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Emotional sounds and the brain: the neuro-affective foundations of musical appreciation

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Abstract

This article summarizes the potential role of evolved brain emotional systems in the mediation of music appreciation. A variety of examples of how music may promote behavioral change are summarized, including effects on memory, mood, brain activity as well as autonomic responses such as the experience of ‘chills’. Studies on animals (e.g. young chicks) indicate that musical stimulation have measurable effects on their behaviors and brain chemistries, especially increased brain norepinephrine (NE) turnover. The evolutionary sources of musical sensitivity are discussed, as well as the potential medical-therapeutic implications of this knowledge.

Keywords: Music; Emotions; Chills; Evolution; Chicks; Humans; Brain

1. Introduction

That music can profoundly effect our moods is a fact of every-day life. However, the manner in which music helps arouse feelings, ranging from joy and belongingness to bittersweet sadness and despair, remains a great mystery. Presumably, if we did not possess the kinds of social-emotional brains that we do, human music would probably be little more than cognitively interesting sequences of sounds and, at worst, irritating cacophonies. Instead, it can help create a variety of peak human affective experiences (Gabrielsson, 1991). While some argue that music does not reflect evolved processes of our brain (e.g. Pinker (1997) who called music ‘cultural cheesecake’), others have suggested that it is an important ingredient in the overall recipe of our evolutionary fitness (e.g. Miller (2000), who emphasized that it helps facilitate the success of male sexual courtship). In any event, most of us listen to music for the emotional richness it adds to our lives, and we rapidly become attached to the music that moves us, yielding, we suspect, bonds that may have underlying neurobiological similarities to the love

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and social devotion that people often feel for each other. As many have declared, music is the language of emotions.

It is remarkable that any medium could so readily evoke all the basic emotions of our brains (and much more), coaxing us to consider our innermost nature and to savor the affective dimensions of our minds. Clearly, music gives a voice to our feelings, and it provides a unique and highly ethical way to study the emotions of the human brain/mind. Unfortunately, this medium is so complex that for a long time methodologically rigorous psychologists despaired of ever distinguishing to what extent emotional changes were due to specific music attributes such as rhythm and melody, as compared to personal memories and acquired dimensions of cultural significance. We still do not know to what degree these, and many other factors, influence the emotional impact of music, but it is bound to be to very complex interactions that vary substantially from person to person. Surely human musicians utilize some culturally shared codes of emotional communication to produce their sound-magic, but we do believe there is a deeper trans-cultural, perhaps trans-species, emotional order to such issues. We will not dwell on such important issues, but call for more cross-cultural work (Balkwill and Thompson, 1999) to address the many fundamental questions raised in this paper.

In addition to the many acquired cognitive influences on the appreciation of music, we believe, there is an even deeper affective mystery within brain organization to which all these cognitive issues are subservient. To begin to clarify them, we need to focus on a series of basic questions: What is it about our brains, our minds, that make them such receptive vessels for the emotional power of music? How much has evolution prepared our neuro-mental apparatus to appreciate music? How deep in mind/brain evolution can we find the stamp of rhythmic 'musical' dispositions within the neurodynamics of 'being'? We do not know the answers to these questions with any confidence, but the aim of this paper is to push the barrier of our ignorance by sharing a large number of approaches we have taken to try to bring some understanding to our profound ignorance about these matters. One of our main aims for this essay is to familiarize readers with the relevant literature in the area as well as to entertain some novel ideas concerning how the emotional impact of music may ultimately arise within the brain.

In this contribution, we also share some recent findings and theoretical perspectives concerning primitive brain systems that may be critical for the affective-emotional appreciation of music (Panksepp, 1998a). We will largely focus on the neurophysiological ways music may enliven our feelings, and shall provide a variety of relatively novel examples how such issues may be empirically approached. We do not share these preliminary results as definitive findings, but as exemplars of future ways to proceed, and also to highlight the many methodological and control issues that will need to be heeded in future research. In general, we tend agree with the view advocated by Langer (1942) that 'there are certain aspects of the so-called 'inner life', physical or mental, which have formal properties similar to those of music, patterns of motion and rest, of tension and release, of agreement and disagreement, preparation, fulfillment, excitation' and so forth (p. 228).

Our overriding assumption is that ultimately our love of music reflects the ancestral ability of our mammalian brain to transmit and receive basic emotional sounds that can arouse affective feelings which are implicit indicators of evolutionary fitness. In other words, music may be based on the existence of the intrinsic emotional sounds we make (the animalian prosodic elements of our utterances), and the rhythmic movements of our instinctual/emotional motor apparatus, that were evolutionarily designed to index whether certain states of being were likely to promote or hinder our well-being. However, upon such fundamental emotional capacities, artists can construct magnificent cognitive structures of sound—musical cultures—that obviously go far beyond any simple affective or evolutionary concerns. In any event, the understanding of how music arouses emotional/affective processes of the brain may be essential for clarifying the extended love affair of our species with music. This simple idea has been resisted by music theoreticians, partly because until recently we have known so little about the emotional processes of the human brain. That is rapidly changing (Toga and Mazziotta, 2000), and modern brain imaging is beginning to reveal the deep subcortical foundations of peak musical experiences in remarkably many brain areas that we share homologously with all of the other mammals (Blood and Zatorre, 2001).

2. Conflicting biological and cultural perspectives on music

When we begin to think scientifically about music and emotional issues, we are rapidly confronted by many conceptual difficulties. As the renowned music theorist Meyer (1956/1994) put it: ‘If we then ask what distinguishes non-emotional states from emotional ones, it is clear that the difference does not lie in the stimulus alone. The same stimulus may excite emotion in one person but not in another. Nor does the difference lie in the responding individual. The same individual may respond emotionally to a given stimulus in one situation but not in another. The difference lies in the relationship between the stimulus and the responding individual’ (p. 11). This places cultural and learning issues at the very heart of the musical experience, with a resulting focus on formal studies of music itself rather than the brain substrates of emotional experience, and that is where it has been left by the great majority of thinkers and investigators. That approach has no chance of identifying the ‘causal’ antecedents of the deeper affective mysteries.

Meyer proceeded to extol cognitive rather than intrinsic affective views of the power of music, as have others (e.g. Kivy, 1990). They believe emotions conveyed in music are fundamentally different from real emotions. However, Meyer’s and Kivy’s views were advanced before we knew much about how the brain elaborated emotions and the degree to which right versus left hemispheres participate differentially in the affective/inward versus logical/outward aspects of human lives (Schiffer, 1998; Springer and Deutsch, 1998). We, along with others (e.g. Clynes, 1978; Krumhansl, 1997), believe that music derives its affective charge directly from dynamic aspects of brain systems that normally control real emotions and which are distinct from, albeit highly interactive with, cognitive processes. This view is corroborated by evidence from brain damaged individuals (Peretz et al., 1998) as well as modern brain-imaging (Blood et al., 1999). Once again, this is not to deny the obvious—that most people appreciate music through the gateways of their cortico-cognitive abilities—but to assert that when music truly moves us, something quite dramatic happens in deep subcortical regions of our brains (Blood and Zatorre, 2001).

Meyer discussed emotional processes in a vein characteristic for his times—as undifferentiated forms of arousal as well as expectations and thwartings—even though he did not neglect the possibility that more specific emotional states might also be involved. Now we know that there is a great deal more differentiation in emotional systems than was long believed (Ekman and Davidson, 1994). There are distinct brain systems that mediate anger, fear, joy and sadness (Panksepp, 1982), as well as a variety of other social emotions (Panksepp, 1998a), and there is increasing evidence that music can activate the body ‘symbolically’ in emotion specific ways (Nyklicek et al., 1997).

From this modern perspective, it is no wonder that humans, whether adults or children, can easily distinguish the basic emotions within music (Dolgin and Adelson, 1990; Terwogt and Van Grinsven, 1991). Similarly, musicians can easily improvise individual emotions, and listeners can identify them accurately and with considerable confidence (Gabrielsson and Juslin, 1996; Gabrielsson and Lindstroem, 1995; Juslin, 1997; Nielzen and Cesarek, 1982). In addition to such emotion specific effects, music is bound to interact with generalized waking arousal control systems such as those based on norepinephrine (NE) and serotonin that regulate emotional responses (Panksepp, 1986). Also, there is a generalized incentive SEEKING system, centered on mesolimbic and mesocortical dopamine (DA) circuits (Ikemoto and Panksepp, 1999; Panksepp, 1998a), that is important in the intra-cerebral estimation of the passage of time (Meck, 1996). Such basic brain mechanisms for anticipatory eagerness may generate ‘seeking’ states which may promote various musical expectancies, especially those related to rhythmic movements of the body which may be ancestral pre-adaptation for the emotional components of music.

