled in London, he immediately sought attention from Dr Richard Mead (1673–1754), a Fellow of the Royal Society and arguably the most influential physician in Britain. Brocklesby dedicated his first publication of 1746 on foot and mouth disease to Mead, and followed this up by sending him four scientific articles (including one proving that fish could hear underwater), which were soon after published in the Society's journal, the *Philosophical Transactions* (Brocklesby, 1748; Heberden, 2009). Mead was so impressed with Brocklesby's scientific writing that he proposed him as a Fellow, and thanks to this support Brocklesby duly became elected a Fellow of the Royal Society in 1747 at the age of 25.

Brocklesby's *Reflections* of 1749 was the next work that he published, replete with references to a range of classical Greek and Roman authors, as well as more recent texts. These references showed him to be a scholar who was capable of drawing together and evaluating the mostly written evidence that he had found to support his argument for using music in certain therapeutic contexts, especially when conventional remedies appeared to have little or no effect. Disappointingly for my purposes, there is no record of him continuing to write on music, nor does it seem

[2]Again, we can see Boerhaave as a model, since as William Burton, in his 1743 *Account of the Life and Writings of Hermann Boerhaave* observed of his subject,

> *When weary [he] revived himself with music, his most delightful entertainment; being not only a good performer on several instruments, particularly the lute, which he accompanied also with his voice, but a good theorist likewise in the science, having read the best ancient and modern authors on the subject, as appears by the lectures he gave on sound and hearing, and during the winter he had once a week a concert at his own house, to which by turns were invited some select acquaintances of both sexes, and likewise patients of distinction from other countries.* (p. 62)

that he himself tried to put into practice his ideas about prescribing it for mentally disturbed patients. However, Brocklesby did publish an article in the *Philosophical Transactions* that described the experiments on certain animals that he had conducted himself, in order to verify Albrecht von Haller's (1708–1777) demonstration that the nerves transmitting pain were separate from those serving motor functions (Brocklesby, 1755). Haller's division of nervous action into "irritability" and "sensibility" was directly relevant to Brocklesby's discussion of nervous ailments in the *Reflections*, which did not give much attention to the anatomy of the nervous system, even though it underpinned his arguments (Smith et al., 2012, pp. 189–192).

The next (and last) book that Brocklesby published in 1764 was aimed at improving the state of military hospitals and has been judged as his most important work, arising directly from his appointment as physician to the army and his service in Germany during the Seven Years' War (Heberden, 2009; Brocklesby, 1764). By this time, his medical practice was flourishing, and as a measure of this in 1763 he had moved to a more fashionable location in Norfolk Street off the Strand, where he remained for the rest of his life. This marks the end of Brocklesby's published output, but his continuing interest in soldiers' health led to his appointment as physician-general to the ordnance in 1793.

As well as being an established writer and elite physician (he was elected as a Fellow of the Royal College of Physicians in 1756), Brocklesby had a reputation for his charitable acts, his sociability and his powers of conversation. Apart from Wilkes and Burke, his most famous patient was Samuel Johnson (1709–1784), whom he began to attend in 1783 and who died a mere 18 months later. It was principally for Johnson's benefit that Brocklesby founded the Essex Head Club in 1783, whose members met to dine regularly in the pub that gave its name to the Society. In the context of this chapter, it is notable that one of the Club's members was Charles Burney (1726–1814), a musician and composer who had been in the middle of publishing his *A General History of Music* (1776–1789) and who had already been elected a Fellow of the Royal Society in 1772. The Club survived for at least another decade after Johnson's death. Meanwhile, Brocklesby maintained his busy practice, and devoted considerable time to the welfare of his great-nephew Thomas Young, who was to become a brilliant scientist and polyglot. It was to Young that Brocklesby at his death in 1797 left his house, furniture, library, and papers, together with the substantial sum of £10,000.

While there is no evidence of Brocklesby making music, we know that Young (who was also raised as a Quaker) developed a taste for both music and dancing while he was in London during 1794, and subsequently cultivated these activities as a medical student in both Edinburgh and Göttingen, where he took lessons on the clavichord twice a week (Cantor, 2009). It might be just a coincidence that Young played music during the same period that he was developing his earliest scientific theories on the nature of light and sound. However, it is notable that his Göttingen medical dissertation engaged with the propagation of sound, and this material was developed into a series of papers that sought to explain various acoustical and musical phenomena in terms of a vibrating medium analogous to the ether he believed served as the medium of light. A detailed study of the analogy between sound and light appeared in a section of the paper he read to the Royal Society in 1800, which was part of his major contribution to physical optics and acoustics (Young, 1800). Although the lines of influence cannot be pursued very closely, it is striking that Young adopted a theory of vibrating matter that was remarkably similar to the thoughts on this topic that Brocklesby had first put down in his *Reflections* some 50 years previously. This suggests that the ideas of his great-uncle, who never published further on the subject, distinctly shaped Young's musico-scientific interests. Indeed the latter's thinking was also influenced by Isaac Newton (1643–1727), whose theory of light and color vision was first presented to the Royal Society in 1671–1672, and after some considerable revision was finally published in his *Opticks* of 1704 (Cantor, 1983).

3 *BROCKLESBY'S* REFLECTIONS *IN CONTEMPORARY CONTEXT*

In the English context, there was not much of a precedent for Brocklesby's *Reflections,* although as I shall show he seems to have been abreast of philosophical thought on music. As I have already indicated, the nearest comparable work in English, as well as being the first to discuss music's effects on the body in any depth, was the apothecary Richard Browne's (1729) *Medicina Musica*.[3] Like Brocklesby, Browne raised the possibility of curing diseases with music, but his focus was more on maintaining a healthy balanced lifestyle (particularly for the "ladies") rather than trying to treat acute mental diseases, such as mania and frenzy, which Brocklesby was advocating. There was a gap of 20 years between their publications, and there is little to suggest that Brocklesby had drawn on Browne's work, except perhaps in a negative sense when he dismisses the "mechanical hypothesis" as an inadequate basis for explaining music's effects on people.

Yet Brocklesby was not writing in a vacuum, and indeed the subjects of music's effects on the body and mind and the comparison between ancient and modern music were well-established topics for philosophical and medical debate. For example, there had appeared a letter addressing this latter topic in the 1698 volume of the *Philosophical Transactions* (Wallis, 1698). Casting our net beyond England, there were a handful of seventeenth- and eighteenth-century medical dissertations that addressed the topic of music's effects on people, for example, Michael Ernst Ettmüller's 1714 *Disputatio effectus musicae in hominem* (MD, University of Leipzig, 1714).[4] Chronologically speaking, the nearest texts to Brocklesby's were Isaac Brown's *Disquisitio medica inauguralis de sonorum modulatorum vi in corpora humana* (MD, University of Edinburgh, 1751)[5] and the French physician

[3] In fact, a version of this book had already been published anonymously by Browne in 1727 (Browne, 1727).
[4] "Disputation on the effects of music upon man."
[5] "Inaugural medical disputation on the force of modulated sound upon human bodies."

Louis Roger's 1758 *Tentamen de vi soni et musices in corpus humanum,*[6] but of course these appeared after Brocklesby's *Reflections* and clearly had no influence on this work.

In fact, although we cannot say that Brocklesby actually read it himself, one source of influence we should not rule out is the seventeenth-century Jesuit Athanasius Kircher's 1650 *Musurgia universalis*, the ninth book of which is devoted to "the magic of consonance and dissonance" where he summarizes most known ancient and modern literature on the therapeutic properties of music (Gouk, 1999, 2001). Among the examples of music's healing powers that Kircher (1601–1680) discusses at length are the cure of Saul's melancholy by David's harp, and the cure of the Tarantula's bite, a discussion of which had already appeared in his 1641 *Magnes, sive de arte magnetica* (Baldwin, 2001). Kircher's publications were widely distributed in Europe and the New World, and it was mainly due to him that these and other instances of music's power became standard topics for later authors writing on the medicinal properties of music. Some of these topics even found their way into *The Gentleman's Magazine*, which Brocklesby read. It is no surprise, therefore, to find that he duly addressed both David's treatment of Saul and the bite of the Tarantula in his *Reflections*.

4 AN ENLIGHTENMENT PERSPECTIVE ON ANTIQUITY

An overview of Brocklesby's *Reflections* will provide a useful starting-point for examining in more detail his scholarly methods and the assumptions that he held about music and its therapeutic potential. The work is divided into six chapters, the first and last of which address the differences between ancient and modern music, the unifying theme that provides a context for the remaining chapters of the *Reflections*. The second chapter focuses on the operation of music on the bodily organs once it has been processed by the mind, an important issue here being that Brocklesby is sure that it is the mind that initiates bodily responses to music rather than these being simply due to music's motion striking the organs of sense and the nerves. The third addresses music's power on the operations of the mind; the fourth deals with the application of music to the cure of diseases "compounded of affections of the body and mind," such as melancholy; and the fifth concentrates on its capacity to retard old age, a theme that also relates closely to Brocklesby's admiration for Baconian experimental philosophy. I will discuss the contents of these middle chapters on music, health and disease further below, at the same time as saying more about how these concepts map on to his broader philosophical views on nature and culture.

In chapter 1, Brocklesby begins by observing that, if the sources are to be believed, ancient music was much more powerful than modern music, but still "examples are not wanting in modern history of its surprising effects on the human frame, which receive every day new proofs from repeated experiments" (p. 1). He then says he will

[6] "Examination of the force of sound and music upon the human body."

discuss whether music might be applied to the cure or mitigation of "such distempers, as have hitherto too frequently eluded the ordinary powers of medicine" (p. 1), after first observing music's "great credit among the wisest of the antients [sic], and their solemn and frequent exercise of it, in most of their religious and civil concerns" (p. 2). He follows this with a potted guide to the origins of music and its various uses in ancient societies, particularly Greece, and he also gives rational explanations for its various effects, including those that the ancients thought to be supernatural or magical in origin. In a typically Enlightened fashion, Brocklesby criticizes the Egyptian priests for deceiving the masses with incredible stories of music's power:

> *Hence then arose their fictions of the power of musick upon unorganized matter; for nothing but a violent propensity to enthusiasm, and a wonderful aptitude for deception, could dispose any people to an implicit belief of the poetical fictions, concerning* Apollo, Mercury*, or their priests,* Orpheus, Amphion *and others... (p. 8)*

By contrast, Brocklesby is more impressed with the ancient Greeks, a "nation of the most refined taste, and truest politeness of the whole world" (p. 10). He explains that they initiated their youth in the study of harmony and music because they supposed that by this means their young minds

> *became formed to the admiration and esteem of proportion, order and beauty, in moral as well as natural subjects; by which means they inferred the cause of virtue itself..., which was nothing else than the harmonious regulation of our minds... (pp. 10–11)*

Another cognitive effect Brocklesby notes is that

> *Musick also extends the fancy beyond its ordinary compass, and fills it with the gayest images: and therefore the divine lawgiver of that nation [i.e., Plato in his* Republic*] allows it a principal share in education, as it is observed to penetrate into the most secret affections of the soul, and frequently to produce such agreeable commotions in them, as abolish all discord, and finally, induce an harmonious oeconomy of the subsiding passions. (p. 11)*

Apart from Plato himself, he observes that "others of old" (maybe Pythagoras or Plotinus?) assumed that the soul was imprisoned in its earthly state, and because of this close connection with the body it had "a certain stamp of folly, from the first hour of nativity impressed on it" (p. 11). This stain induced ignorance that made people "act like fools or madmen," and so these "others" recommended that the powers of music should be applied to compose such disorders, and also used to help efforts to shake off the impressions of early sense (p. 12).[7]

Having focused chiefly on Greek representations of music's powers in the next section, at the end of this first chapter Brocklesby returns to the question of how the

[7]Brocklesby includes in a footnote to this paragraph a reference to Aristides Quintilianus's *De musica* bk. 3 p. 157, as found in Meibomius (1652).

mind presently "comes to be affected by the charms of music" (p. 13). His own opinion is quite guarded, since he says that his inclination is to think that the mind has a faculty or disposition to be pleased or displeased with certain airs or systems of sound on the same principle with which it is delighted or dissatisfied with other sense impressions. However, he then says that, according to "some philosophers" (and here he is thinking chiefly of Francis Hutcheson (1694–1747) and his 1725 *Inquiry into the Origin of Our Ideas of Beauty and Virtue*), the cause depends on a certain law of our mind by which we are forced to "a degree of approbation, in proportion to the absolute quantity of uniformity, amidst the greatest degree of variety." It therefore follows that the most affecting compositions "are made up of diverse notes, whose vibrations regularly coincide with each other" (p. 14); in other words, the consonances of music. Here, Brocklesby inserts a lengthy footnote explaining how the consonances of the octave, fifth and third are created and reinforced by the successive vibrations of sounding bodies that coincide with each other, while other vibrations that are not uniform cancel each other out.[8] In this "consonancy," the mind perceives a very striking uniformity amidst the variety of sounds

> *And from this cause, added to a certain association of ideas [this concept could have been taken directly from Locke], either grave, pleasant, melancholy, or otherwise, necessarily excited in us at the simple perception of different sounds, the mind is expanded or contracted, and its images heightened or diminished, by the charms, or influence of sound, just in proportion as these circumstances concur together at that time. (p. 15)*

At this point Brocklesby introduces Hutcheson's concept of the "internal sense," a faculty which is more or less acute and

> *is that which constitutes what we eminently distinguish as* taste*, whence the poet, painter, and statuary, and every class of the truly curious part of mankind, derive their refined pleasures, so incomprehensible to vulgar minds. (p. 16)*

But as well as the intellectual pleasures gained from exercising musical judgment, Brocklesby emphasizes that another source of pleasure from musical compositions is the power of music to imitate natural sounds precisely, an imitative power which

> *breathes forth the airs, tones, accents, sighs, and inflections of the voice, and in a word every sound in nature, which usually impresses certain sentiments and passions of the mind: but these must surely have a more extensive power than the most persuasive eloquence, seeing all words derive their signification and force merely from custom and vague fashion; whereas natural sounds convey an universal expression and energy from the simple dictates of unbiassed [sic] nature. (p. 16)*

[8]It is not exactly clear where Brocklesby gained his understanding of the "coincidence theory" of consonance, although it was already widely accepted in England by the early 1700s (Cohen, 1984; Wardhaugh, 2008).

It is in the sixth and last chapter that Brocklesby returns to the question of what differentiates ancient from modern music, and says more about the internal faculty that discerns uniformity within variety, and eventually results in a more sophisticated pleasure than that generated by simple music.

5 MUSIC, MIND, AND BODY IN BROCKLESBY'S THOUGHT

As already mentioned, Brocklesby's second chapter focuses on the effects of music on the bodily organs, an influence which he steadfastly maintained is dependent on the mind first processing these sensory impressions. The important thing here is that Brocklesby explicitly rejects the "mechanical hypothesis," which he thinks is inadequate to explain the physiology of music, and proffers an alternative account that anticipates vitalist theories of the body current in the later eighteenth century (Brown, 1974). Nevertheless, Brocklesby's concept of the interaction between body and mind still reflects the influence of his education at the medical schools of Edinburgh and Leiden, where he would have been taught a physiology based on the teaching of the Dutch physician and educationalist Boerhaave. Boerhaave principally adopted René Descartes's (1596–1650) conception of man's body as a machine, but also took into account William Harvey's (1578–1657) discovery of pulmonary circulation and Thomas Willis's (1621–1675) mapping of the nervous system and its connections to the brain, where the higher faculties were located (Smith et al., 2012, pp. 160–170).

At the simplest level, this model divided up the body into fibers and fluids made up of differently sized particles that arguably moved according to the mathematical laws that Newton had discovered operated throughout nature (i.e., there is a clear relationship between the macrocosm and the microcosm). It was therefore widely accepted that the human body's motions could be understood in term of mechanics and hydraulics, with the link between body and mind or soul being served by the animal spirits. Essentially still following Galen, this substance was generally thought to be an extremely fine fluid that was distilled from the blood, and flowed through the hollow nerves both to and from the brain and acted as its agent for sensation, perception and motor functioning. (Haller's discovery that there were two types of nerves, the irritable and the sensible, was not published until 1752 and Brocklesby in the *Reflections* does not adopt this distinction even though he was later to replicate Haller's experiments.)

Given the influence of Boerhaave on early-eighteenth-century medical thought, it is striking that Brocklesby is so emphatic in his rejection of the mechanical hypothesis as a means of explaining how music affects the bodily organs.

> *I must beg leave to dissent from that opinion, which ascribes its operation merely to a mechanical undulatory pulsation of the air, on the extremities of the nerves. I shall therefore proceed to shew what extraordinary commotions it excites in the mind, and what remarkable alterations this, as it in a good measure superintends, and actuates the vital and natural functions, will produce on the body. (p. 17)*

At this point Brocklesby goes on to assert that, just as the temperament and complexion of the body is mostly a true index of the moral habits of the mind, so the animal spirits and other parts of the body are greatly influenced by the habits and dispositions of the mind.

> *For as hath been observed, nature herself has assigned to every emotion of the soul, its peculiar cast of the countenance, tone of voice, and manner of gesture. And the whole person, all the features of the face and tones of the voice answer, like strings upon musical instruments, to the impressions made on them by the mind. (pp. 17–18)*

Despite adopting this musical analogy for grasping the sympathy between mind and body Brocklesby nevertheless concludes that

> *to explain by what hidden means, and secret springs of action the mind comes to have any influence upon matter, is, I apprehend, a problem too difficult to be solved upon our present principles of knowledge, though it should even be granted for once, that we may have equally clear ideas of the properties commonly ascribed to spirit, as we can possibly have of those, of material objects; yet the essences of both are equally involved in obscurity, and may probably remain eternally inexplicable to limited beings. (p. 19)*

This does not prevent him in the rest of the second chapter from marshaling arguments to prove that the mechanical hypothesis is false because it is a system that requires that the same quantity of motion be always maintained in the vital and animal spirits. Thus, for example, he points out that the motion of the heart changes when the mind is violently affected with the passions of anger or love, leading to variations in the flow of fluids, which cannot be admitted within the mechanical hypothesis. A further point of disagreement with the mechanists is that their "Epicurean" theory of generation requires all organs of the body to be made simultaneously, something which must be impossible since no motion of any fluid can form all these at the same time. By contrast, Brocklesby thinks the vital functions of all animals, including man, can only be accounted for with reference to a vital principle that needs reinforcing from time to time by the active cause which initially created them–a belief that he says was held by the "Platonists of old" leading him to quote in Latin the following lines of verse: which are translated here as

> *A spirit feeds [the world] within, and, infused throughout its limbs, a mind stirs the mass and mingles itself with the great body.*[9]

This emphasis on an active spirit in nature is certainly in keeping with Brocklesby's Platonic tendencies which we have already encountered, but it also distinctly recalls

[9] *Spiritus intus alit, totosque infusa per artus/Mens agitat molem et magno se corpore miscet*. This comes from the sixth book of the *Aeneid* and is Anchises' philosophizing rather than a philosophical account of the world. I owe this attribution to Leofranc Holford-Strevens.

Newton's belief in the constant intervention of God in the world system (in contrast, for example, to Descartes, who believed that the cosmos had been given a fixed amount of motion at creation and that all bodies are inert until set in motion by an external force).

6 MUSIC'S POWER TO CURE DISEASES OF THE MIND

Following on from his discussion of the animating world spirit, the starting-point for Brocklesby's third chapter "on the powers of music in disorders of the mind" is another Platonic notion, namely, that "Musick composes the motion both of the animal spirits and mind (p. 26)." The source for this statement is attributed to a commentary on Plato by the latter's fifteenth-century editor, Marsilio Ficino (1433–1499), whose scholarship prompted a revival of Platonism in the Renaissance and beyond (Allen and Rees, 2002). Brocklesby cites the 1590 edition of Plato's edited works, which was published in Leiden, the likelihood being that he had obtained or seen the book while he was studying there. The crucial thing for Brocklesby in this context is that Plato believed that the body is more dependent on the mind than the other way around. Indeed, health demands that the "superintending faculties of the mind" are well balanced and are not suffering from the impact of excessive passions, which are indicated by alterations in some parts of the body. In particular he notes that the passions that produce the most alterations are "anger, grief, excessive joy, enthusiasm in religion or love, the panick of fear, and such-like," the significance being that all these are known to have been allayed by music (p. 29). To illustrate this claim, for example, he describes what we would call the "fight or flight" mechanism, explaining that the passion of fear sends the spirits to the muscles of the knees which makes the legs instantly ready to move the body out of harm's way.

> *But it is the nature of fear, as well as of all the other passions, to increase and become habitual by indulgence; and in consequence of this, all its effects upon the body are produc'd in like manner more or less, according to the frequency of it experience'd in the mind: for the organs of the body are under a sort of mechanical necessity to keep pace with the sensations of the mind. (p. 27)*

By way of a remedy against fear, Brocklesby notes that the ancient Greeks prevented its ill consequences among their soldiers when their armies took to the field by providing musicians playing the best kind of martial music. Indeed, he remarks that many soldiers have told him how their fear was overcome once "the martial trumpet and other warlike instruments had roused their sinking spirits, and inspired them afresh with hopes of victory or contempt of death" (p. 29).

Brocklesby then moves on to discuss the pernicious effects of anger on the body; a passion, which he explains, has many of the same symptoms as madness, though of a shorter duration. We can gloss over his references to ancient and more modern authorities that describe the ailments caused by giving way to anger (e.g., hemorrhages, convulsions, fevers, palsies, etc.), and simply note that his discussion of sorrow (associated with disorders of the stomach and liver, and nervous fevers), and also of the power of the imagination in causing and curing diseases, leads him to conclude that,

> *Seeing then the mind is so powerful an agent in particular diseases, I see no reason why the efficacy of musick should not be tried in many disorders which arise in the animal constitution, from an undue balance of the mental affections; for musick composes the irregular motion of the animal spirits, and more especially allays the inordinate passion of grief and sorrow. (pp. 33–34)*

For his ancient example of this healing power he refers to a passage in Homer's *Iliad* where Achilles soothed his "heartfelt grief for the loss of his mistress with the melodious strains of his harp" (p 34). Perhaps of more interest to us, however, is Brocklesby's comparatively recent example of the cure of grief through music, the earliest English example that I know of where a physician is credited with prescribing music to assuage his patient's mental affliction. Brocklesby recounts the story told to him by an Edinburgh physician of a gentleman who lost two of his three sons, and was himself injured, in the unsuccessful Jacobite uprising of 1715. Although the gentleman survived, because of his inordinate grief and injured pride he fell into a nervous fever that led him to a deep melancholy in which he refused food and medicine and shunned all communication with the outside world. His physician, who knew that his patient had formerly loved playing the harp, took the unusual step of encouraging the man's friends to engage one of the best harpists to play him "soft and solemn" sounds that had formerly given him pleasure. The results were dramatic: as soon as one or two pieces were played "the patient discovered an uncommon emotion both of body and mind."[10] The experiment was repeated on a daily basis and gradually the sick person was induced to speak and take his medicines, "til at length he perfectly recover'd his former state of health" (pp. 34–35).

Having dealt with anger and grief, Brocklesby tells his readers that excessive joy is also a cause of symptoms, such as convulsions, tears, and swooning, and, in some circumstances, leads to death itself. He does not bother to enlarge on this phenomenon, since most people have observed something similar in their own experience. However, he gives a second contemporary example of how music can profoundly alter states of mind, which was related to him by the blind organist and composer John Stanley (1712–1786). The anecdote told of a child of under 2 years old whose parents (who were musical themselves) one day noticed that he was full of good humor after hearing some sprightly airs of music. The father and Stanley decided to experiment with different types of music and found that, when they played some "chromatic and graver strains," the child became melancholy and sad, "which temper was remov'd as soon as pleasanter music was play'd" (p. 37). Indeed they claimed

[10]Brocklesby is using the word "emotion" in this context to signify violent motion, a meaning which has fallen out of use since the nineteenth century when emotions became subject to psychological investigation.

they could raise and allay joy and grief by turns in the infant's mind solely by the art of music. Again, this is the earliest account of such experiments that I am aware of, although they hardly conform to present-day standards of testing.

