Plug-in to Fear: Game Biosensors and Negative Physiological Responses to Music

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This is the author's manuscript of an article published in *Music and the Moving Image*, 2015, vol 8 no. 1, pp.37-57

Abstract

The games industry is beginning to embark on an ambitious journey into the world of biometric gaming in search of more exciting and immersive gaming experiences. Whether or not biometric game technologies hold the key to unlock the "ultimate gaming experience" hinges not only on technological advancements alone but also on the game industry's understanding of physiological responses to stimuli of different kinds, and its ability to interpret physiological data in terms of indicative meaning. With reference to horror genre games and music in particular, this article reviews some of the scientific literature relating to specific physiological responses induced by "fearful" or "unpleasant" musical stimuli, and considers some of the challenges facing the games industry in its quest for the ultimate "plugged-in" experience.

Introduction

Over recent decades the games industry has surged forward in a relentless tide of technological change. Driven by innovation, invention and growing market demand, the industry continues to explore new approaches, all in search of the ultimate gaming experience. A number of current developments indicate that the industry is keen to explore the potential of the human body itself, and associated physiological responses, as the focus of future interface development. In 2010 Sony filed a patent application for biometric controls (designed to measure electro-muscular data, electrocardio data, and galvanic skin resistance).[1] Microsoft has developed plans for a "Joule" heart-rate monitor for the Kinect Play

Fit, and Nintendo are developing a "vitality sensor" to measure pulse response. In addition there is growing interest in brain computer interfaces (BCI) as illustrated by the instigation of an annual NeuroGaming Conference and the development of technologies such as Foc-Us[2] a headset for gamers, which delivers transcranial Direct Current Stimulation (tDCS) with the aim of increasing brain plasticity to improve game play performance, and "MUSE",[3] a brain-sensing (EEG)[4] headband designed to allow some degree of brain control, which has been developed with a wide range of applications in mind – including gaming.

The introduction of biometric interfaces and sensors of this type represents a significant departure from body motion detection systems, heralding a future in which complex physiological data, such as skin response, heart rate, respiration, brain response and so on, might be captured and used to manipulate and customize interactive game-play for the user. Such biosensors would create a feedback loop, constantly measuring physiological data induced by game-play and using this data to trigger further physiological and emotional responses.

If the games industry is tottering on the brink of a new chapter in its development, one in which the voluntary and *involuntary* physiological responses of players become the primary focus of interface development, it stands to reason that the industry will also require a good understanding of physiological responses induced by game-play. This would prove to be quite a challenge. The gaming experience is made up of many interacting elements, each potentially capable of inducing some sort of physiological response, either as individual elements or working in conjunction with one another. However there is one element which game developers would recognize as of particular significance for its potential to manipulate players' responses, and that is audio (music and sound).

Recent years have seen a significant number of scientific studies exploring the responses of test subjects to different types of music and sound. The scope of these studies extends beyond the parameters outlined so far, but clearly studies of this kind provide a valuable and continually growing referential resource for anyone seeking to explore the connection between music, sound, and measurable physiological data. However, in order to tailor such data to the needs of the games industry it would be necessary to focus on responses to those musical characteristics most commonly associated with particular game genres. This at least would provide game developers with some tentative predictive outcomes when designing prototype biosensor interface systems.

Of all the games available to date, horror genre games are perhaps the most likely to induce the strongest and most visceral physiological responses. In a series of scientific tests[5] designed to measure physiological responses to various fear inducing games, *Dead Space 2* was found to trigger, "multiple types of fear response".[6] The game proved to be, "universally frightening" regardless of the participants' previous gaming experience. Clearly, *all* the elements of the game work in synergy to induce responses of this kind, but it is undeniable that the game's use of avant-garde, aleatory music plays a significant role, triggering and sustaining fear responses. Jason Graves, the composer of the music for the *Dead Space* franchise, describes the music for the games as, "non-musical".[7] There are a number of reasons why this description appears to fit: minimal thematic material features in either of the *Dead Space* games;[8] the aleatory approach results in a lack of recognizable patterns or predictable events, creating a persistently dissonant and experimental sound world of constantly shifting textural layers and unexpected, randomized “stingers”,[9] all responding in real-time to interactive game-play.

In order to discover possible musical triggers for the types of fear responses recorded in the *Dead Space* study, it is necessary to review the scientific evidence linking music to negative physiological responses. This information might then be applied within the context of wider games development; anticipating likely physiological responses, predicting and measuring biosensor data and then applying this within real-time game-play.

This article presents some of the scientific findings linking specific negative physiological responses to musical stimuli and seeks to contextualize these results in a preliminary overview of some of the complications presented by the scientific literature currently available. There follows an exploration of the potential challenges faced by those in the games industry tasked with utilizing such physiological responses in the creation of entertaining, biosensor-enhanced gaming experiences. The discussion concludes by suggesting possible benefits of music-related biosensor developments in wider fields.

Reviewing the Scientific Data – A Cautionary Introduction

When reviewing the expansive body of scientific literature currently available, it quickly becomes apparent that there is much we still do not understand regarding the complex interplay between physiological and emotional responses such as fear, particularly within the wider context of everyday-life. Results can be highly inconsistent and contradictory, so at best the literature shows possible trends, generally within controlled conditions. In addition, where connections between physiological and emotional responses are found, it can be difficult to determine which comes first, since physiological responses can be the product of, and trigger for subjective emotional feelings - a process known as "peripheral feedback".[10] For these reasons it can be difficult inferring emotional meaning from physiological responses.

The literature also raises questions about the nature of emotions, whether perceived or felt, and the language or terminology used to describe them. Emotive words such as fear, anger, anxiety and so on, lack scientific precision and clear differentiation, and cannot be universally applied across studies involving animals as well as humans – at least not without resorting to anthropomorphism. For this reason, physiological and emotional responses are often described in terms of defensive and appetitive motivational systems. Responses to negative emotions in particular are frequently linked to survival and defence mechanisms – those activated in the presence of a threat.

This potentially raises problems when exploring negative physiological responses to musical stimuli, since music presents no survival threat, however fearful our perception of it might be. Questions inevitably follow regarding the nature of music-induced "emotional" responses.[11] It might be logical to question whether or not emotions reported by participants when listening to "fearful" music represent genuine feelings and experiences of fear, or only the *perception* of the music itself as fearful or scary.

Nevertheless the scientific literature does show a connection between measurable physiological responses associated with emotional processing, or appetitive and defensive systems, and musical stimuli. However comparative reviews of the resulting data present a number of challenges. For example, in the case of studies exploring musically-induced fear responses, one of the primary triggers for negative physiological responses, of the kind normally associated with unpleasantness, aversion, fear and so on, is dissonance. However, determinations of dissonance, as exemplified in scientific studies, differ significantly. Types of musical stimuli used to test responses to dissonance vary considerably, from consonant excerpts with a few dissonant elements,[12] or processed excerpts in which the melody lines have been transposed against unaltered accompaniments,[13] through to music specifically composed to be atonal and dissonant throughout.[14] In addition stimuli durations also vary significantly from study to study. These differences of approach have a direct bearing on the results reported in these studies and make it difficult to evaluate the data in general terms.

For example, in the case of pitch-manipulated extracts, the *unaltered* musical features hallmark the stimuli with the stylistic fingerprints of tonal music, creating expectations which are constantly frustrated by artificially created dissonances. In such cases it becomes difficult to determine whether or not the physiological responses reported are triggered by dissonance alone, when in fact they might be the product of perceived musical error, or frustrated expectations. Musical examples such as these identify themselves as abnormal or unnatural and therefore are potentially problematic when used as isolated examples of dissonance. Interestingly those utilising musical stimuli of this type appear not to recognize this issue, as can be seen in statements such as this,

> Importantly, consonant and dissonant versions of each piece were, thus, identical in their dynamic outline, their rhythmic structure and tempo, and their melodic contour. Consequently, it is not possible that any of these stimulus properties contribute to differences in autonomic and neural effects between consonant and dissonant pieces.[15]

Another potential problem encountered when reviewing biofeedback literature is that although the musical features of the music vary considerably, in some cases researchers fail to provide sufficiently detailed information regarding the musical stimuli used, simply describing the music in terms of classifications such as arousal and valence,[16] or providing the title of a work and its composer without detailing the specific extracts used.[17] This lack of musical clarity and precision can undermine the potential to differentiate between the musical features or elements responsible for inducing specific physiological responses.

