Music and Medicine
4(2) 82-89

DOI: 10.1177/1943862112436562
http://mmd.sagepub.com
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Musical Piloerection

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Abstract

Piloerection (from the Latin *pilus* for hair) is a skin response which can be observed at many occasions among various species as a reaction to fear, aggression, or coldness. It is also a human response to music and in these cases a highly pleasurable one. Not everyone experiences it, and it is particularly difficult to evoke the reaction in experimental settings. We accidentally happened to catch a spontaneous distinct reaction with finger temperature, skin conductance, heart rate, and respiration. This allows us to study how these emotion correlates online with the music—the dynamics of the event. From this and recent articles, we discuss suggestions of how music causes piloerection.

Keywords

musical piloerection, autonomic nervous system, arousal, valence, sensorimotor system

Introduction

Music is an excellent means to explore bodily reactions. To perform music and even to listen to music is to a large extent procedural (knowledge of the body). The music/body connection is important to research in medical applications such motivation,[1] soothing,[2] pain reduction,[3] and motor training.[4] The authors of this article are involved in brain damage rehabilitation. One of the problems in the rehabilitation of the patient with stroke is to motivate him or her to go through tough physical training. For this reason, we are particularly interested in the music/dopamine connection.

Every event in music has a counterpoint in the listener. The musical score thus produces a "body score." Musical events are reflected online in the nervous system as well as in the cardiovascular and visceral systems. "The body score" is not merely a metaphor—if there were no representation of music in humans, we would not be able to perceive, imagine, or produce music. The body score applies not only to the notes but also to the emotional directions in the score. Music can evoke more emotions and nuances than we have words for.

The research of music and emotion (for an overview see Koelsch)[5] is difficult because there are various theories concerning what an emotion really is, and we are just beginning the mapping of the biological correlates to this concept.

One of the most distinct emotional reactions to music is *piloerection*. It is intriguing because it is hard to explain why we have this skin response to music. In research on fur animals, the importance of piloerection for temperature regulation particularly in infectious states and in cold temperatures has been emphasized.[6] Another line of investigation concerns aggression.[7] Since the piloerection enlarges the body, the evolutionary explanation is that it scares the opponent. Furthermore, piloerection can be observed as part of mating behavior.[8] Humans sometimes show piloerection at sexual arousal which is accompanied with erected nipples. The sight of magnificent scenery may also produce goose bumps.[9]

Musical piloerection (from here on called MPE) denotes a composite of objective signs and subjective experiences. The skin reaction may be accompanied by experiences of chills, shivers down the spine, tears, and bliss. Musical piloerection is a positive experience.[10] Self-reports indicate that the experience is significantly arousing and moving. Although the reaction can be quite distinct, participants sometimes report the sensation when no objective external reaction is at hand.[11] Between 35% and 55% are reported to have the experience, musicians[12] and women[11] more so. Those who are inclined to have it are less adventure seeking than others.[13] It seems that everyday life

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is adventure enough to people who show this kind of sensitivity.

What kind of music leads to piloerection? Interlistener consistency is poor concerning the type of music.[14] However, David Huron points out that sudden changes (volume, tonality, range of melody, sound, etc) typically are reported to cause the reaction.[12]

According to Jaak Panksepp, MPE is a reaction to a call of social loss felt in the music. Panksepp based this claim on a large survey on college students in 1995.[15] He found that music causing piloerection is not primarily happy but more often (twice as often) sad. He suggested that opioids (eg, endorphin) might be involved and thus implicated the reward system. The opioid system has been associated with physical as well as psychological pain, as a means to endure social loss[16] and crying.[17]

In 2001, Ann Blood and Robert Zatorre, using positron-emission tomography (PET), explored the tracks of intensely pleasurable musical feelings (chills) in the human brain.[14] The images indicated that the ventral striatum, the midbrain, the amygdala, the orbitofrontal cortex, and the ventral medial prefrontal cortex were activated (in terms of increased blood flow), that is, areas known to be involved in basic reward. This raises the question why music affects us the same way as sex and food do. And how does this finding agree with Panksepp's finding that sad music causes piloerection? If it is sad, how can it be rewarding? Or, if it is rewarding, how could it be sad?