The remainder of the third chapter addresses enthusiasm in religion and love, a significant source for the first of these topics being Anthony Ashley Cooper, the third Earl of Shaftesbury's (1671–1713) "Letter concerning Enthusiasm," which first appeared in 1708 but was later published along with his other writings in 1711 and reprinted frequently thereafter.[11] With this text in mind, Brocklesby explains that there are some ailments which arise from false conceptions about religion and an overheated imagination, and that every nation at some point experiences "public disadvantages from the visionary dreams of enthusiasts, in what they falsly [sic] call religion"

> *for the mind once unhing'd from the solid basis of right reason, passively yields to the transports of an overheated imagination, and upon a bare supposition of a Divine presence, its views and images become too vast and immane [i.e., huge, monstrous in character] for the scanty human vessel to contain. (p. 37)*

When this is the case, as Shaftesbury has shown in his study, the symptoms of this malady or form of ecstasy (quaking and convulsions, extemporary prayer, prophecy, singing, etc.) closely resemble those of "downright madness." Although he admits the possibility of a real divine impulse that inspired some ancient prophets, Brocklesby thinks that most enthusiasts, both now and in the distant past, are simply deluded by agitations of their animal spirits—the problem being that the tokens of an imaginary divine impulse are the same as the most real, making the behavior of modern fanatics identical to that of the Sybil in antiquity. The difference is that in ancient times they delivered their inspiration in "pompous words and metaphors" to the sound of musical instruments, while in modern times "a strained voice with an affected twang through the throat and nose, supply the want of musick, but too often has the same rapturous effects on the hearers" (p. 40).[12] Brocklesby concludes this part of the chapter with a lengthy quotation from the ancient music theorist Aristides Quintilianus (third century AD), who talks of using music to mitigate the effects of possession as it brings the sufferer to a right constitution of body and mind.[13] As Brocklesby points out, this is demonstrated most notably in the case of Saul, where David expelled the evil spirit in him through playing on the harp (as told in 1 *Samuel* xvi. 23).

[11]Brocklesby's acknowledged source for this text is the first volume of Shaftesbury's *Characteristicks of Men, Manners, Opinions, Times*, p. 50. This collection edition of Shaftesbury's writings was first published in London, in 1711, but there was a more recent edition of 1744–1745 that Brocklesby could have consulted. It is notable that Shaftesbury has also been identified as a Deist (Shaftesbury, 1711).
[12]The "modern" enthusiasts whose actions are described here by Brocklesby were doubtless the members of a French sect of "prophets," who first arrived in England in 1706 and provided the stimulus to Shaftesbury's "Letter" first published 2 years later (Laborie, 2010).
[13]Brocklesbury cites the edition of Aristides Quintilianus that was translated by Marcus Meibom as part of his *Antiquae musicae auctores septem* (Meibomius, 1652, bk 2 p. 65).

In the final section of the chapter Brocklesby turns to the passion of extravagant love, which he says with its jealous thoughts leads even the wisest men into a condition of folly or downright madness. The ancient examples given show that nothing had so great an influence as "the melodious charms of just composition" on their turbulent mental states. Moreover, they also show that symptoms, such as sleeplessness, could be overcome by "soft and soothing strains of distant music," leading to welcome repose in the listener. Indeed, he notes that the practice of nighttime music to aid repose was in high repute amongst the Pythagoreans, the ancient sect of philosophers who likewise played music at dawn to urge themselves into action (p. 45).[14] In a later section, Brocklesby shows that he also admired the Pythagoreans for their long life, which he believed was aided by their habit of regular music making.

7 THE CURE OF DISEASES COMPOUNDED OF AFFECTIONS OF THE BODY AND MIND

The next category of diseases that Brocklesby focuses on in chapter 4 comprise those which proceed from a perturbation of the body but then go on to affect the mind. These notably include delirium, melancholy, frenzy and mania, all of which he says can be helped by music. He observes that all simple perceptions of the mind are primarily the effects of external impulses that are somehow impressed on the organs of sense, which in their turn convey the images of external things to the sensitive part in us, where the mind resides;

> *for the mind perceives nothing but what is present with it; but when a similar impulse is made on our sensory, from the fluids themselves so modified by an alteration of some internal parts, similar causes will have like effects and the same kind of perception will be present to the mind; and if this modification of the sensitive organs be sufficiently strong and lasting, it will consequently preclude every sensation besides, while the mind is only attentive to this creature of its own fancy. (pp. 45–46)*

When this happens the patient may be said to be in a delirium, a disorder that presupposes a "morbid affection of the brain or nerves," which can arise from "obstructions, repletions, or inanition, an irregular motion of the fluids, and such like causes" (p. 46). All the extraordinary symptoms that a delirious person can exhibit (most of which Brocklesby says were long since identified by Hippocrates) stem from these irregularities. The general method of treating this disease when it is accompanied with a fever is to blister and bathe the feet in warm water, and in some cases bleeding, purging, and vomiting are sometimes effective. But according to Brocklesby the best remedy to relieve the patient is music,

[14] Brocklesby's reference here is to 'Cicero's Tusc. Quaest. 4', by which he means Cicero's *Tusculan Disputations,* Book 4, On the Passions. I do not know exactly which Latin edition he was quoting from at this point.

> *As it awakes the attention in the most agreeable manner, and relieves the anxious mind, by substituting a more agreeable series of images; by which means it subverts that habit which was now become almost insuperable, and gradually reduces the mental faculties to the due standard of common sense. (pp. 48–49)*

Rather than drawing on ancient evidence, Brocklesby refers to a comparatively recent case study of music curing delirium, this being the account given in the *Histoire de l'Académie des Sciences, année 1707* that *was* published in Paris in 1730.[15] In this account it is the patient himself who happened to be knowledgeable in music, and who persuaded the doctor to arrange a concert of music in his sickroom. As soon as the music started, his symptoms abated and his fever was suspended, but all these returned when it stopped. On the basis of this success it was arranged that someone would sing and dance before him every night, and in 10 days he was restored to perfect health.

The next disease to be considered by Brocklesby is melancholia, a term then referring to a delirium that has no fever, and where the mind is particularly fixed to one object. Those most prone to this disorder include persons of "a sallow bilious complexion, and of an adust [sic] temperament,"[16] and especially those who live in warm climates because their "radical moisture" is dissipated through perspiration. This leads Brocklesby to embark on a long discussion about the effects of heat, cold and other environmental factors on people's health, especially the impact of the air on temperament. Having noted how a change in climate leads to gross changes in the body, he says it is no wonder that the subtle vessels of the brain should be affected; indeed

> *thought itself seems in us very much to depend on the organization of the brain, and the motion of its contents; so that the genius of every nation must receive a bias some way or other from the temperature of the climate. (p. 54)*

Another long section follows where Brocklesby considers the temperament of different nations, and how often warlike and brave (national) characters become effeminate and unmanly when discipline is relaxed. This digression has nothing to say about music, which only reappears at the point when he introduces another topic,

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[15] Anon (1730a). *Histoire de l'Académie des Sciences, année 1707*. "Diverses observations de physique générale," sec. 1, pp. 7–8. Brocklesby may not have read the original report since it is quite likely that he found a summary of its contents in the anonymous article on "Surprising Instances of the Effects of Music in Acute Fevers, and for the Cure of the Bite of the Tarantula" that was published in *The Gentleman's Magazine* (Anon, 1743).

[16] This sentence reminds us that even in the mid-eighteenth century physicians still used the humoral system as a framework for their understanding of sickness and disease. Someone with an "adust temperament" (p. 50) (a term that went back to the Middle Ages) suffered from one or more of the four bodily humors becoming overheated and dried out, leading to a form of "unnatural" melancholy. I assume Brocklesby learned this doctrine at medical school, but equally well he might be drawing on Robert Burton's (1621) encyclopedic *Anatomy of Melancholy*, which became a reference-point for all later discussions of the topic. For more on Burton's account of adust melancholy and an introduction to the humoral system in general, see Gowland (2006, pp. 33–72, especially pp. 64–65).

namely, the similarity of symptoms between women in southeast Italy who suffer from chlorosis[17] and hysterical affections, and those women in the same region who have been poisoned by the Tarantula, all these diseases being cured by music. As we have already seen, the literature on Tarantism flourished in the seventeenth century thanks to Kircher, but Brocklesby chiefly relies on two more recent sources, both published in London, namely, Georgio Baglivi's (1704) *Practice of Physic* and Richard Mead's (1702) *Mechanical Account of Poisons*. Although differing on points of detail, these authorities agree that the disease of Tarantism is cured through the action of music, whether or not this melancholy affliction is actually caused by a spider's poisonous bite. Brocklesby himself concludes that he cannot tell what the real origins of the disease are, but it evidently returns annually in the province of Apulia, the hottest part of Italy, and is cured by music. He observes that the same music has to be used each year, and although each person responds to a different tune, it is generally the "briskest airs" that serve to restore the health by inciting people to dance in an "extasick [sic] way…'till their former health of body and mind is restored" (p. 60).[18]

Brockelsby at this point moves on to consider using music in the cure of frenzy, a disorder that has all the symptoms of a delirium as well as an acute fever at the same time. For evidence of music curing this disease he refers once more to the *Histoire de l'Académie des Sciences*, notably to the volume covering 1708 in which a certain Monsieur de Mandajor reports on saving a dancing master's life with music (Anon, 1730b).[19] Brocklesby explains that, although those close to the man objected, de Mandajor got a violinist to play some of the dying patient's favorite tunes, at which point the latter tried to keep time with the music with his hands and by nodding his head. Left to himself he fell into a deep sleep and had a "happy crisis," after which his health was eventually restored. For Brocklesby, this modern case of lulling the disordered senses is matched by examples from some of the best authors in antiquity, which should help to persuade people of music's curative powers.

At last Brocklesby explains what has led him to write learnedly about the subject of music's power on diseases of the mind and body: it is the lack of success among present-day physicians in treating maniacs that has prompted him to marshal the evidence in favor of music. He notes that modern practice has few remedies for madness beyond general evacuations, nervous medicines and cold bathing, but the slender success of these remedies

[17]Anemia caused by iron deficiency, especially in adolescent girls, causing a pale, faintly greenish complexion.

[18]At this point Brocklesbury refers to "Marsil. Ficin. Comment. in Platon," p. 787, Ficino being one of the first Renaissance authors to talk about the Tarantula. (This work is listed in Ficino, 1590.) For an introduction to the literature on Tarantism see the articles in Horden (1999), Part 4, "Tarantism," pp. 249–352.

[19]Anon. (1730b), "Diverses observations de physique générale," sec. 1, pp. 22–23. Again, the source for this account and Brocklesby's treatment of Tarantism may have been the article found in the *Gentleman's Magazine* of 1743 (Anon, 1743).

> *demonstrate their insufficiency, and therefore calls on the friends to society, to revive that antient [sic] practice [of music] which was attended with such surprising and salutary effects. (p. 63)*

Although he does not claim to have actually tried this method for himself, Brocklesby suggests that music can be used effectively in conjunction with other medicines, especially if the patient is musical. In conventional treatments of madness it is necessary to use extremely large doses of medicine or purgatives to get any response from the patient at all, who can also stand extreme cold and lack of food and sleep for long periods because his mind's attention is "suspended or unduly stretch'd." Brocklesby suggests that music can be used to sooth the affections,

> *and as it were to re-establish the former union of the body and mind, by the powers of musick, in that interval of time, proper medicines might be administred [sic] to better purpose, by which means the material offending cause may be evacuated, which could never be reached whilst the mind's attention to the bodily organs so far ceased. (pp. 63–64)*

Brocklesby goes on to remark that this method of curing madness had already been touched on in the previous century by Thomas Willis in his 1664 *Cerebri anatome*, a brief section of which Brocklesby quotes in a footnote to his own text (p. 64). It suggests that music can allay turbulent passions by enchanting the spirits in the breast, suppressing any disorders stirred up by them and moderating them "as if to the rhythm and melody of a dance" (*velut ad tripudii numeros et modos componit*).[20] I would say that Willis was hardly offering guidelines to readers here, and so it is perhaps not surprising that there had apparently been no attempt to follow up this remark, which after all was a literary if not a medical commonplace. However, for Brocklesby this neglect "shows . . . how difficult a matter it is for a private man, even of great abilities, to establish any opinion, when the sentiments of his contemporaries do not nearly coincide with his own" (p. 64). I have already shown that Brocklesby makes a point of the initial resistance that the physicians put up in the two French examples of a musical cure, the kind of resistance which he is anxious to overcome by marshaling a wealth of ancient and some more modern cases in the hope of bringing about a general shift in attitude toward this form of musical treatment.

As part of his argument Brocklesby observes that the operations of all medicines depend almost entirely on the motion they appease or excite, and that music is no different from this in that it is a kind of universal incentive to motion or rest. What makes the difference is that music seems to work on the "intelligent principle" itself, as well as solacing the mind, soothing the passions and maintaining the "blissful union" between the healthy mind and body. In fact Brocklesby continues, in a similarly Platonic vein, to claim that it is not only music that can have this unifying

[20] T. Willis (1664). *Cerebri Anatome*, cap. 17. This passage is part of a larger digression by Willis on the phenomenon of tone deafness on the one hand and that of a 'musical ear' on the other. For further discussion, see Lorch (2010) and Gouk (2014).

effect, but whatever is "harmonious and agreeable to the senses" might also work in a similar way, such as delightful prospects of nature, elegant buildings, fine paintings, refreshing odors and the sensations of touch and taste

> *the benefits of which are sometimes outweighed by indulgence in them, beyond the limits of just proportion, which may be termed a kind of universal harmony. (p. 65)*[21]

By way of conclusion to his lengthy chapter, Brocklesby returns once more to the ancients and the diseases they reportedly used music to cure, information about which he apparently drew from "modern" editions (i.e., since the invention of printing) of ancient medical texts.[22] For example, he cites the 1709 Amman edition of Caelius Aurelianus (fl. 5th cent AD), whose work on acute and chronic diseases includes an account of a man who cured sciatica by putting his instrument on the affected part and then playing it.[23] He also refers to Aulus Gellius's (c. 125–after 180 AD) description of the musical cure of the bites of venomous serpents and scorpions.[24] Brocklesby conjectures that, just as in the case of the Tarantula, where music is supposed to be a remedy for its poisonous bite, such bites were not always harmful, and sufferers might therefore have recovered spontaneously even without any form of musical therapy being involved.

After this focus on musical remedies for sciatica and poison bites, Brocklesby goes on to say that the most comprehensive source for examples of musical cures is Martianus Capella's (fl. 5th cent AD) *De nuptis philologiae et Mercurii* which he was able to read in the 1652 edition of Marcus Meibom.[25] Brocklesby offers an English translation of the relevant passage:

> *I have (says he) [i.e. Martianus Capella] often cured disorders of the mind as well as the body with musick, sometimes franticks with symphony; Damon, one of my tribe, restrained some petulant and drunken young men with grave strains, our ancestors cured fevers and stopped wounds with harmony.* Asclepiades *used* musick *for disorders of the ears; who is ignorant (adds he) that ischiadic pains [i.e. of the ischium, a pelvic bone] are discussed [sic] by the melody of the organ.* Xenocrates *by this means cured Lympaticks, and the vision-struck; besides it is well known that* Thales *of* Crete *removed a pestilence and other diseases by the sweetness of his lyre; birds too are charmed with pipes, and elephants tamed by the sound of an organ. (pp. 67–68)*

[21]This concept of "just proportion" as a kind of universal harmony appears to be musically based, being an ideal system of tuning that replaced Pythagorean intonation during the late sixteenth and seventeenth centuries. For further discussion, see Cohen (1984).

[22]Unfortunately, Brocklesby's citation of titles is somewhat cryptic, so I have not been able to identify most of them. For example, who was the editor Vanderlind that is mentioned in note (a) on p. 66? He has not come up in any searches I have made in a whole range of catalogues.

[23]The volume which I have been able to track down is *Caelii Aureliani . . . de morbis acutis & chronicis libri viii, J.C. Amman recens. notulasque adjecit. accedunt.* Amsterdam, 1709.

[24]This is presumably referring to Gellius's *Attic Nights*, Book 4 although he does not say so explicitly.

[25]See Meibomius (1652), bk. 9: 179.

Brocklesby does not indicate which of these examples strikes him as true or false, although he seems to be moving toward a more skeptical position after this summary, when he goes on to mention the doctrine of the pulse as taught by Herophilus (335–280 BC), who, he says, "seems to have been the greatest Enthusiast in this matter, in supposing the ordinary tenor of the pulse was regulated entirely in harmonic proportion" (p. 68). Brocklesby explains that this pulse lore, which excluded any other form of diagnosis, was already criticized by authors such as Pliny, who, he claims, thought it was an "over refined speculation."[26] Brocklesby thinks that the "strange accounts" of the effects of music on dolphins and other animals might also have been the product of over-refined speculation, claims that if made seriously in the present would demonstrate credulity rather than sound judgment (p. 69).

8 MUSIC AND THE RETARDATION OF OLD AGE

It is notable that Brocklesby devotes an entire chapter to the "retardation of old age by the application of musick," and urges physicians to take this practice seriously. Indeed, he suggests that when a doctor has acquired enough knowledge about the "springs of life" and things that hinder their free action, it is his philosophical duty to try and discover the means of "retarding the motion of some wheels of this complex machine" (p. 70). Despite having rejected a mechanical or materialist theory of life, Brocklesby now compares the human (as well as animal) body to a piece of clockwork, its life span being determined by the quantity of absolute motion contained within it, a period that can be extended by various but mostly unused means of slowing this down. He observes that one of the principal causes of decay and premature death to most people in "this busy world" is the waste of animal spirits, which the mind uses in producing innumerable alterations on the body. This process of depletion should make our chief goal the production of a fresh supply of spirits or, failing this, the conservation of such spirits through the control of strong passions.

Brocklesby is clear that the right steps for the prolongation of life will never be taken by the "vulgar herd of mankind," who are for the most part unwilling to forgo the "irregular gratification of each passing fancy" for some future benefit. Also he suspects that the steps themselves are so complex they can only be practiced by a few rather than the bulk of mankind. These rare beings prove to be philosophers, the historical evidence being that of most people who have achieved a very long life, "philosophic and abstemious men have ever been remarkable" (p. 72). In antiquity, these included men such as Democritus and Plato; in modern times, they include "mathematical philosophers in particular" (p. 72) (although he does not mention whom he has in mind). Significantly, we find Brocklesby citing Francis Bacon as a source of inspiration, who apparently asserted in his *History of Life and Death* that

[26] Brocklesby cryptically cites "Pliny, L. 29. §v. & L.3 C. 10." but there are no corresponding references in Pliny's *Natural History*, nor is there any mention of his criticism of Herophilus.

"temperance and a Pythagoric life" are most conducive to longevity.[27] By way of amplifying this claim, Brocklesby notes that Plato and Pythagoras were both masters of music and geometry, suggesting that the use of music, and frequent attention to it, might promote long life. Given that he has already demonstrated music's power to divert and maintain the spirits, and that Bacon says that an invigoration of the spirits is the best way to prolong life, Brocklesby proposes that it might be a good idea for people pursuing this goal to put music to trial and to "recreate their spirits every day with a piece of good music" (p. 74).

Anticipating possible responses to this proposal, Brocklesby admits that it would be a nice idea to find out whether music masters have a longer life expectancy than other people. Confessing himself "at a loss as to facts" about this subject, he suggests that discovering that musicians' lives are no longer than those of other men should not deter the curious from trying these musical experiments. His explanation has a distinctly Platonic air: the problem for musicians is that they abandon the "severity and chastity of composition" in favor of public taste that tends toward the florid and amorous, and as a result soon come to relish the "gaudy and luscious in life" (p. 74). Thus, instead of promoting the desirable ends that all the polite arts are capable of, their music leads to great inconveniences. Most damning of all,

> *Our musicians besides are mostly supported at theatres and other public places, where some irregularities are ever unavoidable, which are more than capable of destroying the natural effects of the best musick on vulgar minds. (p. 74)*

9 ANCIENTS AND MODERNS COMPARED

By way of conclusion to his book, in chapter 6 Brocklesby considers the key question that arises when ancient and modern music are compared: why is it that most present-day music does not affect the listener as strongly as ancient music apparently moved its auditors, according to their poets and philosophers? The two effects he singles out are the magical power to enchant men and beasts and other living things; and the power to alter rapidly people's very nature; that is, to raise and quell the strongest passions. Following Sir William Temple's (1628–1699) influential 1690 *Essay on Ancient and Modern Learning*, Brocklesby observes that the learned agree we have lost the kind of music the ancients practiced, and, citing Isaac Vossius's (1618–1699) (1673) *De poematum cantu et viribus rhythmi*, goes on to explain that this loss is generally ascribed to three reasons. The first is that little regard is paid in modern compositions to "the laws of the rhythmus or variation of time, which is the very soul of harmony" (p. 76). Second, our instruments are not well contrived (and by this he

[27]The nearest reference to a Pythagorean way of life I have found in Bacon's *History of Life and Death* (originally published in Latin in 1623) is in the section on "The operations upon their spirits that they may retain their youth and renew their vigour," § 69. See http://www.sirbacon.org/historylifedeath.htm (accessed 29 July 2014).

means that their tuning makes it difficult to play pure consonances); and thirdly, our musicians "insist too much upon reiterated quavers on the same notes, and introduce too many slurs into the composition" (p. 77).

Brocklesby thinks the first reason is well demonstrated by the way that only the best modern airs keep to the "laws of the rhythmus"; that is, the rhythms of long and short syllables in the verses are properly matched by the measures of music to which they are set. Indeed, the exceptions proving the rule that modern verse settings are poor turn out to be none other than Georg Friedrich Handel's (1685–1759) music for *Milton's L'Allegro, il Penseroso ed il Moderato*, and also that for *Acis and Galatea*, works that of all his music keep "truest to the rhythmus and therefore afford more delight in general, than anything else of the kind" (p. 77). Although he does not say so, the crucial feature of *L'Allegro* is that its two main characters are personifications of contrasting moods, the "joyful" man and the "melancholic" or "contemplative" man, passions which are expressed through the music used to accompany the verses that they sing, which are also indicative of their inner states.

Here, Brocklesby seems to be speaking from direct experience of Handel's music (or maybe he is passing on an opinion formed by someone else), although it is not clear when or where in London he would have heard it. L'*Allegro* was premiered in February 1740 at the Royal Theatre of Lincoln's Inn Fields, while *Acis*, composed during 1718–1719, was performed regularly in London up through 1741. Since Brocklesby only moved to London around 1745, it is most likely that he encountered Handel's works in concert versions; there were numerous venues in the capital where music was commercially available and Handel's music was frequently performed, often by the composer himself. By this time, Handel was a naturalized Englishman (he had officially become a citizen in 1727) and his works were seen to embody all that was best in English music.

Brocklesby has little to say on the subject of instruments, except that, although he accepts that modern instruments have "unavoidable imperfections" (and by this I think he means imperfections in tuning), he does not think that Vossius is right to claim that all ancient ones were better. Of more concern to Brocklesby is the third observation, that modern musicians are attached to "frequent quavering" that obscures for listeners the relationship in a piece between the whole and the symmetry of its parts. I think that here he is talking about the embellishments (e.g., trills, etc.) that Baroque singers customarily used to decorate the vocal line, which in extreme cases could be quite obscured by such ornamentation. The problem with this for Brocklesby is that the ability to perceive structural, especially proportional, relationships proves to be an essential dimension of the refined enjoyment of music as well as painting and other fine arts.

This comment leads Brocklesby to reflect on the processes by which this inner faculty is gradually developed. He explains that, before such taste is cultivated our minds are easily pleased with the first impulses of sense and novelty, making us more likely to enjoy a simple sonnet rather than more complex consort music, which needs reason and induction to be properly appreciated. However, once these skills are developed we have a more exacting standard which simple music does not always measure up to, because the performance "falls so far short of the canon or model pre-established in the mind, that the pleasure abates in proportion" (p. 79). At the same time, engaging with complex music is difficult and relies on induction to discern how the parts are structured, how they relate to each other and are suited to the whole composition. In sum, Brocklesby thinks that, despite this difficulty, the pleasure enjoyed by the critical judge is preferable to that of a man with strong natural taste, which is "little more than the effect of headlong sense and blind opinion" (p. 80). Indeed, a general lack of refinement might be why modern compositions fail to transport listeners in the way that ancient music apparently did, his argument being that a perfect judge of both would actually prefer that of the moderns, because of its greater cultivation of uniformity amidst variety.