For this reason the following biofeedback literature review is structured according to response type[18] rather than being organized according to specific musical features. Where appropriate endnotes identify details of the musical stimuli used in order to clarify references to terms used in the studies reviewed – such as dissonance.

Brain Response

There are many scientific studies exploring the complex responses of the brain and its interactions with other body mechanisms - within the context of emotional processing and responses to musical stimuli. These studies identify a number of structures and regions within the brain, which are important in terms of appetitive and defensive responses. The amygdala[19] in particular emerges as critical to emotional processing, experiences of fear, as well as to fear and defense conditioning in response to external stimuli. In addition, responses to fearful stimuli implicate the amygdala in other bodily responses (endocrine, autonomic and behavioural),[20] such that "Threats . . . not only elicit specific defense responses but also initiate generalized arousal".[21]

A number of music-based studies have served to extend such investigations, utilizing dissonant musical stimuli as a means of investigating the response of the amygdala and other brain structures to unpleasant, aversive or fearful music – founded on the basis of a growing and substantive body of evidence suggesting that dissonance elicits unpleasant judgements in normal listeners.[22] For example, one FMRI study[23] found that dissonant music stimulated increases in blood oxygen levels in the amygdala, the hippocampus,[24] the parahippocampal gyrus[25] and the temporal poles:[26] interestingly the very regions, which showed strong *decreases* in blood oxygen levels in response to pleasant music (these observations are paralleled in other studies).[27]

Evidence such as this has been corroborated by research testing the response of patients following surgery or damage to the brain. For example, it has been found that bilateral damage to the amygdala, impairs the perception of fear, facial expressions and unpleasant emotions. Significantly it also impairs the recognition of fearful music.[28]

Similarly damage to the parahippocampal cortex[29] (or PHC) has also been found to affect the perception and evaluation of dissonance. One study found that patients with larger excisions of the PHC appear to show increased indifference to dissonance.[30] The authors of the study also implicate the parahippocampal gyrus (or PHG) in the avoidance of aversive stimuli. So what emerges from the study is a picture in which the amygdala and the PHC *evaluate* stimuli as aversive whilst the PHG is then engaged to protect by seeking to *avoid* aversive stimuli.

Interesting though such results might be, it is unlikely that commercial gaming biosensors, with the capacity to measure direct responses in the amygdala or hippocampus, will appear any time soon. Even if such gaming biosensors did exist, biometric data generated in response to dissonant music might not indicate a fear response, as Koelsch points out,

> . . . activity changes observed in the amygdala and the hippocampus during the presentation of unpleasant (or threatening) stimuli is not necessarily a result of the generation of fear (or other unpleasant emotions) but could well reflect inhibitory processes activated to prevent the hippocampus from traumatization during exposure to potentially harmful stimuli.[31]

In other words, some of these responses might simply be the result of self-protection mechanisms at work within the brain. Nevertheless, the activation of defensive mechanisms in response to threat detection might well act as a prompt to associated emotional processing.

If the responses of brain structures such as the amygdala and hippocampus cannot currently be accessed directly in commercial gaming contexts, how might brain response be captured? Given recent technological developments[32] it seems likely that the games industry will initially focus its energies on monitoring electrical activity in the brain (EEG measurements). Commercially available EEG devices already use such data (detecting alpha and beta waves) to indicate different states such as relaxation and concentration.

However, to capitalize on EEG developments in gaming, it is likely that the industry would wish to extend the interpretive scope of such physiological data beyond simply detecting levels of concentration or relaxation. A significant number of studies have used EEG data as a measure of emotional and physiological response and these could serve as a springboard to more specific game related research in future.

In one particularly interesting music-based study, researchers explored EEG and fMRI data in conjunction with subjective emotional evaluations in response to music taken from the atonal and athematic score for the film *Danton* (1983), composed by Jean Prodromidès. In contrast to musical stimuli used in many other studies as a stimulant to fear, this music was *specifically* composed to underscore dark and emotive onscreen events,[33] and belongs to a sound world more closely aligned with horror genre games such as *Dead Space*. It is interesting therefore that the authors found that, "Activation areas involving right cortical regions were found only for unpleasant emotions",[34] and go on to suggest that,

> The predominance of left hemisphere activation with pleasant musical feelings and right activation with unpleasant ones is consistent with findings [[35]] that relate right frontal activation with negative affect and left frontal activation with positive affect.[36]

If the right and left hemispheres activate differently in response to unpleasant and pleasant musical stimuli, and these responses can be measured via EEG, then the implications of such research could be significant in terms of gaming applications. However the study does raise questions regarding the stimuli used. For example, it is not clear which extracts of the original film score were used, which makes any analysis of *specific* musical features and associated appraisals of unpleasantness or fear, impossible. Unresolved dissonance is a general characteristic of the entire score, and based on other studies, this is a musical feature strongly linked to unpleasantness and negative emotional and physiological responses. The authors of the study also point out that Prodromidès "breaks classical musical grammar rules", frustrating expectations in terms of melody and harmony, so triggering "the participation of limbic and right hemisphere regions in the search for emotional comprehension".[37]

However other factors might play part in the responses found: some sections of the score make extensive use of disturbing vocal textures and pitch oscillations, creating an aural evocation of tortured humanity. If the extracts were taken from passages such as these, might the responses found be due to participants' reactions to alarming and apparently distressed voices, rather than other compositional and instrumental features?

Nevertheless, the findings of the study are of relevance because they suggest that it is possible to differentiate patterns of electrical activity in specific brain regions in response to musical stimuli designed to trigger polarized emotive responses. Clearly however there remain challenges regarding the precise characteristics of the musical stimuli used and the extent to which these can be linked to specific emotional and physiological responses. In addition, the results do not account for the additional cognitive processes involved in game play, or for the bombardment of the senses by simultaneous stimuli whilst gaming. However they do indicate avenues to explore in the development of EEG-based gaming devices.

EEG devices may represent the most likely avenue for the detection of direct brain response in game play scenarios, but what of other aspects of brain response, such as coordinating the activity of various body systems? Some studies frame the brain's emotional response within the context of survival circuits.[38] In layman's terms these survival circuits might be described in terms of thriving and surviving - with circuits involved in defense, energy maintenance, fluid balance, nutrition supplies, thermoregulation and reproduction, to name a few.[39] These circuits coordinate the body's integrated systems and behavioral interactions with the environment.

For example, if the specialized defense circuits of the amygdala detect a threat, a number of consequences follow: "hard-wired" behavioral reactions occur; relevant goal-directed actions are learned and performed (or stimulus response habits activated); and arousal responses are triggered in the central nervous system[40] (CNS), the autonomic nervous system[41] (ANS), and endocrine system. The result is a heightened state characterized by increased attention and sensitivity to stimuli, linked to associated functions of learning, memory formation and retrieval. This in turn creates a feedback loop, which continues to drive the survival circuits.

Given the connection between survival circuits in the brain and generalized arousal in the body, it would seem logical to deduct that physiological responses, such as those of the autonomic nervous system, might be exploited by the games industry as *indirect* indicators and triggers of brain response. Generalized arousal responses have also been linked to a number of theories of emotional processing,[42] potentially presenting the games industry with indicators of emotion as well. A number of these theories of emotion present the autonomic nervous system as a major component of emotional response[43], appearing to confirm the potential of ANS response biosensors as possible indicators of emotion.