Thus, one overall question will concern us here: without the ancestral emotional systems of our brains, would music still be a meaningful and desired experience? We believe the correct answer is ‘no’. Well constructed music is uniquely efficacious in resonating with our basic emotional systems, bringing to life many affective proclivities that may be encoded, as birthrights, within ancient neural circuits constructed by our genes, many of which we share homologously with other mammals.

This is not to suggest that there is any single gene or brain ‘module’ that controls music appreciation. Music is not a uni-dimensional process, and many distinct, but widely distributed, brain areas participate in the neural coding of music (Blood and Zatorre, 2001; Halpern and Zatorre, 1999; Liegeois-Chauvel et al., 1998). Classic work on the neurology of music (e.g. Critchley and Henson, 1977; Steinberg, 1995) has highlighted a critical role of the right ‘prosodic’ hemisphere in affective musical appreciation (Zatorre, 1984) and expression (Perry et al., 1999), while many of the analytical components are elaborated more by the left side of the brain (Peretz, 1990; Sergent et al., 1992). This simple fact—that emotional and affective sensitivity are both elaborated more robustly in the right hemisphere (Peretz, 1990; Zatorre, 1984)—again suggests an intimate relationship exists between affective and musical processes in the brain. However, it does seem that some of the positive affective aspects of musical appreciation arouse left frontal areas while negative emotions arouse right frontal areas (Schmidt and Trainor, 2001).

Although an enormous amount of our musical proclivities are undoubtedly learned, the exquisite sensitivity of our species to emotional sounds may be related to the survival benefits that subtle emotional communications had for us during our evolutionary history. For instance, it may well be that we can rapidly convey levels of love, devotion and empathy through music that would be hard to achieve with any other mode of communication, except perhaps for physical touch itself (and we must recall that sound is a special form of touch). Thus, it is certainly reasonable to hypothesize that music was built upon the prosodic mechanisms of the right-hemisphere that allow us affective emotional communications through vocal intonations. Parenthetically, the possibility that rhythmic body movement (e.g. Muybridge, 1957) and the brain rhythm generators, may have been pre-adaptations for the emergence of music has rarely been considered (Radocy and Boyle, 1997).

By contrast, the left hemisphere tends to elaborate skills needed to deal with musical information in more cognitive ways, skills which are not essential for everyday enjoyment of music (Zatorre, 1984). For example, following a left-hemisphere stroke, Ravel sustained his appreciation for music, but lost his ability to render it into any standard notational system (Cytowic, 1976 as cited in Cytowic, 1998). Perhaps when musical appreciation shifts to the left hemisphere as a function of intense musical education, the raw affective appreciation of music may decrease in perceived value. This may be an implicit reason why emotional issues are so commonly minimized in musical research, and all too often, in musical education.

Although the structural characteristics of music that convey emotions are being clarified (Clynes, 1978, 1995; Gabrielsson, 1995; Peretz et al., 1998), there are only a few peppercorns of evidence for how the affective dynamics of music directly modify brain activities. There is some work on how the affective properties of music affect the human electroencephalogram (see Hodges, 1995; Schmidt and Trainor, 2001; Panksepp and Bekkedal, 1997, including work to be summarized later in this paper). In contrast, there is a great deal more evidence for how music effects electroencephalographic (EEG) parameters independently of affective issues (see Petsche et al., 1988; Sarnthein et al., 1997). EEG is of course the only brain imaging method we have for directly tapping neuronal activities, but it cannot visualize subcortical systems that are probably critical for generation of emotional feelings (Panksepp, 2000b). However, the indirect approaches (i.e.

PET and fMRI) that monitor brain variables correlated with neuronal activities can visualize those system, and recent PET evidence highlights that pleasurable aspects of musical consonance can arouse subcortical areas such as the septum (Blood et al., 1999). More recent evidence using music that could evoke 'chills' has highlighted arousal of even more primitive subcortical regions of the mind/brain (e.g. Blood and Zatorre, 2001) including ancient brain areas such as the periaqueductal gray (PAG) of the midbrain that have been implicated in the generation of human affective experiences (Damasio et al., 2000; Panksepp, 1998a,b). Hence, we would advance the idea that the emotional impact of music is largely dependent on both direct and indirect (i.e. cognitively mediated) effects on subcortical emotional circuits of the human brain that seem to be essential for generating affective processes (Panksepp, 2002).

3. Musical aesthetics, emotions and the brain

Our overriding premise is that, although all our musical preferences are ultimately culturally conditioned, our minds have been prepared by brain evolution to resonate with certain affective features of life, especially social life, that can be encoded and symbolized in the melodic variations, harmonic resonances and rhythmic pulsations of sound. Indeed, the ability of music to stir our emotions rather directly is a compelling line of evidence for the conclusion that cognitive attributions in humans may not be absolutely essential for arousing emotional processes within the brain/mind. For instance Peretz et al. (1998) have described an individual, similar to Ravel, who no longer had intact musical cognitions following a left hemisphere stroke but who still enjoyed music very much. Indeed, one such individual (C.N.) could only recognize familiar musical pieces by the emotions the music aroused (Peretz, 1996).

With the advent of deep brain imaging it is possible to specify the brain processes that are most important for generating the affective experiences as individuals listen to the music they love (Blood and Zatorre, 2001). Indeed, our ability to decipher the neural underpinnings of aesthetic responses may turn out to be easier for music than for the visual arts (e.g. Ramachandran and Hirstein, 1999). Music probably has more direct and powerful influences on subcortical emotional systems than do visual arts. For instance, an obligatory brainstem way-station for auditory processing, the inferior colliculus, is where our mother's voice may leave its first affective imprints: that brain region clearly mediates affective processes (Bagri et al., 1992) and is richly endowed with opiate receptors (Panksepp and Bishop, 1981), which may mediate attachments we develop to certain sounds (e.g. the voices of those we love) and hence, by a parallel line of reasoning, to certain types of music (Panksepp, 1995). The inferior colliculus is also adjacent to the PAG where all emotional systems converge upon a coherent self-representation of the organism, a primordial core consciousness (Damasio, 1999; Panksepp, 1998a,b). Within such a view, affective consciousness (i.e. the generation of valenced feelings, generated largely by the neurodynamics of subcortical emotional/instinctual system we share with other animals) needs to be distinguished from more cognitive forms of consciousness which generate propositional thoughts about the world (Panksepp, 2002). Thus, a worthy hypothesis is that music can arouse such basic emotional circuits at fairly low levels of auditory input. There are many reasons to believe that intrinsic emotional sounds may be decoded within the brainstem. Indeed, Blood and Zatorre (2001) have recently found that such deep brain areas can be aroused by chill-inducing music.

However, our current understanding is that emotional circuits, and hence the resulting neural resonances, are widely distributed in the brain, resembling a tree-like structure, with roots and trunk-lines in subcortical areas, and branches interacting with wide canopies in cortical regions (Panksepp, 1998a). Accordingly, music is bound to access these emotional systems at many levels. For instance, auditory processing of musical information could easily access the higher reaches of various emotional systems through temporal lobe inputs into the amygdala, frontal and parietal cortical inputs into other basal ganglia such as the nucleus accumbens as well as more direct inputs to limbic areas such as the cingulate and medial frontal cortices (Blood et al., 1999; Blood and Zatorre, 2001). In other words, there may be no restricted brain 'module' that is devoted simply to musical appreciation. Our love of music is most likely to emerge from the interplay of many brain areas, even though, as for all other basic psychobehavioral processes, there are also bound to be systems and neurochemistries of first-order importance (e.g. Panksepp, 1986, 1993). The study of the role of neurochemical systems that encode affect within the brain on musical experiences have barely begun.