At this point, Brocklesby ends his treatise rather summarily, by suggesting that gentlemen still curious about the ancient-modern debate should peruse Vossius's treatise since the author has already discussed the topic exhaustively. He then concludes with a brief reference to the scale system used by the ancients and the fact that some modern authors have criticized this and replaced it with a more satisfactory alternative system. Although he does not say so explicitly, this discussion is about the difference between the Pythagorean scale, which dominated Western music theory until the sixteenth century, and the so-called just scale, which the Italian music theorist Gioseffo Zarlino adopted as the norm in his *Istitutioni harmoniche* in 1558, and which later theorists accepted (Cohen, 1984). It is clear that Brocklesby understands the essential differences between the two systems (e.g., the harsh major and minor thirds in Pythagorean intonation; the limitation of the just scale to single keys), but he recognizes that the subject is too abstruse for the essay in hand. Consequently he refers the inquisitive reader to a letter published in 1746, in number 481 of the *Philosophical Transactions*. This was by Dr. Johann Christ of Pepusch (1667–1752), a German-born composer who spent most of his working life in England, and who was interested in the theory of ancient music as well as that of modern times (Pepusch, 1746).

10 CONCLUSIONS

A chapter on Brocklesby appears in this volume because his *Reflections* is one of the earliest English medical sources to focus explicitly on the use of music as a therapy in cases of severe mental distress, which contemporaries understood as being caused by unruly passions. His Baconian emphasis on the need to build up experiments, observations, and histories to support the medical case for music therapy led him to put together a range of evidence for its healing powers, which included some "modern" or contemporary case studies as well as those that went back to unspecified periods of ancient history. It is this relatively systematic approach to his sources that has earned Brocklesby's reputation as being a pivotal figure in the history of music therapy (Rorke, 2001). As I hope to have made clear, however, there is much more to be learned from Brocklesby's idiosyncratic essay if we broaden our attention to encompass the other contents of the book.

Published when the author was 29, the *Reflections* provides a window onto Brocklesby's thinking about music's relationship to medicine, its curative potential, and its role in education and society more generally. Although explicitly styled as a series of reflections rather than a systematic treatise, his essay has a scholarly feel about it because of his use of footnotes to identify the eclectic body of printed sources that informs his argument. The range of his interests is revealed to be quite ambitious, since typically for Enlightenment scholarship Brocklesby does not limit himself to present-day material but also harks back to ancient times, the general assumption being that it was possible to separate out nuggets of useful knowledge about music's place in antiquity from the more fanciful thinking that was such a feature of ancient learning. In a nutshell, Brocklesby regarded Egyptian wisdom as suspect and was much more favorably inclined toward the ancient Greek philosophers and their establishment of a harmonious society along the lines suggested by Plato in his *Republic*.

Although there is no evidence that he ever learned to play a musical instrument, his essay, I believe, reveals a love of music (particularly Handel's?), and an awareness of the processes involved in its cultivation by the higher faculties of the mind. This is made particularly clear in Brocklesby's first and final chapters, where he deliberately distinguishes between simple music that immediately strikes the listener and moves the passions, and more complex music, or harmony, which requires a more sophisticated exercise of musical appreciation involving memory and judgment that has to be deliberately learned. Indeed, he suggests that this exercise of taste applies to other areas of a civilized life, such as the enjoyment of fine paintings and the appreciation of good architecture, because these are also harmonious in their natures; the only danger being that it is possible to overindulge in these and other pleasures of the senses (p. 65).

Throughout his book, Brocklesby displays a particular respect for Plato's views on the power of music, and indeed it seems that he was strongly influenced by Neo-Platonic philosophy in the way that he saw music as an organizing principle of the universe (the macrocosm) as well as that of the body and soul (the microcosm). Also his insistence on the similarity between the vibrating matter filling the universe (*spiritus*) and the animal spirit that links the body and soul suggests a similar influence at work. Indeed, reading between the lines, the same Platonic influence also appears to lie behind his avocation of using music in everyday life as an aid to sleeping and waking, and in the longer term as a benefit in old age, because of its capacity to restore and regenerate the spirits. Although he clearly believed music to be potentially a good thing for society in general, except when it became too commercialized, I think that in Brocklesby's mind its function in daily life was associated particularly with the learned academies of Pythagoras and Plato, communities that he understood had been designed to train their disciples in mathematics and philosophy before they devoted themselves to higher metaphysical truths. Is it too fanciful to imagine that Brocklesby, as a fellow of the Royal Society, a philosopher and a man of letters who was cultivated in music, saw himself following in the footsteps of these ancient philosophers?

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CHAPTER

Neurological implications and neuropsychological considerations on folk music and dance

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Abstract

Neurological and neuropsychological aspects of folk music and traditional dance have been poorly investigated by historical and scientific literature. Some of these performances could be indeed the manifestation of latent pathological conditions or the expression of liberation rituals. This chapter aimed at analyzing the relationships between traditional dance, folk music, and neurological and psychiatric disorders. Since ancient times, dance has been used in the individual or collective as treatment of some diseases, including epilepsy and movement disorders (dyskinesia, chorea, etc.). Dionysia in Ancient Greece, St. Vitus dance in the Middle Age, tarantism and other traditional dances of southern Italy and of non-Western countries might be credited as curative rituals of these neurological and psychiatric conditions. During the nineteenth century, dance was also used for the treatment of psychiatric patients; the relationship between dance and insanity could also be reflected in classical ballets and music of that period. Nowadays, neuropsychiatric manifestations could also be evidenced in modern dances (mass fainting at rock concerts, flash mobs); some ballroom dances are commonly used for the rehabilitation of patients suffering from neurodegenerative and psychiatric conditions. Interdisciplinary research on these subjects (ethnomusicology and cultural anthropology, clinical neurology and dynamic psychology, neuroradiology and neurophysiology, and socioneurology and neuromusicology) should be increased.

Keywords

folk dance, folk music, chorea, tics, dyskinesia, St. Vitus dance, choreomania, ballet, tarantism, flash mob

1 INTRODUCTION

Folk dance and music—originally developed in the countryside, in rural villages, and in the suburbs—may be looked upon as an expression of an alternative vision of world. They are generally transmitted through an oral tradition, often related to national or regional cultures, so playing an important role in social cohesion, especially in immigrant societies (Cinque, 1987). In particular, folk dance and music play a fundamental part in religious festivals, and historical anniversary or personal events (birthdays, weddings, and funerals), usually being performed by people with little or no professional training, following traditional patterns and models.

Music and dance being orally and visually transmitted may develop many variants, since this kind of transmission cannot produce step-for-step and note-for-note accuracy. Furthermore, since people could have mixed backgrounds, traditional dance and music sometimes appear as a blend of influences. Therefore, it comes as no surprise that amazing similarities and contaminations may be found in dances and music derived from different cultural contexts, such as the lower classes in the Western world and the primitive societies in developing countries (Bartók, 1977; Bohlman, 2008; Leydi, 2008).

The neurological and neuropsychological substrates underlying these performances have been poorly analyzed in scientific and historical literature. They could be not only the manifestation of latent or evident pathological conditions, but also the expression of normal neuropsychological mechanisms, which assume an important role in an emotional and physical "liberation" of the individual. The first part of this chapter investigates the connections between dance and neurological and psychiatric disorders throughout the centuries, while the final part is mainly focused on neurological and neuropsychological aspects, which could be found in folk music and traditional dances.

2 CATHARTIC AND THERAPEUTIC ROLE OF DANCE IN THE ANCIENT WORLD

Dance is a spontaneous expression of emotion and feelings, which uses a language of action, intention, and aspiration.

> *The dance is, undoubtedly, the oldest of the arts, for rhythm was the first-born element and was created for and with the dance. No sooner did man walk than he began to give vent to his simple emotions by swaying his body and beating his feet. This then, is the origin and definition of the dance: expression of emotion through rhythmic, physical movement.*
>
> **La Meri (1933), p. 21**

Sense of rhythm is a peculiar characteristic of humans, since primates and other animals do not show similar appreciation of it.

> *There is not a single report of an animal being trained to tap, peck, or move in synchrony with an auditory beat. No doubt many pet lovers will dispute this notion, and many animals, from the Lippizaner horses of the Spanish Riding School of Vienna to performing circus animals appear to 'dance' to music. It is not clear whether they are doing so or are responding to subtle visual or tactile cues from the humans around them.*
>
> **Sacks (2007), pp. 239–240**

According to the neurobiologist Freeman (2000), dance played a central evolutionary role in enabling the bonding necessary to create human societies. Dance was indeed used in primitive societies to build up hostility and gather courage before battle but also in courtship rituals.

Since ancient times, dance has not only been a collective entertainment and celebration but also has allowed personal—and somehow therapeutic—enjoyment and gratification. As in the classical theatrical plays of Greek tragedians, Aeschylus, Sophocles, and Euripides,[1] traditional dance had a "cathartic" effect of purgation and purification among the participants.

The early Indians and Egyptians used music therapeutically and prescribed it accompanied by dancing. In the Hebrew tradition, dance had a positive value, being considered as an effective way people could show their gratitude to God. For example, after the consecration of the Ark of the Covenant, King David is said to dance "before the Lord with all his might, wearing a priestly garment" (2 Samuel 6:14). In the Greco-Roman world, the relationship between medicine, music, and dance is well evidenced by the fact that Apollo, one of the most ancient healing deities, was assumed as the leader of the Muses[2] and director of their choir (Grimal, 1990).

Therapeutic music and dance have mainly been used to treat disorders of the mind, and, in particular, to relieve melancholy and apathy, and to tranquilize the agitated and the insane. The sedative and relaxing effects of music and rhythm on the human emotions were well known in the ancient times; classical myths and legends reported that music and songs of the poet Orpheus could charm wild beasts and all living beings, and even stones (Grimal, 1990).

Leaving myths aside, philosophers, early scientists, and naturalists, such as Pythagoras of Samos, Thales of Miletus, and Aristotle, suggested using the emotion derived from listening of music for the treatment of mental illnesses (Russell, 1979). The sound of flute was believed to be an effective treatment for sciatica (Democritus, Aulus Gellius), seizures (Asclepiades of Samos), and depression (Aristides of Miletus). In Rome, Celsus and Galen sustained the therapeutic effects of music against insomnia, Heliodorus of Emesa and Lucan reported that the sound

[1]Even in the classical Greek theater, dance and music played a fundamental role in the plays, as demonstrated by the "chorus." It consisted of 12–50 players, who variously danced and sang, offering background and summary information to help the audience follow the performance.

[2]According to Hesiod (*Theogony*) the Muses were nine goddesses, considered as the personification of knowledge and the arts; among them Terpsichore was prayed to as the deity of dance.

of drum could arrest bleeding, and Plutarch described how music was used in the treatment of plagues and pestilences. Notably, the Latin writer Martianus Capella stated, "I have often cured disorders of the mind as well as body with music" (Russell, 1979).

"Psychotropic" effects of music and dance on nervous systems were well known in the ancient world. *Dionysia* and *Bacchanalia* were religious and popular festivals, celebrated in Athens and Rome, respectively, and dedicated to the god of wine, Dionysus/Bacchus. During these rites, probably characterized by maniacal dancing to the sound of loud music and crashing cymbals, the revelers—called Maenads (*Bacchantes* in Rome)—whirled, screamed, became drunk and incited one another to ecstasy.

> *[The dancers] also on occasion practiced the dance with a forward bending and back arching of the body. But in general they favored abrupt crouching on one leg, followed by leaps that straightened the bent leg and bent the previously straight one, wild caperings in which they often had maenads as partners, together with various contortions and swaying movement of the hips accentuated by angular movements of the arms.*
>
> **Séchan (1930), p. 173**

In this state, the souls of attendees felt temporarily freed from their mortal bodies, allowing them to communicate with their deity (Grimal, 1990). The descriptions of *Bacchanalia* and *Dionysia* demonstrate that the combined effects on central nervous system of alcohol and drugs, along with unbridled music and frenetic dancing, were widely used to induce ecstasy and other altered states of mind during religious rites and festivals in the ancient world.

Actually, Dionysiac frenzy cannot be only reduced to drunkenness, but it could be also expression of a possession trance and of a therapeutic ritual. According to the Greek philosopher Plato (Laws 790d–791b), this kind of dance brought calm in the soul and a cessation of the palpitations of the heart in frightening people. Movement was indeed believed as the basis of health in man's body and soul, thus dance, counterbalancing external and internal movements, reestablished equilibrium when it had been lost. In particular, the fright and other negative passions were internal movements and, with the benevolence of the gods, dance intervened as an external shaking that restored calm and tranquility.

> *By virtue of their movement, dance and "musia" are thus able, in short, to reintegrate into the ordering of the Universe the individual who had become separated from it by the disordered movement of fright.*
>
> **Rouget (1985), p. 204**

In ancient times, relationships between medicine, music, and dance may be also found in non-Western cultures. Music is used for clinical diagnosis and treatment in traditional Chinese medicine: a correct combination of rhythm, timbre, energy, and other factors can have a positive impact on the inner harmony of the human body. The theory of "Five Zang-organs Harmonize Pitch" considers that each of the five *zang* organs[3] provides a "pitch" or musical vibration. The five organs are correlated with the five pitches of Chinese traditional music—*Gong* (do), *Shang* (re), *Jiao* (mi), *Zhi* (sol), and *Yu* (la)—which are also correlated with the five elements of *Yin-Yang* (earth, metal, wood, fire, and water). Vital organs can produce different vibratory frequencies according to their conditions and health, allowing physicians to diagnose alterations of organism through detecting their different pitch. So, Chinese physicians diagnosed patients and made prognoses by listening for the five pitches and relating them to *Yin-Yang* disorders and their sources.

Able to balance the harmony of human organs, music was also used by the Chinese in the treatment of some diseases. Curiously, in traditional Chinese medicine, the brain does not appear to provide any pitch, probably due to the lower consideration of this organ. The functions associated with the brain today (thought, emotion, etc.) were instead scattered over the human body. In particular, the five *zang* organs were believed to arouse various emotions and, specifically, the heart, liver, spleen, lung, and kidney were thought to arouse happiness, anger, deep thinking, melancholy, and fear, respectively (Fiorenzola and Parenti, 1987; Muramoto, 2010).

The relationship between music and health may be also evidenced in Arabic medicine, developed in the Early Middle Ages through the interactions of the indigenous Arab traditions with Western (Greco-Roman) and Eastern (Indian and Chinese) influences. In Islamic hospitals (*bimaristan*), musicians were often employed to comfort and cheer patients up, confirming the knowledge of the sedative and relaxing power of music in this medical tradition. In the Muslim tradition, dance also has a religious meaning. In particular, nowadays in some mystic Islamic movements (Sufism) ancient ceremonies, called *sama*, are still commonly performed and include cathartic dance, in addition to singing and playing instruments (e.g., Whirling Dervishes). Similar rituals may be also found in some modern Christian communities, such as the Khlysty in the Russian Orthodox Church and the Shakers (United Society of Believers in Christ's Second Appearing) in Northern America (Rouget, 1985).

3 FROM THE MIDDLE AGES TO THE EARLY MODERN ERA: ST. VITUS AND CHOREOMANIA

Arabic culture influenced the Christian Middle Ages in many ways and different fields, including medicine. The importance of the relationship between music and cardiac pulse, derived from the Arabic world, led medieval physicians to have a basic knowledge of music theory. The use of the notes as semeiotic signs in medicine may explain why musical harmony could have been considered as a therapeutic element to restore

[3]In traditional Chinese medicine, all parts of the human body are classified into *Yin* or *Yang*. For example, the interior, anterior, and abdominal parts of the human body and five *zang* organs (spleen, lung, liver, heart, and kidney) are classified as *Yin*, while the exterior, posterior, chest, and six *fu* organs (small intestine, large intestine, gall bladder, urinary bladder, stomach, and sānjiaō or triple warmer) are classified as *Yang*.

the upset balance or bodily disharmony generated by disease. In addition, it could clarify why "move to the rhythm of the music" (dance) could be considered a motor activity that blends positive energies, bodily fluids and humors in a healthy balance.

In this period, dance and neurological disorders—particularly epilepsy—became to be correlated, as happened in the legend of St. Vitus, who, in the fourteenth century, was made one of the Fourteen Holy Helpers.[4] In particular, the saint's powers were invoked against nervous disorders and epilepsy, although traditionally he was also looked upon as the patron saint of dancers (Pazzini, 1937). According to legend, Vitus became a Christian in his childhood and moved to Rome, where the young boy expelled a demon, which had possessed the son of Emperor Diocletian and had forced him to continuously move and dance. Even though he cured a member of the imperial family, Vitus was tortured and martyred in the year 303 because of his Christian faith. His legendary healing of the Emperor's son from frenetic dancing led his name to be invoked against seizures and muscular spasms, and to be venerated as the protector of those suffering from what became known as "St. Vitus dance" (Park and Park, 1990).

During the Middle Ages, the eponym of the young saint was further associated with a mysterious disorder called "choreomania." Choreomania (from the Greek word χορεία, dance), dancing mania, or St. Vitus dance was a strange phenomenon of crowd behavior of epidemic size that appeared in medieval Europe. Crowds of people would suddenly form circles, start dancing, and continue for many hours until exhausted. During the compulsive dancing, participants often appeared to have hallucinations and epileptic seizures.

Between the late 1300s and the early 1550s, several outbreaks of dancing mania occurred in northern Europe, especially along the Rhine and Mosel rivers. Town authorities organized plans to control the dancers, using musicians to steer the victims away from urban areas[5] and employing strong men to restrain the dancers. Because some were cured after pilgrimages to St. Vitus chapels, the cult of this saint quickly became widespread, leading to the eponym St. Vitus Dance (Park and Park, 1990; Waller, 2008).

A colorful description of an epidemic of dancing mania that occurred in Strasbourg may be found in the words of Waller (2008):

> *Some time in mid-July 1518 a lone woman stepped into one of its narrow streets and began a dancing vigil that was to last four or even 6 days in succession. Within a week another 34 had joined the dance. And by the end of August, one chronicler*

[4]In the Christian tradition, the Fourteen Holy Helpers are a group of saints believed to intercede effectively against various diseases. They are Agathius (migraine), Barbara (fever and sudden death), Blaise (throat illness), Catherine of Alexandria (tongue disease and sudden death), Christopher (bubonic plague), Cyriacus (diabolic obsessions), Denis (headache), Erasmus (bowel disorders), Eustace (burns), George (skin affections), Giles (madness), Margaret of Antioch (childbirth problems), Pantaleon (consumption), and Vitus (epilepsy).

[5]Some similarities could be found with the legend of the Pied Piper of Hamelin and its clear references to the hypnotic power of music.

> *asserts, 400 people had experienced the madness, dancing wildly, uncontrollably around the city. As the dance turned epidemic, troubled nobles and burghers consulted local physicians. Having excluded astrological and supernatural causes, the members of the medical fraternity declared it to be a 'natural disease' caused by 'hot blood'. This was orthodox physic, consistent with Galen's view that bloody fluxes could overheat the brain, causing anger, rashness and madness. But the response of the authorities was neither to bleed nor to provide cooling diets. Instead they prescribed 'more dancing'.*
>
> *To this end they cleared two guildhalls and the outdoor grain market and they even had a wooden stage constructed opposite the horse fair. To these locations the dancers were taken so they could dance freely and uninterrupted. The victims would only recover their minds, said the authorities, if they persisted both day and night with their frantic movements. And to facilitate this supposed cure, the authorities next paid for musicians and professional dancers to keep the afflicted moving.*
>
> **Waller (2008), p. 117**

What explanation could be provided on this phenomenon? Some authors suggest that wild dancing was part of the ecstatic ritual of a heretical sect, an energetic counterpart of the flagellant's cult (Bartholomew, 2001). Actually, sources reported that people did not want to dance and expressed fear and desperation in their faces; moreover, many clerical and lay authorities considered them victims of diabolic possession or curses, and not as heretics. Other scholars claimed that choreomania was a result of a collective food poisoning, in particular due to ergot, a fungus that grows on damp rye, and one containing neurotoxic alkaloids (methylergometrine, ergotamine, etc.). Indeed, in addition to vascular gangrenous manifestations (known as "holy fire" or "Saint Anthony's fire" during the Middle Ages), ergot derivatives can cause neurological and convulsive symptoms, such as painful seizures and spasms, paresthesias, headaches, and mental disorders, including mania or psychosis (Waller, 2008; Lucchini et al., 2012). Still, the theory of ergot poisoning for all of these epidemics is hard to sustain, since chemical compounds in the fungus can trigger violent convulsions and visions, but not coordinated "dancing" movements that can last for days or more.

An alternative hypothesis is that the dancing mania was the result of a shared stress and tension caused by plagues, poverty, famines, and floods. Proponents of this idea contend that the afflicted people might have danced to relieve themselves of the stress and poverty of the day, attempting to become ecstatic and have visions (Waller, 2008).

Finally, choreomania could be considered as a collective therapeutic ritual. In particular, the motor manifestations of a nervous disorder, such as epilepsy, generalized dyskinesias, cerebellar damage, and ergotism might have been construed as demonic manifestations and, therefore, "exorcized" through ritualistic dancing. Community dancing could have involved subjects suffering from repetitive motions (involuntary muscular contractions, twisting movements, broad tremors of the extremities, rhythmic, or irregular motions), aimed at curing and healing them, since witches danced on the Sabbath to cast maleficent spells and evil curses to these and other humans.

These forms of collective treatment were, in fact, approved by the Church and by lay authorities. For example, during the fifteenth century on St. Bartholomew's Feast Day (August 24th), epileptics in Belgium and France attempted to spend all day dancing around their parish churches, praying the saint to protect them from seizures for the rest of the year. In the small town of Echternach in Luxemburg, the dancing procession continues to take place annually: dancers proceed through the streets to St. Willibrord's tomb, to honor him for saving the town from a convulsive epidemic in the sixteenth century, and to petition him to intervene on behalf of people with epilepsy today (Krack, 1999).

According to French neurologist, Jean-Martin Charcot (1825–1893) (Charcot and Richer, 1887), an episode of the dancing procession in Echternach may be found in a drawing by the Flemish painter Pieter Brueghel the Elder (ca. 1525–1569). Even if this attribution is likely incorrect, in his Salpêtrière lectures and some of his books (e.g., "Les démoniaques dans l'art," 1887) the famous French neurologist used this painting to demonstrate that "hysteria and hystero-epilepsy played a predominant role" in dancing mania epidemics (Aubert, 2005).

One of the first attempts to free the choreomania from superstition was made by Paracelsus (1493–1541). Coining the term *chorea Sancti Viti*, he divided this disorder into three types: *chorea imaginativa* (arising from the imagination), *chorea lasciva* (arising from sensual desire), and *chorea naturalis* (arising from corporal causes). While the first two types were rare and may be considered psychosomatic manifestations today, *chorea naturalis* was the mildest and most diffuse form of the disease, and was accompanied by involuntary laughter and an urge to dance. According to Paracelsus, this form of the disorder was caused by an alteration of certain vessels and a commotion of vital spirits, producing involuntary fits of intoxicating joy and a propensity to dance. The Swiss physician recognized that the loss of emotional stability and voluntary motor control were central in the course of the disease (Park and Park, 1990).

A century later, the term "St. Vitus dance" was also used by English physician Thomas Sydenham (1624–1689) in his description of fever-related involuntary, purposeless, rapid movements of the limbs, muscular weakness, and emotional lability in children. In his *Schedula monitoria de novae febris ingressa* (1686), Sydenham wrote:

> *This [St Vitus dance] is a sort of convulsion which attacks boys and girls from the tenth year to the time of puberty. It first shows itself by limping or unsteadiness in one of the legs, which the patient drags. Then hand cannot be steady for a moment. It passes from one position to another by a convulsive movement, however much the patient may strive to the contrary. Before he can raise a cup to his lips, he makes as many gesticulations as a mountebank; since he does not move it in a straight line, but has his hand drawn aside by spasms, until by some good fortune*

> *he brings it at last to his mouth. He then gulps it off at once, so suddenly and so greedily as to look as if he were trying to amuse the lookers-on.*
>
> **Sydenham (1848), pp. 257–258**

Park and Park (1990) suggest that Sydenham used the term "St. Vitus dance" after observing victims of Paracelsus' *chorea naturalis*. The so-called father of English medicine did not connect this disorder with rheumatic fever, which Richard Bright did in 1831 (Pearce, 1995).