The road to a full scientific understanding of the complex neural systems of the human brain and its response to music and emotion still stretches out a long way before us. Undoubtedly there is evidence to support the association found between dissonant musical stimuli and unpleasant, negative, and potentially aversive responses.[44] Accessing associated brain responses directly however presents very real challenges of understanding, as well as practical and technical implementation. In terms of *direct* access to brain activity, EEG-based devices offer the most feasible future pathway, but the responses of the autonomic nervous system, such as heart rate and skin conductance, potentially offer less difficult terrain to explore.

Heart Rate and Skin Conductance

A number of studies confirm that listening to music has an effect on the ANS.[45] If the ANS is a component of emotional processing as has already been suggested, then it is logical to deduct that these physiological responses might be indicative of music-induced emotions. Whether or not it would be possible to differentiate specific emotions such as fear, based on distinct "autonomic signatures", is a more controversial matter.[46]

Sylvia Kreibig's detailed review of literature exploring ANS activity and emotion, notes that many studies report increases in heart rate and skin conductance in response to fearful stimuli, indicating heightened arousal.[47] Other studies report similar results.[48] However, when reviewing music-based studies notable exceptions soon become very apparent. A significant number of these show that heart rate *decelerates* significantly in response to unpleasant, dissonant musical stimuli. In addition skin conductance tends to heighten as levels of dissonance increase.[49] (Interestingly the same results have been reported in response to negative, emotional films, pictures and sounds.[50]) Some have tried to explain these results,[51] but they do appear to be counterintuitive.

Heart rate accelerations (tachycardia) and decelerations (bradycardia) appear to be triggered by a number of musical characteristics such as rhythm, texture and dynamics. Some studies have sought to analyse these relationships more closely, attempting to identify specific psychoacoustic features linked to particular levels of arousal, valence, and emotional states.

One particularly interesting study by Eduardo Coutinho and Angelo Cangelosi[52] selected six psychoacoustic features (loudness, pitch level, pitch contour, tempo, texture, and sharpness), and used these to create a predictive computer model of emotional response – based on arousal and valence.[53] They found heart rate changes linked to specific sound features, such as increasing loudness - indicating higher arousal. Heightened arousal was also associated with higher pitch, faster tempi and sharper sounds. Valence correlated with tempo and pitch levels.[54]

It is difficult rationalizing some of these results with the findings of other studies showing heart rate deceleration in response to fearful musical stimuli, since some of the features identified with heightened arousal are also associated with horror genre music. Clearly other factors are also at work.

For example, a study by Bradley and Lang suggest that the presence of pleasant and unpleasant sounds has an impact on heart rate fluctuations. They found that,

> . . . heart rate deceleration was significantly greater when listening to highly arousing unpleasant sounds . . . than when listening to unpleasant sounds that were rated lower in arousal . . . For unpleasant arousing sounds, the largest heart rate decelerations were obtained for a male scream . . . a female scream . . . and sounds of attack.[55]

Given that non-musical sounds often feature in horror genre music, there is certainly scope to activate heart rate decelerations associated with highly arousing and unpleasant sounds. It is also likely that the wider sonic context of horror games would also be a contributing factor in this regard, providing disturbing and fearful sound effects with the potential to intensify any negative physiological impacts triggered by the music.

Interestingly however there is also evidence suggesting that unpleasant aural stimuli might prime people to be startled and intensify the effect when it occurs. One study which measured the magnitude of startle response by measuring blink reflex, found that, "larger blinks elicited to visual startle probes when listening to unpleasant compared with pleasant sounds . . . [and] . . . blink reflexes were faster when listening to emotionally evocative sound".[56] These reactions were accompanied by greater activity of the facial muscle associated with frowning (corrugators supercilli). Another intriguing finding of this report was that high arousal sounds triggered a strong memory response.[57] So it would appear that unpleasant aural stimuli can act as a primer for fear (intensifying and speeding up reactions) ensuring that once experienced, the fear is not forgotten.

Significantly however, the startle reflex is characterized by an *increase* in heart rate. Music written for "stingers" (sudden onset cues or "hits" designed to surprise) plays to the "startle reflex", so given the frequent use of stingers in horror genre music, one might expect to see significant heart rate acceleration. Within the context of horror music this is not the case. One intriguing study found that, "suspenseful [horror] music works as a mild pre-pulse and therefore limits the effectiveness of a startle that follows it",[58] effectively making the stinger moments less scary. Ironically it is the fearful horror context, which inhibits cardiac acceleration.

Another factor influencing heart rate fluctuations appears to be the subjects' familiarity with, or knowledge of music, as reported in a study by J.E. and H.F. Landreth,

> Heart rate response appears to be linked with the presence or absence of learning and repetitive exposure to music. . . Results of this study demonstrate that physiological responses of the listener can be affected by his increased knowledge and understanding of a musical score. [59]

Findings such as this might be of particular significance in relation to repeated videogame-play; indicating that over time, physiological responses to games potentially change as players become increasingly familiarized with musical stimuli and learn what to expect. In addition, if players are already familiar with the musical sound world of particular games due to wider listening or educational experiences, then their physiological responses might be very different from those of players who are less familiar with those musical genres. Familiarity is linked to expectation to some degree; if we are familiar with something and have knowledge of it, we know what to expect, which in turn affects physiological response. Conversely the same applies with regards to the unfamiliar and unexpected.

It is thought that significant and novel stimuli trigger orienting responses, engaging motivational circuits and prompting the disposition to act. Some physiological responses are considered to be "indices of orienting and attention", governed by appetitive and defensive neural motivational systems.[60] Significant stimuli might be defined in terms of pleasure and arousal, suggesting links with motivational systems associated with emotional processing and also task-relevant contexts. Novel stimuli tend to be linked to danger and the engagement of defense systems.[61] The degree of threat, arousal, and novelty presented by the stimulus, modulates resulting responses.

It might be logical to assume therefore that novel stimuli might trigger cardiac acceleration, however the reverse is true. Significant cardiac deceleration occurs in response to novel stimuli, particularly in the case of aversive and unpleasant cues – indicating enhanced sensory intake and orienting. Skin conductance changes are also heightened in response to novel stimuli.

Studies suggesting that sudden musical changes induce cardiac deceleration appear to be consistent with orienting responses to novel stimuli. For example, one study found that, "musical segments with eminent changes in rhythm, texture, and dynamics produced bradycardia in the experimental subjects".[62] Perhaps indicating that sudden juxtaposed contrasts trigger orienting responses associated with novel stimuli. The music of *Dead Space* and other horror genre games and films is often characterized by dramatic and unpredictable musical changes and unexpected sonic events. On this basis, orienting responses to novel stimuli might be tentatively proposed as one factor in the connection between fearful musical stimuli and cardiac deceleration.

However, orienting responses to novel stimuli are fairly short-lived. Physiological changes are most noticeable in the first few seconds following the stimuli presentation. In addition, repeated exposure to the stimuli presented appears to lessen the orienting response (heart rate habituates fairly rapidly; skin conductance habituates more slowly). This raises questions regarding the ways in which physiological responses change over time, particularly with regard to fearful musical stimuli, and confirms the significance of familiarity as an influencing factor in physiological response. Whether or not prolonged, or repeated exposure to horror genre music would result in similar habituation, particularly within the context of dynamic mixing, would be a matter of some significance in biometric gaming applications.

The connection between orienting responses and novel stimuli only explains relatively momentary physiological changes such as cardiac deceleration and heightened skin conductance. If there is a link between orienting responses and "eminent" musical changes, such a link would not explain the findings of studies showing more prolonged examples of lowered heart rate or increased skin conductance in response to fearful music.