In any event, any notion that the human brain has evolutionary dispositions for the appreciation of music must be advanced with one enormous proviso. Despite the attractiveness of certain evolutionary scenarios (Miller, 2000), it remains possible that the human brain is not adapted specifically for music. Rather, in some yet unfathomed way, the emergence of music may reflect the pre-existing emotional adaptations of the brain. A similar point has been made for language, leading certain scholars to suggest that the emergence of language may indirectly reflect the evolved complexities of the brain (Deacon, 1997). The evidence certainly does not yet mandate the existence of evolved language modules in the human brain (Clark, 1997; Panksepp and Panksepp, 2001), even though it is bound to have distinct brain systems that mediate communicative urges. By accepting the likelihood that many cultural dispositions arise developmentally (via learning), we can avoid falling into the empirically problematic postulation of specialized cerebral modules that are presently so popular in 'evolutionary psychology' but which may have no genetically dictated neurological reality (for critique, see Panksepp and Panksepp, 2000, 2001).

Obviously, further progress in unraveling such issues will depend critically on our ability to understand, in some detail, how social emotional feelings are actually created within the nervous system. That project is beginning to crystallize (Damasio, 1999; MacLean, 1990; Panksepp, 1998a, 2002), and once the neurochemistries of specific emotions have been decoded within the mammalian brain, then we should be able to directly evaluate how those systems contribute to the deep human feelings evoked by music. At present one of the few emotion-specific predictions that could be tested, because of the availability of clinically approved drugs, is whether opiate receptor antagonists such as naloxone and naltrexone can diminish our emotional appreciation of music (for rationale of this prediction, see Panksepp, 1995). Indeed, preliminary data provided by Goldstein (1980) have long indicated that such manipulations can reduce the chills or thrills that many people experience when they listen to especially moving music. We believe these effects are centrally mediated. Thus, a most interesting issue would be whether pharmacological manipulations that diminish our peripheral autonomic arousal would markedly diminish the emotional impact of music, as might be predicted by peripheralist somatic-marker theories like those of James–Lange and Damasio (1994). Preliminary evidence with such manipulations has indicated that minimal doses of tranquilizers that reduce peripheral autonomic effects do not abort the emotional impact of music (Harrer and Harrer, 1977).

Obviously many higher neural systems are involved in the various distinct aspects of music information processing and music appreciation (Penhune et al., 1999; Peretz, 1990; Peretz et al., 1994), but we postulate that a great deal of the emotional power may be generated by lower subcortical regions where basic affective states are organized (Damasio, 1999; Panksepp, 1998a,b). The ability of certain types of music to evoke a deep desire for bodily movements, and the induction of various autonomic changes by music is congruent with powerful subcortical influences of music (Hodges, 1995; Blood and Zatorre, 2001).

In contrast, the perceptual appreciation of the structural intricacies of music, with the attending images and expectancies are surely more critically dependent on higher regions of the brain. Obviously, for the full musical experience many brain systems need to be coordinated, and one of the functions of ancient brain emotional operating systems is to do that (Panksepp, 1998a). It is now well accepted that as one becomes a skilled musician, capable of deploying acquired analytical and skilled motor abilities, the brain locus of control for music appreciation tends to shift from the more emotionally resonant right hemisphere to the more analytical-intellectual left hemisphere (Zatorre, 1984). However, this in no way implies that the intensity and clarity of the emotions induced by music requires much education. In many studies, there has been little difference in skilled musicians and everyday listeners in decoding the emotional content of music (e.g. Juslin, 1997; Robazza et al., 1994), even though differences are evident in their detection of certain affective indices of speech (Nilsonne and Sundberg, 1985) as well as in the precision of attentional processes that are essential for musical intelligence (Tervaniemi et al., 1997). In other words, how we are moved by music and how we produce moving music entail vastly different psychological processes. Our concern here is with the former rather than the latter.

4. Evolutionary antecedents of musicality

As already indicated, many dynamic aspects of music probably gain access to human emotional systems quite directly without having to be processed propositionally. This suggests that our brains' ability to resonate emotionally with music may have a deep multidimensional evolutionary history, including issues related to the emergence of intersubjective communication, mate selection strategies, and the emergence of regulatory processes for other social dynamics such as those entailed in group cohesion and activity coordination. All these social abilities can impact our moods and hence it is easy to imagine how affective experiences evoked by emotional sounds and hence eventually music could have an adaptive evolutionary basis. Thereby, we can appreciate why many brain/mind processes (e.g. our deep inner feelings) that are hard to communicate in mere words can be more easily expressed in music (Langer, 1942).

Unfortunately, we do not know and may never know, with any certainty, how much musicality comes down to us from some ancestral appreciation of the inanimate sounds of nature, how much from the animate sounds of the many creatures on whom we have depended for sustenance and companionship throughout our evolutionary journey, how much comes from the various intrinsic emotional sounds we readily make, providing a prosodic background for our intrinsic urges to communicate with each other through the medium of sound, and how much from the ability of music to coordinate group activities, as in hunting and herding large and dangerous animals or harvesting crops. These possibilities have been extensively discussed elsewhere (Roederer, 1984; Storr, 1992; Wallin et al., 1999). Unfortunately such issues may forever remain lost in an evolutionary past that cannot be resurrected with any accuracy (Wallin, 1991).

However, there is one viewpoint that strikes us as more compelling than the rest: The foundation of music, as everything else, was surely shaped by its ability to promote mate-selection and reproductive fitness. In other species, the amount of vocal activity generated in the service of sexual attractiveness and arousal is phenomenal (Bradbury and Vehrencamp, 1998; Hauser, 1996). Considering the likelihood that emotional feelings provide simple metrics that monitor fitness issues, the capacity to generate and decode emotional sounds should be excellent tools for survival. Hence, it is quite understandable that theoreticians might be enticed by the possibility that adolescents of our own species may be able to effectively exhibit their fitness resources by displaying various forms of musical virtuosity (Miller, 2000). However, in theorizing about such issues, the potential role of musicality in mother-infant communication as well as between family and friends (i.e. group-selection issues) should loom equally large.

Whether the dynamics of social communication prepared our own brains for music appreciation may never be known with any assurance, but the argument is compelling. In social creatures like ourselves, whose ancestors lived in arboreal environments where sound was one of the most effective ways to coordinate cohesive group activities, reinforce social bonds, resolve animosities, and to establish stable hierarchies of submission and dominance, there should have been a premium on being able to communicate shades of emotional meaning by the melodic character (prosody) of emitted sounds. Sound is an excellent way to help synchronize and regulate emotions so as to sustain social harmony, as is still dramatically evident in such species as Gelada monkeys (Richman, 1987), albeit the social 'songs' of the other primates are vastly more instinctual and stereotyped that those of humans (Marshall and Marshall, 1976). In sum, there is much to commend the idea that the most important evolutionary influences that still govern our affective responses to music are the natural neurodynamics of our brain socio-emotional systems that appear to be exquisitely responsive to the dynamics of emotional sounds. We would anticipate that group selection views, which are again in ascendancy (Sober and Wilson, 1998), may be clarified by a close analysis of emotional vocalizations in animals and the emergence of musical cultures in humans.

Of course, we are bound to have more empirical success when we begin to deal with proximal causal rather than distal evolutionary issues. Let us consider one straightforward example: Many suspect that our capacity to sing, first evident in the sing-song babbling of babies, is an adaptation that facilitates teaching and learning between mother and child. Perhaps an especially important affective–cognitive transition was made when mothers started to communicate with their infants with attention grabbing shifts in tempo and melodic intonations within their spontaneous, affectively tinged communications known as motherese (Fernald, 1992; Papousek et al., 1991; Snow and Ferguson, 1977; Trehub and Trainor, 1988). It is certainly possible that information is more easily acquired when it is encoded in the context of dynamically rich musical structures (Shepard, 1999), an effect that is evident even in retarded children (Farnsworth, 1969). Fig. 1 summarizes the magnitude of this effect in one of our projects with undergraduates being taught the new and intimidating world of neuroanatomical terminology. Retention of information was significantly better when information had been provided with a musical rather than a non-musical acoustic carrier.

Parenthetically, similar dynamics may be present in the recently heralded ability of classical music to enhance general spatial abilities, the highly controversial 'Mozart Effect' (for a summary and critical analysis of the issue by investigators who originally reported the effect, see Rauscher and Shaw, 1998). However, we should not forget that this debated and debatable effect could simply arise from the effects of positive mood arousal on cognitive performance. Positive mood effects induced by music can increase creative output (Adaman and Blaney, 1995).