After Paracelsus and Sydenham, the Greek word for dance—chorea (χορεία)—was officially introduced in medical terminology and, in particular, it was used to describe neurological symptoms and signs (Eftychiadis and Chen, 2001). Chorea now also referred to an abnormal involuntary dance-like movement disorder, often occurring with athetosis, that has twisting and writhing movements. In addition to *chorea minor* (Sydenham's chorea), this term is now further used for Huntington's disease (*chorea maior*) and involuntary abnormal movements in pregnant women (*chorea gravidarum*). Regarding Huntington's chorea, Loi and Chiu (2012) hypothesized that women affected by this disorder in the sixteenth century were accused, brought to trial, and executed (even burnt at the stake). Dance-like movements, violent body fits, twisting, bowing and grimacing in women and in their daughters (*chorea maior* is hereditary as well as witchcraft) led people to accuse them of being witches and to state that the Devil had possessed them.

4 BETWEEN THE ENLIGHTENMENT AND ROMANTICISM: DANCE AND INSANITY

In the following centuries, the evolution of society and science led to contrasting superstitions and metaphysical interpretations. By the eighteenth century, witch trials had become rare across much of Europe, in parallel with the decline of heresy and blasphemy as a crime against the Church and the State. In this regard, a well-renowned statement of the French Enlightenment philosopher Voltaire (1694–1778) should be mentioned:

> *Philosophy alone has at length cured men of this abominable delusion [sorcerers' execution], and has taught judges that they should not burn the insane.*
>
> **Voltaire (1824), p. 332**

Over time the dance-like movements of chorea and other neurological disorders became to be "scientifically" explained by physicians as manifestations of hysteria or mental disorders. People suffering from these conditions were often admitted to the psychiatric asylums, where they were diagnosed by officials as unbalanced and insane. For example, during the nineteenth century, cases of hysterical chorea were often diagnosed in young girls 13–18 years old.

In his study of eccentrics in Paris, Georges Gilles de la Tourette (1857–1904) described a male patient—known as "*l'Idiot*" or "*le danseur*"—with an overriding compulsion to dance. The French neurologist considered this behavior as a manifestation of a psychic disorder, a way of improving mood and gaining people's attention by wild arm movements. *Le danseur* was indeed said to be melancholic and to have suicidal tendencies (Gilles de la Tourette, 1893).

Examples of uncontrolled and insane dance may be also found in popular culture. *The Red Shoes* (1845), a fairy tale by Danish writer Hans Christian Andersen (1805–1875), tells the story of a peasant girl adopted by a rich old woman, who deceptively bought a pair of red shoes. Even if her adoptive mother was ill, the young lady preferred to attend parties in her red shoes. Due to her vanity and indifference, a divine spell led the girl to suddenly begin to dance, and she cannot stop or control her shoes, which are stuck to her feet (Crone Frank and Frank, 2005). Therefore, as shown in this tale, the popular belief considered that dancing was still being linked to sinning.

During the industrial revolution, the compulsion to dance was also believed to be a manifestation of insanity due to metal intoxication, and in particular mercury poisoning. This belief is exemplified by a rather overlooked Irish folk story, *The Pudding Bewitched*, by William Carleton (1794–1869; Carleton, 1834). In this story, a male fairy bewitches (poisons) a pudding, so that all of the people that taste it start to dance frenetically. At the end of the tale, the reason for this "dancing mania" is presented as a "half a pound of quicksilver" that he put into the pudding. This tale clearly demonstrates that the neurotoxic side effects of mercury were well known in the folk culture of this period.

A therapeutic relationship between dancing and insanity can also be found at this time. In particular, patients in insane asylums were sometimes allowed recreational activities as a part of their cure, the basic idea being that gentle exercise (in this case, dance) might be beneficial. The "Lunatics Ball" was a nineteenth-century attempt to use dance in the treatment of psychiatric patients (Lees, 1990). Indeed, during the Romantic era, music, opera, and song were also being successfully employed in this endeavor (Riva et al., 2014).

Suggestive descriptions of these performances were reported in nineteenth-century newspapers:

> *Twenty couples entered the hall, ranged in two lines facing each other, and stood still in profound silence, waiting the music. [. . .] The music burst forth and a simultaneous movement followed; all sorts of movements, some cultivated steps, but for the most part a mere violent shuffling exercise. [. . .] There was some peculiarity about every individual, but in every one was observable a sort of ecstasy [sic].*
>
> **Canton Asylum for Insane Indians (2014)**

This relationship between madness and dance can also be curiously identified in the history of music, especially in the Iberian dancing tradition, where body movements appeared to be uncompounded, persistent, and repeated. In particular, some ancient Lusitanian dances, where shepherds or peasants seemed to lose their reason in fertility rituals, represented a model for the melody *La Folia*, also named *Folies d'Espagne* in French, *Follies of Spain* in English, and *Follia* in Italian. The same etymon of the word "Folia" contains its strong relationship with insanity, because of the "foolish," improvised rhythm of this musical theme. The *folia* [insane] melody has also influenced several composers of the Romantic era, including Franz Liszt (*Rhapsodie Espagnole*) and Ludwig van Beethoven (*Fifth Symphony*). These famous compositions use short musical sequences related to circular harmonic–rhythmic dance steps, which favor improvisation and variation through their hypnotic repetition. These sequences were not only the musical architecture of "*La Folia*" but also of some Italian forms of songs and dances, such as *Romanesca*, *Ruggiero*, *Aria di Genova*, *Fedele*, and *Alta Regina*, that form the basis of the *bel canto* and operatic tradition in southern Europe.

Finally, not only the musical compositions but also nineteenth-century classical ballets reveal connections between dance and insanity. The presence of a "mad-scene" in the most renowned Romantic ballet, *Giselle* (Gautier, 1841) confirms the importance of the "insanity" issue in this kind of dance performance.[6] *Giselle* is the story of a young peasant girl who dies of grief after being betrayed by her lover, Albrecht, the Duke of Silesia. In it, the protagonist of the ballet loses her mind, since she has transgressed the social order (a peasant who loves a nobleman). Critics generally use Giselle's mad-scene to evaluate ballet dancers' technical skills, since it provides dancers an opportunity to display their dramatic capabilities and interpretations.

Among the neurological issues in other Romantic ballets, the sleepwalking scene in *La Somnambule* should be mentioned. This was a *comédie-vaudeville* by Eugène Scribe and Casimir Delavigne, which was staged in 1819. The storyline would later reappear in a famous opera, Bellini's *La Sonnambula* (see Riva et al., 2010, and Finger et al., this volume).

5 CHOREIC AND MUSICAL DISPLAYS IN SOUTHERN ITALY BETWEEN THE 1800S AND 1900S

Tarantella, a fast-paced traditional Italian dance typical of southern Italy, and of Apulia in particular, share many characteristics with certain African music genres, and through the latter also with some African-American rhythms (Haitian voodoo and Brazilian *macumba*). This expressive manifestation is the structured form of a status of "mental impairment" called "tarantism," which people believed was caused by the bite of a kind of wolf spider, called the "tarantula" (*Lycosa tarantula*), or by that of the so-called Mediterranean black widow or steppe spider (*Latrodectus tredecimguttatus*) (De Martino, 1961; Turchini, 1987).

[6]There are mad-scenes also in other ballets, such as *Le Déserteur* (1789) and *Nina, ou la folle par amour* (1813).

A Neapolitan lawyer reported an accurate and colorful depiction of an episode of tarantism in Early Modern Ages:

> *We heard the sound of drums, whistles and flutes in all the towns and villages and upon inquiring as to the meaning of it we were informed that in these regions it was a means of healing the people bitten by the tarantula. Then we went to a village and saw a young man affected by this disease. He seemed to have become insane, singing absentmindedly to the beat of a drum, while his arms and legs and the entire body moved in beat with the music. It was obvious that the sound of the drums pleased him and lessened his pain and he started to listen more and more to the instrument. It could appear to someone as being humorous and ridiculous but when the drummer stopped to play for a short period of time, the patient suddenly seemed to go numb, lose his senses and faint. However, as soon as the sound of drums could be heard again, the patient regained his strength and started to dance with more vigour than before.*
>
> **Katner (1956), p. 20**

From a phenomenological point of view, *tarantella* may be considered a precise dancing and sonorous curative ritual: a choreic–musical module configuring a protective technique in a magical-religious context, finalized to conserve an individual's psychophysical integrity and his community's social balance. Individual and collective crisis elements are in evidence throughout the whole ritual: in the musicians' rhythm, and melody; in the participants' choreic mimicry; and finally in the therapeutic resolution for both the individuals and their community. It is therefore a joint phenomenon of music and dance therapy, with both social and personal therapeutic effects.

In every society, more or less overtly, some kinds of diseases caused by alterations of the relationship between an individual and its social group can be found. These are usually characterized by deep psychic unease, which can show itself either through severe melancholic depression (up to catatonia) or through expressions of recurrent somatic anxiety, as well as psychic restlessness (up to insomnia and phobic-obsessive) and motor restlessness (with uncontrollable manias and complex tics). Within this context, tarantism's choreic and musical expressions provide a therapeutic answer to psychic unease and existential imbalance. The use of particular musical rhythms can have an "unblocking" function, eliminating catatonia, and unleashing a motor frenzy channeled in an institutional dance with liberating and curative roles. Equally, this recurrent choreic movement conveys the chaotic energy of tics and manic motor restlessness in a ritualistic, orderly, structured dance, freeing energy from potentially destructive intentions. People affected by tarantism appear to be characterized by general malaise accompanied by a psychic symptomatology reminiscent of hysteria, with reduced states of consciousness and emotional disturbances, sometimes even with forms of complex partial epilepsy (Cinque, 1987).

As well as *tarantella* in Apulia, *tammurriata* is a melodic–rhythmic traditional dance from Campania, played with a *tammorra*, a kind of large colored tambourine with big tin rattles attached. The dancers' movements are usually disorganized and almost casual, perhaps showing their need of freeing body and mind from daily oppressions that, in this Camorra-infested land, can easily reach mental and physical prevarication. Other variants of tarantism are the *Pecorara* or *Pasturara*, a shepherd's dance in Calabria, and similar dances in Sicily and in Sorrento (Russell, 1979).

From a medical viewpoint, the dancers seem to show signs of simultaneous activation of emotional and motoric neuronal circuits in the tarantella and other folk dances of southern Italy. Indeed, these neuronal circuits are related from a neurophysiological and even neuropathological point of view, as shown for instance in Tourette's syndrome. Anthropologically, they might somehow represent the deepest feelings of our contradictory society. These folk dances could break (not only musically but also morally and socially) the silence and indifference of those "average men," who suffer from our society's flattening, conformity, and loss of true spiritual values (Porta and Sironi, 2009).

Another typical folk instrument, this time from Sardinia, is the *luneddas*, a three-piped wind instrument deriving from an ancient, southern Italian version of the clarinet and traditionally played by shepherds. This musical instrument often accompanies the *ballo tondo*, a sort of rhythmic propitiatory dance against individual and communitarian adversities. The *luneddas* can only be made by artisans, and their work on the mouthpiece is of particular importance. The reed is usually made of silver, and its loud tone and significant vibrations can cause paroxysms and losses of consciousness (hysterical manifestations) (Cinque, 1987). These instruments can be played uninterruptedly even for 3–4 h in a row, during which the players adopt a specific breathing technique so they never interrupt the airstream: cheeks are used as a reservoir; the air is breathed in through the nostrils, while the cheek muscles push the previously stored air down to the *luneddas*. When the required breathing is not done properly, players can experience hyperoxia and thus severe neurological symptoms, including hallucinations and loss of consciousness.

6 FOLK MUSIC AND DANCES IN NON-WESTERN CULTURES

In several African, Asian, Central and South American cultures, music and dance were often born as a function of specific existential, working, or social situations. Analogies between musical instruments and working tools are often found. They may also cover a magical function, according to a totemic vision of the world; for instance, a hunting bow played as a stringed instrument or against an emptied pumpkin before starting a hunt to propitiate it, or drum-vases (rice or wheat containers) played before sowing the rice or harvesting the wheat.

These ties between work, music, and the supernatural—a primitive magical world—caused the development of instrumental, vocal, and choreic rituals that encouraged a more direct relationship between the natural and the social environments, usually opposed to the "culture" imposed by European colonialists (Bohlman, 2008). An alternative "other culture" derives from this, causing the persistence of a marked collective identity on neurological and psychological levels: theoretically an "ethnomusical archetype" able to "awaken" the primary neuronal circuits of sound and movement. This is applicable to African chants and ritual dances, and Asian heart-breaking music and delicate choreic movements, as well as Native American songs and dances, such as the Haitian *macumba*. The simultaneous activation of emotional and motoric neuronal circuits may also be evidenced in these folk dances, demonstrating that these are universally based on the use of rhythms, sounds, harmonies, and movements able to activate nonspecific neuronal circuits mediating musical perception, and also involved in the processes of interpersonal collective recognition and cultural identification.

The construction process of "primitive music"—"folk music" in a broad sense—probably starts not only from a magical-religious conception of reality but also from an anthropomorphic vision of the musical world, typical of totemic societies. The natural world appears to be populated by an infinite quantity of good and evil spirits, all capable of speaking through Nature's sounds. If a man is capable of reproducing a sound or an animal's call, he is also capable of absorbing, thus breaking the barrier between subject and object. Since these populations believe that sound is the essence of everything, the importance of music is clear. Voices, sounds, music, and dances become part of a complex etiquette, involving formulas, melodies, and movements, often only known by very few "initiated" people, who link earthly existence to a supernatural world. Such music and mystical rituals cause "states of trance" essential for letting the different worlds communicate. This happens in shamanistic rituals and in the Indian Vedic tradition.

In Indian musical culture, vocal music plays an important role, followed by instrumental music and dance. Words and chants accompanied by hand movements and prearranged steps represent the heart of Vedic sound rituals, also differentiated from the Western musical system by a different octave classification (Cinque, 1987).

African chants and rhythms also derive from words modulated from sounds produced by simple natural tools, such as wooden sticks beaten on hollow logs, seeds, or plant parts shaken in small containers, and primitive drums made out of animal skins stretched out on wooden cases. This is how traditional African songs were born, before being rearranged in more sophisticated spiritual songs by African-American (former slaves) (Southern, 1983).

According to recent studies on physiological and pathological function of rational and emotional areas of brain (Packard and Cahill, 2001; Phelps, 2004; Shin et al., 2004; Goldin et al., 2008; Pessoa, 2008), these sounds, music, and movements may be supposed to stimulate the brains' emotional and sensory areas (regions of limbic, temporal, and parietal cortices), as a function of tragic experiences handed down through the centuries. They can also stimulate more rational areas (frontal cortex), arousing hopes for a better future in a self-conscious way, allowing these oppressed groups to gain more freedom and dignity. When the African Americans started owning and mastering European instruments, they adapted them to their expressive timbres by opposing or supporting them with the singing. Slaves' chants became thus more elaborate and blues turned gradually into jazz, i.e., a Westernized African folk music.

Finally, some suggestive pathophysiological explanations may be also provided on the relationship between folk music, tribal dance, and disturbances. According to Zempléni (1966), in Cameroon, where "the ritual crisis is the normal termination of the [ritual] dance and collapse is the natural conclusion of the 'crisis'," the physiological trigger of collapse is vestibular autostimulation due to increasing volume and pace of the music, leading the possessed person to extreme muscular exhaustion and spatial disorientation. In particular, movements of neck and torso, both resulting in frenzied movements of the head, would cause a violent excitation of the labyrinth and consequently a special state of exaltation (Aubin, 1948).

7 MODERN FOLK DANCE AND MUSIC

Music and dance related to the most modern singing and dancing expressions (i.e., jazz, pop, rock metal, Latin American music, etc.) are striking examples of a "neuropsychological short circuit" generated by a combination of emotional components (limbic and temporal neuronal networks) and motor connections (basal ganglia, somatosensory area of parietal lobe, and cerebellum) in the brain. Some dance movements related to these sounds recall forms of extrapyramidal dyskinesias.

> *The pogo dancing and head banging of the punks of the 1980s and the narcissistic introverted contortions of acid house music are also reminiscent of movements seen in Tourette syndrome.*
>
> **Lees (1990), p. 103**

Furthermore, mass fainting at rock concerts seem to be somewhat like the hysterical manifestations of Medieval St. Vitus dance (Morens, 1995).

Nowadays, neuropsychological features can be also evidenced in ballroom dances (e.g., waltz, tango, salsa, mazurka, and merengue), since they often derived from ancient folk dances, and therefore could have had, and might still have, liberating and cathartic actions. It is curious to note that some nineteenth-century medical authors considered the waltz as a risk factor for the devolvement of apoplexy and other cerebral vascular disorders, especially in young women (Ferrario, 1834). Today, Viennese waltzes and other ballroom dances (including Latin dances) are being used in the physical and social rehabilitation, including for people with paralyses, radiculopathy, and neurodegenerative disorders, such as dementia and Parkinson's disease. In the elderly involved in ballroom dances, improvements in physical functioning, balance, coordination, strength, and health-related quality of life have been demonstrated (Lewis et al. 2014).

Even collective forms of involvement seem to ensue from neuropsychological mechanisms of separation-integration of emotional and motor components. Flash mobs could be cited as example. Young people realize them often for the purposes of entertainment, satire, and artistic expression: first, they organize the event via telecommunications, social media, or viral e-mails, and only afterward do they decide to gather physically in a prearranged public place, to sing, dance, and share experiences, impressions, and ideas. It is a singing and motor ritual that, through music and dance, stimulates the entire brain and the entire individual; a folk display of music-vocal and choreic-motor experiences.

8 CONCLUSIONS

According to Italian ethnomusicologist Diego Carpitella (1924–1990), folk music and traditional dances come from "a background that has nothing to share with cultured music [. . .], and [they] use pentatonic, modal, diaphonic and polyphonic scales" (Cinque, 1987), which do not traditionally belong to cultured music. It is a tonal use of music, dealing with precise peculiar rhythmic characteristics, as in the aforementioned *tarantella*, *tammurriata*, and *ballo tondo*. These rhythms are not only peculiar to a certain way of playing music but also of different acoustical expressions that may stimulate selective, deep limbic neuronal circuits. Traditional dance and music may cause an emotional involvement, binding the subjective experiences of individuals (player or listener) with a dynamic, objective reality of the community—also involving the motor side in the dance rhythm, in what could be construed as a symbolic and therapeutic function (Sterman and Friar, 1972; Sutton and Davidson, 1997; Tomarken and Keener, 1998; Ellison et al., 2004; Zotev et al., 2011; Zotev et al., 2012; Proverbio et al., 2014).

Indeed, this rhythm represents not only an aspect of socio-ethnomusicological reality but also the rotating center of human biological and social life. Every person owns their rhythmic drive, resulting from the union of several components: the organs' biological rhythm (*in primis*, the heart rate), the mind's psychological rhythm (as determined by the relationships with their own self and with other individuals), and the existence's social rhythm (deriving from the structure of the society and community) (Gallese et al., 2004; Proverbio et al., 2014).

Rhythm marks out time and even life. This natural and primitive essence of rhythm is captured by folk music and traditional dance better than by cultured music, and passed on to brain and self. Rhythm is indeed neglected by most cultured musical cultures, especially in the Western world.

The study of Western and non-Western traditional musical cultures illustrates how feudal polyphony, Gregorian monophony, tribal heterophony, pop music, and computer music might represent not only well-defined social products but also forms of expression that "naturally" stimulate the neuronal circuits associated with emotion. Ancient musical and dancing events, neurological clinical features caused by pathological changes (such as St. Vitus's dance), and psychopathological expressions of social unease (hysteria, seizures, or dyskinesia and tics in tarantism) might all be thought of as expressions of well-structured bonds that could exist between traditional music and other forms of neuropsychological stimulation.

Pathological semeiotic signs (e.g., dyskinesia, complex motor, vocal and behavioral tics, and likely complex partial seizures) and psychological disorders due to existential unease (i.e., stress, anxiety, and depression) can be often found in traditional music and dance. Dynamic relationships between emotional and motoric neuronal circuits seem to be the common pathophysiological pattern connecting these events. In other words, folk dance and music are the products of "natural sonority and motility," which after being "culturally processed," might set up a sonorous, vocal, and choreic archetype capable of activating the deepest, most basic structured circuits of human neuropsychological apparatus. For this reason, it would be desirable to increase interdisciplinary research on this subject (ethnomusicology and cultural anthropology, clinical neurology and dynamic psychology, neuroradiology and neurophysiology, and socioneurology and neuromusicology), so that these interactive phenomena could be further clarified.

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CHAPTER

Music and dementia

11

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Abstract

There is an increasing incidence of dementia in our aging population, and consequently an urgent need to develop treatments and activities that may alleviate the symptoms of dementia. Accumulating evidence shows that persons with dementia enjoy music, and their ability to respond to music is potentially preserved even in the late or severe stages of dementia when verbal communication may have ceased. Media interest in this topic has contributed to the public perception that music abilities are an "island of preservation" in an otherwise cognitively impaired person with dementia. In this chapter, we review the current literature on music cognition in dementia and show that there has been very scarce rigorous scientific investigation of this issue, and that various types of music memory exist and are differentially impaired in the different types of dementia. Furthermore, we discuss the recent development of music activities as a nonpharmacological treatment for dementia and highlight the methodological limitations of the current literature on this topic. While it has been reported that music activities can improve behavior, (particularly agitation), mood, and cognition in persons with dementia, recent large-scale randomized control studies have questioned the specificity of the effect of music and found that it is no more beneficial than other pleasant activities. Nevertheless, music is unique in its powerful ability to elicit both memories and emotions. This can provide an important link to individual's past and a means of nonverbal communication with carers, which make it an ideal stimulus for persons with dementia.

Keywords

music cognition, music memory, music therapy, nonpharmacological trial, Alzheimer's disease, frontotemporal dementia, aging

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1 INTRODUCTION

Dementia is a neurological condition characterized by gradual death of brain cells that causes a decline in cognitive functioning or thinking skills such as memory. According to a recent report (Alzheimer's Disease International, 2013), the number of people living with dementia worldwide is 44 million and it will triple to more than 135 million in 2050. Given the increasing aging population, the overwhelming incidence of dementia will become a public health priority and be one of the greatest social and economic challenges of our time. There are various types and causes of dementia, with the most common form due to Alzheimer's disease (AD). Diagnostic criteria for AD are impaired memory and at least one other cognitive deficit such as aphasia (impaired language) that leads to significant impairment in social or occupational functioning. Frontotemporal dementia (FTD) is the second most common form and typically has an earlier age of onset than AD (45–60 years vs. over 65 years in AD). FTD is characterized by significant changes in social and emotional behavior and has three variants: (1) behavioral variant of FTD, which produces behavioral symptoms such as disinhibition, (2) semantic dementia (SemD), which is characterized by impaired naming and comprehension abilities, and (3) primary progressive aphasia, the main feature of which is impaired expressive language functions. Various sensorimotor, cognitive, and emotional deficits have been described in the different types of dementia, which are associated with loss of functioning, reduced independence, and social isolation.

There is currently no cure for dementia. Although numerous pharmacological treatments can alleviate some symptoms, their limited efficacy with the iatrogenic effects of medication has led several health institutions to recommend in parallel the development of nonpharmacological approaches (NICE guidelines: National Institute for Health and Care Excellence, 2006; Vink et al., 2011). Among them, music activities are seeing a growing success for persons with dementia as well as for caregivers.

It is widely acknowledged that music is enjoyed by persons with dementia, even in the late or severe stage when verbal communication skills may be lost. Music activities in various forms can have positive effects on persons with dementia. Listening to familiar music can elicit pleasurable responses such as smiling or liking judgments (Cuddy and Duffin, 2005; Quoniam et al., 2003). Participating in music activities or singing has been shown to improve behavior, mood, and cognitive functioning in persons with dementia (Narme et al., 2014; Sakamoto et al., 2013; Särkämö et al., 2014). Physiological effects such as changes in heart rate (Raglio et al., 2010) and hormone levels following music therapy sessions in these individuals have also been documented (Suzuki et al., 2004). Other research has even proposed that playing a musical instrument decreases the risk of developing dementia (Verghese et al., 2003) and delays the onset of age-related cognitive decline (Hanna-Pladdy and Gajewski, 2012). All these findings suggest that music functions might remain relatively preserved compared with other verbal or spatial abilities (Tzortzis et al., 2000; Warren et al., 2003). This potentially spared ability has motivated the development of music interventions in dementia.