In 2005, Menon and Levitin, using functional magnetic resonance imaging (fMRI), found that Beethoven's Fifth Symphony and Mozart's *Eine kleine Nachtmusik* triggered correlated activity in nucleus accumbens, the hypothalamus, the insula, and the orbitofrontal cortex.[18] Since this area is associated with the mesolimbic (or dopamine) pathway, it was suggested that music causes dopamine release. Dopamine mediates reward and motivation. Menon and Levitin's idea was recently verified by Salimpoor et al.[19] Using raclopride C11 PET, the authors were able to detect dopamine release in the striatal system at MPE. Thus, 11 years after Panksepp's suggestion that MPE implies the reward system, this seemed to be definitely confirmed. Whether opioids are involved is still not confirmed, nor rejected.[12]

Salimpoor et al[19] claim that they can differentiate between the expectation of MPE and the climax itself, since the caudate area was activated before the peak experience which in turn activated the nucleus accumbens. From this the authors conclude that listeners are *craving* the piloerection.

Considering the observation made by Panksepp that sad music more often than happy music causes goose bumps, the typical situation would be a sudden change in a flow of sad music.

In the following we discuss the surprise reaction, reward, and craving and finally Panksepp's claim that MPE is a reaction to a cry of social loss heard in the music.

The Surprise Reaction

Recently one of our participants had a strong spontaneous MPE during a session when he listened to an improvising musician. The participant was hooked up to equipment measuring autonomic nervous system (ANS) reactions. A microphone was adapted at the participant's nostril to record his breathing in order to inform the musician of the breath of the participant. Through a recording of the music we were able to reconstruct the improvised music. Thus, we have a recording of ANS reflectors such as skin conductance, finger temperature, breath rate, and heart rate, as well as the music at the same time axes during an unusually strong MPE. This is available online at http://sskkii.gu.se/assets/vickhoff/

The basic structure of the music was a 2-bar sequence. The first bar generally consisted of a dominant chord, a rising melody, and crescendo (increasing volume), and the second bar was a tonic chord with a falling melody and diminuendo (decreasing volume). The tonic is generally experienced as the center of gravity in tonal music—a resting point—the point the music strives to return to. The dominant again usually precedes the tonic; it is leading to the tonic and thus is felt as a tension. This corresponds to breathing in the sense that inhaling is energetic and exhaling is relaxing. The heart tends to beat quicker when we inhale than when we exhale.[20] The phenomenon is called respiration sinus arrhythmia (RSA).

The MPE occurred at bar 40, 1 minute 40 seconds into the piece. Before this there was a series of changes during half a minute (see Figure 1).

At 1.18 (bar 31), the musician slightly changed the harmonic pattern and started playing more emotionally (*espressivo*). At 1.27, he broke the basic 2-bar sequence and started a harmonic excursion with a diatonically falling baseline accompanied with an increase in volume. During the first 9 bars in this part (bar 31-39), the finger temperature and the heart rate were slightly increasing while skin conductance remained constant. At the MPE (1.40; bar 40), the diatonically falling bass movement was broken as the bass fell a half (instead of the expected whole) step. Harmonically, the third of the chord (which was situated in the bass), dropped a half step, which turned the harmony from major to minor and indicated a tonal shift. This is an elegant move, experienced as a revelation—an unexpected possibility. Suffice it to note that there was a series of surprises: the change in the harmonic pattern, the change in espressivo, the change in volume, and finally the indication of change in tonality which forced the listener to rethink the musical context. The subjectively reported MPE was accompanied by a fall in finger temperature of more than half a degree in centigrade in the space of 40 seconds (indicating a robust skin vasoconstriction), a sudden and dramatic rise in skin conductance, and an increase in heart rate. The green graph in Figure 1 indicates the amount of carbon dioxide in the breath. The peaks thus represent exhaling and the valleys inhaling. The RSA is seen as the coordination of peaks in heart rate and the valleys in carbon dioxide. As can be seen in the figure, this RSA coordination ends abruptly at the MPE. From now on the heart rate follows the skin conductance level remarkably well. Since RSA is a sensitive measure of parasympathetic control,[21] the fall in RSA indicates arousal.[22] It has recently been demonstrated that lowering RSA by means of biofeedback increases α and decreases