5. Music, body and dance

Rhythmic movements of the body characterize the instinctual life of animals, and the dynamics of these movements may contain ancestral emotional expressions that are captured in music (Clynes, 1978). The ancestral relationship between movement and sound is probably fundamental to our nature (Todd, 1985), and it may highlight a deep adaptation that is still instantiated in the urgent power and immediacy of dance. Much of the ancestral knowledge in our species has been traditionally handed down through ritualized chanting and dance movements that captured essential lessons concerning how complex procedures needed to be sequenced. Presumably, the preadaptations that allowed humans to utilize such ritual performances for cultural ends were related to the capacity of emotions to be expressed in rhythmic body movements. Thus, the ability of rhythmic emotional sounds to energize and coordinate bodily movement patterns may have served as an impetus for the cultural co-evolution of music and dance, and injected a special energy into other orgiastic events.

In any event, the impact of music on the brain systems that control bodily movement are profound. As an example, if someone were to measure them, we would suggest that the copulatory rhythms of the human species are well encoded in the rhythms of rock and roll. Thus, in considering the ability of music to generate affective states, we should not ignore the ability of the basic emotional systems to generate distinct forms of action readiness (Fridja, 1986; Panksepp, 2000a). The basic dynamics of these systems may be the

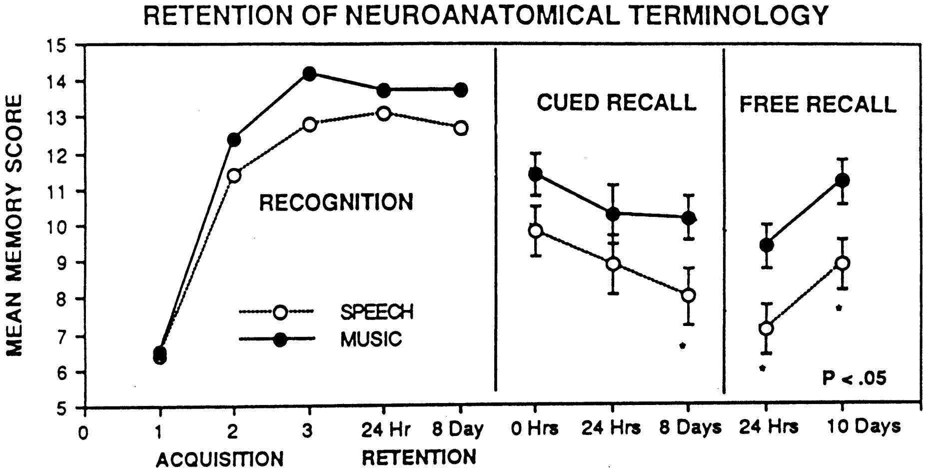

Fig. 1. Acquisition of neuroanatomical terminology. The fifteen anatomical plates that were used as instructional materials are depicted in Panksepp (1998a), figure 6.8). Half the subjects were given successive exposure to the individual plates with the anatomical term outlined and read in a regular voice ($n = 12$) or sung operatically ($n = 12$) (both by the same female). Three successive acquisition sessions were given followed immediately as well as at 1 and 8 days post-acquisition by 'recognition' recall from a mixed, visually presented list of the anatomical names (no significant differences were evident in recognition memory). Also immediately following training as well as at 1 and 8 days, subjects were presented with the anatomical plates and requested to identify each brain area from memory (middle panel), followed by a session of 'free recall' of as many anatomical terms as possible just from memory (right panel). Significant, memory improvements were observed with musically trained subjects during the long retrieval interval cued and free recall tasks.

very basis of music and dance. Indeed, we have recently found that joyous music (Irish jigs) can increase overall movements in young children in the midst of rough-and-tumble play (Scott and Panksepp, 2002).

In this context, it would be most interesting to know when children begin to exhibit an appreciation of music, and perhaps this could be monitored prior to the emergence of propositional speech by non-verbal measures of musical preferences and attentional processes (Masataka, 1999; Rock et al., 1999) as well as by measuring changes in spontaneous rhythmic movements in children during music, as well as by related autonomic changes. For instance, Chang and Trehub (1977) found that infants less than half a year of age exhibit changes in heart rate when the contour of a short melody was changed. Zentner and Kagan (1996) report visual orientation changes in 4 month old infants exposed to dissonant harmonic stimuli which are not evident with consonant stimuli.

The intimate relations between music and movement may be evident in the neural systems that control our gross axial body movements such as basal ganglia of the extrapyramidal motor system. When some of these neural systems become imbalanced, as in Parkinson's disease, some symptomatic relief of motor difficulties may be achieved through the insistent rhythms of music (see Sacks, 1973, even though more experimental work on this topic is still urgently needed, including how musical appreciation changes with this and other types of neurological damage). In this context, it is also noteworthy that in some traditional cultures, a distinction between music and dance is not made: For example, the Igbo (African) term 'nkwa' denotes 'singing, playing instruments, and dancing', and there is apparently no concept in that culture of 'music' being solely based on sound.

Still we would again re-emphasize that any attempt to explain music in either evolutionary or neurophysiological terms will miss the enormity of musical meaning that is constructed through diverse socio-cultural dimensions of aesthetics, to promote any basic psychobiological knowledge in this difficult field. We must tolerate many provisional simplifications of the underlying complexities. Thus, to highlight how we might empirically proceed, we will now consider some concrete ways we might aspire to fathom the emotional dynamics that may underlie certain emotional aspects of musical appreciation. Thus, in the rest of this paper, we will (a) delve into the potential meaning of some of the physiological effects induced by music (e.g. chills), (b) cover some of our animal studies evaluating the physiological and behavioral consequences of music, and (c) summarize some recent studies of the effects of music on the human brain. Finally, we will briefly discuss some therapeutic implications of such lines of investigation.

6. The physiological effects of music: with a focus on chills evoked by music

A considerable amount of work has been devoted to analyzing the effects of music on the body. The fact that music would have fairly robust effects on various body parameters is to be expected simply from the fact that music arouses emotions, and emotions are characterized by many autonomic changes (for a summary of early work see Critchley and Henson, 1977 and for more recent work see Hodges, 1995; Steinberg, 1995). In this context, it is important to emphasize that different individuals have distinct physiological responses to music (Nyklicek et al., 1997; VanderArk and Ely, 1992), suggesting that personality may be an important component of how people respond to music. Although still unexplored territory, the manner in which musical likes and dislikes relate to temperamental variability is a question that deserves empirical attention. It may even help explain why some people take the affective (Dionysian) and others more cognitive (Appolonian) points of view to music appreciation. Our approach here is decidedly Dionysian.

Here, we shall focus on one phenomenological bodily effect that we have studied systematically, namely the feeling of ‘chills’ or ‘shivers’ that many people experience when they listen to music that moves them, especially bittersweet songs of unrequited love and longing (Panksepp, 1995) as well as music that expresses patriotic pride through the commemoration of lost warriors (e.g. for many American audiences ‘The Battle Hymn of the Republic’ is quite effective, and seems to evoke intense frontal lobe arousal, Panksepp and Bekkedal, 1997). Parenthetically, it should be noted that there are other chilling sounds, like the sound of fingernails scraping across a blackboard, that are very aversive (Halper et al., 1986), but that is probably engendered by a very different brain response than the ‘chills’ discussed here (but which may be a useful ‘control’ maneuver for physiological studies).

In any event, a subjective experience that people commonly report when listening to moving music is a shiver on the neck and back, which commonly spreads down the limbs and often envelops the whole body. Although no one has yet adequately characterized this response, this ‘rush’ experience probably reflects, at least in part, a galvanic skin response that is common in emotional situations (some pilot data provided in Panksepp, 1995, even though a definitive and properly controlled study remains to be done). Parenthetically, we have sought to measure musically induced ‘chills’ using sensitive thermo-camera imaging of skin responses in four individuals without any success, but three of the four individuals we tested experienced no chills in the medical situation where the testing occurred, highlighting the importance of proper environmental conditions for this type of research. In this context, it is also important to note that skin conductance changes are commonly observed in emotion experiments without any accompanying subjective reports of chills. Perhaps piloerection would be a more specific correlate of the experience. We would suggest that future investigators may actually want to take videos of skin areas to monitor changes in piloerection associated with the experiential changes.