In this chapter, we review the existing literature on the integrity or impairment of various music functions including music memory and emotions in people with different types of dementia. Then, we describe the impact of music on behavior (in particular agitation), mood and affective responses, as well as cognitive functions. More specifically, studies reporting the use of music or song as a memory aid or as a cue to evoke autobiographical memories will be presented. We also discuss music expertise and its relationship to cognitive reserve or brain reserve capacity, aging cognition, and risk of dementia.

2 MUSICAL FUNCTIONS IN DEMENTIA

Several lines of evidence suggest that compared with other cognitive functions musical abilities may remain relatively preserved in advanced dementia and serve as a means of communication between patient and caregiver. This statement does not imply that musical functions are entirely spared in dementia. Despite the popularized notion that music remains an "island of preservation" in persons with dementia, there has been very scarce rigorous scientific investigation of this issue, and consequently there is very little known about the musical abilities of this population. Most of the existing literature on this topic concerns musical memory, and relatively few studies have investigated musical perception and even less musical production (i.e., singing) in people with different types of dementia (but see Warren et al., 2003 for a case study of preserved singing in an amateur musician and singer with primary progressive aphasia). In principle, deficits in music perception could impact on other aspects of music cognition, including memory. It is important to note that appropriate interpretation of memory results requires a measure of music perception within the same individuals, which is rarely the case in the literature to date. As described below, most studies investigated patients with AD and there is currently limited knowledge about musical abilities in nonAD dementias such as SemD and FTD.

2.1 MUSIC MEMORY

The relationship between music and memory in persons with dementia is particularly noteworthy. Although impaired memory is considered the hallmark symptom of AD, memory for familiar music can be relatively spared in AD when memory for verbal information is severely impaired (Cuddy and Duffin, 2005; Cuddy et al., 2012, 2014; Kerer et al., 2013; Vanstone and Cuddy, 2010). Surprisingly, the ability to respond, to recall, or to produce music by singing, instrumental playing, or composing is often remarkably well preserved even in the severe stage of AD (Beatty et al., 1988, 1997) or primary progressive aphasia (Tzortzis et al., 2000; Warren et al., 2003), as in the famous composer Ravel (Alajouanine, 1948; Amaducci et al., 2002), although the exact nature of his neurodegenerative condition and the impact of his traumatic brain injury is unclear (Alonso and Pascuzzi, 1999; Otte et al., 2003). Case studies of musicians with AD have even reported the ability to learn to play new tunes (Cowles et al., 2003; Fornazzari et al., 2006).

The notion that memory for music is preserved in patients with AD has been questioned (for review, see Baird and Samson, 2009). In keeping with models of memory described in the nonmusical domain, we proposed that various forms of musical memory exist and may be differentially impaired in AD. Based on this literature review, implicit, specifically procedural musical memory, or the ability to play a musical instrument or to sing a song can be spared in musicians with AD. In contrast, explicit musical memory, or the recognition of familiar or unfamiliar melodies, is typically impaired. Thus, the notion that music is unforgettable in AD is not wholly supported.

Few recently published studies complement the case and group studies previously reviewed (Baird and Samson, 2009). To specify short- and long-term memory for unfamiliar music as compared to verbal information, Ménard and Belleville (2009) tested persons with AD and healthy older adults using unfamiliar material (unfamiliar melodies and pseudowords). The authors demonstrated that verbal as well as musical memory is impaired in AD, whether tested with short- or long-term memory paradigms. To ensure that memory difficulties did not result from perceptual impairments, pitch and verbal discrimination tasks were used. Because patients with AD achieved excellent performance on the discrimination tasks, the memory deficits found in AD cannot be accounted for by difficulties in music perception. A similar profile of responses was reported by Vanstone and collaborators (2012) who showed that deficits in long-term (episodic) musical memory were not associated with perceptual difficulties in AD.

In a subsequent study, learning and memory of tunes were examined in patients with AD (Samson et al., 2012). Persons with AD showed preserved recognition of familiar tunes (i.e., sense of familiarity) that was in keeping with healthy controls during the presentation phase, but their learning and recognition after a 24-h delay was impaired for both unfamiliar and familiar melodies. When comparing explicit with implicit memory abilities (i.e., task of categorization developed by Tillmann and McAdams, 2004), Moussard et al. (2008) demonstrated that unlike explicit recognition, implicit learning abilities of musical information are spared in patients with AD. Such findings illustrate a dissociation between explicit and implicit retrieval of musical information. In line with the conclusion of our review paper (Baird and Samson, 2009), these results indicate that *explicit* memory for music is as vulnerable as verbal or other types of nonmusical memory in AD pathology, which contrasts with the robustness of implicit recognition in this population.

As described before, the sense of familiarity for music appears to be relatively intact in patients with AD and this probably underlies their spared recognition of well-known songs (i.e., Vanstone et al., 2009). It has been shown that this sense of familiarity increases with repeated exposures of new melodies (Samson et al., 2009). Although the patients generally performed poorly, behavioral responses measured with a rating scale specifically developed for patients with severe dementia (Table 1) indicated greater familiarity with repeated compared with unrepeated music, and this effect persisted for 2 months.

Table 1 Behavioral response rating scale for recognition memory used with patients with severe dementia

Score 1	Lack of recognition or interest
Score 2	No sign of recognition, but slight interest when listening to the stimuli
Score 3	Weak sense of familiarity revealed by facial expressions and humming
Score 4	Sense of familiarity, "I may have heard this before, a long time ago, I forgot it"
Score 5	Stronger sense of familiarity, "Yes, I always knew this tune"
Score 6	Remembering or episodic retrieval attested by any responses providing the contextual information, "Yes, I heard this recently with you here"

Adapted from Samson et al. (2009).

In a large-scale group study in 50 patients with AD, Cuddy et al. (2012) showed that both familiar tunes and familiar lyrics were well recognized across all stages of AD. Due to close associative bonds formed early in life between highly familiar song tunes and lyrics, the ability to recognize such information seems to be still functional in patients with AD (for additional evidence, see Bartlett et al., 1995; Basaglia-Pappas et al., 2013). In contrast, the ability to detect pitch distortions (distorted tunes test, from Drayna et al., 2001) or to recall a song prompted by spoken lyrics is frequently impaired. These observations have led Cuddy and colleagues (2012) to conclude that semantic memory may be spared (or at least superior to episodic memory) in the mild and moderate stages of AD, constituting a preserved ability in the face of widespread cognitive decline. These studies suggest semantic and episodic memory abilities for music dissociate consistent with other kinds of material (for a review on semantic memory for music in dementia, see Omar et al., 2012).

These findings can also be explained by the dual process model of recognition described in nonmusical domains (for review, see Yonelinas, 2002). According to this model, recognition memory or the capacity to judge whether a stimulus has been encountered before can be supported by two qualitatively different retrieval processes based on (1) recollection of details of previous events or (2) the assessment of stimulus familiarity (i.e., Daselaar et al., 2006; Davachi et al., 2003; Eichenbaum et al., 2007; Ranganath et al., 2004). This distinction is illustrated by the common experience of recognizing a song as familiar but not being able to recollect its title or where and when it was previously heard. Familiarity, which is relatively automatic, is the feeling associated with retrieving an event without necessarily remembering contextual information, whereas recollection gives rise to the conscious experience of "remembering" and involves retrieval of contextual information. Several lines of evidence suggest that these two processes are dependent on distinct brain regions that are differentially impaired by dementia (Samson et al., 2012). The existing literature previously reported suggests that the sense of familiarity is preserved, whereas recollection is impaired in persons with AD.

Musical memory has been rarely examined in other types of dementia. In a recent study, music knowledge has been investigated in two musicians, one with AD and the other with SemD (Omar et al., 2010). The patient with SemD showed preserved recognition of musical composition, but, unlike previous findings, the patient with AD showed fine-grained deficits on musical semantic memory tasks as compared to healthy musicians. The presence of semantic memory deficits for music in AD has been supported by another group study (Kerer et al., 2013). More specifically, the authors found that the breakdown of musical semantic memory in these patients followed a pattern similar to semantic memory in nonmusical domains with knowledge of superordinate musical categories (i.e., composer) being better preserved than item-specific knowledge. This apparent discrepancy between studies may reflect an intrinsic heterogeneity of musical semantic memory capacity in the AD population (as described by Omar et al., 2012). These findings also indicate that musical memory can be differently impaired in AD and other types of dementia.

As previously highlighted, hearing familiar music can modify our affective responses by triggering various types of behavior and/or emotions (i.e., smile, clapping the hands, and liking). This phenomenon has been examined using a paradigm of mere exposure effect. Exposure induces various behavioral changes and it shapes emotional judgments by increasing positive affect toward presented stimuli. A unique feature of music is its ability to elicit memories and emotions. In the classical paradigm, exposure to unfamiliar material during the study phase is followed by a preference task in which studied and nonstudied stimuli are presented. Typically, participants prefer studied over nonstudied stimuli even in the absence of stimulus recognition. Such a preference for previously studied items is a very robust finding. Initially described by Meyer (1903) (for a review, see Bornstein, 1989), the increase of positive ratings with familiarity reveals a direct relation between emotional valence and memory. This phenomenon is well documented in the visual domain and has also been observed with musical stimuli. Only three studies to date have examined this effect in patients with AD, with inconsistent results. One study reported a preserved exposure effect on liking judgments in patients with severe explicit recognition disorders (Quoniam et al., 2003) but the other two failed to demonstrate such an effect (Halpern and O'Connor, 2000; Vanstone et al., 2012). Given that the melodic excerpts were presented only two or three times in these latter studies compared with several times (up to 10 times) in the first one, it is plausible that they were not sufficiently repeated to enhance liking judgments (for further discussion, see Samson and Peretz, 2005). These results suggest the possible influence of musical memory on affective responses that should be further studied in patients with dementia.

Unfortunately, standard neuropsychological tests for assessing musical memory are not currently available, but we have summarized the most commonly used tests in the literature to date in Table 2 to assist with future investigations of music memory functions in patients with dementia. Note that The Montreal Battery of Evaluation of Amusia from Peretz et al. (2003) can be used to assess melodic and rhythmic perception.

2.2 MUSIC EMOTION

The first study to examine recognition of emotion by using musical excerpts (i.e., happiness, sadness, and anger) in dementia was conducted 20 years ago (Allen and Brosgole, 1993). Although the results demonstrated deficits in recognizing

Table 2 Methods of assessment of musical memory in patients with dementia

Type of musical memory	Task	Stimuli (mode of presentation)	Instructions	Control data	Authors (year)
Explicit					
Familiar music	Familiarity decision	Songs and instrumental pieces (auditory)	Judge if musical excerpt is familiar or unfamiliar	Yes	Cuddy and Duffin (2005), Bartlett et al. (1995), Liégeois-Chauvel et al. (1998, version MBEA) and Vanstone et al. (2012)
	Famous melodies	Songs and instrumental pieces (auditory)	Recall of title	Yes	Cuddy and Duffin (2005) and Polk and Kertesz (1993)
		Unknown (auditory)	Recall of last note by singing	No	Polk and Kertesz (1993)
		Songs (auditory)	Recall of lyrics, type of tune	Yes	Bartlett et al. (1995)
		Songs (auditory)	Recall of composer, or title if given composer	No	Crystal et al. (1989)
		Classical pieces (auditory)	If recall of title unsuccessful, given four alternatives	Yes	Beatty et al. (1997)
		Type of stimuli unknown (written)	Recall title from written notation	No	Polk and Kertesz (1993)
	Melody generation (lyrics prompt test)	First phrase of song spoken in a monotone or written lyrics	Recall (sing) melody from spoken or written lyrics	No	Cuddy and Duffin (2005) and Cuddy et al. (2014)
	Within-modality semantic matching	Two different melodic fragments belonging to same or different famous tunes	Deciding whether two different samples belong to the same tune	Yes	Omar et al. (2010)

Continued

Table 2 Methods of assessment of musical memory in patients with dementia—cont'd

Type of musical memory	Task	Stimuli (mode of presentation)	Instructions	Control data	Authors (year)
	Old/new recognition	Christmas, children, and patriotic songs (auditory)	Respond "yes" if melody is old (heard before in testing session) or no if melody is new (not heard)	Yes	Bartlett et al. (1995) and Samson et al. (2012)
	Distorted tunes[a]	Songs (auditory)	Identify if tune altered	Yes	Cuddy et al. (2014) and Drayna et al. (2001)
Unfamiliar music	Old/new recognition	Unfamiliar melodies (auditory)	Respond "yes" if melody is old (heard before in testing session) or no if melody is new (not heard before)	Yes	Bartlett et al. (1995), Halpern and O'Connor (2000),[b] Quoniam et al. (2003),[b] and Samson et al. (2012)
Implicit					
Mere exposure effect Unfamiliar music	Preference judgment	Unfamiliar melodies (auditory) multiple presentations (1–10 presentations for Quoniam, or only twice for Halpern)	Rate preference (liking judgment) for melody on: 10-point likert type scale (1 = I don't like it to 10 = I like it a lot)	Yes	Quoniam et al. (2003)
			5-Point likert scale (1 = least pleasant to 5 = most pleasant)	Yes	Halpern and O'Connor (2000)
Procedural Familiar music	Cued recall	(Instrumental playing) Classical pieces	Play first bar of piece and ask patient to continue	No	Crystal et al. (1989)
	Recorded performance	Songs with lyrics	Rate patient performance against controls	Yes	Beatty et al. (1988)
	Play unfamiliar	Dixieland jazz pieces	Rate pre- versus postdementia onset performance	Yes: within subject	Beatty et al. (1994)
	Instrument	Twinkle Twinkle Little Star	Play simple piece on novel instrument (e.g., xylophone)	No	Beatty et al. (1988)
	Live performance	Music from patient's repertoire	Play to command (when given title)	No	Beatty et al. (1988) and Cowles et al. (2003)

New learning and recall	Instrumental playing	Violin piece published after dementia onset (written notation)	Training over three sessions. Recall without written notation	No	Cowles et al. (2003)
Unfamiliar novel music published after dementia onset	New learning and recall by playing of novel piece	Piano piece published after dementia onset (auditory and written notation)	Training over 6 days. Recall without written notation	No	Fornazzari et al. (2006)
Unfamiliar music	Sight read novel piece	Song published after onset of dementia	Sight read novel piece	No	Beatty et al. (1988)
Autobiographical memory	Background music while doing a recall task	Use of familiar classical music such as four seasons	Play music while performing autobiographical memory recall task such as Autobiographical Memory Interview	Yes	Irish et al. (2006) and Foster and Valentine (2001)
	Song/music to prompt a personal memory	Use of highly familiar instrumental pieces or self-selected/personally preferred songs/music	Play music (excerpt) and then ask if elicits a personal memory	Yes	Cuddy et al. (2014) and El Haj et al. (2012a,b)

[a] *Perceptual task.*
[b] *Incidental memory test as participants not informed that they had to memorize the melodies.*

different categories of musical emotions, they are difficult to interpret because the severity and the type of dementia were not specified. Other studies have subsequently investigated this in various types of dementia demonstrating different profiles of responses in patients with AD (Drapeau et al., 2009; Gagnon et al., 2009; Hsieh et al., 2011, 2012; Kerer et al., 2014; Omar et al., 2010), or other dementias, notably FTD and SemD (Hsieh et al., 2011, 2012; Omar et al., 2010, 2011).

To measure emotional responses in patients with dementia, a categorical approach has typically been adopted. This "categorical" approach is based on the natural tendency of human beings to decompose reality into categories, even when it concerns emotions conveyed by music. In this perspective, emotions are defined as belonging to discrete classes. Indeed, basic emotions that had been previously identified in nonmusical areas (Ekman, 1984) have been used in musical tasks. The idea that emotion expression in music corresponds to specific categories is, however, not shared by all. Some authors suggest that music produces diffuse emotions that would not allow for categorical distinctions (Hanslick, 1854 Meyer, 1956). This second "dimensional" approach is likely to better reflect the richness and complexity of emotional feelings induced by music listening. The feelings evolve continuously in dimensions, such as emotional valence (i.e., pleasant vs. unpleasant) or arousal (i.e., calm vs. dynamic), but no study, to our knowledge, has used this approach in patients with dementia.

By using the categorical approach, results obtained in patients with AD suggest that recognition of happiness, peaceful, sadness, or fear conveyed by music (Drapeau et al., 2009) or judgments of happy and sad music (Gagnon et al., 2009; Kerer et al., 2014) remain preserved. Subsequent studies have compared patients with AD and other dementias such as SemD. One such study investigated two professional musicians, one with SemD and the other with AD (Omar et al., 2010). Whereas labeling of emotions, particularly negative emotions conveyed by familiar music (classical or film music) was impaired in the musician with SD, this was not the case in the musician with AD confirming previous findings.

This question was further explored in groups of patients with SemD and mild AD (Hsieh et al., 2012) using unfamiliar pieces of music (same as Drapeau et al., 2009). In line with the profile of responses obtained in musicians, the SemD group showed greater deficits in recognizing musical emotions than the AD group. The AD group, however, was also impaired in identifying emotional categories of musical excerpts inducing fear, happiness, sadness, and peacefulness as compared to healthy aged participants, which was not in agreement with results of prior studies carried out in small groups of patients (Drapeau et al., 2009; Omar et al., 2010). In addition, emotional recognition of music was associated with the degree of atrophy of the right insula and amygdala as well as anterior temporal poles bilaterally. These studies suggest that patients with degenerative disease, such as SemD and to a lesser extent AD might be globally impaired in emotional recognition, and the deficit is not limited to scary music excerpts, as demonstrated in patients with focal dysfunction involving the amygdala (Gosselin et al., 2005, 2007). This finding provides additional evidence supporting the multimodal deficit in recognizing emotions, already reported in SemD (Rosen et al., 2002; Werner et al., 2007).

To identify the cerebral network responsible for deficits in music emotion recognition in patients with dementia, Omar et al. (2011) examined the profile of brain atrophy associated with frontotemporal degeneration in 16 patients with behavioral variant of FTD and 10 patients with SemD using voxel-based morphometry. Both groups displayed emotional deficits in comparison to healthy controls, but performance did not differ between the two types of dementia. These patients seem to have lost the pleasure from listening to music, a sort of "musical anhedonia" (Mas-Herrero et al., 2014). They found that impaired music emotion recognition was associated with gray matter loss in a large distributed cerebral network including insula, amygdala, various frontal, temporal, parietal cortices, and the subcortical mesolimbic system. All these structures are involved in various emotional judgments, reward, coupling of subjective feeling, and autonomic responses and representation of stimulus value from music. As noted by Omar and colleagues, "musical emotion recognition may probe the interface of these processes, delineating a profile of brain damage that is essential for the abstraction of complex social emotions" (p. 1814). This idea has been validated by a recent study by the same research group (Downey et al., 2013), which showed that individuals with behavioral variant of FTD showed impaired ability to attribute emotional mental states in a music task and this correlated with gray mater changes in the anterior temporal lobes and ventromedial prefrontal cortex.

Overall, these findings suggest that processing of musical emotions is relatively spared in AD (Drapeau et al., 2009; Gagnon et al., 2009; Kerer et al., 2014; Omar et al., 2010) or at least less impaired compared with other dementia types (Hsieh et al., 2012). Deficits in music emotion recognition appear to be relatively specific to certain neurodegenerative pathologies from the FTD spectrum.

2.3 ARTISTIC SKILLS

Whereas some patients with FTD can develop music anhedonia (as described above), others can manifest new artistic (including musical) skills after the clinical onset of their dementing illness (Miller et al., 1998). In a large-scale study ($n=69$), Miller et al. (2000) identified 12 patients with new or preserved creative skills, with five of these patients demonstrating new musical skills. The authors concluded that this facilitation or new manifestation of artistic skills is associated with loss of function in the left anterior temporal lobe. As proposed by Kapur (1996), these patients might have benefited from "paradoxical functional facilitation" that may underlie the unexpected emergence of artistic talent. This finding contrasts with the artistic and musical skills of patients with AD that can dissipate rapidly due to diminished function in posterior parietal and temporal regions (Cumming and Zarit, 1987), although this is not always the case (Beatty et al., 1997).

The emergence of musical abilities (such as composing) and enhanced interest in music (musicophilia) has subsequently been documented in other cases of FTD and SemD (Boeve and Geda, 2001; Fletcher et al., 2013; Miller et al., 2000). Using voxel-based morphometry, Fletcher and his colleagues (2013) recently found that musicophilia was more frequently observed in patients with SemD than behavioral variant of FTD and was associated with relative preservation of the volume in the left *posterior* hippocampus. This finding updates the initial proposal of Miller et al. (2000) who argued that the underlying mechanism of enhanced artistic skills in dementia was left *anterior* temporal dysfunction based on single photon emission tomography results.

3 IMPACT OF MUSIC IN DEMENTIA

A large number of studies reported in the literature have claimed that music-based interventions have positive effects on various measures of functioning including behavior, agitation, mood, emotion, and cognition in persons with dementia. Even if the development of better-controlled studies in recent years is incontestable, the experimental rigor of these clinical trials is often lacking as outlined in several reviews (Herholz et al., 2013; Raglio et al., 2012; Samson et al., 2014; Ueda et al., 2013; Vink et al., 2011), and various biases might have contaminated the results (i.e., unspecified selection criteria, small sample size, lack of randomization and of blind assessors, group dissimilarity at baseline, and no control group). A list of criteria that should be considered in randomized controlled trials (RCTs) investigating the impact of music in dementia is proposed in Table 3. Unfortunately, many studies did not report information regarding these criteria. We should therefore remain cautious about the hasty conclusions concerning the efficacy of musical interventions on persons with dementia (for further discussion, see Samson et al., 2014).

3.1 BEHAVIOR AND AGITATION

One of the most common behavioral symptoms of dementia is agitation, affecting nearly half of the participants in various studies (for example, Okura et al., 2010; Ryu et al., 2005). Three subtypes of agitation in persons with dementia have been characterized: (1) physically nonaggressive behavior such as wandering, (2) physically aggressive behavior such as hitting and kicking, and (3) verbal or vocal agitation, such as shouting, verbal aggression, repeating words, or demanding attention. The most common assessment tool used to measure agitation in persons with dementia is the *Cohen Mansfield Agitation Inventory* (Cohen-Mansfield et al., 1989). Agitation is associated with poor quality of life and carer distress (Cohen-Mansfield et al., 1989; Draper et al., 2000). It predicts nursing home admission (Morris et al., 1988) and results in greater use of restraint and psychotropic drugs (Testad et al., 2010). Psychotropic medications are commonly prescribed for

Table 3 Criteria for randomized controlled trial (RCT)

Clinical population
Sample size
Attrition bias
Single- or multiple-center
Eligibility criteria
Study design (parallel or crossover)
Intervention group (music)
Control intervention group (i.e., nonmusic or other intervention)
Control group (usual care)
Random group assignment
Test–retest (no differences in baseline data)
Type of intervention (individual or group)
Time period of intervention
Intensity (number of times per week)
Dosage (duration of intervention)
Duration of follow up (from the beginning of intervention)
Number of therapists
Therapists' personal preference
Primary outcome measure
Secondary outcome measures
Time of outcome measure assessments relative to intervention
Blind assessment (experimenter/interviewer)
Blind assessment (raters of video recording)
Similarities between interventions (music vs. nonmusic)
– Proportion of active and passive activities
– Proportion of familiar and unfamiliar activities
– Attractiveness
– Novelty between sessions

agitation but can result in undesirable effects such as increased cognitive decline and increased risk of cerebrovascular events and death. This has highlighted the important need for nonpharmacological therapies such as music to manage agitation, explaining the large number of studies reported in the literature.

Numerous methodological differences exist between studies examining the effect of music (in various forms) on agitation in persons with dementia, including the participants' severity of dementia, assessment tool used to measure agitation (for example, self or carer rated, questionnaire or direct observation), type of musical intervention (group or individual music therapy with or without a specific protocol, listening to personally preferred music or "relaxing" classical music), frequency and duration of the musical intervention, time of assessment of agitation relative to music intervention, and the type of activities undertaken by the comparison group (standard care or other recreational activity such as reading). Many studies have reported reduced agitation during and immediately after a period of music therapy or listening, but methodological limitations such as small sample sizes or no control group are common.