There are, however, a number of studies, which appear to indicate connections between fearful anticipation and suspense, or increasing unpleasantness over time, and cardiac deceleration and increased skin conductance. One particularly interesting film-based study demonstrated that skin conductance increased during longer periods of anticipation, leading up to an unpleasant accident scene.[63] The results indicated that suspense was more disturbing than surprise.[64] This finding is consistent with other research indicating that physiological responses increase over time.[65] For example, one study reported, " a significant correlation showing that . . . heart rate deceleration increased linearly with increasing unpleasantness".[66] In a review article Koelsch reports that,

> The strongest physiological effects for each emotion type generally tended to increase over time, suggesting that the intensity of an emotional experience is likely to increase over time during the perception of a musical excerpt.[67]

If, as the evidence indicates, long periods of anticipation induce significant physiological stress reactions and emotional intensity increases over time, these findings would appear to contradict the opinion expressed by Theodor Adorno and Hanns Eisler in relation to suspenseful anticipatory cues,

> If the screen shows a peaceful country house while the music produces familiar sinister sounds, the spectator knows at once that something terrible is about to happen, and thus the musical accompaniment both intensifies the suspense and nullifies it by betraying the sequel.[68]

In one sense this is true, the music does, "let the cat (or, in the case of horror, monster) out of the bag", but the physiological evidence suggests that knowing the monster is going to be let out of the bag and anticipating or imagining what might happen, can be far more stressful than being faced with the surprise of it jumping out suddenly. In one sense however Adorno and Eisler were right: since if the "sequel" were to be accompanied by a "stinger" monster cue, the suspenseful horror genre music would nullify the physiological impact of the resulting startle reflex.[69]

Discussions regarding the respective physiological effects of suspense versus surprise pivot around the concept of "expectation". Scientific literature points to a number of musical characteristics governing expectancy, such as, "melodic interval size . . . melodic contour . . . rhythmic features . . . and tonal and harmonic structures".[70] Harmonic violations appear to have attracted the greatest share of research attention. For example, in drawing together the findings of a number of research studies, Stefan Koelsch asserts that,

> unexpected chords . . . violate the sensory expectancies of listeners . . . the violation of musical expectancies has been regarded as an important aspect of generating emotions when listening to music . . . Moreover, the perception of irregular chord functions has been shown to lead to an increase of perceived tension . . . and the perception of tension has been linked to emotional experience during music listening.[71]

These findings are shared by another report, also published in 2005, which states, "It can be argued that . . . [harmonic] violations lead to an increase in physiological 'arousal,' which in turn leads to a heightened emotional experience of the musical pieces." Further the authors suggest that there is, "compelling support for the idea that suspensions of musical expectations are an important pathway to generating emotions in the listener".[72]

One study which attempted to explain the connection between frustrated harmonic expectation and physiological responses suggested that, "the number of perceived pitches common to successive chords might be one factor governing musical tension: the weaker the pitch commonality values, the greater the perceived tension". Further, the authors surmised that "horizontal motion" might also be significant, indicating that, "the larger the melodic interval in each voice, the greater the perceived tension".[73]

The power of unexpected musical or sonic events of any kind (whether harmonic or not) to trigger physiological responses is consistent with studies linking musical characteristics to fear vocalisations. For example, with reference to a study by Arne Öhman,[74] Klaus Scherer suggests that,

> . . . musical stimuli sharing the acoustic characteristics of . . . fear vocalisations (sudden onset, high pitch, wide range, strong energy in the high frequency range) may be appraised by . . . extremely powerful detection systems and may provoke . . . physiological defence responses.[75]

Whatever the basis for our physiological responses to unexpected musical events, to suspense and dissonance, or to any other musical or sonic characteristics for that matter, one fact emerges unequivocally from the evidence, namely the physicality of our response to aural stimuli, whether in the brain or the body. More specifically, research indicates that musical or sonic characteristics commonly associated with musical portrayals of fear, horror, evil and so on (in the popular media), such as unresolved dissonance and those already outlined, tend to induce responses more normally associated with unpleasant or stressful stimuli. The evidence also stresses the importance of the wider extra-musical context in determining physiological responses: for example, the sonic context (the affect of unpleasant, non-musical sounds); the visual context (the affect of visual stimuli such as film); the personal context (the familiarity of the subject to the stimuli). Whether or not such associations are biologically predetermined or acquired, as a product of social and cultural conditioning, is difficult to ascertain.

Nature or Nurture?

Scientific data throws some light on this question but it is not unequivocal. A number of studies have shown that young infants show a marked preference for consonant as opposed to dissonant music. A 2002 study reported that babies as young as two months old exhibit a preference for consonance.[76] The results confirmed the outcomes of an earlier study by Trainor and Heinmiller exploring the development of evaluative responses to music, which had found that infants aged four to six months preferred to listen to consonance as opposed to dissonance.[77] Research by Zentner and Kagan, examining infants' perception of consonance and dissonance in music, further supported these findings.[78] The Trainor and Heinmiller study reports that,

> . . . although infants do not yet have the musical-system-specific knowledge of scale structure that is involved in adults' emotional reactions to music, infants are similar to adults in their evaluative reactions to consonance and dissonance.[79]

The authors state that infants can also, "discriminate consonant from dissonant intervals"[80] and cite a number of articles to support this.[81] Further they suggest that,

> Because 6-month-old infants do not yet have knowledge of musical scale structure . . . emotional reactions to music cannot arise in an identical manner in infants and adults . . . Thus it is particularly interesting for the study of the origins of emotional responses to music that infants show similar affective reactions to those of adults to consonance and dissonance. It indicates first of all that infants have affective responses to an aspect of musical pitch structure early in life. It also indicates that the consonance/ dissonance dimension is very basic to musical processing.[82]

If this is indeed the case can we feel confident asserting that responses to dissonance are innate and not learned? Not according to the authors of the study, who write,

> It remains an open question whether 6-month-old infants' preference for consonance is a direct consequence of auditory system structure or whether it is learned early in life through exposure to sounds in the natural environment.[83]

If a preference for consonance is not innate but learned, the onset of the learning process is occurring remarkably early and is taking root very quickly. Innate or learned, there is no denying that, "consonance is highly salient to infants".[84] Might the speed of the learning process be linked to an innate or learned association between dissonance and fear or danger? Unfortunately the "learned versus innate" debate also applies to associations linking dissonance to fear or danger. If learned it has been suggested that the learning process occurs from an early age, "rooted in the infant's response to the mother's voice expressing disapproval".[85] In a review of studies relating to vocal expression and musical performance, Juslin and Laukka similarly suggest that music perceived as scary may mimic characteristics associated with vocal responses to danger.[86] However this association is acquired in children, it is a fact that, "the perception of danger links music with biologically important functions".[87]

Whether pre-programmed into the fabric of brains and bodies or acquired rapidly during early development, associations between perceived danger and physiological response can be difficult to disconnect in adulthood, influencing not only our perception of danger but also our perception of other people. For example, a recent psychology study found that thriller music tended to inhibit audience identification with onscreen characters, making them appear less likeable and their thoughts more uncertain. The music discouraged empathy and identification, encouraging viewers to distance themselves from the potential danger of unreadable and unpredictable people; effectively ostracising them as "other".[88]

Viewed collectively the scientific evidence shows that from the earliest age music can stimulate a range of different physiological responses, which in turn have the power to influence perception and associated behaviour. More specifically, the evidence indicates strong connections between musical characteristics commonly associated with depictions of fear and horror, such as those found in the *Dead Space* franchise, and negative physiological responses more normally associated with fear, stress, unpleasantness and aversion. The commercial success of the *Dead Space* games indicates that the ability to induce real fear, as evidenced by corresponding physiological responses exhibited during game-play, might carry a significant financial incentive. However might we not assume that the generation of any strong physiological responses, whether positive or negative, could potentially indicate likely commercial success and healthy sales? This study has focused on negative physiological responses, but for every piece of scientific data revealing the links between music and negative physiological responses, there is other data showing the potential of music to trigger positive physiological responses. Games designed to exploit these responses might well create such positive, "feel good" experiences that they translate into further sales. Against this backdrop, the development of biosensor interfaces appears to make commercial sense for the games industry, whilst also offering the potential to create more exciting and responsive gaming experiences as well. However, the scientific research also points to a number of problems for game developers seeking to capture and exploit physiological data of this type.