In any event, there are great individual differences in the incidence and specific musical selections that evoke this response, but the most frequent stimuli are new or unexpected harmony, crescendos and other dynamic shifts (Sloboda, 1991). Although some people—perhaps the less socially emotional ones—rarely have such experiences, most others delight in them whenever they occur. In our experience, females generally exhibit music-induced shivers more frequently than males, and in accordance with the usage of most people, we will refer to this autonomic 'rush' as a 'chill' response. In this context, it is noteworthy that girls use music for mood regulation more than boys (North et al., 2000). In preliminary analysis of 'big five' personality dimensions (i.e. agreeableness, orderliness, extraversion, openness to experience, and emotional stability/neuroticism), we have also found that the number of chills exhibited is correlated only with 'agreeableness' suggesting that the phenomena is related to pro-social, nurturant dynamics of individual emotional patterns. And in our experience females typically score higher on measures of 'agreeableness' than males. The following brief summary of our knowledge about the phenomenon is derived largely from our admittedly limited work on the psychological nature of the response (Panksepp, 1995).

Females are more likely than males to recognize that sad music evokes the chill response more robustly than happy pieces. However, when one evaluates this proposition experimentally, it is clear that sad music generally evokes more reports of chills than happy music in both males and females, although the effect is larger in females. Likewise, musical selections that evoked many chills were rated as being more sad than those that did not. Usually, everyone tends to have more chills to music that they already have an emotional relationship with, than to music that others have selected, indicating that the response is partially based on learned associations that individuals have developed to the music they enjoy. But, what is the underlying source of this emotional response?

In our estimation, a high-pitched sustained crescendo, a sustained note of grief sung by a soprano or played on a violin (capable of piercing the 'soul' so to speak) seems to be an ideal stimulus for evoking chills. A solo instrument, like a trumpet or cello, emerging suddenly from a softer orchestral background is especially evocative. Accordingly, we have entertained the possibility that chills arise substantially from feelings triggered by sad music that contains acoustic properties similar to the separation call of young animals, the primal cry of despair to signal caretakers to exhibit social care and attention. Perhaps musically evoked chills represent a natural resonance of our brain separation-distress systems which helps mediate the emotional impact of social loss. In part, musically induced chills may derive their affective impact from primitive homeostatic thermal responses, aroused by the perception of separation, that provided motivational urgency for social-reunion responses. In other words, when we are lost, we feel cold, not simply physically but also perhaps neuro-symbolically as a consequence of the social loss.

This hypothesis is also based on the assumption that the evolutionary roots of social motivation may be linked to thermoregulatory systems in subcortical regions of the brain. Thus, the sound of someone in distress, especially if it is our child, may make us feel cold, sending shivers down our spine. This may be one of nature's ways to promote reunion; the experience of separation may evoke thermoregulatory discomfort which can be alleviated by the social 'warmth' of coming together again. In this context, it is worth noting that happy music played to the left ear (preferentially stimulating the right hemisphere) tends to increase body temperature, while negatively-valenced music has the opposite effect (McFarland and Kennison, 1989). Whether there are several distinct autonomic/affective phenomena related to bodily experiences of this type (e.g. perhaps some people experience a thrill-type warming effect) needs further investigation. Also, in this context it is important to emphasize that emotions can trigger brief 'fevers,' and there may be relations of musically-evoked 'chills' to shifts in thermoregulatory set-points whereby shivers and vasoconstrictions are evoked in order to raise core-temperature (see Briese and Cabanac, 1991; Cabanac, 1999).

If the above lines of thought are on the right track, then we should be able to reduce the experience of chills by filtering out the primary acoustic components of the separation call from the music. Fig. 2 shows one such experiment where the bittersweet sounds and crescendos in Meat Loaf's rendition of 'For Crying Out Loud, You Know I Love You' were evaluated. The filtering of several of the acoustic harmonics (i.e. formants) of the human separation call dramatically reduced

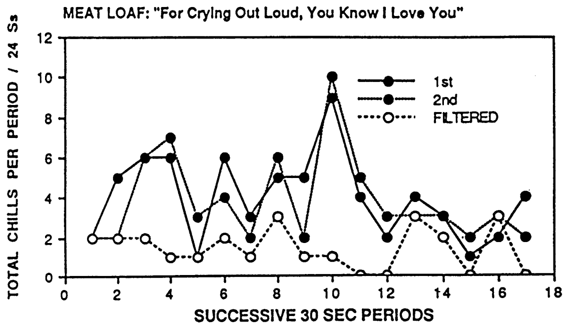

Fig. 2. Total number of self-reported chill responses in 24 college-age subjects during the listening of 8.5 min song by the group Meat Loaf. During the middle session the output to speakers was notch filtered by a 40 decibels reduction at the 2, 3 and 4 kHz formants of the separation call.

the number of chills reported. Of course, in the absence of a more detailed analysis of other parameters, this effect may be deemed to simply reflect the degradation of the overall musical resonance of the piece, even though that may not simply be an orthogonal explanation. We would note, however, that the vocal comprehensibility of the piece was not diminished by the filtering.

In sum, within musical performances that evoke chills, a wistful sense of loss blended with the possibility of reunion may be so well represented in the dynamics of sound that we become deeply moved. Such musical experiences speak to us of our humanness and our profound relatedness to other people and the rest of nature. The musical experience may communicate to us the possibility of redemption, the joy of being found and nurtured if one is lost. Since naloxone can reduce the incidence of chills, we can conclude that the chill response to music is partly controlled by endogenous opioids, perhaps induced by a rush of endorphins (Goldstein, 1980), and/or perhaps by a sudden decline in endogenous opioid activity (Panksepp, 1995). It was suggested that chills may be related to socio-emotional systems that generate separation-distress, circuitry that is concentrated in the bed nucleus of the stria terminalis and septal area, the medial diencephalon and the PAG (Panksepp, 1998a). A recent PET imaging study has yielded robust arousal of such brain regions during music that induced abundant chills, with positive correlations to positive affective arousal in ventral striatum and midbrain regions that include the PAG (Blood and Zatorre, 2001). This last brain area has been implicated as an epicenter of affective consciousness in mammalian brains (Panksepp, 1998a,b). In sum, the study of such musically induced autonomic and affective responses may have profound consequences for understanding not only the nature of musical aesthetics but the psychology and neurobiology of human emotions. Of course a great deal more research is needed.

7. The effects of music on moods

Music is one of the more effective mood induction procedures in experimental psychology (Camp et al., 1989; Kenealy, 1988; Mayer et al., 1995; Stratton and Zalanowski, 1991). Stronger effects are typically obtained if one uses music selected by subjects rather than the experimenters (Carter et al., 1995; Thaut and Davis, 1993). For the conduct of future research, it would be especially useful to know how long the mood effects of music are sustained, and how specific mood changes are to the specific emotions conveyed by music.

To evaluate such issues, specific affective state changes were monitored in the following way: the mood changes of 16, 19–23 year old college students were measured following two music listening sessions, one in which the participants listened to 40 min of happy music and another they listened to 40 min of sad music. A seven-point Likert-type mood scale was used to monitor the self-rated levels of happiness, sadness, anxiety and anger at four time points: just before the listening session, immediately following the session, and at two 10-min intervals thereafter. Each of the participants had brought in one selection for each of the sessions (mostly common popular American tunes of the early 1990s) and they were randomly played; following each piece, individuals rated their levels of happiness and sadness, as well as how much they liked the music and how much emotional content each selection contained. Most of the selections had clear emotional content and the happy selections were clearly perceived to be happy and the sad selections sad. Since the main question of this study was to determine how long music-induced feelings lasted, and participants were asked not to talk to each other during the exercise, it was important to minimize boredom and irrelevant distractions during the post-music intervals. The time-filler selected was for all participants to simply write for two 10-min periods about anything on their mind. This also helped assure that individuals would continue focussed on themselves during the post-listening period, and it was also deemed a satisfactory way to minimize boredom and to control for other extraneous variables during those intervals. However, this raises the interesting methodological issues of what type of activities should be used during such intervals. If students wrote about the music (which was not typically the case) might it prolong the mood? Would mood change differently, if participants were asked to write about specific topics? We simply do not know at present.

In any event, the average data for the mood rating scales are summarized in Fig. 3, and the overall pattern was clear. The happy music elevated feelings of happiness, and the sad music elevated feelings of sadness. For both, the mood effects were significantly highest immediately after the music ($P < 0.01$) and were still significant, but also significantly diminished at the 10 min time period ($P < 0.05$). The music-induced changes had declined to non-significant levels at the 20-min time point. It was also noteworthy that both types of music reduced feelings of anxiety and anger equally, but those effects were statistically significant only at the immediate post-music measurement period.