A recent systematic review of nonpharmacological interventions for managing agitation by Livingston et al. (2014) included music therapy studies and categorized them as "with" or "without" protocol (lead by a trained music therapist and including specific content, such as a well-known "warm up" song, music listening followed by joining in with music activities). They included 10 studies of "music therapy by protocol" and concluded that it is effective for decreasing agitation but has no long-term effect. They noted that there is no evidence for people with severe agitation and minimal evidence for people outside care homes. "Music therapy without protocol" included 11 studies and they reported that it was unclear whether this was therapeutic for agitation.

Larger scale randomized control studies investigating the effect of music on agitation in persons with dementia have recently found that music was no more effective than other nonmusical control conditions such as reading or cooking (for example, Cooke et al., 2010; Narme et al., 2014; Vink et al., 2013). These findings suggest that the reductions in agitation attributed to music in earlier studies may be the result of social interaction during the group music therapy session rather than the music *per se*. As noted by Vink et al. (2013) and Narme et al. (2014), it is noteworthy that previous studies that have reported positive effects of music on agitation have used standard care as a control condition (e.g., Lin et al., 2011; Ridder et al., 2013), as is the case for recent studies documenting the positive effects of singing on agitation. Hammar and colleagues (2011) have coined the term "music therapeutic caregiving," which involves singing with or to persons with dementia when assisting with activities such as dressing or bathing. They have found significantly reduced aggression and resistant behaviors (such as pulling away) during individual "music therapeutic caregiving" compared with standard care.

Overall, the findings in regard to the effects of music therapy on agitation are inconsistent, with early, less methodologically rigorous research reporting reduced agitation, but more recent large-scaled randomized control studies documenting no additional benefit of music compared with other recreational activities. These studies, however, have all performed group-based music activities rather than individually tailored or personally preferred music. The importance of choosing the favorite music of the person with dementia has been emphasized by several researchers. Gerdner (2000) compared effects of listening to "individualized" or personally preferred music versus "relaxing" classical music and found that agitation was only reduced with individualized music. This prompted the development of "evidence-based guidelines for individualized music for elders with dementia" (Gerdner, 2012; Gerdner and Schoenfelder, 2010).

The dramatic effects of this approach have recently been demonstrated in a documentary "Alive Inside," which shows the responses of persons with dementia to hearing personally preferred music (see www.aliveinside.us). This film has promoted the popular view that music is superior to other activities for persons with dementia, but scientific evidence for the special effect of music (over other activities or stimuli) is still lacking. A recent study by Cohen-Mansfield and colleagues (2014) addressed this issue. They investigated a range of individually tailored nonpharmacological interventions (including music) for reducing agitation in persons with dementia (type not specified) living in residential facilities. The specific interventions were selected according to agitation etiology, past/present preferences, and cognitive functioning and identified in a preintervention phase. They found that music was one of the most commonly utilized interventions and had one of the highest levels of impact on agitation. In specific comparisons, they found that music was more effective than several other activities (such as squeeze ball, puzzle, robotic animal) in the trial phase, but only superior to robotic animal in the intervention phase. Unfortunately, no information was provided in regard to the nature of the music, and how this was selected, but given that the activities were noted to be "individually tailored," it is assumed that the music was self-selected and personally preferred. This study supports the results of the studies reviewed above and highlights that music may be effective at reducing agitation, but its possible greater therapeutic effect over all other activities remains to be demonstrated.

3.2 MOOD AND EMOTION

Music therapy has also been found to reduce mood symptoms, in particular depression and anxiety, which are very common in persons with dementia (i.e., Chu et al., 2014). In their recent "narrative synthesis systematic review" of music therapy in dementia, McDermott and colleagues (2013) concluded that there was evidence for short-term improvements in psychological (and behavioral) disturbance, as measured by a range of formal mood questionnaires, such as the *Geriatric Depression Scale* and *Beck Depression and Anxiety Inventories*. A meta-analysis by Ueda and colleagues (2013) reported that longer term music therapy (over 3 months) was particularly effective at reducing anxiety symptoms. Guétin et al. (2009) found that the beneficial effects of individual music therapy on anxiety and depression lasted up to 8 weeks after the intervention. Overall, there is accumulating evidence that music is an effective nonpharmacological treatment for mood symptoms in persons with dementia.

In three recent studies (Clément et al., 2012; Narme et al., 2014; Sakamoto et al., 2013), emotional state has been measured by calculating the number of positive and negative facial expressions during short video interviews and assessed by raters blind to group activity (music or other). By comparing passive (music listening) and interactive interventions involving individualized and personally preferred music to a nonmusic control condition, Sakamoto et al. found that both music interventions (but particularly interactive ones) reduced stress and elicited positive emotional responses in patients with severe AD. In a more recent study, Narme et al. (2014) confirmed the efficacy of musical interventions in improving the emotional state of patients with mild-to-moderate AD as measured by facial expressions, mood, and content discourse but showed that there was no difference in benefit compared with another pleasant group activity, specifically a cooking intervention.

3.3 COGNITION

Music activities have been reported to improve various cognitive functions in persons with dementia. Enhanced language functions, specifically verbal fluency, are a consistent finding in studies on the effects of music therapy on cognition in these patients (Brotons and Koger, 2000; Suzuki et al., 2004). Several studies have used the *Mini Mental State Examination* (MMSE) to assess cognition and one found improved scores of up to three points immediately after music interventions (Breuer et al., 2007). Caution needs to be taken in interpreting the significance of these findings, however, due to practice effects from task repetition and the lack of blinded assessors.

One recent large-scale study has investigated the effects of regular music activities on cognitive functioning using various neuropsychological tasks in addition to the MMSE in persons with dementia (Särkämö et al., 2014). In an RCT that compared standard care to regular singing or music listening sessions (weekly over 10 weeks and at home with caregivers) in 89 persons with dementia (type not specified), the authors found maintained or enhanced cognition in both music groups, in addition to improved mood and quality of life. Specifically, assessment immediately after the intervention period showed that music sessions improved general cognition (MMSE total score), attention, and executive functions (Frontal Assessment Battery) compared with standard care, although the authors noted that the differences were only marginally significant after controlling for baseline differences. Improved orientation was seen in music groups at the 6-month follow-up. Singing was particularly effective in evoking personal remote memories, as shown by increased recall of names of childhood friends/acquaintances (Autobiographical Fluency Test) and improving working and verbal memory function (Wechsler Memory Scale digit span reversed and Logical Memory I—immediate short story recall).

In addition to the general impact of music intervention on cognition, other studies have examined more specifically the use of song or music to aid verbal or autobiographical memory retrieval.

3.3.1 Music/Singing as a Memory Aid

Music in the form of song has been shown to be an effective verbal memory aid in persons with mild AD. Specifically, verbal information that is presented as lyrics to an unfamiliar song rather than as spoken words is better recognized in forced choice paradigms (Simmons-Stern et al., 2010, 2012). In particular, it has been found that presenting information in song facilitates recognition of "general lyric content", or the theme, or topic of the information, but there is no difference in recognition memory of sung or spoken "specific lyric content" or specific details. In line with the hypothesis previously discussed, Simmons-Stern et al. (2012) attributed this finding to the dual process model of recognition memory and proposed that music enhances the process of familiarity to a greater extent than explicit recollection.

In a detailed case study of a person with mild AD, Moussard and collaborators (2012) found that sung lyrics were learnt and recalled better than spoken lyrics after a 4-week delay. In a subsequent group study (Moussard et al., 2014), the authors found that song did not benefit initial learning but confirmed their case study that it enhanced delayed recall. Several explanations have been offered for the facilitation of long-term retention of sung compared with spoken information, including the functional and anatomical overlap between music and language processing, similar structural characteristics between the melody and lyrics, musical facilitation of lexical search and retrieval strategies, and enhanced encoding and consolidation of musical material due to its emotional and arousing effect.

The previous studies documenting the mnemonic effect of song have either made no distinction between those participants with or without musical training (Simmons-Stern et al., 2010, 2012) or examined nonmusicians (Moussard et al., 2012, 2014). Given the known cognitive and neuroanatomical differences between musicians and nonmusicians (as reviewed in Section 4), a worthy question to explore is whether musical training modulates the effect of learning and recall of verbal information presented in song. This has recently been explored by Baird and colleagues (submitted) in a group study of musicians and nonmusicians with and without AD. They found non musicians with AD showed significantly better total learning of spoken compared with sung information, whereas musicians with AD showed the reverse pattern, but this failed to reach statistical significance. Musicians (healthy and AD) showed better 30-min recall of sung compared with spoken information, and this facilitation of recall of sung information remained at a 24-h delay for healthy musicians only, but these differences were not significant. There were no differences in recall of sung compared with spoken information for non-musicians (healthy or with AD). Of note in this study there was only one learning session (five trials), which contrasts with Moussard et al. (2014) who had six learning sessions. This methodological difference may account for the inconsistent results between these two studies.

To date, there has only been one study using music as a memory aid for nonverbal information, specifically gestures (Moussard et al., 2014). In the same mild AD participants who completed the song as a verbal memory aid study (Moussard et al., 2014), they investigated memory for a sequence of gestures performed with music or metronome beat and learnt in synchrony or not. They found that AD participants showed a modest advantage for the music condition, with significantly more gestures recalled on the immediate recall trial, and a marginal effect of recall of gesture sequence on 10-min delay. In contrast, healthy controls showed no difference in recall of gestures between the music or metronome condition. They proposed that music may be of greater benefit to those with cognitive impairment due to the arousing effect of music and/or the dual coding of motor and auditory information, which may reinforce the memory trace and consequently enhance encoding and recall.

In summary, there is only scarce literature to date on the use of music as a memory aid in dementia. Given the potential benefits to persons with dementia, this topic is worthy of further research. While the current results are promising, there is much scope for further investigation including whether music aids in learning of nonmusical information, how music differs form other verbal or visual stimuli as a memory aid and whether differences in music appreciation and expertise between individuals modulates the effectiveness of song or music as a mnemonic.

3.3.2 Music-Evoked Autobiographical Memory

Music is a powerful and effective stimulus for eliciting autobiographical memories. "Music-evoked" autobiographical memories (MEAMs) have been characterized in healthy individuals (Janata et al., 2007), people with severe brain injury (Baird and Samson, 2014), and persons with dementia, specifically mild-to-moderate AD (Cuddy et al., 2014; El Haj et al., 2012a,b, 2013). MEAMs occur in people with or without musical training, although Cuddy et al. (2014) noted that in their pilot work, "musicians tended to produce memories of the musical and technical structure of pieces rather than personal memories."

Several studies have reported that music listening facilitates recall of personal memories (autobiographical memory) in persons with AD (El Haj et al., 2012a,b; Foster and Valentine, 2001; Irish et al. 2006). These studies have various methodological limitations, such as practice effects due to repetition of the same memory task, collapsing results across different music conditions (familiar, unfamiliar music) or a lack of nonmusic auditory condition, in other words, only comparing music and silence. Of note, one study found no significant difference between the effect of music and cafeteria noise on autobiographical memory, suggesting that the beneficial effect is not specific to music *per se* but may be due to any type of auditory stimulation (Foster and Valentine, 2001).

MEAMs have been elicited in persons with AD in response to personally selected music (El Haj et al., 2012a) or experimenter selected familiar instrumental music excerpts (Cuddy et al., 2014). El Haj et al. (2012a) found that memories recalled after hearing music of their own choice compared with a silent condition were more specific, recalled more quickly, and rated higher in emotional content. MEAMs also had higher grammatical complexity and proposition density and contain fewer empty words compared with autobiographical memory narratives after silence (El Haj et al., 2013). MEAMs are considered "involuntary" as they can be evoked spontaneously, recalled quickly, are more specific and have greater emotional impact than voluntary autobiographical memories. This distinction is emphasized by Cuddy and colleagues (2014) who proposed that the neural substrates underlying involuntary autobiographical memories remains relatively preserved in AD. They found that compared with younger and older healthy adults, people with mild-to-moderate AD showed fewer MEAMs in response to familiar instrumental music excerpts than healthy younger and older adult groups, but this difference in frequency was not significant. MEAMs contained more positive than negative content, and ratings of affect toward the memories evoked showed that older adults and people with AD had more positive feelings about the events recalled compared with younger adults.

Cuddy and colleagues attribute this to the "positivity effect" and consider this further evidence for the involuntary nature of MEAMs.

Several studies have found that MEAMs are more likely to be evoked by music that is rated high on familiarity and emotion (Baird and Samson, 2014; Cuddy et al., 2014; Janata et al., 2007). The intimate relationship between music and personal identity in persons with dementia has been explored by McDermott et al. (2014b) who proposed a "psychosocial model of music in dementia." They highlighted that the majority of research on music therapy in dementia has investigated the psychological, behavioral, or physiological effects of music, but not "how and why music might have worked." Three interrelated themes emerged from their interviews with carers (family and staff), music therapists, and persons with dementia about the importance and meaning of music in their lives; "who you are" ("fixed" psychosocial factors such as personal or cultural identity, personal life events), "here and now" ("tractable" psychosocial factors such as emotional experience), and "connectedness" (interpersonal such as shared experience/social interaction in care homes). Furthermore, they found that personal preference of music is preserved throughout all stages dementia and that "recognition of familiar music was considered emotionally meaningful, particularly for people at late stages of dementia" (p. 714).

Overall, these observations show that even in individuals with no musical training, music remains highly effective in eliciting autobiographical memories and associated emotions in persons with dementia. For this reason, it is a unique and powerful stimulus for reaffirming personal identity and social connectedness in persons with dementia, which is crucial for optimal well-being. Based on the findings to date, it appears that music can serve as a unique pathway to one's personal past despite severe memory impairment in conditions such as AD. Nevertheless, further studies are necessary to clarify the specificity, the content, and the emotional properties of such music-evoked autobiographical memories.

4 MUSIC EXPERTISE, AGING COGNITION, AND RISK OF DEMENTIA

There is extensive evidence that music training might promote brain plasticity. Both structural and functional brain differences between musicians and nonmusicians have been documented. For example, musicians show greater volume of primary auditory cortex (Heschl's gyrus), primary and premotor regions, cerebellum, and anterior corpus callosum (for review, see Herholz and Zatorre, 2012; Omigie and Samson, 2014). In regard to functional differences, compared with nonmusicians, musicians are more likely to recruit both hemispheres of the brain when performing music tasks, (such as detection of pitch variation) and use multiple rather than a single strategy to perform music cognition tasks.

Functional differences in the form of enhanced cognitive and perceptual functions have recently been observed in elderly musicians. Hanna-Pladdy and colleagues have found that elderly musicians show better cognitive functioning in both verbal and visual domains (Hanna-Pladdy and Gajewski, 2012; Hanna-Pladdy and MacKay, 2011). Amer et al. (2013) found that elderly musicians outperformed nonmusicians on tasks assessing auditory processing tasks and cognitive control. Elderly musicians also show preservation of auditory perceptual functions-such as comprehension of speech in noisy environments (Zendel and Alain, 2012) and auditory brainstem timing to speech sounds (Parbery-Clark et al., 2012). Interestingly, functional changes have been documented in elderly individuals with minimal early music training, or even after a short period of training in those with no previous music training. White-Schwoch et al. (2013) found that music training early in life was associated with faster neural responses to speech in elderly individuals. Improved performance on cognitive tests (working memory, speed, and motor skills) was found in musically naïve participants (30–85 years) who had received 6 months of piano lessons compared with a no-treatment control group (Bugos et al., 2007). Seinfeld and collaborators (2013) compared music training (piano lessons) with other leisure activities in healthy elderly people and found that the former resulted in improved performance on specific cognitive tasks (the Stroop test, an “executive” task assessing response inhibition, and Trail Making Test A, a speed of processing task) in addition to enhanced mood. Overall, these observations suggest that music training may have a protective effect in the face of age-related cognitive decline and that music-induced plasticity can occur even after a short period of training in the elderly brain. This raises the question of whether musical expertise gives rise to greater “cognitive and brain reserve capacity,” enhanced redundancy and access to different strategies, or facilitates metaplasticity in the musician brain (Omigie and Samson, 2014), and potentially reduces the risk of dementia (Verghese et al., 2003).

Cognitive and brain reserve models have sought to explain the paradoxical observation that some individuals fail to show clinical symptoms of AD despite evidence of Alzheimer’s neuropathology on autopsy. Stern and colleagues consider reserve to be an active process whereby alternative strategies are used to perform a function (Stern, 2006; Stern et al., 2005), while others have associated reserve with the extent to which cerebral damage has depleted neural substrates (Katzman, 1993; Mortimer et al., 1981; Satz, 1993). This latter group of models refers to a theoretical construct known as *brain reserve capacity*, which corresponds with biological measures such as number of synapses and brain size. Individual differences in the size of brain reserve capacity mean that there are variations in cognitive outcomes in response to a given brain injury or disease, as a fixed threshold is reached before cognitive deficits are manifested. This threshold is lower in individuals with lesser brain reserve capacity, and therefore, they are more likely to show cognitive impairment that those with greater brain reserve capacity.

The notion that music training and expertise may correspond to greater brain reserve capacity has been proposed (Omigie and Samson, 2014). Two studies have directly addressed this hypothesis in relation to risk of dementia. Grant and Brody

(2004) proposed that dementia is less common in orchestral musicians. They interviewed 23 elderly musicians (mean age 76.9 years) who were former orchestra members and found that no participant was aware of any current or former member of the orchestra with dementia. The authors suggested that playing a musical instrument may have a protective effect against the risk of developing dementia but acknowledged the methodological limitations of their small-scale study. This hypothesis has been addressed by Verghese and colleagues (2003) who measured frequency of engagement in leisure activities in a prospective study of 469 people over 75 years of age who did not have dementia. Over a follow-up period of 5 years, they documented the incidence of dementia and found that playing a musical instrument was one of several leisure activities associated with a reduced risk of dementia (AD and vascular dementia).

In summary, the potential protective effect of musical expertise in the face of neuropathology requires further investigation. Given the aging population and the increasing incidence of dementia, there is an urgent need for further research on musical training and associated brain plasticity in the elderly.

5 CONCLUSION AND FUTURE DIRECTIONS

Study of the neurodegenerative conditions such as the various types of dementias can potentially yield insights into brain mechanisms underlying musical functions. Several lines of evidence suggest that music abilities are not completely spared in dementia (some deficits are reported but not always) and most importantly, persons with dementia should not be considered as a single clinical profile. The type and causes of dementia have different effects on musical functions. Consequently, patients with AD, FTD, or other dementia types might respond differently to music interventions.

Music is widely accessible, easy to utilize, and enjoyed by the majority of people. Its unique ability to elicit both emotions and memories means that it can potentially provide a link to the persons past and promote feelings of interconnectedness with carers and others with dementia. This makes it an ideal stimulus to present to persons with dementia and an important topic for more rigorous scientific research.

Current interpretations of the data, however, are limited by the lack of methodological rigor, as emphasized by several review papers (Baird and Samson, 2009; Omar et al., 2012; Samson et al., 2014). Standardized tests to assess musical functions should be developed to allow comparison with results obtained in nonmusical domains and to determine the significance of the current findings in regard to incidence of preserved functions. A strict control of task difficulty across domains is necessary and specific attention should be given to premorbid musical training and competencies.

Even if the integrity of music cognition and emotion in the face of dementia can be questioned, recent RCTs have demonstrated the efficacy of music interventions in improving the well-being of persons with dementia and their caregivers. The ‘how and why’ music might have been beneficial to these individuals and the extent to which the efficacy of music surpasses that of other pleasant activities remain to be clarified.

It will also be important to determine who is most likely to benefit from music, rather than using a “one-size-fits-all” approach. This issue has been addressed by the development of formal questionnaires to assess music interest and engagement in the general population (Chin and Rickard, 2012; Müllensiefen et al., 2014), and two such questionnaires are specifically for use in people with dementia. McDermott et al. (2014) designed the Music in Dementia Assessment Scales (MiDAS) to measure engagement with musical experience and provide insight into who is likely to show improved quality of life or reduction in psychiatric symptoms in response to music therapy. Very recently, Cuddy and collaborators (2014) also proposed a questionnaire to assess musical engagement that supports the factor structure of earlier questionnaires (such as Use of Music in Daily Life, Responses to Music, Musical Consumer Behavior), including a section that could be answered by caregivers. This questionnaire focuses on current musical behaviors and does not require the caregiver to speculate about the person’s inner state or to have knowledge of their past musical involvements. Use of these assessment tools will be important in future studies to determine individual differences in the efficacy of music interventions and allow crosscomparison between studies and standardized assessment of music skills in persons with dementia.

The recent findings that musical training delays cognitive decline and promotes plasticity in the elderly brain are promising. There is an urgent need for further methodologically rigorous investigations of this topic in light of our rapidly aging population and the corresponding increasing incidence of dementia.

To conclude, it is necessary to pursue in parallel studies to (1) better understand the musical abilities of the different types of dementia by using appropriate methods and (2) to develop and test the efficacy of music as a nonpharmacological treatment for symptoms of dementia following the advise of the CONSORT statement (*Con*solidated *S*tandards *o*f *R*eporting *T*rials, Altman et al., 2001) to improve the quality of RCTs. These two lines of research will inform each other and will be crucial to optimize and understand the effects of music interventions in dementia. This research will also contribute to our knowledge of the brain regions mediating music cognition and provide important insights into the relative preservation of some cognitive functions in dementia.

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CHAPTER

Apollo's gift: new aspects of neurologic music therapy

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Abstract

Music listening and music making activities are powerful tools to engage multisensory and motor networks, induce changes within these networks, and foster links between distant, but functionally related brain regions with continued and life-long musical practice. These multimodal effects of music together with music's ability to tap into the emotion and reward system in the brain can be used to facilitate and enhance therapeutic approaches geared toward rehabilitating and restoring neurological dysfunctions and impairments of an acquired or congenital brain disorder. In this article, we review plastic changes in functional networks and structural components of the brain in response to short- and long-term music listening and music making activities. The specific influence of music on the developing brain is emphasized and possible transfer effects on emotional and cognitive processes are discussed. Furthermore, we present data on the potential of using musical tools and activities to support and facilitate neurorehabilitation. We will focus on interventions such as melodic intonation therapy and music-supported motor rehabilitation to showcase the effects of neurologic music therapies and discuss their underlying neural mechanisms.

Keywords

brain plasticity, melodic intonation therapy, music-supported training, neurologic music therapy, neurorehabilitation

1 MUSIC AS A DRIVER OF BRAIN PLASTICITY

Apollo's gift, music, is one of the richest human emotional, sensory-motor, and cognitive experiences. It involves listening, watching, feeling, moving and coordinating, remembering, and expecting musical elements. It is frequently accompanied by strong

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emotions resulting in joy, happiness, and bittersweet sadness or even in overwhelming bodily reactions like tears in the eyes or shivers down the spine. A large number of cortical and subcortical brain regions are involved in music listening and music making activities (for reviews see Altenmüller and McPherson, 2007; Tramo, 2001).

Primary and secondary regions in the cerebral cortex are critical for any conscious perception of sensory information, be it auditory, visual, or somatosensory. However, music also influences and changes activity in multisensory and motor integration regions in frontal, parietal, and temporo-occipital brain regions. The frontal lobe is involved in the guidance of attention, in planning and motor preparation, in integrating auditory and motor information, and in specific human skills such as imitation and empathy. The two latter play an important role in the acquisition of musical skills and emotional expressiveness. Multisensory integration regions in the parietal lobe and temporo-occipital areas integrate different sensory inputs from the auditory, visual, and somatosensory system into a combined sensory impression; it is this multisensory brain representation, which constitutes the typical musical experience. The cerebellum is another important part of the brain that plays a critical role in musical experience. It is important for motor coordination, but it also plays an important role in various cognitive tasks especially when they include demands on timing. Typically, the cerebellum is activated in rhythm processing, or tapping in synchrony with an external pacemaker such as a metronome. Finally, the emotional network (comprising the basis and the inner surfaces of the two frontal lobes, the cingulate gyrus and brain structures in the evolutionarily old parts of the brain such as the amygdala, the hippocampus, and the midbrain) is crucial for the emotional perception of music and therefore for an individual's motivation to listen to or to engage in any musical activity.