The Challenges

Perhaps one of the most significant challenges facing game developers is the acquisition of a comprehensive understanding of the ways in which the body and brain respond to different types of music and sound. Significant strides have been made by the scientific community in recent years with regards to understanding our responses to music and sound, but this field of scientific endeavor still presents many unanswered questions. Difficulties of understanding are further compounded by the fact that game-play itself is not simply a passive experience in which one listens to music in isolation; the music, as in film, performs dramatic functions relating to visual stimuli and narrative contexts, which in turn also trigger physiological responses. Unlike film, these experiences then influence the players' interaction with the game, further affecting their responses. Scientific data relating to music alone, or even music and film, although potentially informative, would not fully address the complexity of the active gaming experience. The development of games utilizing biosensor data to create an interactive feedback loop, measuring physiological responses and then adapting game-play to affect those responses even more, would further compound the challenges for those seeking to understand the relationship between music, sound and physiological responses within the context of game-play. It could be argued that without an adequate understanding of these complex relationships, and with many questions still waiting to be addressed by the scientific community, the potential of biosensors to enhance the gaming experience could be compromised, and in worst-case scenarios, poorly implemented biosensor data might even detract from the gaming experience.

Even if the games industry honed their approach and focused on developing biosensor systems utilizing biofeedback data from one type of physiological response only, such as heart rate, problems would still remain. For example, the challenge of isolating *reliable,* individual physiological responses on the basis of biofeedback literature examining multiple responses and interactions between variables of response, general patterns and trends would be significant. It is unlikely that individual bio-signals could be read as reliable or universal emotional indicators, particularly within the real-time context of interactive game play.

In the case of skin conductance response for example, individuals can have very different levels of response. Some people (labelled as labiles) exhibit significant responses even when at rest, others (stabiles) have skin responses with very little variation when at rest. It is thought that such variations in baseline response might be linked to personality type. Whatever the underlying causes might be, the evidence points to significant variations in individual response; in other words, it is not simply a case of "one shoe fits all".

Should questions of reliability of response be successfully addressed, other challenges would still remain. For example, a simple biosensor designed to measure heart rate alone, might detect a drop in heart rate during a particularly frightening sequence of game-play, in response to disturbing music, sound and graphics. Unless the game developer is aware that this response potentially indicates a negative, stress response, the data might be interpreted within the programming of the game as an indicator of falling tension. The misinterpretation of this data could potentially result in inappropriate adaptations within the game. Understanding therefore has a direct bearing on successful data integration and implementation, as well as biosensor design and development.

If individual physiological responses can be unreliable and misunderstood, it might be logical to assume that the development of interfaces with multiple sensors, perhaps measuring skin conductance, and even brain response, as well as heart rate, might provide greater clarity in terms of overall response. Utilizing comprehensive arrays of physiological measures to detect patterns of response and associated variables is an approach advocated by many scientific studies.[89] For example, in the gaming scenario described above, heightened skin conductance might provide a more reliable and less unexpected measure of physiological response, which might help to contextualize heart rate data. However, the development of multiple biosensor systems would not be without challenges: data from different sensors might appear to be contradictory, creating complications of interpretation and integration; processing complex data streams and successfully implementing them within the interactive environment of *real-time* game-play would be technically and creatively challenging; finally, designing *practical* multi-sensor systems for home use, which would be capable of measuring the complexities of brain response, would be difficult.

For composers of music for games, systems such as these, requiring some understanding of the musical triggers responsible for specific physiological responses, accompanied by a grasp of the ways in which these responses might be musically manipulated, represents a significant challenge. As it stands composers already face challenges in terms of creating music suitable for use in the interactive environment of game play and dynamic real-time mixes. In addition, their levels of involvement in the integration process vary significantly, potentially creating further complications.

In a new dawn of biosensor interfaces, few composers would be aware of findings in scientific literature linking specific musical or sound-based stimuli to physiological responses; even if they had the inclination to explore such literature it is unlikely that they would have the time to do so, particularly given current commercial production schedules. Most composers would base their musical depictions of particular emotions or dramatic situations on simple "gut feelings" about what would be most musically appropriate. It might well be that these "gut feelings" result in music which stimulates the hoped for physiological responses, but then again, it might not.

In an ideal scenario, it might be desirable to be able to predict the physiological responses for individual musical cues, whether experienced individually or layered together in a dynamic mix with other randomized musical or sound based elements. Once the resulting data is received and processed, musical adaptations might occur to manipulate these responses in *known* ways. Whether or not this scenario is achievable hinges on a number of factors: levels of understanding regarding the relationship between music and physiological responses, or the accuracy of the "gut feeling" approach as a trigger for predictable responses; the potential of music to be truly adaptive in response to complex and continually changing real-time data streams; finally, that the technical and creative challenges relating to integration are addressed.

It might well be that efforts to answer challenges such as these results in a move towards algorithmic composition in which pre-composed music is discarded in favor of music generated and adapted in real-time in response to continual data feedback, based on known relationships between specific musical or sound based stimuli and physiological responses. Given that pre-composed music cannot be truly adaptive, this outcome might appear to offer a solution. However, substituting the role of the composer for a set of algorithms (based on scientific data) is unlikely to produce the most satisfactory musical results, regardless of the physiological responses induced.

Alternatively, composers might work to guidelines set in place by game developers; guidelines based on scientific evidence linking specific musical triggers to associated physiological responses. A different approach might be to develop predictive computer models of physiological and emotional response, based on scientific data showing generalized patterns and trends – those most likely to be triggered by specific music elements or sound-based characteristics. Such models might then be integrated alongside existing industry middleware tools,[90] providing composers and sound designers with predictive data, which in turn might guide their creative work towards the achievement of specific and anticipated physiological responses. It might also be possible for the industry to release gaming products with adaptable and intelligent predictive gaming models, which incorporate some degree of customization - such that generalized data would eventually give way to the unique response profile of individual gamers.

The development of predictive computer models[91] such as those created in the studies by Coutinho, Cangelosi[92] and Dibben[93] possibly suggest a way forward for the games industry, particularly given the surprising levels of accuracy shown. If as the authors conclude, a "significant part of the listeners' reported emotions can be predicted from a set of six psychoacoustic features",[94] then it is not difficult to see the potential for predictive models in biometric gaming.

Putting aside the obvious difficulties involved in creating fully comprehensive predictive models or guidelines, it is unlikely that composers would welcome anything that might constrain their creative approach. Even if computer models and guidelines such as this were instigated and standardized across the industry it is likely that strikingly similar musical characteristics would be shared across musical depictions of similar dramatic or emotional contexts. The danger of standardization in this context would be predictability and familiarity; gamers would become acclimatized to such musical manipulations, and their potency as triggers for physiological responses would be diluted. It is also unlikely that the games industry would wish to introduce creative guidelines which could result in "samey" musical outputs. The current lack of standardization within the games industry, and a desire to produce games exhibiting originality and innovation, potentially predetermines against the adoption of such an approach.

Even if satisfactory musical solutions could be found, challenges and questions would still remain. For example, if biosensor data becomes the focus of interactivity in games, such that the involuntary physiological and subconscious responses of players govern the dynamic and adaptive changes occurring during game-play, might players' begin to lose their sense of conscious and voluntary control when gaming?

Perhaps game developers might preserve the players' sensation of control against an adaptive game environment which responds to changing physiological data, by creating a hierarchical prioritization structure within the programming of the game, such that voluntary responses take precedence when multiple interactive data streams are detected. Whatever the potential solutions to this challenge might be, other significant questions would still need to be addressed.

For example, evidence already outlined shows that familiarity with musical stimuli results in changes to physiological response, such as heart rate. Familiarity, repetition and predictability are already problematic issues for game developers seeking to create games capable of sustaining the interest of players for many hours. The fact that physiological responses change as players become familiarized with game elements, such as music and sound, adds a further layer of complication when developing games relying on biosensor data of this sort.