In sum, these data suggest that one can specifically elevate feelings of happiness and sadness with music, but these effects lasted no longer than 10 min under the conditions employed. This is about as long as the controversial 'Mozart Effect' has lasted in spatial reasoning tasks (Rauscher and Shaw, 1998), leading again to the possibility that those effects are partially mediated simply by the non-specific emotional or attentional arousal effects of music. The fact that feelings of anxiety and anger were also reduced by these manipulations indicates an interesting interaction among the emotional processes, but also poses problems in our ability to interpret any behavioral changes that may be observed right after the mood-induction procedures. Although happiness and sadness can be selectively increased, the concurrent and less specific reductions in anxiety and anger are important. Such general emotional effects may be important in explaining the many other types of behavioral and potential 'therapeutic' changes (vide infra) that emerge as a consequence of being exposed to music.

8. The social effects of music—some animal studies

It is an obvious fact that music serves as a magnet for human social activities. This is not a trivial observation, for it may highlight one of the major adaptive functions of music in human evolution, the ability of music to promote social interactions is an evident aspect of music use in all societies. As already mentioned, this dimension is also a salient aspect of motherese, the tendency of mothers, and other emotionally sensitive individuals, to engage babies with melodious sing-song communications. From such social perspectives, we might anticipate that music would have some clear effects on brain neurochemical systems that help mediate social processes. Of course, such work is almost impossible to pursue in humans, except for peripheral plasma or salivary measures (e.g. VanderArk and Ely, 1992), which, unfortunately, are unlikely to clearly reflect central transmitter dynamics.

Because of difficulties in conducting such work in humans, we have expended substantial efforts in determining whether music can affect the brain and behavior of experimental animals. At first we had the naive hope that common laboratory mammals might enjoy our music, but up to now we have never been able to obtain compelling evidence for that thesis, nor, to our knowledge, has anyone else. In any event, after a considerable effort studying the musical preferences of laboratory rats, which yielded very little coherent data perhaps because most of their social communications are in the ultrasonic range (20–60 kHz), we proceeded to an avian model, the newborn domes-

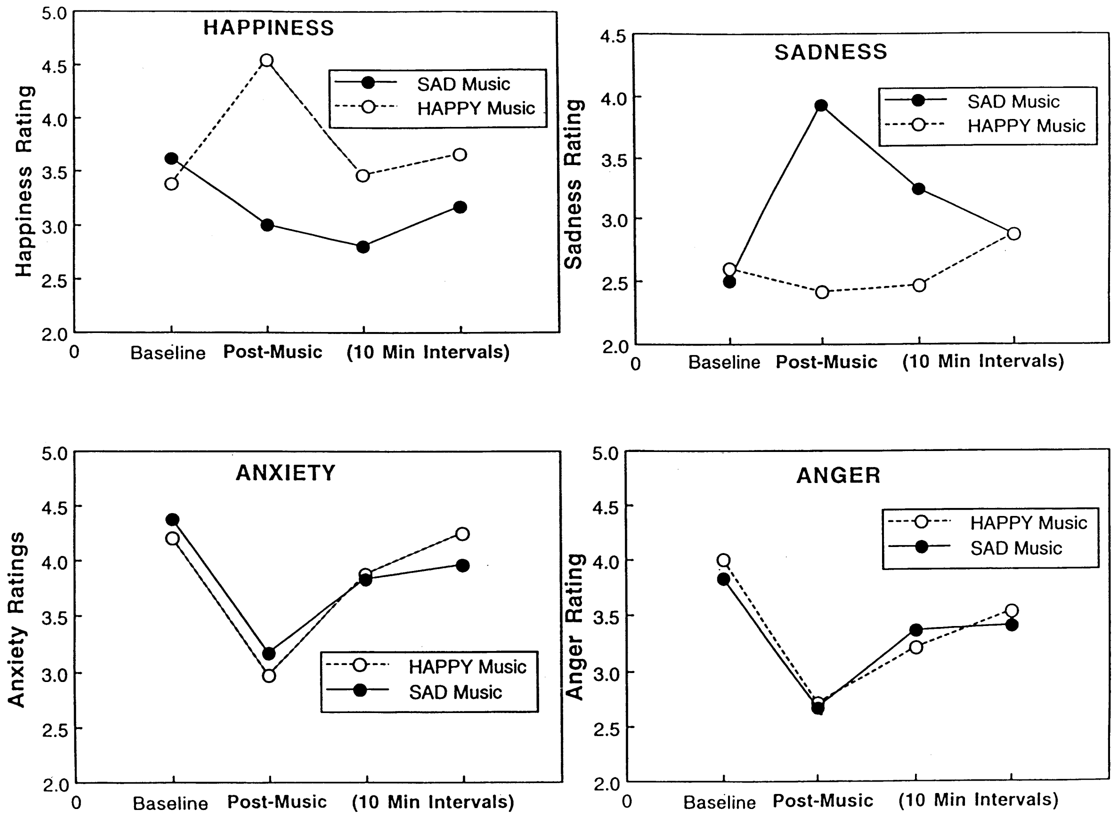

Fig. 3. Affective ratings as a function of time on a seven-point Likert scale (one low, seven high) for four emotions before and after 40 min of exposure to happy and sad musical selections.

tic chick, whose vocal activities are well within our own range. The results have been striking and consistent. Although we do not wish to argue that these effects are consequences of any music appreciation, we would note that none of the effects have been simulated with white noise or mere human voices speaking.

Music can effectively reduce the separation calls that young domestic chicks exhibit when they are briefly isolated from social companionship (e.g. figure 14.8, Panksepp, 1998a). Since separation-distress is alleviated by very specific neurochemical manipulations, especially intra-cerebroventricular infusions of the neuropeptides oxytocin, prolactin, and all molecules that activate the addiction sustaining mu-receptor of the opioid family (Panksepp, 1993, 1998a), we might anticipate that music may activate some of these systems. Although we have not conducted direct tests of this hypothesis (indeed, straightforward assays for synaptic release of these neuropeptides are not routinely available for small experimental animals), we would note that music can also produce some simple fixed-action patterns in chicks, the most noticeable being a lateral head-flicking response, yawning, and slight increase in feather ruffling (Fig. 4). Quite remarkably, these are exactly the types of fixed-action patterns that are evoked by infusions of oxytocin into the chick brain, or of the ancestral neuropeptide vasotocin, both of which are among the most powerful ways to reduce separation-distress in birds (Panksepp, 1998a). From this concordance, we would hypothesize that music may arouse that neuropeptide system, one of the best established social-emotional systems of the vertebrate brain (Carter, 1998; Insel,

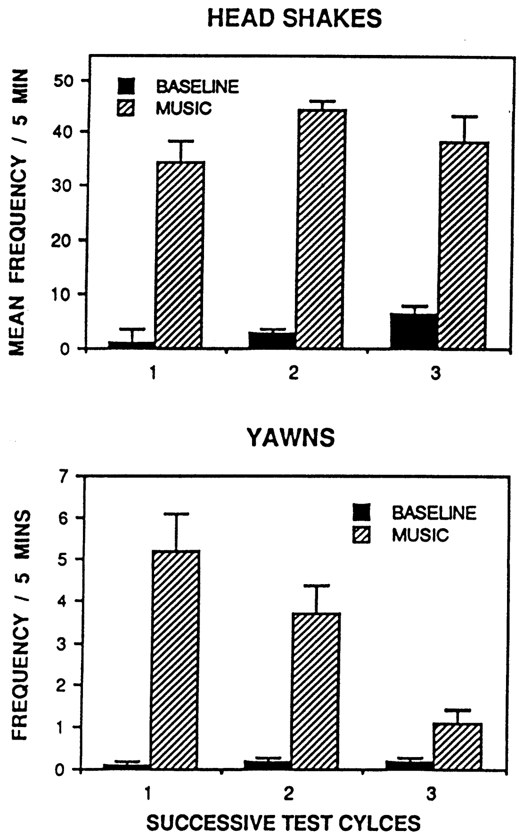

Fig. 4. Frequencies of head shakes and yawns in 7-day-old domestic chicks as a function of being tested without external auditory input and exposure to a taped performance of Beethoven's Hammerklavier played at an average sound pressure level of 86 decibels.

1997; Nelson and Panksepp, 1998). However, in this context, we would note that the capacity of music to increase milk production, as has been reported in the popular press, remains controversial and not adequately documented.