The brain is a highly dynamically organized structure that changes and adapts as a result of activities and demands imposed upon it by the environment. Musical activity has proven to be a powerful stimulus for this kind of brain adaptation, or brain plasticity (Wan and Schlaug, 2010). Effects of plasticity are not restricted to musical prodigies, they occur in children learning to play a musical instrument (Hyde et al., 2009) and in adult amateur musicians (Bangert and Altenmüller, 2003), albeit to a lesser extent. Thus, with the main topic of our article in mind, we suggest that brain plasticity induced through making music may produce manifold benefits. This holds not only for changing and/or restoring compromised sensorimotor brain networks, but also for influencing neurohormonal status as well as cognitive and emotional processes in healthy and neurologically diseased/disordered individuals. Thus, various sensory-motor, coordinative, or emotional disabilities can be improved with music-supported therapy (MST).

This chapter briefly reviews the literature on music-induced brain plasticity, its underlying mechanisms, and the impact that music has on emotion and neurohormones. Subsequently, we will demonstrate transfer effects of music exposure and music making to other cognitive and emotional domains and finally show examples of the potential of music making to support and facilitate neurorehabilitation. Our intent is not to provide an exhaustive review, but to focus our chapter on music-supported interventions geared toward improving the rehabilitation of speech- and limb-motor impairments following brain injury.

2 SOME MECHANISMS OF MUSIC-INDUCED BRAIN PLASTICITY

During the past decade, brain imaging has provided important insight into the enormous capacity of the human brain to adapt to complex demands. These adaptations are referred to as brain plasticity and do not only include the quality and extent of functional connections of brain networks, but also fine structures of nervous tissue and even the macroscopic gross structure of brain anatomy (Bangert and Schlaug, 2006). Brain plasticity is best observed in complex tasks, including, for example, temporospatially precise movements with high behavioral relevance. These behaviors are usually accompanied by emotional arousal and motivational activation of the reward system. Furthermore, plastic changes are more pronounced when the specific activities have started before puberty and require intense training. Obviously, continued musical activities throughout the life of a musician provide an ideal setup for brain plasticity to occur. It is therefore not surprising that the most dramatic effects of brain plasticity have been demonstrated in professional musicians (for a classic review see Münte et al., 2002; for more recent reviews Wan and Schlaug, 2010; and Altenmüller and Schlaug, 2012, 2013).

Our understanding of the molecular and cellular mechanisms underlying these adaptations is far from complete. Brain plasticity may occur on different time scales. For example, the efficiency and size of synapses may be modified in a time window of seconds to minutes, the growth of new synapses and dendrites may require hours to days. Other changes require up to several weeks. They include an increase in gray matter density, reflecting either an enlargement of neurons, a change in synaptic density, more support structures such as capillaries and glial cells or a reduced rate of physiological cell death (apoptosis). White-matter density also changes as a consequence of musical training. This effect seems to be primarily due to an enlargement of myelin cells: The myelin cells, wrapped around the nerve fibers (axons) are contributing essentially to the velocity of the electrical impulses traveling along the nerve fiber tracts. Under conditions requiring rapid information transfer and high temporal precision, these myelin cells are growing, and, as a consequence, nerve conduction velocity will increase. The axons within these myelin sheaths can potentially sprout and form more and new connections particularly between the nodal cortical points that are connected by white tracts (for a recent publication on this see Wan et al., 2014). Finally, brain regions involved in specific tasks may also be enlarged after long-term training due to the growth of structures supporting the nervous function, for example, blood vessels/capillaries that are necessary for the oxygen and glucose transportation sustaining nervous function or glial cells as supporters of the local homeostasis.

Comparison of the brain anatomy of skilled musicians with that of nonmusicians shows that prolonged instrumental practice leads to an enlargement of the hand area in the motor cortex (Amunts et al., 1997). Furthermore, Gaser and Schlaug (2003) could demonstrate enhancement of gray matter density in cortical sensory-motor regions, auditory regions, the left dorsolateral prefrontal cortex, and in the cerebellum in professional instrumentalists as compared to nonmusicians and amateurs. Interestingly, these plastic adaptations depend on critical periods: musicians, who start early, before the age of seven do not display these structural adaptations of the brain at least in the sensory-motor cortices and the callosal fibers, however, they seem to have an "early optimized network," which allows superior performance of motor tasks without enlarged anatomical structures (Steele et al., 2013; Vaquero et al., 2014). In contrast, relatively late starters, after age seven do show the abovementioned structural adaptations accounting for the effects observed in many morphological brain imaging studies (e.g., Bangert and Schlaug, 2006; Gärtner et al., 2013).

With respect to the larger callosal body in musicians, it seems plausible to assume that the high demands on coordination between the two hands, and the rapid exchange of information may either stimulate the nerve fiber growth—the myelination of nerve fibers that determines the velocity of nerve conduction—or prevent the physiological loss of nerve tissue during the typical pruning processes of adolescence or during aging. These between-group differences in the midsagittal size of the corpus callosum were confirmed in a longitudinal study comparing a group of children learning to play musical instruments versus a group of children without instrumental music experience (Hyde et al., 2009).

Halwani et al. (2011) recently showed another impressive adaptation of white-matter structures. They reported differences in macrostructure and microstructure of the arcuate fasciculus (AF)—a prominent white-matter tract connecting temporal and frontal brain regions—between singers, instrumentalists, and nonmusicians. Both groups of musicians had higher tract volumes in the right dorsal and ventral tracts compared to nonmusicians, but did not show a significant difference between each other. Singers had higher tract volume and different microstructures of the tract on the left side when compared to instrumental musicians and nonmusicians. This suggests that the right-hemisphere AF might show a more general effect of music making, while the left-hemisphere AF has a stronger response to the specific aspects of vocal-motor training and control that singers engage in. Microstructural parameters (i.e., fractional anisotropy) of the left dorsal branch of the arcuate fasciculus correlated with the number of years of participants' vocal training, suggesting that long-term vocal-motor training might not only lead to an increase in volume, but also to an increase in microstructural complexity of specific white-matter tracts constituting the so-called aural–oral loop and connecting regions that are fundamental to sound perception, production, and its feed forward and feedback control. Similarly, Bengtsson et al. (2005) and recently Rueber et al. (2013) have found structural differences in the corticospinal tract, particularly in the posterior limb of the internal capsule, between musicians and nonmusicians as well as within musicians groups (keyboard players compared to string players). Between group differences were related to measures of training intensity as well as to the specific requirements of the instruments played. It is worth to mention that instrumental training does not only affect cortical regions, but subcortical structures also seem to show adaptation.

For example, professional musicians in comparison to matched nonmusicians, seem to have a larger cerebellar volume or cerebellar gray matter (Gaser and Schlaug, 2003; Hutchinson et al., 2003). The cerebellum plays a role in the precise timing, accuracy, and coordination of motor actions, which is an important aspect of instrumental music activities.

In summary, instrumental music training, particularly when it starts at a young age, leads to plastic adaptations of various cortical and subcortical brain structures and functional networks. These changes can also include enlarged cortical representations of, for example, specific fingers or specific sounds or timbre of sounds (e.g., a string timbre vs. a brass timbre) within existing brain structures.

3 THE ROLE OF MUSIC-INDUCED EMOTIONS FOR BRAIN PLASTICITY

An intriguing question is why music is such a powerful driver of beneficial brain plasticity. This brings us to the specific motivational and emotional role of musical experience. Emotional responses to music are often cited when people describe why they value music and why they ascribe certain effects of music on health. Music is known to have a wide range of physiological effects on the human body including, for example, changes in heart rate, respiration, blood pressure, skin conductivity, skin temperature, muscle tension, and biochemical responses (for a review see Hodges, 2010; Kreutz et al., 2012).

Joyful musical behaviors, for example, learning to play a musical instrument or to sing is characterized by curiosity, stamina, and the ability to strive for rewarding experiences in future. This results in incentive goal directed activities over prolonged time periods, which are mainly mediated by the transmitter substance dopamine. Most nerve cells sensitive to this neurotransmitter are found in a small part of the brain, which is localized behind the basis of the frontal cortex, the so-called mesolimbic system, an important part of the “emotional” brain. Dopamine plays a dominant role in the neurobiology of reward, learning, and addiction. Virtually all drugs of abuse, including heroin, alcohol, cocaine, and nicotine activate dopaminergic systems. So-called natural rewards such as musical experiences and other positive social interactions likewise activate dopaminergic neurons and are powerful aids to attention and learning (Keitz et al., 2003). There is ample evidence that the sensitivity to dopamine in the mesolimbic brain regions is largely genetically determined resulting in the enormous variability in reward-dependent behavior. The genetic “polymorphism” of dopaminergic response explains the different motivational drives we observe in children with a similar social and educational background. It is intriguing that there is a strong link of dopaminergic activity to learning and memory, which in turn promote plastic adaptations in brain areas involved in the tasks to be learned.

Serotonin is another neurotransmitter important for music-induced brain plasticity. It is commonly associated with feelings of satisfaction from expected outcomes, whereas dopamine is associated with feelings of pleasure based on novelty or newness. In a study of neurochemical responses to pleasant and unpleasant music, serotonin levels were significantly higher when subjects were exposed to music they found pleasing (Evers and Suhr, 2000). In another study with subjects exposed to pleasing music, functional and effective connectivity analyses showed that listening to music strongly modulated activity in a network of mesolimbic structures involved in reward processing including the dopaminergic nucleus accumbens and the ventral tegmental area, as well as the hypothalamus and insula. This network is believed to be involved in regulating autonomic and physiological responses to rewarding and emotional stimuli (Menon and Levitin, 2005).

Blood and Zatorre (2001) determined changes in regional cerebral blood flow (rCBF) with PET technology during intense emotional experiences involving sensations such as goose bumps or shivers down the spine whilst listening to music. Each participant listened to a piece of their own favorite music to which they usually had a chill experience. Increasing chill intensity correlated with rCBF decrease in the amygdala as well as the anterior hippocampal formation. An increase in rCBF correlating with increasing chill intensity was observed in the ventral striatum, the midbrain, the anterior insula, the anterior cingulate cortex, and the orbitofrontal cortex: Again, these latter brain regions are related to reward and positive emotional valence.

In a newer study by the same group, the neurochemical specificity of [(11)C] raclo-pride PET scanning was used to assess dopamine release on the basis of the competition between endogenous dopamine and [11C]raclopride for binding to dopamine D2 receptors (Salimpoor et al., 2011). They combined dopamine-release measurements with psychophysiological measures of autonomic nervous system activity during listening to intensely pleasurable music and found endogenous dopamine release in the striatum at peak emotional arousal during music listening. To examine the time course of dopamine release, the authors used functional magnetic resonance imaging (fMRI) with the same stimuli and listeners, and found a functional dissociation: the caudate was more involved during the anticipation and the nucleus accumbens was more involved during the experience of peak emotional responses to music. These results indicate that intense pleasure in response to music can lead to dopamine release in the striatal system. Notably, the anticipation of an abstract reward can result in dopamine release in an anatomical pathway distinct from that associated with the peak pleasure itself. Such results may well help to explain why music is of such high value across all human societies. As stated above, dopaminergic activation regulates and heightens arousal, motivation and supports memory formation in the episodic and the procedural memory (Karabanov et al., 2010) and thereby will contribute to memorization of auditory stimuli producing such strong emotional responses. In a very recent study, the authors could even demonstrate that the degree of activation and connectivity in a network comprising the nucleus accumbens, auditory cortices, amygdala, and ventromedial frontal cortex predicted the amount of money, subjects were willing to spend in an auction paradigm (Salimpoor et al., 2013).

Taken together, these powerful music-induced modulations of neurohormonal status may not only account for pleasurable experiences but may also play a role in neurologic music therapy.

4 FACILITATING RECOVERY FROM NONFLUENT APHASIA THROUGH A FORM OF SINGING

The ability to sing in humans is evident from infancy, and does not depend on formal vocal training but can be enhanced by training. Given the behavioral similarities between singing and speaking, as well as the shared and distinct neural correlates of both, researchers have begun to examine whether forms of singing can be used to treat some of the speech-motor abnormalities associated with various neurological conditions (Wan et al., 2010).

Aphasia is a common and devastating complication of stroke or other brain injuries that results in the loss of ability to produce and/or comprehend language. It has been estimated that between 24% and 52% of acute stroke patients have some form of aphasia if tested within 7 days of their stroke; 12% of survivors still have significant aphasia at 6 months after stroke (Wade et al., 1976). The nature and severity of language dysfunction depends on the location and extent of the brain lesion. Accordingly, aphasia can be classified broadly into fluent or nonfluent. Fluent aphasia often results from a lesion involving the posterior superior temporal lobe known as Wernicke's area. Patients who are fluent exhibit articulated speech with relatively normal utterance length. However, their speech may be completely meaningless to the listener and littered with jargon. Furthermore, it may contain violations to syntactic and grammatical rules. These patients also have severe speech comprehension deficits. In contrast, nonfluent aphasia results most commonly from a lesion in the left frontal lobe, involving the left posterior inferior frontal region known as Broca's area. Patients who are nonfluent tend to have relatively intact comprehension for conversational speech, but have marked impairments in articulation and speech production.

The general consensus is that there are two routes to recovery from aphasia. In patients with small lesions in the left hemisphere, there tends to be recruitment of both left-hemispheric, perilesional cortices with variable involvement of right-hemispheric homologous regions during the recovery process (Heiss and Thiel, 2006; Heiss et al., 1999; Hillis, 2007; Rosen et al., 2000). In patients with large left-hemispheric lesions involving language-related regions of the frontotemporal lobes, the only path to recovery may be through recruitment of homologous language and speech-motor regions in the right hemisphere (Geschwind, 1971; Schlaug et al., 2008). It has been suggested that recovery via the right hemisphere may be less efficient than recovery via the left hemisphere (Hillis, 2007), possibly because patients with relatively large left-hemispheric lesions that encompass all of the relevant speech-motor regions of the left hemisphere are generally more impaired and recover to a lesser degree than patients with smaller left-hemisphere lesions. Nevertheless, activation of right-hemispheric regions during speech/language fMRI tasks has been reported in patients with aphasia, irrespective of their lesion size (Rosen et al., 2000). For patients with large lesions that cover the language-relevant regions on the left, therapies that specifically engage or stimulate the homologous right-hemispheric regions have the potential to facilitate the language recovery process beyond the limitations of natural recovery (Gerstman, 1964; Keith and Aronson, 1975). Based on clinical observations of patients with severe nonfluent aphasia and their ability to sing lyrics better than they can speak the same words (Albert et al., 1973; Schlaug et al., 2010; Sparks and Holland, 1976), an intonation-based therapy called Melodic Intonation Therapy (MIT) that would emphasize melody and contour and engage a sensorimotor network of articulation on the unaffected hemisphere through rhythmic tapping was developed (Albert et al., 1973; Schlaug et al., 2010). The two unique components of MIT are first the intonation of words and simple phrases using a melodic contour that follows the prosody of speech, and second the rhythmic tapping of the left hand that accompanies the production of each syllable and serves as a catalyst for fluency.

To date, studies using MIT have produced positive outcomes in patients with nonfluent aphasia. These outcomes range from improvements on the Boston Diagnostic Aphasia Examination (BDAE; Goodglass and Kaplan, 1983), to improvements in articulation and phrase production (Bonakdarpour et al., 2000; Wilson et al., 2006) after treatment. The effectiveness of this intervention is further demonstrated in a recent study that examined transfer of language skills to untrained contexts. Schlaug et al. (2008) compared the effects of MIT with a control intervention (speech repetition) on picture naming performance and measures of propositional speech. After 40 daily sessions, both therapy techniques resulted in significant improvement on all outcome measures, but the extent of this improvement was far greater for the patient who underwent MIT compared to the one who underwent the control therapy.

The therapeutic effect of MIT is also evident in neuroimaging studies that show reorganization of brain functions. MIT resulted in increased activation in a right-hemisphere network involving the premotor, inferior frontal, and temporal lobes (Schlaug et al., 2008), as well as increased fiber number and volume of the arcuate fasciculus in the right hemisphere (Schlaug et al., 2009; Wan et al., 2014). These findings demonstrate that intensive experimental therapies such as MIT—when applied over a longer period of time in chronic stroke patients—can induce functional and structural brain changes in a right-hemisphere vocal-motor network, and these changes are related to speech output improvements (Wan et al., 2014).

The mechanisms that are underlying the recovery-enhancing effects of MIT are not completely clear. However, it has been argued that we suggest that there are four possible mechanisms by which MIT's therapeutic effect is achieved (for details, see Schlaug et al., 2008): (1) *reduction of speed* to approximately one syllable/sec. which may specifically engage right-hemisphere perceptual and perception–action coupling on the right hemisphere, as the right hemisphere has been shown to integrate sensory information over a larger time window than the left (Abrams et al., 2008;

Poeppel, 2003); (2) *syllable lengthening* that isolates/emphasizes individual phonemes even as they remain part of the continuously voiced words/phrases; and (3) "*chunking*" that not only combines prosodic information with meaningful content to facilitate production of longer, more fluent phrases, but has also been shown to lead to more right- than left-hemisphere activation in healthy subjects (Meyer et al., 2002; Ozdemir et al., 2006; Zatorre and Belin, 2001). Given that, patients with right-hemisphere lesions have greater difficulty with global processing tasks (e.g., melody and contour processing) than those with left-hemisphere lesions (Peretz, 1990; Schuppert et al., 2000), it is possible that the melodic element of MIT does, indeed engage the right hemisphere, particularly the right temporal lobe, more than therapies that do not make use of tonal information or melodic contour, and again intervention that would integrate information over a larger timescale favoring right over left-hemispheric processing (Poeppel, 2003). The fourth mechanism—*Left-hand tapping* (*one tap/syllable*, *one syllable/sec*.)—is likely to play an important role in engaging a right-hemispheric, sensorimotor network capable of providing an impulse for verbal production in much the same way that a metronome has been shown to serve as a "pacemaker" when rhythmic motor activities prime and/or entrain sensorimotor networks (Thaut and Abiru, 2010; Thaut et al., 1999). In addition, research suggesting that hand movements and articulatory movements may share neural correlates (Gentilucci et al., 2000; Meister et al., 2003; Tokimura et al., 1996; Uozumi et al., 2004) further supports the notion that hand tapping is critically important for facilitating the coupling of sounds to orofacial and articulatory actions (Lahav et al., 2007). Since concurrent speech and hand use occurs in daily life, and gestures are frequently used to emphasize/accompany important and/or elusive concepts in speech, rhythmic hand movements, in synchrony with articulatory movements, may have similarly beneficial effects on speech production and in particular in relearning of speech-motor functions after a stroke.

5 MUSIC-SUPPORTED MOTOR THERAPY IN STROKE PATIENTS

MST in the rehabilitation of fine motor hand skills was first systematically investigated by Schneider et al. (2007). Patients were encouraged to play melodies with the paretic hand on a piano, or to tap with the paretic arm on eight electronic drum pads that emitted piano tones. It was demonstrated that these patients regained faster their motor abilities, and improved in timing, precision, and smoothness of fine motor skills. Along with fine motor recovery, an increase in neuronal connectivity between sensory-motor and auditory regions was demonstrated by means of EEG-coherence measures (Altenmüller et al., 2009; Rojo et al., 2012; Schneider et al., 2010). Therefore, establishing an audio-sensory-motor co-representation may support the rehabilitation process (see Fig. 1). This notion is corroborated by findings in a patient who underwent music-supported training 20 months after suffering a stroke. Along with clinical improvement, fMRI follow up provided evidence for the establishment

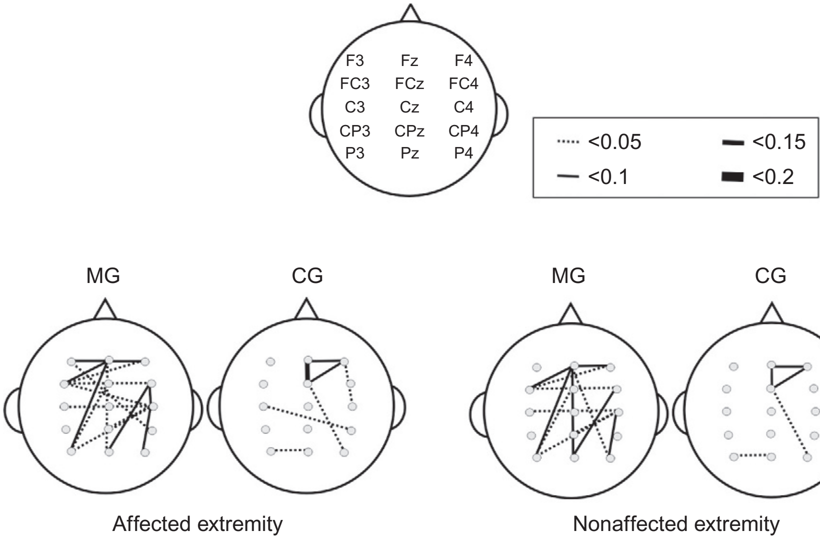

FIGURE 1

Topographic task-related coherence maps for the Music group (MG) compared to the control group (CG) during self-paced arm movements for the drum pad condition in the beta band (18–22 Hz). Statistically significant increases in task-related coherence during the motor performance after 3 weeks and 15 sessions of music-supported therapy on sonified drum pads are displayed.

From Altenmüller and Schlaug (2013) with permission.

of an auditory-sensory-motor network due to the training procedure (Rojo et al., 2012). Recently, in a larger group of 20 stroke patients, changes in motor cortex excitability following a 4 weeks intervention were demonstrated with the transcranial magnetic stimulation technique. These changes were accompanied with marked improvements of fine motor skills (Amengual et al., 2013).

Music-supported training is undoubtedly efficient and seems to be even more helpful than functional motor training using no auditory feedback, but otherwise similar fine motor training. A randomized prospective study comprising all three groups is presently under the way and will clarify the differential effects of functional motor training and music-supported training. With respect to the underlying mechanisms, a number of open questions still remain. First, the role of motivational factors must be clarified. From the patients' informal descriptions of their experience with the music-supported training, it appears that this was highly enjoyable and a highlight of their rehabilitation process. Thus, motivational and emotional factors might have contributed to the success of the training program. Furthermore, according to a study by Särkämö et al. (2008), music listening activates a widespread bilateral network of brain regions related to attention, semantic processing, memory, motor functions, and emotional processing. Särkämö and colleagues showed that music exposure significantly enhances cognitive functioning in the domains of verbal memory and focused attention in stroke patients. The music group also experienced less depressed mood than the control groups. These mechanisms may also hold true for the music-supported training we applied.

Another issue is related to the auditory feedback mechanisms. Up to now, it has not been clear whether any auditory feedback (e.g., simple beep tones) would have a similar effect on fine motor rehabilitation or whether explicit musical parameters such as a sophisticated pitch and time structure are prerequisites for the success of the training. This has to be addressed in a study comparing the effects of musical feedback compared to simple acoustic feedback. With respect to the latter, according to a study by Thaut et al. (2002), simple rhythmic cueing with a metronome significantly improves the spatiotemporal precision of reaching movements in stroke patients.

Furthermore, it is not clear, whether timing regularity and predictability is crucial for the beneficial effect of MST using key-board playing or tapping on drumpads. Although it has been argued that the effectiveness of this therapy relies on the fact that the patient's brain receives a time-locked auditory feedback with each movement, new results challenge this viewpoint. In a recent study, 15 patients in early stroke rehabilitation with no previous musical background learned to play simple finger exercises and familiar children's songs on the piano. The participants were assigned to one of two groups: in the *normal* group, the keyboard emitted a tone immediately at keystroke, in the *delay* group, the tone was delayed by a random time interval between 100 and 600 ms. To assess recovery, we performed standard clinical tests such as the nine-hole-pegboard test and index finger tapping speed and regularity. Surprisingly, patients in the delay group improved more in the nine-hole-pegboard test, whereas patients in the normal group did not. In finger tapping rate and regularity both groups showed similar marked improvements. The normal group showed reduced depression whereas the delay group did not (van Vugt et al., 2014). Here, we conclude that music therapy on a randomly delayed keyboard can improve motor recovery after stroke. We hypothesize that the patients in the delayed feedback group implicitly learn to be independent of the auditory feedback and therefore outperform those in the normal condition.

Finally, the stability of improvements needs to be assessed in further studies, and the length and number of training sessions might be manipulated in future research. Additionally, the effect of training in chronic patients suffering from motor impairments following a stroke for more than a year will be assessed.