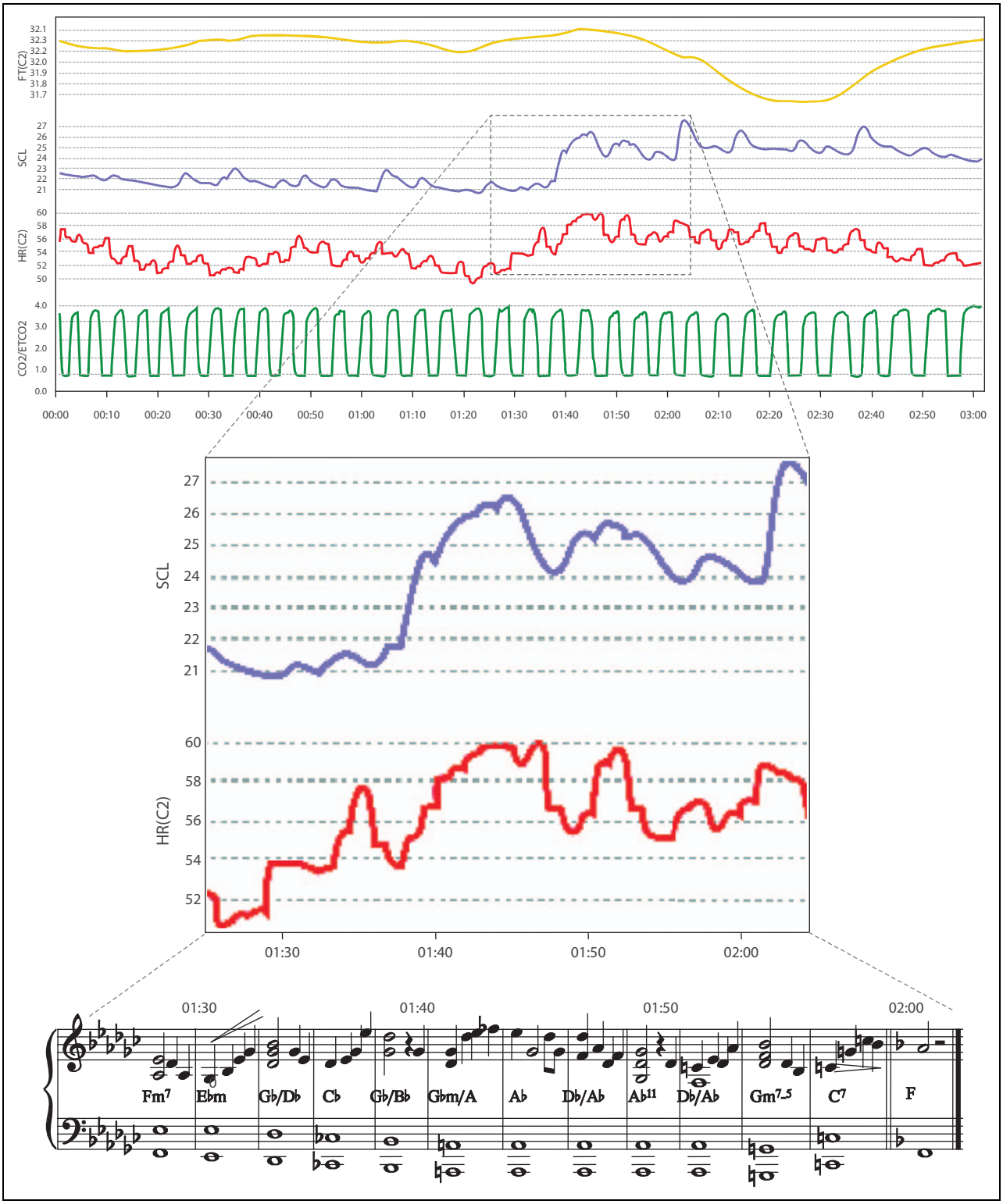

Figure 1. Yellow indicates finger temperature; blue, skin conductance; red, heart rate; green, breath carbon dioxide. MPE occurred at 1.40. The blow-up shows the musical score compared to the body score.