It is to be expected, of course, that music and other sounds may arouse an enormous symphony of neurochemical effects within the brain. Indeed, we have evaluated this proposition in another unusual line of research measuring the efficacy of a music-based treatment for early childhood autism, auditory integration training (AIT). In this context, we would again worry a bit about methodological issues, such as exposing animals to stimuli to which they are not accustomed. Might some of the effects be simply due to threatening aspects of the testing environment. At present, we simply do not know, but the behavioral and physiological changes we have observed have been reasonably strong.

AIT is a popular new music-based somatic therapy for autistic children. It is reported to reduce auditory sensitivities and to produce a wide spectrum of beneficial behavioral effects ranging from increased attention to sociability (Rimland and Edelson, 1995). In an open trial with 33 autistic children, we were able to replicate those effects, and extended them to an animal model that might allow analysis of the underlying brain effects (Waldhoer et al., 1995). Chicks were again selected for the reasons mentioned above. They were given standard AIT 'therapy' (20 half-hour sessions of listening to modulated wide-band popular instrumental music, at a mean level of 86 db with bass and treble components randomly enhanced and dampened by 40 db, with 30 min of music in the morning and 30 min in the afternoon for ten successive days at day 2–12 days of age in a group-housed listening situation) and their behavioral, bodily and brain responses were contrasted to those that had listened to the same music unmodulated as well as a 'silent' control group that had been handled equally but received no special auditory stimulation. Post music 'therapy' effects, replicated now across several experiments, included increased bodily growth and a reduced inhibition of separation-induced distress vocalizations in response to music, but not in response to self-reflective social cues (i.e. mirrors). Social approach behavior was not different among groups.

We then proceeded to study the neurochemical effects of these manipulations (Bernatzky et al., 1997). Starting on the second day of life, birds were given either the AIT type of treatment commonly used for the treatment of autistic children (described above), a group that received the music without modulation, a control group that listened to a mixture of male and female human speech on the exact same schedule, and a control group that received all aspects of the experiment except they received no systematic exposure to sound. One to 2 days following the end of treatment, whole-brain neurochemical changes were markedly and similarly changed in response to both forms of music. No clear changes were evident following exposure to human voices as compared with the no-sound controls. Following both forms of music, significant elevations were seen in NE levels ($\sim$400%), monohydroxyphenylglycol (MHPG, a major NE metabolite) levels ($\sim$600%), DA levels ($\sim$200%), and homovanillic acid (HVA, a major DA metabolite) levels ($\sim$200%). There were no clear change in brain levels of serotonin (5-HT), epinephrine and calcitonin gene related peptide (CGRP). Apparently, music can have quite powerful effects on the NE turnover of developing avian brains. Since it is well established that this amine is important in regulating attentional resources in all animals that have been studied (Panksepp, 1986, 1998a), it is possible that AIT treatment can elevate the attentional resources of the brain.

In further evaluation of these changes we determined if these effects could be replicated with classical music, and whether these effects interacted with social housing conditions (Bernatzky et al., 1998). Half the animals ($n = 32$) were socially housed in groups of four, and the other half were individually housed. Animals were exposed to 30 min of Mozart's Kroenungskonzert in the morning, and again in the afternoon for ten successive days. At the same time the control animals were exposed to an audiotape of people speaking at approximately the same 86 decibel level. A day following the end of treatment, animals were sacrificed, and brains were assayed for NE, 5-HT, DA and the DA metabolites HVA and dihydroxyphenylserine (DOPAC). Although the overall effects were more modest than observed in the earlier experiment, the results confirmed that extended early exposure to classical music could have complex effects on brain biogenic amine levels and metabolism in an avian species. Exposure to classical music elevated whole brain NE by 31% ($P = 0.001$) and reduced DOPAC by 28% ($P < 0.005$), and this last effect was significantly larger in social than isolate animals. Overall, these results suggest one reason why AIT training may have had beneficial effects in young autistic children in certain studies, the music tends to promote certain brain neurochemical, especially brain NE, activities, and hence facilitate attentional processes.

Although there are still many control issues to be addressed in such research (especially the full delineation of the specific aspects of sound that may be mediating the observed effects), the above work leads us to wonder whether members of other species might also enjoy some of our music. To our knowledge, no such preference have ever been adequately documented in birds, and our many studies on young chicks so far (not described herein) have not been any more promising than they were in rats. In this context, we must remember that the emotional systems of other animals are probably tuned to very different sounds than ours. Considering that they have styles of vocal communication of their own (Hauser, 1996), they would be expected to find those sounds rather than ours to be more attractive, and there is abundant evidence for that in the socio-sexual realm (e.g. Bradbury and Vehrencamp, 1998). Assuming that human music is a supra-liminal affective stimulus based partly on our ability to appreciate emotional prosody, we should consider the possibility that we might be able create simple forms of 'music' that other species would appreciate by amplifying the acoustic signals that are emotionally relevant to them. This could be an intriguing exercise in cross-species aesthetics, and we hope some composer will eventually devote some effort to evaluate such possibilities.

9. The effects of music on the human brain

Many investigators have now tried to characterize how music effects the human brain (for an up to date review see proceedings of a recent NYAS meeting, Zatorre and Peretz, 2001, which we did not have available to us when the paper was written). Many of these findings are outside the present coverage since they have not sought to characterize specific emotional effects on the brain. Although a great deal of brain imaging of emotional processes has now been published, rather little work has been conducted to determine how emotions encoded in music modify brain activities. To fill that gap, we evaluated topographic EEG changes in males and females to standardized happy and sad pieces from the Terwogt and Van Grinsven (1991) selections, with the same segments repeated about 30 times (which is certainly not an ideal condition for maintaining the desired aesthetic resonances). In any event, the repetition was used so that we could utilize the sensitive ERD and ERS algorithms developed by Pfurtscheller et al. (1990) which can be used to map the topography of cognitive processes on the cerebral surface.

The results were not especially compelling, but within the sensitive alpha range (8–12 Hz), there were modest tendencies in females for happy music to produce less cortical arousal (more ERSs) and sad music to produce more arousal (more ERDs), especially in posterior parts of the brain (Panksepp and Bekkedal, 1997). In males this pattern, if anything, was reversed. However, when we repeated this experiment in males with self-selected music, the changes were robust, and the patterns were similar to females, with happy music producing more ERSs (i.e. decreased cortical arousal) and the sad music producing more ERDs (i.e. increased cortical arousal). This pattern of results is reasonable for during a sad emotional state one has more cognitive issues to dwell on, leading to cortical desynchronization, than when one is happy. We saw no clear laterality effects, unlike those seen for simple repeated tones and melodies (Breitling et al., 1987) perhaps because the dynamic brain changes fluctuate greatly as a function of time and task (Petsche, 1996).

Of course, the control issues in this type of research are enormous, with many differences among the musical selections other than the affective components. In other words, in selecting different pieces of music for their emotional qualities, a host of non-affective acoustic variables would need to be controlled. One possible way around this dilemma would be to select a single powerful musical passage, and attempt to modify the conveyed affective feelings by such means as playing the piece backwards or increasing or decreasing the tempo at which a single passage is played.

We pursued the latter avenue using the simple and memorable melody in the first few bars (~ 7 s) of Beethoven's Für Elise. This was played at three speeds, normal as well as sped up and slowed down by 10%. At least for the senior author of this paper, speeding up the piece gave it a happier, almost carnival, type of feeling; slowing it down made it considerably more melancholic. And these three renditions produced very different patterns of ERDs in the first author's brain (Fig. 5). Unfortunately, when this was repeated on three other subjects, all of whom were quite fond of this piece of music, there were no differences among the three runs—all three speeds yielded essentially the same cerebral patterns—the main effect being marked frontal arousal on the left side, where positive emotional effects are commonly observed (Davidson, 1992). However, it is noteworthy that none of these individuals reported that the slowing or speeding of the piece modified their affective responses, suggesting the distinct cerebral effects depicted in the subject in Fig. 5 may only be evident when individuals have different affective experiences to the same piece of music.