6 CONCLUSIONS

Emerging research over the past decade has shown that long-term music training and the associated sensorimotor skill learning can be a strong stimulant for neuroplastic changes in the developing as well as in the adult brain, affecting both white and gray matter as well as cortical and subcortical structures. Making music including singing and dancing leads to a strong coupling of perception and action mediated by sensory, motor, and multimodal brain regions and affects either in a top-down or bottom-up fashion important relay stations in the brainstem and thalamus. Furthermore, listening to music and making music provokes motions and emotions, increases between-subject communications and interactions and—mediated via neurohormons such as serotonin and dopamine—is experienced as joyous and rewarding through activity changes in amygdala, ventral striatum, and other components of the limbic system. Making music makes rehabilitation more enjoyable and can remediate impaired neural processes or neural connections by engaging and linking brain regions with each other that might otherwise not be linked together.

As other experimental interventions, music-based experimental interventions need to be grounded on a neurobiological understanding of how and why particular brain systems could be affected. The efficacy of these experimental interventions should be assessed quantitatively and in an unbiased way. A neuroscientific basis for music-based interventions and data derived from randomized clinical trials are important steps in establishing neurologically based music therapies that might have the power to enhance brain recovery processes, ameliorate the effects of developmental brain disorders, and neuroplasticity in general.

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CHAPTER

13 The discovery of human auditory–motor entrainment and its role in the development of neurologic music therapy

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Abstract

The discovery of rhythmic auditory–motor entrainment in clinical populations was a historical breakthrough in demonstrating for the first time a neurological mechanism linking music to retraining brain and behavioral functions. Early pilot studies from this research center were followed up by a systematic line of research studying rhythmic auditory stimulation on motor therapies for stroke, Parkinson's disease, traumatic brain injury, cerebral palsy, and other movement disorders. The comprehensive effects on improving multiple aspects of motor control established the first neuroscience-based clinical method in music, which became the bedrock for the later development of neurologic music therapy. The discovery of entrainment fundamentally shifted and extended the view of the therapeutic properties of music from a psychosocially dominated view to a view using the structural elements of music to retrain motor control, speech and language function, and cognitive functions such as attention and memory.

Keywords

entrainment, neurologic music therapy, neurorehabilitation, neuroscience, rhythm

1 INTRODUCTION

Entrainment is a universal phenomenon that can be observed in physical (e.g., pendulum clocks) and biological systems (e.g., fire flies) when one system's motion or signal frequency entrains the frequency of another system. The use of entrainment for therapeutic purposes was established for the first time in the early 1990s by Thaut and colleagues in several research studies, showing that the periodicity of auditory rhythmic

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patterns could entrain movement patterns in patients with movement disorders (Thaut et al., 1999). Physiological, kinematic and behavioral movement analyses showed very quickly that entrainment cues not only changed the timing of movement but also improved spatial and force parameters. We know now that anticipatory rhythmic templates are critical coordinative constraints in the brain for optimal motor planning and execution. This discovery showed for the first time that a structural element in music, i.e., rhythm, could be a successful stimulus for therapeutic purposes.

Rhythmic entrainment is one of the most important underlying mechanisms for the successful application of rhythmic-musical stimuli in motor rehabilitation for movement disorders associated with stroke, Parkinson's disease (PD), traumatic brain injury, cerebral palsy, etc. Temporal rhythmic entrainment has been successfully extended into applications in cognitive rehabilitation and speech and language rehabilitation, and thus became one of the first major neurological mechanisms linking music and rhythm to brain rehabilitation. Multiple treatment techniques in neurologic music therapy (NMT) utilize entrainment concepts in sensorimotor, cognitive, and speech/language training (Thaut and Hoemberg, 2014).

However, the discovery of structural elements in music as important mechanism facilitating therapeutic change has also motivated a previously not well-represented view to explore other elements in music as well as a language of rehabilitation: for example, the perception of melodic patterns to retrain attention and memory, singing and vocal exercises to retrain speech and language production, or elementary improvisation and composition exercises in a clinical context to train complexity thinking and facilitate executive functions. In this way, clinical rhythmic entrainment research became a model for a very different way of thinking about music in therapy and how to research it (Thaut, 2005). Approximately 25 years later, these discoveries have revolutionized how we use music successfully as a language of brain rehabilitation. The affective properties remain an important aspect of music in therapy but they are now functionally focused on dysfunctions that have critical affective and social components (Hallam et al., 2009). The clinical "music perception" model, however, has opened very new and very effective ways to apply music-based therapeutic exercises functionally to a broad range of dysfunctions of the human nervous system.

The remainder of this chapter will introduce the concept of entrainment more closely and show with examples from clinical research how profound the effects of rhythmic auditory–motor entrainment are in the rehabilitation of movement disorders. Furthermore, I will discuss why the discovery of entrainment had such a dramatic impact on changing the concepts of how music operates in therapy. Finally, illustrations will be provided how this conceptual change has led to the development of new NMT techniques in speech/language and cognitive therapy and rehabilitation.

2 WHAT IS ENTRAINMENT?

In 1666, the Dutch physicist Christian Huygens, the inventor of the pendulum clock, discovered that the pendulum frequencies of two clocks mounted on the same wall or board became synchronized to each other. He surmised that the vibrations of air molecules would transmit small amounts of energy from one pendulum to the other and synchronize them to a common frequency (Bell, 1947; Garber, 2003). However, when set on different surfaces the synchronization effect disappeared. As it turned out, the transmitting medium was actually the vibrating board or wall. For air molecule vibrations, there would have been too much dampening of the energy transmission, as was later discovered. The effect he observed was subsequently confirmed by many other experiments and was called entrainment. In entrainment, the different amounts of energy transferred between the moving bodies due to the asynchronous movement periods cause negative feedback. This feedback drives an adjustment process, in which the energy is gradually eliminated to zero until both moving bodies move in resonant frequency or synchrony. The stronger "oscillator" locks the weaker into its frequency. When both are equally strong, the faster system slows down and the slower system speeds up until they lock into a common movement period (Pantaleone, 2002).

Technically, entrainment in physics refers to the frequency locking of two oscillating bodies, i.e., bodies that can move in stable periodic or rhythmic cycles. They have different frequencies or movement periods when moving independently, but when interacting they assume a common period. Incidentally, Huygens' pendulums assumed a common period 180° out of phase, which he humorously called "odd sympathy." It is now known that entrainment can occur in various phase relationships of the movement onsets of the oscillating bodies—often one can observe a stable phase relationship between the two bodies. A stable phase relationship is achieved when both bodies start and stop their movement period at the same time. However, this is not a necessary prerequisite for entrainment to occur. The deciding factor for entrainment is the common period of the oscillating movements of the two bodies. This phenomenon is of considerable importance for clinical applications of rhythmic entrainment in motor rehabilitation (Kugler and Turvey, 1987; Thaut et al., 1998a,b).

Entrainment is a common phenomenon in the physical world—e.g., coupled oscillators, fluid waves, etc. Entrainment also occurs in nature, e.g., fireflies flashing their light signal and in circadian rhythms entraining to light–dark cycles within the 24-h day period (Roenneberg et al., 2003). Unfortunately, the term entrainment is often also used loosely and has been connected to many unrelated claims—usually in the context of claims for health or healing—with little or no scientific evidence, e.g., brain wave entrainment, altered states of consciousness, trance, drum circles, or binaural beat entrainment. Therefore, it is important for the clinician who follows an evidence-based intervention model to check the scientific validity for therapeutic claims (Thaut, 2005; Thaut and Hoemberg, 2014).

3 THE AUDITORY SYSTEM AND RHYTHM PERCEPTION

The ability of the auditory system to construct stable temporal templates rapidly is well known (Thaut and Kenyon, 2003). The auditory system is superbly constructed to detect temporal patterns in auditory signals with extreme precision and speed, as required by the nature of sound as only existing in temporal vibration patterns (Moore, 2003). The auditory system is faster and more precise than the visual and tactile systems (Shelton and Kumar, 2010). Since sound waves that are most important for speech and music and other perceptual tasks are based on periodic motions that repeat themselves in regularly recurring cycles, the auditory system is also perceptually geared toward detecting and constructing rhythmic sound patterns. However, the observation of timing in the auditory system does not stop its function there. From culture and history, we know and experience every day that the auditory and the motor system have a special relationship. For example, Thaut et al. (1998a,b) demonstrated that finger and arm movements instantaneously entrain to the period of a rhythmic stimulus (e.g., metronome beat) and stay locked to the metronome frequency even when subtle tempo changes are induced into the metronome that are not consciously perceived. These findings have been confirmed by other studies (Large et al., 2002).

Two early electrophysiological studies (Paltsev and Elner, 1967; Rossignol and Melvill Jones, 1976) also showed how sound signals and rhythmic music can prime and time muscle activation via reticulospinal pathways. The pathway connections between the auditory and the motor system—which had not been given much emphasis when compared to visual and proprioceptive systems in motor control—have been researched much more carefully in the past 20 years, ever since our discovery between 1991 and 1993 that rhythmic entrainment in human movement is possible and can be effectively applied to improve motor function in movement disorders (Thaut et al., 1992, 1993). It is now well established that the auditory system has richly distributed fiber connections to motor centers from the spinal cord upward on brain stem, subcortical, and cortical levels (Felix et al., 2011; Koziol and Budding, 2009; Schmahman and Pandya, 2006). Clinical applications based on auditory–motor connectivity will be discussed in the next section.

4 CLINICAL APPLICATIONS OF ENTRAINMENT

In a number of experiments between 1991 and 1993, Thaut and colleagues demonstrated that auditory rhythm and music can entrain the human motor system and be used to improve functional control of movement in healthy subjects and subjects with stroke (Thaut et al., 1991, 1992, 1993). This entrainment process in human movement—especially with patients with severe motor dysfunction like stroke—was previously unknown and never applied clinically. Gait patterns in hemiparetic stroke training, however, showed massive entrainment effects resulting in highly significant improvements in velocity, stride length, cadence, and stride symmetry, as well significant reductions in variability and amplitude of motor unit recruitment (i.e., muscle activation) (Thaut et al., 1993). Based on these findings we developed a standard gait training protocol—rhythmic auditory stimulation (RAS)—which proved to be very effective when compared to traditional gait therapies (Thaut et al., 2007). Immediate entrainment effects could be translated into long-term training effects over 3 weeks (Thaut et al., 1997) and 6 weeks (Thaut et al., 2007), respectively. Patients entered the studies in the subacute stage, approximately 2 weeks post stroke. These clinical findings have been replicated by a number of other research groups substantiating the existence of rhythmic auditory–motor circuitry for entrainment (Ford et al., 2007; Roerdink et al., 2007, 2011). RAS is now recognized among the evidence-based, state of the art motor therapies for cardiovascular accidents (Hoemberg, 2013).

Of greatest importance was the finding that the injured brain can indeed access rhythmic entrainment mechanisms. These observations led to studying rhythmic motor circuits in the brain more carefully. It is now well accepted that rhythm processing and auditory–motor interactions take place in widely distributed and hierarchically organized neural networks, extending from brain stem and spinal levels to cerebellar, basal ganglia, and cortical loops (Konoike et al., 2012; Thaut, 2003). Cortico-cerebellar networks underlying rhythmic auditory entrainment have been demonstrated by Thaut et al. (2008). Differential engagement of prefrontal (Stephan et al., 2002) and primary auditory cortex areas (Tecchio et al., 2000) have been identified mediating rhythmic motor entrainment below levels of conscious perception, depending on the magnitude of the rhythmic tempo changes. Common and distinct neural substrates for different components of musical rhythm (e.g., pattern, tempo, meter) have been described in a recent study investigating the neural basis of musical rhythm perception (Thaut et al., 2014a,b,c). The involvement of basal ganglia areas via cortico-striatal loops in the perception of harmonic changes in musical cadences was recently described for the first time by Seger et al. (2013). The involvement of the basal ganglia in auditory rhythm perception has been researched by Grahn and Brett (2009) and Grahn and Rowe (2013). Interestingly a study using rhythmic entrainment with patients with cerebellar dysfunction (Molinari et al., 2007) showed that entrainment ability, even on a subliminal level, was not affected by the presence of cerebellar damage, excluding the cerebellum as the chronometric timekeeper of the brain as had been suggested in earlier research (cf. Ivry et al., 2002).

In subsequent experiments, researchers studied rhythmic entrainment in the gaits of people with PD (McIntosh et al., 1997; Miller et al., 1996; Thaut et al., 1996). Although PD presents itself with a different neuropathology and different movement dysfunctions, we also discovered for the first time with this patient group strong entrainment effects that benefited mobility, most noticeably in improvements in bradykinesia, more stable stride symmetry and stride length, and strengthening of motor unit recruitment. Long-term maintenance of improvements over 4–5 weeks was demonstrated in a later study (McIntosh et al., 1998). RAS is now recognized as state of the art mobility treatment for PD (Archibald et al., 2013; Dietz, 2013; Hoemberg, 2005).

After successful experiments entraining endogenous biological rhythms of neural gait oscillators, a new question emerged. Can rhythmic entrainment also be applied to entrain whole body movements, especially arm and hand movements that are not driven by underlying biological rhythms? We found the answer by turning upper extremity movements, which are usually discrete and nonrhythmic by nature, into repetitive cyclical movement units which now could be matched to rhythmic time cues.

Our research group carried out two experiments studying hemiparetic arm reaching movements in patients with stroke. In one study, we investigated the immediate effect of rhythm on kinematic movement patterns, especially reaching trajectories, variability of movement timing, and elbow range of motion. Elbow range as well as both cyclical movement timing and smoothness of reaching trajectories improved significantly (Thaut et al., 2002). In a second study, we measured the effect of repetitive rhythmic arm training using a patterned sensory enhancement (PSE) protocol. Outcomes were assessed with the wolf motor function action test and the self-reporting motor activity log. Both measures were improved significantly in a within-subject design (Malcolm et al., 2009). The improvements were comparable in size to a parallel study we carried out using constraint induced therapy (CIT; Massie et al., 2009). We also compared trunk flexion and shoulder rotation in a discrete arm reaching versus cyclical reaching task cued by auditory rhythm. The rhythmic cyclical task reduced trunk flexion and increased shoulder and trunk rotation comparable to normal patterns, whereas in the discrete task subjects relied mostly on extended forward flexion of the trunk to reach the targets (Massie et al., 2009). Lastly, CIT significantly increased shoulder abduction, bringing the arm into a more circular outward motion, compared to pretest measures, whereas PSE decreased shoulder abduction, helping to bring the arm into a more forward trajectory. These findings might be interpreted as CIT being an excellent protocol to overcome nonuse of the paretic side, to stimulate associated brain plasticity, and increase quantity of movement, whereas auditory rhythm also addresses recovery of the quality of movement, such as increase in trunk rotation during reaching, which CIT does not facilitate. These findings have also been supported by similar findings in other research groups (Peng et al., 2011; Schneider et al., 2007; Whitall et al., 2000).

5 MECHANISMS OF ENTRAINMENT IN MOTOR CONTROL

The comprehensive effect of rhythmic entrainment on motor control raises some important theoretical questions as to the mechanisms modulating these changes. We know that firing rates of auditory neurons, triggered by auditory rhythms and music, entrain the firing patterns of motor neurons, thus driving the motor system into different frequency levels. However, that is not all. There are two additional mechanisms are of great clinical importance in regard to entrainment. The first is that auditory stimulation primes the motor system toward a state of readiness to move. Priming increases subsequent response quality.

The second, more specific aspect of entrainment refers to the changes in motor planning and motor execution it creates. Rhythmic stimuli create stable anticipatory time scales or templates. Anticipation is a critical element in improving movement quality. Rhythm provides precise anticipatory time cues for the brain to plan ahead and be ready. Furthermore, successful movement anticipation is based on foreknowledge of the duration of the cue period. We may remember that during entrainment two movement oscillators—in our case neurally based—of different periods entrain to a common period. In auditory entrainment, the motor period entrains to the period of the auditory rhythm. Entrainment is always driven by frequency or period entrainment—that is, the common periods may or may not be in perfect phase lock (i.e., the onset of the motor response would be perfectly synchronized to the auditory beat). Beat entrainment is a commonly misunderstood concept. Entrainment is not defined by beat or phase entrainment—it is defined by period entrainment (Large et al., 2002; Nozaradan et al., 2011; Thaut and Kenyon, 2003).

Period entrainment offers the solution to why auditory rhythm also changes the spatial kinematic and dynamic force measures of muscle activation. For a while, we lacked a conceptual link to connect time cuing via rhythmic stimuli to spatiodynamic parameters of motor control, before the analysis of acceleration and velocity profiles of our subjects offered an intriguing explanation. Why is time cuing via period entrainment so helpful for the patients' overall motor control in space, time, and force? The answer is simple and complex at the same time: rhythmic cues give the brain a time constraint—they fix the duration of the movement. Foreknowledge of the duration of the movement period changes computationally everything in motor planning for the brain. Velocity and acceleration are mathematical time derivatives of movement position. We realized that, by fixating movement time through a rhythmic interval, the brain's internal timekeeper now has an additional externally triggered timekeeper with a precise reference interval, a continuous time reference. This time period presents time information to the brain at any stage of the movement. The brain knows at any point of the movement how much time has elapsed and how much time is left, enabling better mapping and scaling of optimal velocity and acceleration parameters across the movement interval. The brain tries to optimize the movement now by matching it to the given template. This process will result not only in changes in movement speed but also in smoother and less variable movement trajectories and muscle recruitment. We can conclude that auditory rhythm, via physiological period entrainment of the motor system, acts as a forcing function to optimize all aspects of motor control. Rhythm not only influences movement timing—time as the central coordinative unit of motor control—but also modulates patterns of muscle activation and control of movement in space (Thaut et al., 1999).

With this understanding of the underlying mechanisms of entrainment it is less important if the patients synchronize their motor responses exactly to the beat—it is important that they entrain to the rhythmic period, because the period template contains critical information to optimize motor planning and motor execution. Consequently, patients might actually move, as Huygens once worded it, in any stage of "odd sympathy" to the actual beat.

6 MORE CLINICAL APPLICATIONS OF ENTRAINMENT

Rhythmic entrainment extends beyond motor control. Speech rate control affecting intelligibility, oral motor control, articulation, voice quality, and respiratory strength could greatly benefit from rhythmic entrainment using rhythm and music. Recent findings in aphasia rehabilitation suggest that the rhythmic component in Melodic Intonation Therapy might even be as important as the activation of intact right-hemispheric speech circuitry through singing (Stahl et al., 2011). Rate control via auditory rhythmic cues has been successfully applied to fluency disorders (e.g., stuttering, cluttering), as well improvements in intelligibility in dysarthria (Lansford et al., 2011; Pilon et al., 1998; Thaut et al., 2001; Van Nueffelen et al., 2009, 2010). NMT has an excellent standardized repertoire of evidence-based techniques for speech and language training based on rhythmic entrainment mechanisms (Thaut and Hoemberg, 2014).

Lastly, the potential of temporal entrainment of cognitive function has only recently emerged as an important driver of therapeutic change. NMT techniques in cognitive rehabilitation are relying to a large extent on the role of timing in music and rhythm. For example, in the context of new research findings the time structure of music and rhythm might be considered an effective mnemonic device to improve memory functions (Kern et al., 2007; Thaut et al., 2014a,b,c; Wallace, 1994).

7 OTHER MUSICAL ELEMENTS AS THERAPEUTIC DRIVERS

Kindled by the discovery of the clinical effects of rhythmic entrainment experimenters drawing on new research concepts began to examine other musical elements for their usefulness in rehabilitation. Especially in speech/language functions and cognitive functions, additional mechanisms in music perception beyond rhythm might be needed to address therapeutic needs.

In the area of speech and language therapies, two shared functions became important from a biomedical perspective: (1) the acoustical, anatomical, and neural perception and production features shared between spoken language and vocalization in music; and (2) the ability of both systems to embed communicative functions in the auditory modality. In the research and clinical literature underlying NMT, five areas of therapeutic mechanisms and clinical applications have emerged:

1. *Differential neurologic processing of music and speech*: the fact that the neural circuitry for speaking and singing is partially overlapping but also partially segregated has led to applications, such as Melodic Intonation Therapy, especially in regard to expressive aphasia rehabilitation, where singing could engage undamaged speech circuitry in the hemisphere contra lateral to the damage.
2. *Commonalities between speech and vocal production in music:* there is evidence that common prosodic, acoustical, and physiological production features are enhanced in music versus speech. For example, singing creates a broader overtone spectrum and a stronger fundamental voice frequency. Prosodic elements are amplified leading to enhanced oral motor ranges, better phonemic enunciation, and enhanced voice control. Singing could enhance phonation, and

enhance respiratory control and capacity, due to longer durations in sound production. Longer sound durations are the basis for the slower pace in singing versus speech. Slower pacing might enhance voice control regarding articulation and intelligibility.

3. *Verbal and nonverbal auditory communication systems:* music and speech are two auditory communication systems that—in regard to certain structural elements—have common counterparts, for example, in regard to phonology, prosody, pragmatics, and rule-based systems of composition. For example, musical patterns can simulate communication gestures found in speech: dialogic turn taking, question/answer forms, expressive statements, repeating, simultaneous expressions, etc.
4. *Enhanced auditory perception through music*: music creates an enriched, complex auditory environment that can help enhance sound perception. There is research evidence that shows how musical training enhances auditory sensitivity, which can also translate into enhanced speech perception (Strait et al., 2012).
5. *Musical development mirrors speech and language development:* very interesting parallels have been found between musical and speech/language development in early childhood, showing that engaging in both can have mutually supportive developmental effects (Brandt et al., 2012). Verbalization through singing offers an additional mode of expression and language learning, which can be further integrated into other related activities, like playing musical instruments or dancing.

The role of music in cognitive rehabilitation emerged as the last rehabilitation domain in NMT. There are two likely reasons for this. Human neurocognition research could only fully develop once noninvasive research tools to study the human brain, such as brain imaging, became available. The first focus of these research endeavors was to study the neural bases of higher cognitive functions in humans before a clinical rehabilitative perspective could be established to develop neuroscience-based intervention paradigms. Second, the traditional view of music in therapy was very much characterized by an emphasis on emotional and social factors as therapeutic mechanisms and goals. Cognitive functions, such as attention or memory, were given much less interest in more psychotherapeutically oriented concepts (Thaut et al., 2014a). However, a growing body of recent research has demonstrated intriguing links between music as a complex auditory language and higher cognitive functions, including temporal sequencing (Conway et al., 2009), temporal order learning (Hitch et al., 1996), spatiotemporal reasoning (Sarntheim et al., 1997), auditory attention (Drake et al., 2000), visual discrimination (Feng et al., 2014), hemispatial neglect (Soto et al., 2009), auditory verbal memory (Thaut et al., 2014a,b,c), emotional adjustment (Kleinstauber and Gurr, 2006), and executive control (Thaut et al., 2009). By linking music cognition and perception research to models of music learning—and finally linking music learning to retraining the injured brain, a new model has emerged that has allowed for the development of functional intervention techniques in the cognitive domain of NMT.

8 CONCLUSIONS

In conclusion, entrainment for therapeutic purposes has been used since the early 1990s, with strong research evidence that the periodicity of auditory rhythmic patterns could improve movement patterns in patients with movement disorders. Clinical research studies have demonstrated that auditory rhythmic cues elicit changes in motor patterns in gait and upper extremity movements. Changes in motor patterns are possibly due to priming of the motor system and anticipatory rhythmic templates in the brain that allow for optimal motor planning and execution with an external rhythmic cue. The ability of the brain to use rhythmic information to anticipate and plan the execution of a motor pattern has made rhythmic entrainment a valuable tool in motor rehabilitation. More recently, temporal rhythmic entrainment has been extended into applications in cognitive rehabilitation and speech and language rehabilitation, with initial successes indicating that mechanisms of rhythmic entrainment might prove to be an essential tools for rehabilitation in all domains.

The discovery of the clinical effectiveness of rhythmic motor entrainment also brought into focus for the first time that the structural elements of music have enormous potential in clinical applications to retrain the injured brain. As such, the discovery of entrainment was not just about the usefulness of entrainment, but more importantly served as a new vantage point for researching and understanding that the complex "language architecture" structure of music contains critical stimuli for effective brain rehabilitation. The new "clinical science" of music has been the bedrock for the development of NMT. Standardized clinical techniques were developed around clusters of research evidence to address motor, speech/language, and cognitive goals in brain rehabilitation. This treatment system constitutes historically the first medically endorsed form of music therapy.

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