β electroencephalographic (EEG) wavelengths in areas critical to arousal.

Emotions are not absolute but dynamic and in constant change.[23] The subjective report indicated that the piloerection feeling was experienced to come in waves. Interestingly the skin conductance level mirrors this. In fact, 3 of the aftershocks are more intense than the first wave. The sound recording in the video reveals a deep breath at the point of MPE. This is in

concordance with a recent study by Benedek et al who compared participants who had MPE with those who had not at passages where MPE could be expected.[11] The 2 groups had similar reactions except in that the group who had MPE had a stronger skin conductance reaction and breathed more deeply.

We compared the recorded changes with autonomic physiological profiles for emotions presented in a meta-study involving 134 publications.[24] Our results fit the signatures of anger, fear, and surprise in this study, consistent with a state of general arousal. Our participant did not report experiencing fear, anger, or surprise. There was nothing in the music that would cause fear or anger, but there were, as we have just discussed, some surprising elements preceding the MPE. Could these subconscious surprises cause the reaction?

Violated expectations have been one of the themes in music and emotion since Meyer.[25] The very fact that we have musical expectations has been explained in terms of Gestalt psychology (Meyer)[25] and learning through exposition (Huron).[26]

A surprise is something that does not fit the map or expected pattern. Just as we have maps for geographic areas, we have maps for tonal structures.[27] Through exposure to music, we create expectancies for musical styles.[28] These styles have implicit rules: if this, then this. When such rules (expectancies) are violated, we have a surprise reaction. The brain has to try other patterns to make sense of the unexpected piece of information in order to prevent chaos. It has to find the map fitting the unexpected stimulus. It strives to make sense of the situation and get back on track.

Musical expectation has been confirmed in a number of event related potential (ERP) studies; potentials detectable by EEG on violated expectations. The brain reacts on unexpected events in pitch,[29] melody,[30] rhythm,[31] major/minor keys,[32] and chords.[33] This shows that, as we listen to music, we create a probable continuance. Interestingly, we do not have to listen attentively to get the ERP reaction which indicates that even if we are not aware of it, anticipation is created.

Harmonic surprise reactions have been examined in a number of studies where the expected cord has been substituted—Koelsch et al ERP, and physiological variables.[34,35] The authors point out that the skin conductance reaction foremost is a sign of arousal. These studies indicate that skin conductance rather than heart rate is affected by unexpected chords.

This latter statement has been confirmed in a study where skin conductance reactions were examined for various emotions. Intuitively arousing (fear and happiness) emotions caused the strongest reactions.[36]

David Huron has suggested that MPE has affinity with the aggressive piloerection in animals.[28] The common factor could be this: the general arousal.

Do We Crave MPE?

As has already been pointed out, Salimpoor et al emphasize the difference between the state preceding MPE and the MPE itself, since the first state showed caudate activation and the second showed nucleus accumbens activation. From this the authors deduce that we are craving the piloerection. In order to crave piloerection, we must have some expectancy of when it will occur. This demands familiarity to the music. Indeed this was the case in Salimpoor's study, but in our case there was no such familiarity, since the music was improvised. The piloerection was completely spontaneous. Guhn, Hamm, and Zentner showed zero correlation between piloerection frequency and familiarity to the music.[37] Benedek et al even found significant negative correlation.[38] A possible explanation is that if the music is familiar, the surprise effect would not be so pronounced. Interestingly, Benedek showed that heart rate responses correlate between listeners during musical "piloerection passages," even for those participants who do not reach the state of piloerection.[37] This indicates that MPE is more than a surprise reaction, since, as we have seen, harmonic surprises produce skin conductance rather than heart rate reactions. Bendeck's study also indicates that although piloerection is quite a distinct sensation, there may be an underlying state of general arousal. The water has to be warm before it is boiling.