We present these results not with the aim of trying to share any definitive results regarding how happy and sad music affects the human brain, but rather, to highlight the problems that must be dealt with in this kind of research. The control issues are, to put it mildly, enormous. This is one

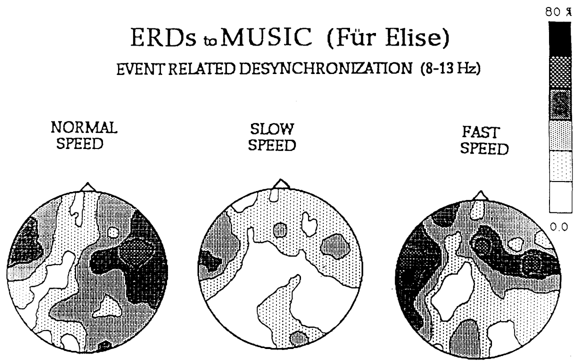

Fig. 5. Averaged event related desynchronization levels for a subject receiving repeated exposure to the first several bars of Beethoven's Für Elise at three speeds (normal, 10% slower and 10% faster). Right is right and left is left on the topographic maps, with the frontal pole oriented toward the top and the occipital pole to the bottom of the plate.

reason good work has been slow to emerge in this area, but we hope human curiosity will prevail.

10. Promoting health through music

It should come as no surprise that music could have various beneficial health consequences. The role of emotions in regulating body processes is so clear, that it would be expected that music would have various tonic effects on the body. The power of social processes on bodily health have recently been recognized (Mayer and Saper, 1999), and since music can stimulate so many social-emotional processes, we might expect music to have demonstrable effects on health. Of course, the healing effects of music were recognized even in Grecian times, where it was employed as a mainstream psychiatric treatment, and music therapy and music medicine continue to be lively and active fields (Pratt and Spintge, 1996; Spintge and Droh, 1992). Unfortunately, the data base is not as consistent and robust as one would wish it to be, and in part this is surely due to the fact that musical tastes vary so enormously and many of us are so accustomed to listening to lots of music, that it is hard to find populations which could be deemed to be adequate 'controls' for music interventions. For instance, there are good reasons to believe that music could be used as a mild antidepressant (Pratt and Spintge, 1996), but it would be difficult in present-day society to find a group of individuals that is not getting any exposure to music on a fairly regular basis. Would it be ethically justified to take people off their normal diets of musical stimulation to evaluate the efficacy of various types of music in the treatment of depression? One could of course add additional music to the daily aesthetic menu of clinically described participants, but the time required might make compliance problematic. In any event, it will be a major problem to determine whether any consistently demonstrable benefits are due to the music itself or only secondarily due to the specific affective changes evoked by the music.

Although this is not the place to delve into the methodological intricacies of evaluating music-based therapies, we would like to summarize some of the recent work we have conducted evaluating the effects of music on the perception of pain. There is a large literature on such topics, including our positive results indicating that music can alleviate pain, stress and feelings of depression in patients suffering from chronic back pain (Bernatzky et al., 1999) but no definite overall conclusion can yet be reached. Indeed, in a large series of individuals, we determined whether music-induced analgesia could be evident using rigorous methodological procedures. No clear evidence of any analgesia was observed in healthy people when precisely controlled radiant heat was the source of pain, and a pain-escape threshold procedure was used (Bernatzky et al., 1996).

However, this should not be taken to mean that music cannot provide relief for individuals suffering from pain or a variety of other negative feelings. The long term consequences of aversive emotional states are due more to suffering than the threshold at which pain is perceived, and it is reasonable that music might relieve the undesired stress that many medical patients feel (e.g. Guzzetta, 1989). Accordingly, we encourage the conduct of well-controlled studies in this area, with a focus on the emotional suffering rather than simply the physical aspects of pain.

11. Coda: the future of music research

Although we may never know, with any assurance, the evolutionary and cultural transitions that led from our acoustic-emotional sensibilities to an appreciation of music we can now begin to empirically decode the effects of music on the brain-mind and body. Investigators are finally endeavoring to fathom how music establishes affective resonances within the brain, and we would suggest that it is within an understanding of the ingrained emotional processes of the mammalian brain that the essential answers to the affective questions will be found. It is not yet clear that our brain contain evolved distinct emotional 'modules' for the processing of the emotional aspects of music, but we think that is a remote possibility. Still, we suspect that the role of subcortical systems in our sustained human love affair with music has been greatly underestimated. Without the intrinsic ancestral dynamics of these ancient emotional systems, music may forever remain affectively flat. We will need much more work on the neurodynamics of these neural systems to truly understand how emotions are elaborated by within the brain (Panksepp, 2000b).

Indeed, there may be formal functional as well as mathematical relationship between acoustic dynamics and emotional dynamic, an idea that convinced Clynes (1990, 1995) to 'train' computers to render classical music electronically better than ever before (i.e. Superconductor®, see http://www.superconductor.com). His solution to the 'microstructure' problem of musical notation has now provided an invaluable general-purpose tool for manipulating many relevant acoustic parameters individually that will help us experimentally understand how the affective impact of music is generated by the modulation of sound. Clynes's system can even render classic music as different composers might have, by having abstracted their musical 'personas' in the 'pulse' structure of performance (Clynes, 1990, 1995). Indeed, there are now several excellent software programs to provide flexible synthesis of musical performance that are invaluable research tools. For the first time, researchers have orchestras at their fingertips so they can systematically modify parameters to systematically evaluate the consequences of musical dimensions on human affective and aesthetic experiences. In order to conduct well-controlled research, we no longer need to restrict ourselves to readily available but difficult to modify musical performances generated by the great artists of our times.

Another reason the study of musical emotional experience languished for most of the 20th century is because robust and highly reliable methodologies for evoking and measuring emotional experience did not emerge as rapidly as they did for many other psychological processes. There is abundant room for improvement (e.g. Asmus, 1985). Emotion research became even more problematic, as grave ethical issues were raised concerning the propriety of inadvertently evoking powerful emotions without the full consent of participants, whether humans or other animals. This led investigators to study ever milder emotional processes, and thereby perhaps ever milder cognitive notions of how emotions control human behavior. Except for the possibility of harvesting data from individuals who are undergoing real-life emotional episodes, we are confronted by a conundrum of enormous proportions, ranging from extremely artificial situations that barely arouse true affect to the problem of unmotivated subjects.

The wider utilization of music in emotion research could help solve both problems. We, along with others (Clynes, 1978; Gabrielsson, 1991; Krumhansl, 1997) believe that music can evoke 'real' affective processes, although these are obviously different from the full-blown emergency emotional responses that are aroused by situations such as those that provoke, fear, panic and rage. Music appears to resonate especially well with basic socio-emotional feelings (and certainly many socially constructed ones as well, such as bittersweet nostalgia and tenderness), but it may require some coaching (e.g. encouragement of individuals to listen in a certain way to get fully into the moods suggested by the music), with perhaps the use of associated imagery to recruit deeper affective structures.

Although music-based mood-induction techniques have been available for some time, the amount of research using such techniques has remained modest. Part of the problem is that music preferences are highly individualized and idiosyncratic, and the choice of items may need to be optimally tailored for each individual. We recognized this in our first study seeking to discriminate the effects of happy and sad music on the human EEG, and the use of the same standardized pieces across individuals was not nearly as effective as selecting music with which the subjects already had deep personal relationships (Panksepp and Bekkedal, 1997). Clearly, such individualization needs to be considered in most experimental designs where we aspire to evoke intense emotional experiences.

Perhaps, the least understood process in music-emotion research as well as human emotion research in general is the fundamental nature of affective experience. Investigators still use emotional terms as if they do not need to be explained any farther. As a result, the fundamental nature of affect remains the most important and the most unstudied topic that is essential for future progress in this area of research. Only a few ideas have been placed on the intellectual table so far (Damasio, 1999; Panksepp, 1998a,b). Probably avoidance of the topic is based on one simple fact—an understanding of such deep processes of the inner life will require brain research into subcortical brain areas that are typically inaccessible to investigation in human beings (Panksepp, 2002).

Of course, the amount of emotional research that could be done with music from the first person subjective perspective remains enormous. Such work has great promise not only to clarify the phenomenology of human emotions but the nature of music. Since it has generally been recognized that music is the language of emotions and it is coming to be recognized that the basic emotions and motivations may constitute the very foundation of consciousness (Panksepp, 1998b; Watt, 1999), music research has a vast potential, largely untapped, for helping highlight how both affective and cognitive forms of human consciousness emerge from brain matter. Such investigations could eventually inform us how music might be used more effectively in our educational and therapeutic initiatives. Work on such interesting problems has barely begun.

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