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Predictive Coding in Music Perception: Emotional Influences and Therapeutic Implications in Depression

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Abstract: This literature review examines the intricate relationship between music prediction and its emotional influence on depression. Drawing on theoretical frameworks such as predictive coding and empirical evidence from neuroimaging, psychophysiological studies, and clinical trials, the review explores how the brain's anticipation and processing of musical cues evoke emotional responses. Foundational work and recent advances underscore the role of hierarchical predictive networks in modulating emotional experiences during music listening. In healthy individuals, the balance between predictability and surprise—especially as influenced by rhythmic complexity and cultural learning—creates a rich palette of emotional reactions. In contrast, individuals with depression often exhibit distorted predictive processes, characterized by overly rigid and negatively biased expectations, which may reinforce depressive cognitions and emotional dysregulation. Music-based interventions, as evidenced by systematic reviews, have shown promise in alleviating depressive symptoms by engaging both psychological and physiological pathways. However, gaps remain—particularly regarding the impact of violated musical predictions on emotional processing in depression. Future research integrating neuroimaging and psychophysiological measures is essential to better understand these mechanisms and to optimize music-based therapeutic strategies. This review thus highlights both the potential and current limitations of leveraging music's predictive properties for improving mental health outcomes in depression.

Keywords: Music, predictive coding, emotion, depression, emotion regulation

1. Introduction

Music is recognized as a universal form of artistic expression and a powerful modulator of emotion. Foundational work by Huron [1] emphasized that the anticipation, fulfillment, and violation of musical expectations are central to evoking emotional experiences. More recently, Vuust et al. [2] have further advanced this concept by highlighting how the brain's hierarchical predictive networks mediate the intricate interplay between musical structure and emotion. According to the predictive coding framework, the brain continuously generates and updates predictions about incoming sensory inputs. The dynamic interaction between expectation and its confirmation—or violation—is fundamental to the emotional impact of music.

In the context of depression, growing evidence suggests that these predictive mechanisms may be altered [3-5]. Predictive coding theory proposes that the brain constantly forms predictions regarding incoming information and adjusts them based on discrepancies, known as prediction errors. These mechanisms become skewed—negative expectations and overly precise harmful prediction errors

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dominate. This imbalance reinforces negative beliefs and cognitive distortions, making it difficult for individuals to update their internal models even when positive information is available. Such maladaptive processing not only contributes to the maintenance of depressive symptoms but also highlights potential targets for therapeutic intervention aimed at recalibrating these predictive processes.

This literature review aims to synthesize current research on music prediction and its emotional influence on depression. Specifically, it examines the fundamental principles that link musical expectation to emotional experience. It also explores the application of predictive coding models to understand the neurobiology of depression and evaluates the potential and limitations of music-based interventions as therapeutic modalities for depressive disorders. By integrating insights from cognitive neuroscience, music psychology, and clinical studies, this review seeks to illuminate the complex interplay between music, predictive mechanisms, and emotional regulation in depression, while also outlining promising directions for future research.

2. Music and Emotion: Principle and Development

2.1. Predictive Coding and Emotional Response

According to Vuust et al. [2], music's emotional power arises from the brain's ability to predict and respond to musical structure. The brain builds hierarchical models to forecast upcoming musical events, and when these predictions are either met or violated, distinct emotional responses are triggered. This predictive coding mechanism is central to the emotional engagement with music.

The process begins with the brain anticipating rhythmic patterns, harmonies, and melodies. As listeners become familiar with specific musical styles, their internal models become increasingly refined, allowing for more sophisticated emotional experiences. When musical events align with these expectations, reward circuits—such as those involving the mesolimbic system—are activated, resulting in pleasurable sensations. Conversely, unexpected deviations can generate tension, surprise, or even discomfort, illustrating the dual nature of prediction confirmation and error in shaping emotional responses.

Furthermore, the development of these emotional responses is influenced by both biological predispositions and cultural exposure. Over time, the interplay between inherent neural mechanisms and experiential learning allows individuals to form complex emotional associations with music. This dynamic process not only explains why music is universally engaging but also underscores its potential to modulate mood and affect through finely tuned predictive processes.

Vuust & Witek [6] specifically highlight the importance of rhythmic complexity in shaping our emotional responses to music. Their work suggests that moderate rhythmic complexity maximizes emotional engagement by balancing between predictability and surprise. When the rhythmic patterns are too simple, they fail to stimulate the brain's predictive mechanisms, leading to reduced emotional engagement. Conversely, overly complex rhythms can overwhelm these mechanisms, reducing the overall enjoyment. This optimal balance facilitates activation of reward circuits when expectations are confirmed and elicits meaningful emotional tension or surprise when expectations are violated.

2.2. Biological and Cultural Influences on Musical Emotion

Emotional responses to music are influenced not only by these predictive processes but also by an intricate interplay between innate biological predispositions and cultural learning. Juslin and Västfjäll [7] argue that biological mechanisms establish a universal foundation for emotional reactions. For instance, the human brain is naturally equipped with neural circuits that respond to musical elements—such as specific intervals, rhythms, and harmonies—by activating areas involved in emotion and reward processing. These responses can include measurable physiological changes, such

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as shifts in heart rate or the release of neurotransmitters, which are hypothesized to have evolved to help individuals rapidly evaluate environmental stimuli.