It is however possible and even likely that we learn to have MPE at certain passages in familiar music, in the sense that we are more sensitive at passages that triggered MPE before. It would be enlightening to compare dopamine release in the caudate nucleus for familiar versus unfamiliar music (in order to explore whether the caudate reaction can really be linked to expectation).

Is MPE a Basic Reward?

No neurophysiological experiment has provided a satisfactory explanation of why MPE is such a positive experience. Not even the studies showing dopamine release and caudate/nucleus accumbens activation. Indeed the dopamine pathway is activated by pleasurable music and indeed this pathway is activated by the presence of a reward, but recent studies show that dopamine is implicated not only in motivation and reward but in aggression[39] and fear[40] as well. Experiments on mice reveal that mesolimbic (including the nucleus accumbens) dopamine enhances approach as well as avoidance behavior. These findings propel the question whether the dopamine pathway, although activated in the presence of possible rewards, is not in fact a valence independent arousal system.

According to Morten Kringelbach and Berridge the reactions in identified pleasure (hedonic) hot spots such as the nucleus accumbens are context dependent: "a shift in psychological context can 'retune' the valence generated by a hotspot and reverse the psychological consequences from desire to fear."[41] The feeling of a hand on the buttock depends on the owner of that hand. The stimulus is the same but the context (love/sexual harassment) is divergent. The context (the understanding of the situation) has a representation in the brain: the contextual network.

Arousal and Valence in Piloerection

The idea that emotions could be depicted in a 2-dimensional coordinate system with the axes valence and arousal was first

introduced by Wilhelm Wundt in 1874.[42] This understanding of emotion is also known as the circumplex model of affect.[43] *Valence* is the hedonic tone of the subjectively experienced emotion, whereas *arousal* is alertness or responsiveness to stimuli.[44] The dimensional model is opposed to the claim that we have a handful of discrete basic emotions.[45] Whereas fMRI studies of the basic emotion theory are inconsistent, the dimensional model has been verified by several fMRI studies indicating distinct arousal/valence networks.[44,46,47] The 2 models are however not incommensurable since any emotion, even the emotions in the basic model, can be discussed in terms of valence and arousal.

Music in terms of sudden changes, rough sounds, high volumes, fast tempos, and so on arouse us in a direct way. This seems to be a hardwired and thus universal reaction. The surprise reactions to violations to expected music patterns are probably also hardwired, although memory is involved in the sense that the expectancy is based on learning through exposition. So even if the surprise reaction is universal, it will be elicited differently in different cultures.

Music triggers autobiographical memories.[48] Such memories are known to be emotionally charged. This makes music, if appreciated, a secondary reward. We learn to like or dislike music styles because we have connected them to situations involving, for example, identification with the artist and the fans. This is in agreement with the common observation of cultural, subcultural, and tribal differences of music appreciation for example the fact that dissonant chords are disliked by naive listeners but highly appreciated by the lovers of Brazilian bossa nova, or the fact that distorted guitar sounds are embraced by rock fans, whereas classical music habitués remain less responsive.

This model resonates with Marianne Frankenhaeuser's discussion on stress.[49] Frankenhaeuser used the dimensions degree of effort and liking/aversion. She claimed that great effort combined with liking leads to "eustress," whereas great effort combined with aversion leads to "distress." Distress is harmful to health; eustress is not. Frankenhaeuser showed experimentally that both eustress and distress cause adrenalin increase in the blood, whereas cortisol increase could only be associated with distress.

Translated to arousal/valence this suggests that arousal alone is not distressing. The music has to be disliked to have a negative stressing effect.

It was recently found that listening to music of your own preference reduces negative stress in terms of cortisol level decrease.[50] It may even be the case that *death metal*, although highly arousing, may reduce negative stress in the members of the death metal tribe. It depends on personal preference.

Empathy?

So far we have discussed MPE in terms of reward, craving, arousal, and valence. Now let us bring this together in a comment to Panksepp's intuitive claim that the MPE is a response to a cry of sadness in the music.