In addition, familiarity with certain musical and sound-based stimuli might not be acquired as a result of gaming alone. For example, when playing *Dead Space,* and encountering its music for the first time, the physiological responses of someone with a penchant for avant-garde music (in its less approachable forms) would probably differ from those of someone who is completely unfamiliar with music of this type. Any assumptions that game developers make regarding likely physiological responses might be undermined by exceptions such as this, potentially creating gaming experiences that are not satisfactory for all.

This raises the question of standardization; something which already presents a challenge to the games industry. Physiological responses are not standardized or universal for all. At most, scientific studies reveal general patterns, indicating likely types of response and associated parameters, which might be described as "normal" or within the normal range. However, other factors can result in exceptions. Familiarity has already been considered, but physical and mental health conditions might also alter physiological responses to musical stimuli, as outlined earlier in relation to brain injury patients. Variables such as these would make it very difficult for the games industry to develop standardized systems capable of universally predicting, measuring and integrating physiological responses.

There might also be additional medical and ethical issues to consider in the development of games utilizing biosensor data. For example, a biosensor detecting an increase in heart rate might trigger adaptations within the game designed to further increase the intensity of this response. If the player however, suffers from a heart condition, this outcome might carry a significant risk. The use of biosensors to measure physiological responses, and the use of this data to sustain, intensify, and manipulate those responses through adaptations within the game, connect the player far more directly to the gaming experience.

As technologies develop with the capability of enveloping players in gaming experiences, which feel more physical and vivid, the boundary between real experiences and virtual game experiences might become more blurred. For games carrying higher age certifications, this might be a cause of ethical concern.

It certainly seems likely that as new immersive technologies evolve alongside biometric gaming and are used in conjunction with them, the sense of being *in* game worlds will be heightened still further. The founder of the NeuroGaming Conference, Zach Lynch outlined this very scenario in a recent interview,

> I think the answer is convergence. It's OculusRift [95] with a Foc.us headset [96] to improve your concentration with an EEG to understand your emotional reactions, to facial tracking technology to capture pupil dilation and figure out what you're actually looking at. All four of those combined with sound, some haptics [97] oriented headsets, in a haptics oriented chair.[98]

Exciting though such developments may appear to enthusiastic gamers, futurists and game industry insiders, it is undeniable that the convergence of such technologies only serves to magnify ethical and health concerns relating to biometric gaming, particularly with regard to higher certification games. Such ethical and health concerns cannot simply be addressed by the certification of games alone as a "catch all" means of preventing harm. At some point the industry will need to address these questions with specific reference to rapidly evolving developments in biometric and immersive gaming technologies. Otherwise, the intensification or reinforcement of physiological responses during game-play might result in undesirable psychological, physical or behavioral impacts.

The Benefits

The development of game technologies, designed to capture and react to physiological responses, clearly presents new challenges, only some of which have been outlined above. Aside from any potential difficulties or concerns presented by these new technologies, it would be wrong to suggest that future developments in this area might not result in wider benefits.

Within the context of music therapy for example, the development of user-friendly technologies, which measure physiological reactions and then respond by triggering musical events designed to prescriptively treat through the generation of positive physiological responses, might provide an additional and useful tool for music therapists.

Further health benefits might be found in the treatment of significant medical problems such as dementia. Scientific evidence already exists which proves that music elicits associations in the memory, and can act as a cue to emotional memory.[99] Academic and scientific research exploring the potential of music as a means of treating dementia and related conditions is ongoing, but there is significant interest in developing technologies which use music as a form of prescriptive treatment, as the music adapts to particular brain responses.

Alternatively technologies such as this might be applied as a simple form of stress relief or as “pick-me-ups”, either through recreational gaming, inducing positive physiological responses, or through related, non-gaming “spin-off” products, simply designed to de-stress or lift the spirits when relaxing.

Conclusion

The games industry appears to be standing on the brink of a new phase in its development, one in which the human body itself becomes the focus of interface development. The development of biosensors designed to capture the diverse range of complex physiological responses produced by the human body is already in progress. One of the primary triggers for such responses in gaming is music and sound. Recent years have produced a growing body of scientific research, which indicates that particular types of music and sound are capable of triggering significant and measurable physiological reactions. The technical and creative challenges for games developers seeking to exploit these findings within the context of gaming are significant. However, the commercial success of games such as *Dead Space 2,* with its proven ability to trigger strong physiological responses, would indicate that the ability to trigger significant physiological responses carries a certain financial incentive. Motivated by the potential to outstrip competitors in a crowded marketplace through new developments in gaming and associated hardware, it seems likely that these challenges will be addressed to some degree.

In the case of games designed to induce negative physiological responses, the successful achievement of these goals potentially raises some legitimate concerns relating to health, ethics, and even behavior. However it is also true that in its quest to create the ultimate gaming experience, the games industry might develop technologies with the potential to unlock the therapeutic power of music through adapted applications in music therapy, medicine and the home. If so, this next phase of development in the industry might offer new avenues of exploration and related technological developments, with the potential to tap the curative benefits of music for gamers and non-gamers alike.

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[1] Electrodermal or galvanic response (the ability of the skin to conduct electricity) – used to measure emotional or physiological arousal. There are different types of electrodermal measurement used in research today, for a summary see: http://www.bem.fi/book/27/27.htm, accessed August 28th, 2013. For more detailed information regarding the use of skin conductance in research of this type see, Bernd Figner & Ryan O. Murphy, "Using Skin Conductance in Judgment and Decision Making Research," in *A Handbook of Process Tracing Methods for Decision Research,* eds Michael Schulte-Mecklenbeck, et al. (New York: Psychology Press, 2010),163 -184.

[2] Further details available online, accessed August 29th, 2013, http://www.foc.us/

[3] Online details, accessed August 28th 2013, http://www.indiegogo.com/projects/muse-the-brain-sensing-headband-that-lets-you-control-things-with-your-mind

[4] Electroencephalogram – measures the electrical activity of the brain.

[5] Tests conducted by the company Vertical Slice. Online information accessed August 29th, 2013, http://www.gamasutra.com/view/feature/6480/scary_game_findings_a_study_of_.php?print=1

[6] Ibid.

[7] Taken from a telephone interview with the author (2011).

[8] The second game in the series makes greater use of thematic material than its predecessor.

[9] For *Dead Space* Jason Graves composed a large number of stingers (surprise "hits" or cues), which he called his, "bucket of fear". These stingers can be triggered at random when required by the game engine and integrated dynamically within the music mix.

[10] See Eduardo Coutinho and Angelo Cangelosi, "Musical Emotions: Predicting Second-by-Second Subjective Feelings of Emotion From Low-Level Psychoacoustic Features and Physiological Measurements", in *Emotion,* Vol. 11, No. 4 (2011): 923

[11] As Coutinho and Cangelosi suggest, "the goal-oriented nature usually attribute to emotions clashes with music's ability to elicit all kinds of strong and mild emotional reactions in its listeners, an aspect that has been at the very center of a long-standing controversial discussion: Can music induce emotions? Are MEs just like other ("real") emotions?" Ibid: 921.

[12] Gosselin et al., "Impaired Recognition of Scary Music Following Unilateral Temporal Lobe Excision," *Brain* 128(3)(2005): 628–640. In this study pieces were rated on a dissonant scale, from 1 to 5.

[13] Nathalie Gosselin, Séverine Samson, Ralph Adolphs, Marion Noulhiane, Mathieu Roy, Dominique Hasboun, Michel Baulac, and Isabelle Peretz, "Emotional Responses to Unpleasant Music Correlates with Damage to the Parahippocampal Cortex," *Brain* 129(10) (2006): 2585- 2592. In this study Western Classical instrumental excerpts were altered by transposing the melody lines up or down a semitone leaving the accompaniments unaltered, thus creating dissonance. A number of other studies have applied similar approaches in the creation of dissonant stimuli. See, Stefan Koelsch, Thomas Fritz, Yves V. Cramon, Karsten Müller, and Angela D. Friederici., "Investigating Emotion with Music: an fMRI Study," *Human Brain Mapping* 27 (2006): 239 –250, and Daniela Sammler, Daniela, Maren Grigutsch, Thomas Fritz, and Stefan Koelsch, "Music and Emotion: Electrophysiological Correlates of the Processing of Pleasant and Unpleasant Music," *Psychophysiology*, 44(2)(2007): 293-304. In both of these studies instrumental recordings of dance-tunes from the last four centuries were electronically processed, simultaneously combining the original recordings with two pitch shifted versions (one a tone above and another a tritone below).