Fritz et al. [8] provide compelling evidence that, while the recognition of some basic emotions in music appears to be universal, cultural context critically influences how these emotions are interpreted. Their study demonstrated that individuals from diverse cultural backgrounds—including those with minimal exposure to Western music—could reliably identify core emotions such as happiness, sadness, and fear from musical excerpts. This suggests shared neural mechanisms for processing emotional cues in music, potentially reflecting evolutionary adaptations for social communication.

However, while these fundamental emotional responses are consistent across cultures, cultural learning refines and modulates the emotional impact of music. The universal recognition of basic emotions provides a common foundation, but the nuances—such as the intensity, valence, or contextual significance of the emotional experience—vary based on an individual's cultural background. Over time, cultural practices, musical traditions, and individual experiences inform how these basic emotional cues are interpreted, leading to variations in how music is experienced on a more complex level. Thus, the study by Fritz et al. [8] underscores a dual-process model: a biologically grounded, universal mechanism for detecting basic emotions, overlaid by culturally specific refinements that shape the full spectrum of musical emotional experiences.

2.3. Music, Reward Systems, and Neurophysiology

At the core of the reward system is the mesolimbic dopamine pathway. Neurons in the VTA project to the NAc and other limbic areas, where dopamine release is associated with the feelings of pleasure and motivation. This pathway is crucial not only for primary rewards like food and sex but also for abstract rewards, such as those provided by music. The reward circuit is sensitive to both the anticipation of a reward and the experience of the reward itself. Dopamine levels rise in expectation of a pleasurable event, and then surge again when the event occurs, reinforcing behaviors that lead to the reward. Regions such as the orbitofrontal cortex integrate sensory input with reward value, while other areas (like the amygdala) contribute emotional significance. This integration is what allows complex stimuli, such as music, to be experienced as highly pleasurable [9].

Blood and Zatorre [10] demonstrated that intensely pleasurable responses to music are associated with increased activity in brain regions implicated in reward and emotion. This suggests that when we listen to music that moves us, our brain's reward circuits are activated much like they would be by other, more tangible rewards. Salimpoor et al. [11] provided evidence that music triggers dopamine release in two distinct phases: during the anticipation phase (as musical tension builds) and during the peak emotional moments (when musical resolution occurs). This dual-phase response indicates that music not only primes the reward system through anticipation but also delivers a potent reward when expectations are met or artfully subverted.

Music often plays with our expectations—by establishing a pattern and then deviating from it—which can amplify the emotional and dopaminergic responses. The brain's prediction mechanisms are engaged when listening to music, and the degree to which these predictions are met or violated can modulate the intensity of the pleasure experienced.

3. Predictive Coding in Depression

Predictive coding theory offers a robust framework for understanding major depression. It posits that the brain continuously generates predictions about sensory inputs and updates these predictions based on incoming information. In a healthy system, prediction errors (the differences between expected and actual sensory input) are used to refine internal models. However, in major depression, this

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mechanism appears to be distorted, leading to persistent negative expectations and maladaptive cognitive processes [3,4]. One of the central ideas in this framework is that the brain relies on hierarchical priors to interpret sensory data. In individuals with depression, these priors often become overly rigid or negatively biased, leading to incorrect precision weighting of prediction errors. Specifically, negative information is overemphasized, while positive feedback is consistently undervalued. Such imbalances contribute to the maintenance of depressive cognitions and emotional states, as the brain persistently anticipates negative outcomes even in the face of contradictory evidence [3].

The framework advanced by Clark [12] provides a broader theoretical context for these findings by arguing that altered precision weighting in predictive coding may underlie a variety of psychiatric conditions, including depression. Additionally, distorted predictive mechanisms may contribute to the cognitive distortions commonly observed in depression, such as pervasive hopelessness and negative self-perception. Kube et al. [4] highlight that when the brain fails to adequately update its predictions based on new, positive experiences, it entrenches maladaptive beliefs that reinforce depressive symptoms. This failure to correct erroneous predictions perpetuates a cycle of negative bias, further deepening the depressive state.

At the neurobiological level, disruptions in predictive coding have been linked to altered functioning in brain regions critical for emotion regulation and cognitive control, such as the prefrontal cortex and limbic system. Gilbert et al. [3] integrate these findings into a comprehensive framework that not only explains the cognitive symptoms of depression but also suggests potential targets for therapeutic intervention. By correcting dysregulated processing of prediction errors, new treatments could help recalibrate the brain's internal predictive models and alleviate depressive symptoms. Clinically, these findings have significant implications for the treatment of depression. Disruptions in predictive coding—which manifest as abnormal activity in regions like the prefrontal cortex and limbic system—are directly linked to the cognitive and emotional symptoms observed in depressed patients.