Since context, as argued earlier, is crucial to valence, we should ask, which are the possible contextual networks when we experience MPE? Since the ascending reticular activating system causing arousal[51] involves neurotransmitter pathways which affect cortical as well as subcortical sensorimotor systems partly coinciding with the pleasure circuit, we should primarily look for such sensorimotor networks. Functional MRI studies reveal that music listening activates auditory–motor interaction.[52] Not surprising, since music has an obvious connection to motor activity.

The MPE is associated with tears. The results from our case of MPE do not match "sadness noncrying" but fit "sadness crying" in Kreibig's meta-study,[24] since noncrying shows a decreasing heart rate and skin conductance, while crying implies higher heart rate and skin conductance. The function of crying is a debated subject. Some scholars claim that crying signals a need for comfort, others that the main function is to reduce stress, and still others that it is a little bit of both.[53] In the case of MPE, it is the signal of need of comfort that is interesting. But it is not the listener who is signaling; it is the music. The listener is the receiver of the signal. Being touched or moved is a reaction to someone else's emotion. It is an empathetic reaction. Sad music triggers piloerection more often than does other music. The emotional interaction was an obvious ingredient in our case study since the music was performed live in a one-to-one communication. It should be noted that the piloerection occurred exactly when the music made a salient shift from major to minor. Why minor cords and minor keys are experienced as sad is a mystery but a fact in Western music cultures.

It has been argued that empathy is rooted in mirror neuron processes.[54] When someone cries, we automatically tend to cry. Laughter is contagious. We are able to take the perspective of others. By way of imitation, we activate motor circuits involved in the production of the emotional expression. William James proposed already in 1884 that feelings are brain reactions to bodily states.[55] His influential article has bearing on the works of present day scholars on emotion such as Antonio Damasio.[56] The insula is the receiver of bodily information and thus an important locus in the emotional process.[57] The insula and the mirror neuron system are connected.[58] Therefore, argue Marco Iacoboni and Mirella Dapretto, "a large-scale network composed of the mirror neuron system, the insula, and some limbic structures could provide the ability to empathize with others through the representation and 'inner imitation' of the actions (facial expressions, body postures) of others."[59]

The question of why music moves us has a long story. The mirror neuron theory of empathy offers an explanation of how musical emotions may be communicated from body to body, or, to be more specific, from the neural body representation of the musician to the neural body representation of the listener.[60] Empathy is a prerequisite to comfort. Mirror neurons, so called because of the discovery that they are active during imitation, are in fact also (more so) active during complementary action. To be touched is to feel the sorrow of the other, but

there is also an obvious complementary ingredient: love—the need to comfort. If so, music moves us when it is felt as an expression of sadness. Love, and especially lost love, is a major musical theme in all genres. When music cries, it brings tears to our eyes. From this point of view, Panksepp's idea that MPE is a reaction to a separation call in the music does not seem remote. This line of reasoning offers a solution to the problem why sad music can cause positive experiences such as MPE: the complementary love reaction.

Limitations

The single case study is always limited in the sense that we do not know how representative it is. We cannot claim to have measured the autonomic effectors of MPE in an absolute sense, which would be a doubtful enterprise anyway since no 2 MPEs are the same. But the single case is the superior method to demonstrate the online dynamics of the music/body interplay.

Conclusion

No 2 MPEs are alike. There may be several contributing causes. The evidence from studies of MPE indicates arousal caused by unexpected changes in the music. The often heard claim that MPE is a basic reward is not necessarily supported by dopamine findings, since dopamine is released by arousing stimuli generally—positive and negative. Rather, we suggest that music is a secondary reward that is that the experience of pleasure is learnt, and thus personal and culturally restricted. Finally we argue that in the case of sad music, the mirror neuron theory of empathy and completion, may offer the answer to the enigma of how sad music can be rewarding.

Acknowledgment

The authors thank Daniel Ruhe and Christina Nodin for graphic design, Professor Mikael Elam, Professor Gunnar Bjursell, and Dr Cecilia Bjursell for valuable input on this study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was funded by the Sten A. Olsson Foundation for Research and Culture, Gothenburg, Sweden.

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