[14] Enrique O. Flores-Gutiérrez, José-Luís Díaz, Fernando A. Barrios, Rafael Favila-Humara, Miguel Á. Guevara, Yolanda del Río-Portilla, and Maria Corsi-Cabrera, "Metabolic and Electric Brain Patterns During Pleasant and Unpleasant Emotions Induced by Music Masterpieces," *International Journal of Psychophysiology* 65 (2007): 69-84. This study used atonal music from the film score *Danton*, composed by J. Prodromidès as a stimulus for fear.

[15] Sammler et al., "Music and Emotion," 295. Also Koelsch et al., "Investigating emotion," 241.

[16] Valence being a scale of response ranging from positive to negative (good/ bad or pleasure/ displeasure); arousal representing a range from calm and peaceful to excited and energetic.

[17] As in, Flores-Gutiérrez et al., "Metabolic and Electric Brain Patterns," 69-84.

[18] Brain response, heart rate, and skin conductance. Respiration is not included in this study.

[19] The amygdala is a key component of the limbic system in the brain, and is involved in the experience of anxiety, distress, and fear. One study describes it as, "the heart of the brain's emotional system", and states that the structure is involved in, "simple fear conditioning, contextual conditioning, recognition of fearful facial expressions, and emotion-guided decision making" (Eran Eldar, Ori Ganor, Roee Admon, Avraham Bleich, Talma Hendler, "Feeling the Real World: Limbic Response to Music Depends on Related Content," *Cerebral Cortex,* 17(12)(2007): 2828-2840.) The amygdala has also been found to be involved in the processing of positive emotions (Elisabeth A. Murray E, "The Amygdala, Reward and Emotion," *Trends in Cognitive Sciences,* 11(11)(2007): 489–497). In a review article Stefan Koelsch suggests that, "different nuclei of the amygdala are involved in modulating activity of different emotion networks". See "Towards a Neural Basis of Music-Evoked Emotions," *Trends in Cognitive Sciences*, 14(3)(2010): 133.

[20] For further details see, Joseph LeDoux, "The Emotional Brain, Fear, and the Amygdala", in *Cellular and Molecular Neurobiology*, Vol. 23, Nos. 4/5, (2003): 727-738. Also, J. LeDoux, "Rethinking the Emotional Brain", in *Neuron* 73, February 23, (2012): 653-676

[21] Ibid: 662-3

[22] Gosselin et al., "Emotional Responses to Unpleasant Music," 2585. The authors cite a number of studies, all of which appear to confirm the association between dissonance and unpleasantness.

[23] Koelsch et al., "Investigating Emotion," 239 –250. Dissonant musical stimuli – electronically pitch processed melody (original melody combined with two pitch shifted versions – one up a tone, one down a tritone). Mean duration 55 seconds.

[24] The Hippocampus functions as an important component of the limbic system and of memory processing.

[25] The parahippocampal gyrus, "receives direct projections from visuospatial processing areas . . . and substantial input from other polymodal areas and has reciprocal connections with [other structures in the brain such as] . . . the amygdala, hippocampus and striatum in mediating distinct forms of memory". Online information accessed August 22nd, 2013,

http://www.bookrags.com/tandf/parahippocampal-gyrus-tf/

[26] The most prominent anterior part of the temporal lobes of the brain.

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[27] Anne J. Blood, Robert J. Zatorre, Patrick Bermudez, and Alan C. Evans., "Emotional Responses to Pleasant and Unpleasant Music Correlate with Activity in Paralimbic Brain Regions," *Nature Neuroscience* 2(4)(1999): 382-387; Blood and Zatorre, "Intensely Pleasurable Responses to Music Correlate with Activity in Brain Regions Implicated in Reward and Emotion," *Proceedings of the National Academy of Sciences of the United States of America* 98(20)(2001): 11818-11823; Nathalie Gosselin, Isabelle Peretz, Marion Noulhiane, Dominique Hasboun, Christine Beckett, Michel Baulac and Séverine Samson, "Impaired Recognition of Scary Music Following Unilateral Temporal Lobe Excision," *Brain* 128(3)(2005): 628–640; Gosselin et al., "Emotional Responses," 2585–2592.

[28] Gosselin et al., "Impaired Recognition," 628-640.

[29] There is some debate about the functions of the parahippocampal cortex (PHC). It has been implicated in the processing of place-related information. It has also been implicated in episodic memory. Others suggest that the PHC plays a role in, "processing contextual associations in general," http://cercor.oxfordjournals.org/content/17/7/1493.abstract. Others argue that it is concerned with the representation of three dimensional local space and objects (see http://www.ncbi.nlm.nih.gov/pubmed/21593327). Online information accessed August 22nd, 2013.

[30] Gosselin et al., "Emotional Responses," 2591-2.

[31] Koelsch, "Towards a Neural Basis," 135

[32] See endnotes 2 and 3.

[33] Stimuli presented in consecutive 30 second segments, alternated with 30 seconds of noise, for a total duration of 10 minutes.

[34] Flores-Gutiérrez et al., "Metabolic and Electric Brain Patterns," 81.

[35] Richard J. Davidson, "Anterior Cerebral Asymmetry and the Nature of Emotion," *Brain and Cognition*. 20(1)(1992): 125–151

[36] Flores-Gutiérrez et al., "Metabolic and Electric Brain Patterns," 81

[37] Ibid: 82

[38] LeDoux, "Rethinking the Emotional Brain,"653-676

[39] Ibid: 655

[40] Consisting of the brain and spinal cord.

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[41] "The part of the vertebrate nervous system that regulates involuntary action, as of the intestines, heart, and glands, and that is divided into the sympathetic nervous system and the parasympathetic nervous system." Online information accessed August 22nd, 2013, http://www.thefreedictionary.com/autonomic+nervous+system

[42] LeDoux "Rethinking the Emotional Brain," 662, provides further citations of a number of these studies.

[43] However as Kreibig points out, "Positions on the degree of specificity of ANS activation in emotion . . . greatly diverge." See Sylvia D. Kreibig, "Autonomic Nervous System Activity in Emotion: A Review", in *Biological Psychology* 84 (2010): 394.

[44] However, as one study points out, "these studies do not exclude that cultural experiences can modify judgments about the pleasantness of certain dissonances". See Koelsch et al., "Investigating Emotion . . . an fMRI Study," 240.

[45] For citations of some of these studies see Coutinho and Cangelosi, "Musical Emotions," 923

[46] Ibid.

[47] Kreibig, "Autonomic Nervous System Activity in Emotion," 404-5

[48] Coutinho and Cangelosi, "Musical Emotions," 929

[49] Julian F. Thayer and Robert W. Levenson "Effects of Music on Psychophysiological Responses to Stressful Film," *Psychomusicology,* 3(1)(1983): 44-52. This study measured the slow varying component of skin conductance, defined as skin conductance level or SCL.

[50] Margaret M. Bradley and Peter J. Lang, "Affective Reactions to Acoustic Stimuli," *Psychophysiology*, 37(2)(2000): 204-215; Sammler et al., "Music and Emotion," 293-304; Robert J. Ellis and Robert F. Simons, "The Impact of Music Subjective and Physiological Indices of Emotion While Viewing Films," *Psychomusicology*, 19(1)(2005): 15 – 40. (This study measured the faster changing component of skin conductance, known as skin conductance response or SCR. SCR is associated with the activity of the palmar sweat gland.)

[51] In a review paper, Kreibig suggests that these results indicate "an element of passivity, and may be taken to suggest vagal mediation". Kreibig, "Autonomic Nervous System Activity in Emotion," 408.