In summary, the predictive coding perspective provides a valuable lens through which to understand the cognitive and neural disturbances in major depression. By highlighting the role of distorted expectations and error processing in maintaining depressive states, this framework opens promising avenues for both research and clinical innovation.

4. Applications of Music in Depression

Recent evidence supports the use of music as an effective intervention for depression, with research highlighting its multifaceted benefits. Maratos et al. [13] conducted a comprehensive Cochrane systematic review examining music therapy for depression. Their analysis of multiple randomized controlled trials indicates that music therapy—whether implemented as a standalone treatment or in conjunction with conventional approaches—can significantly alleviate depressive symptoms. These benefits are primarily attributed to music's ability to enhance emotional expression, foster social interaction, and promote adaptive mood regulation.

Complementing these clinical findings, Fancourt et al. [14] explored the psychoneuroimmunological mechanisms underlying the effects of music. Their systematic review proposes a model in which music influences psychological well-being not only through direct modulation of emotional states but also by inducing physiological changes. Specifically, music has been demonstrated to reduce stress by modulating neuroendocrine responses—such as lowering cortisol levels—and enhancing immune function. This dual impact suggests that musical engagement can create a beneficial feedback loop, where improved physiological health further supports mental well-being.

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Additionally, clinical studies by Erkkilä et al. [15] and Gold et al. [16] provided empirical evidence that individual music therapy can effectively alleviate depressive symptoms. These studies underscore that music interventions' ability to engage both psychological and physiological pathways, offering a comprehensive, accessible, and non-invasive treatment option with minimal side effects. Erkkilä et al. [15] conducted a randomized controlled trial comparing individual music therapy to standard treatment in patients with depression. This difference between the groups was statistically significant ($p = 0.03$) and corresponded to a moderate-to-large effect size (Cohen's $d \approx 0.8$), indicating that music therapy not only produces measurable improvements in depressive symptoms but does so with clinically meaningful magnitude. In a related meta-analysis, Gold et al. [16] examined data from multiple randomized controlled trials and found that music therapy interventions yielded an overall effect size of approximately 0.52 in reducing depressive symptoms. This finding suggests that, on average, music therapy was associated with a 25–30% reduction in symptom severity compared to baseline levels. Importantly, these interventions were noted for their ability to engage both psychological and physiological pathways.

5. Limitations and Prospects

Despite these promising results, current research on music prediction and its emotional influence on depression faces several limitations. Firstly, many existing studies are constrained by small sample sizes and substantial heterogeneity in clinical populations and intervention protocols, complicating direct comparisons and generalizations. Moreover, although predictive coding models have significantly advanced our understanding of music perception, few studies have explicitly examined how violations of musical predictions impact emotional processing in individuals with depression. This gap limits our understanding of the nuanced interplay between expectation, surprise, and emotional regulation in depressed populations.

Looking forward, there are several promising avenues for future research to emerge. One key direction is to systematically investigate the emotional influence of violated music predictions in depression. Future studies should aim to clarify how unexpected deviations in musical structure—such as sudden changes in rhythm or harmony—affect emotional responses and whether these effects differ between depressed and non-depressed individuals. Integrating neuroimaging and psychophysiological measures can help elucidate the underlying neural mechanisms and refine predictive coding models in the context of depression.

Additionally, longitudinal research is necessary to assess the long-term efficacy of music-based interventions and to determine the optimal balance between predictability and surprise in therapeutic settings. Such studies could explore if deliberately modulating musical expectation violations might recalibrate maladaptive predictive mechanisms, potentially providing innovative therapeutic strategies for depression.

In summary, addressing these methodological limitations and exploring the emotional impact of violated musical predictions represent important steps toward harnessing the full therapeutic potential of music in depression.

6. Conclusion

This review has highlighted the complex interplay between music, predictive coding, and emotional processing in the context of depression. Music engages the brain's predictive mechanisms, where the anticipation and occasional violation of musical expectations trigger profound emotional responses. In healthy individuals, these processes contribute to the rich and varied emotional experiences elicited by music. However, in depression, the predictive coding framework appears to be skewed—

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characterized by overly rigid, negatively biased expectations and maladaptive error processing—which reinforces depressive symptomatology.

Music-based interventions have shown promise as complementary treatments for depression, with evidence suggesting that they can improve mood, enhance emotional expression, and modulate physiological stress responses. Despite these encouraging findings, limitations remain. Notably, there is a significant research gap regarding the emotional impact of violated musical predictions in depressed individuals. Investigating how unexpected deviations in musical structure affect emotional responses could provide valuable insights into recalibrating dysfunctional predictive processes in depression.

Future research should focus on longitudinal studies that integrate neuroimaging and psychophysiological measures to explore the long-term efficacy of music interventions. Additionally, systematically examining the role of violated music predictions may uncover new therapeutic strategies to balance predictability and surprise, ultimately enhancing the emotional well-being of those suffering from depression.

In summary, integrating cognitive neuroscience, music psychology, and clinical research offers a promising framework for understanding and harnessing music's therapeutic potential in depression. By addressing current limitations and exploring new research directions, the field can move toward more effective, tailored interventions that leverage music’s unique ability to influence both emotion and cognition.

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