COMMENTARY

Musical pleasure and musical emotions

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In a pharmacological study published in PNAS, Ferreri et al. (1) present evidence that enhancing or inhibiting dopamine signaling using levodopa or risperidone modulates the pleasure experienced while listening to music. This result is the latest development in an already remarkable series of studies by the groups of Robert Zatorre and Antoni Rodriguez-Fornells on the implication of the reward system in musical emotions. In their seminal 2001 study, Blood and Zatorre (2) used the PET imaging technique to show that episodes of peak emotional responses to music (or musical "chills") were associated with increased blood flow in the ventral striatum, the amygdala, and other brain regions associated with emotion and reward. In a 2011 follow-up study, Salimpoor et al. (3) then relied on [^{11}C]raclopride PET—a technique that allows estimating dopamine release in cerebral tissue—to show that peak emotional arousal during music listening is associated with the simultaneous release of dopamine in the bilateral dorsal and ventral striatum. With the increasing spatial resolution of fMRI techniques, in 2013 the same team was able to narrow in on a specific dopaminoceptive subregion of the ventral striatum, the nucleus accumbens (NAcc) (4). Specifically, they found that NAcc activity during music listening is associated with how much money participants are subsequently willing to pay for the songs that they found pleasurable. In a final salvo to establish not only the correlational but also the causal implication of dopamine in musical pleasure, the authors have turned to directly manipulating dopaminergic signaling in the striatum, first by applying excitatory and inhibitory transcranial magnetic stimulation over their participants' left dorsolateral prefrontal cortex, a region known to modulate striatal function (5), and finally, in the current study, by administrating pharmaceutical agents able to alter dopamine synaptic availability (1), both of which influenced perceived pleasure, physiological measures of arousal, and the monetary value assigned to music in the predicted direction.

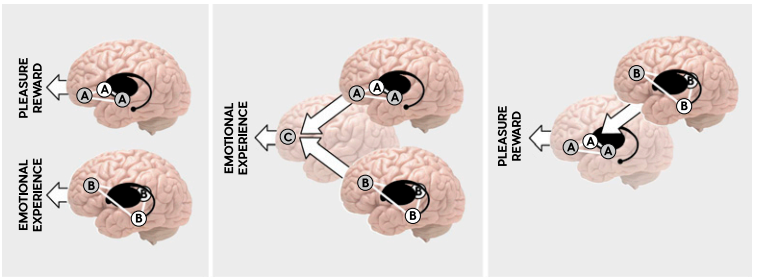

Fig. 1. (*A*) The corticostriatal model of musical pleasure of Ferreri et al. (1), linking the auditory and orbitofrontal cortices to the NAcc, and (*B*) one of the many possible mechanisms of musical emotion induction discussed in the literature, hypothetically linking the auditory thalami, the amygdala, and the dorsolateral prefrontal cortex engaged, for example, when experiencing heavy metal (14). As of yet, it is unclear how mechanisms such as these relate to one another. It is possible (*Left*) that they operate independently and that the constructs of musical pleasure and musical emotions are not functionally related. It is also possible (*Center*) that the dopaminergic model A operates at the same level as B and constitutes one of many possible first-order inputs to the construction of the integrative emotional experience (*C*). Finally, it is also possible (*Right*) that the model of Ferreri et al. (1) constitutes the evaluative process by which the outputs of mechanisms such as B are valuated. Clarifying these relations will be a major objective for future research.

With a cumulated 4,000 citations since 2001 (bibliometric data based on a search using Google Scholar on January 16, 2019), these four studies (2–5) have had a remarkable influence on the neuroscience literature, and on the music neuroscience community in particular, for which the 2001 study can be considered one of the founding acts: Of these citations, 1,770 (44%) include the words "music" or "musical" in their titles. While the question of the musical expression of emotion has a long history of investigation, including in PNAS (6), and the 1990s psychophysiological strand of research had already established that musical pleasure could activate the autonomic nervous system (7), the authors' demonstration of the implication of the reward system in musical emotions was taken as inaugural proof that these were veridical emotions whose study has full legitimacy to inform the neurobiology of our everyday cognitive, social, and affective

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functions (8). Incidentally, this line of work, culminating in the article by Ferreri et al. (1), has plausibly done more to attract research funding for the field of music sciences than any other in this community.

The evidence of Ferreri et al. (1) provides the latest support for a compelling neurobiological model in which musical pleasure arises from the interaction of ancient reward/valuation systems (striatal–limbic–paralimbic) with more phylogenetically advanced perception/predictions systems (temporofrontal). Given the popularity of these results in the literature, it may come as a surprise, however, that this model is not more tightly integrated with other modern cognitive and psychological views on musical emotions, which, while not contradictory, seem to coexist in relative independence. We would do well, collectively, to consider the paper by Ferreri et al. (1) as a pressing call to reconcile and clarify the theoretical links between these approaches.