[52] Coutinho and Cangelosi, "Musical Emotions,"921-937

[53] Based on findings of a previous study which found "evidence that spatiotemporal dynamics in psychoacoustic features resonate with two psychological dimensions of affect underlying judgments of subjective feelings: arousal and valence". See Coutinho and Nicola Dibben, "Psychoacoustic Cues to Emotion in Speech Prosody and Music", in *Cognition and Emotion,* Vol. 27, No. 4 (2013): 658-684.

[54] Coutinho and Cangelosi, "Musical Emotions," 927.

[55] Bradley and Lang, "Affective Reactions," 211.

[56] Ibid.

[57] Ibid:212.

[58] Hannah Lynch, Parth Patel, Stanislav Konrath, and Devin Blodgett, "The Effect of Music as a Prepulse Stimulus on the Activation of the Sympathetic Nervous System" (2012): 1. Online paper, accessed August 22nd, 2013, http://jass.neuro.wisc.edu/2012/01/Lab%20601%20Group%203%20The%20Effect%20of%20Music.pdf

[59] Janet E. Landreth and Hobart F. Landreth, "Effects of Music on Physiological Response," *Journal of Research in Music Education*, 22(1)(1974): 11-12.

[60] Margaret M. Bradley, "Natural Selective Attention: Orienting and Emotion," in *Psychophysiology* 46(1) January (2009): 1–11.

[61] Ibid. Bradley cites a number of studies exploring responses to novel and significant stimuli

[62] Landreth and Landreth, "Effects of Music," 7.

[63] Whilst there is some evidence suggesting that there might be an additive relationship when musical and film stimuli are presented simultaneously it is thought that this additive affect is less significant when the visual stimuli is highly negative (Ellis and Simons, "The Impact of Music," 15-40).

[64] Markellos Nomikos, Edward Opton Jr., J.ames Averill, and Richard S. Lazarus, "Surprise Versus Suspense in the Production of Stress Reaction," *Journal of Personality and Social Psychology*, 8(2, Pt. 1)(1968): 204-208. This study does not specify which type of skin conductance measure was adopted.

[65] Stefan Koelsch, "Investigating Emotion" with Music Neuroscientific Approaches," *Annals of the New York Academy of Sciences* 1060 (2005): 415-6; Koelsch et al., "Investigating Emotion . . . an

fMRI Study," 239-50; Sammler et al., "Music and Emotion," 301; Emmanuel Bigand, Richard Parncutt, and Fred Lerdahl, "Perception of Musical Tension in Short Chord Sequences: The Influence of Harmonic Function, Sensory Dissonance, Horizontal Motion, and Musical Training," *Perception and Psychophysics,* 58(1)(1996): 124-141; Carol Krumhansl, "An Exploratory Study of Musical Emotions and Psychophysiology," *Canadian Journal of Experimental Psychology,* 51(4)(1997): 336–353. (The Krumhansl study used skin conductance levels as one measure of physiological response, amongst others).

[66] Sammler et al., "Music and Emotion," 298.

[67] Koelsch, "Investigating Emotion with Music Neuroscientific Approaches," 415-6

[68] Theodor Adorno and Hanns Eisler, *Composing for the Films.* (London: Continuum, 2005): 16. (The first edition was published in 1947).

[69] See Lynch et al.,"The Effect of Music as a Prepulse Stimulus," 1

[70] Bigand et al., "Perception of Musical Tension," 126.

[71] Koelsch, "Investigating Emotion with Music Neuroscientific Approaches," 414-5

[72] Nikolaus Steinbeis, Stefan Koelsch, and John A. Slobodab "Emotional Processing of Harmonic Expectancy Violations," *Annals of the New York Academy of Sciences* 1060(2005): 460.

[73] Bigand et al., "Perception of Musical Tension," 139.

[74] Arne Öhman, "Preattentive Processes in the Generation of Emotions," in *Cognitive Perspectives on Emotion and Motivation*, eds. Vernon Hamilton et al. (Dor-drecht: Kluwer Academic Publishers, 1988), 127–144.

[75] Klaus Scherer, "Which Emotions can be Induced by Music? What are the Underlying Mechanisms? And How can we Measure Them?" *Journal of New Music Research,* 33(3)(2004): 7.

[76] Laurel J. Trainor, Christine D. Tsang, and Vivian H. W. Cheung. "Preference for Sensory Consonance in 2- and 4-Month-Old Infants," *Music Perception* 20(2)(2002): 187-94

[77] Laurel J. Trainor and Becky M. Heinmiller. "The Development of Evaluative Responses to Music: Infants Prefer to Listen to Consonance over Dissonance," *Infant Behavior and Development*, 21(1)(1998): 77-88.

[78] Marcel R. Zentner and Jerome Kagan. "Infants' Perception of Consonance and Dissonance in Music," *Infant Behavior and Development*, 21(1998): 483-492.

[79] Trainor and Heinmiller, "The Development of Evaluative Responses," 77.

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[80] Ibid, 79.

[81] Glenn E. Schellenberg and Laurel J. Trainor "Sensory Consonance and the Perceptual Similarity of Complex-Tone Harmonic Intervals: Tests of Adult and Infant Listeners," *Journal of the Acoustical Society of America,* 100(5)(1996): 3321-3328; Glenn E. Schellenberg, and Sandra E. Trehub. "Natural Musical Intervals: Evidence From Infant Listeners," *Psychological Science*, 7(5)(1996): 272-277; Laurel J. Trainor, "The Effect of Frequency Ratio on Infants' and Adults' Discrimination of Simultaneous Intervals," *Journal of Experimental Psychology: Human Perception and Performance,* 23(5)(1997): 1427-38.

[82] Trainor and Heinmiller, "The Development of Evaluative Responses," 85

[83] Ibid.

[84] Ibid.

[85] Gosselin et al., "Impaired Recognition," 635.

[86] Patrik N. Juslin and Petri Laukka, "Communication of Emotions in Vocal Expression and Music Performance: Different Channels, Same Code?" *Psychology Bulletin* 129(5)(2003): 770-814. A study by Coutinho and Dibben suggests that with regards to speech prosody and music, "the subset of psychoacoustic cues that carry emotional 'meaning' is very similar". "Psychoacoustic Cues to Emotion," 677

[87] Gosselin et al., "Impaired Recognition," 635.

[88] Berthoid Hoeckner, Emma W. Wyatt, Jean Decety, and Howard Nusbaum. *Psychology of Aesthetics, Creativity, and the Arts*, 5(2)(2011): 146-153.

[89] Kreibig, "Autonomic Nervous System Activity in Emotion," 394-421.

[90] Industry specific software (such as Audiokinetic's Wwise and Firelight Technologies Fmod) developed as audio toolkits for composers and sound designers, to facilitate integration within dynamic mixes.

[91] Outlined earlier, in "Heart rate and skin conductance".

[92] Coutinho and Cangelosi, "Musical Emotions," 921-937

[93] Coutinho and Dibben "Psychoacoustic Cues to Emotion," 658-684

[94] Coutinho and Cangelosi, "Musical Emotions," 921.

[95] A virtual reality headset for immersive gaming. Online information accessed August 22nd 2013, http://www.oculusvr.com/

[96] A headset for gamers, which delivers transcranial Direct Current Stimulation (tDCS). Online information accessed August 22nd 2013, http://www.foc.us/

[97] Haptic technologies can be used in many different applications, and integrated into many different physical objects, from hand-held devices through to furniture, shoes, vests, and gloves. The aim of the technology is to ensure that what is seen is also felt, so creating further sensory feedback.

[98] Online information accessed August 22nd 2013, http://neurogadget.com/2013/07/14/interview-with-neurogaming-conference-founder-zack-lynch/8398#more-8398.

[99] Klaus Scherer, "Which Emotions can be Induced by Music?," 239-251. Also, Stefan Koelsch, "A Neuroscientific Perspective on Music Therapy," *The Neurosciences and Music III—Disorders and Plasticity: Ann. N.Y. Acad. Sci.* 1169(2009): 374–384.

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