One elephant in the room is, first, whether we are in fact talking about identical psychological constructs when addressing (like in ref. 1) musical pleasure or (like in much of the literature citing it) musical emotions. Previous work by the same authors has described pleasure as "one particular aspect of musically elicited affective responses" (9) and found that it is strongly correlated to the emotional arousal induced by the music (10). However, strikingly, the manipulation of dopamine used here did not affect the participants' reported valence and arousal, but only their reported pleasure and willingness to pay for the music. Thus, how the construction of musical pleasure is linked to, or interacts with, the manifold facets of musical emotions studied in the music cognition literature (11) remains unclear (Fig. 1, *Left*). Is the construction of musical pleasure/reward similar for the participants of Ferreri et al. (1) who listened to the happy, upbeat pop music of Spanish singer Vanesa Martín, for the sobbing fans of British singer Adele who find solace in the sad, heart-wrenching inflections of the "Someone Like You" tearjerker (12), and for death metal fans who are able to convert the growling, heavily distorted sounds of Cannibal Corpse into a pleasing experience of power and peacefulness (13)? How is musical pleasure built from vastly different emotional experiences? More generally, is music always pleasurable? Ferreri et al.'s (1) methodology opens up the possibility to answer these questions by studying whether dopamine-dependent musical pleasure is a ubiquitous aspect of the musical listening experience.

Another stumbling block in integrating the corticostriatal model of musical pleasure with research on musical emotions is its status as a mechanism. It is now widely accepted in the community that several neurologically distinct mechanisms contribute to the induction of emotions by music (11), all of which involve separate sensory subsystems (allegedly, for the Adele and Cannibal Corpse examples above, the registration of sad pitch contours in the voice areas of the right superior temporal gyrus for the former and the rapid activation of the amygdala by thalamically encoded cues of auditory threat for the latter; Fig. 1). One tentative model is that different aspects of music, including acoustic signals (e.g., low-pitch and low-frequency content for Adele and roughness for Cannibal Corpse), harmonic and temporal structures (e.g., minor chords and slow pace versus fast pace), familiarity, and so on, are interpreted in parallelly working subsystems, before being cognitively interpreted and integrated to give rise to idiosyncratic, conscious emotional experiences (15, 16). It is unclear whether the dopaminergic model should be considered one of these mechanisms, that is, one of many possible first-order inputs to the construction of the integrative emotional experience (Fig. 1, *Center*), or whether, alternatively, it constitutes the evaluative process by which the outputs of such mechanisms are valuated (Fig. 1, *Right*). In the former case, the so-called expectancy mechanism is of particular relevance.

In a pharmacological study published in PNAS, Ferreri et al. present evidence that enhancing or inhibiting dopamine signaling using levodopa or risperidone modulates the pleasure experienced while listening to music.

This influential theory, which postulates that musical emotion/pleasure is computed from the violation of temporal or harmonic expectations, was originally formulated by the philosopher of music Leonard B. Meyer (17) but resonates with recent suggestions that music perception is an active process relying on predictive coding (18). While Ferreri et al. (1) appear agnostic as to what exact cognitive computation serves as input to striatal activity (citing expectations, but also, e.g., associative conditioning and episodic memory), the well-established fact that striatal activity encodes expectations of reward outcomes (19) has led many to consider these results as empirical support to Meyer's theory. Of the 1,770 music cognition articles citing the work, 691 (39%) do so to discuss expectation/expectancy, and 348 (20%) cite it in conjunction with Meyer (17). In fact, the expectancy theory of musical emotions has received relatively little direct support (20), and when it has it has implicated the orbitofrontal cortex and amygdala, but not the NAcc (21). Thus, the links between expectations and musical pleasure remain underspecified at this stage, and more research will be required to understand how exactly predictions relate to dopaminergic release during music listening. Importantly, and in contrast with previous work by the same authors, Ferreri et al. (1) show here that dopamine not only modulates anticipated emotional peaks or "chills" but also a range of less-intense and more continuous pleasurable episodes. This finding suggests that, beyond peak events such as chills, musical pleasure is a more continuous phenomenon that may involve a variety of underlying mechanisms.

However, the final question raised by the work of Ferreri et al. (1) may lead us even further in elucidating what constitutes the core of our drive to engage with music. While the authors cautiously adopt the premise that music does "not seem to have any specific survival advantage," many authors, dating back at least to Darwin and Rousseau, have been interested in the potential functions of music, proposing for instance that music plays a central role for sexual selection, interpersonal coordination, mood regulation, or the definition of self-identity (22). The finding that music constitutes a privileged stimulus able to activate phylogenetically ancient systems involved in valuation and motivation may very well be interpreted as an indication that the human brain contains an adaptive neural specialization for processing music as a rewarding stimulus. As such, one might wonder whether the crucial question for future research is not so much whether music is rewarding, but rather why.

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