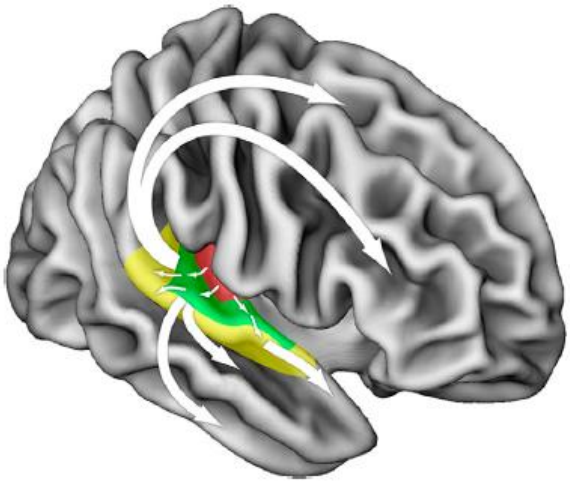
From perception to pleasure: Music and its neural substrates

Robert J. Zatorre[a,1] and Valorie N. Salimpoor[a,b]

[a]Montreal Neurological Institute, McGill University, Montreal, QC, Canada H3A 2B4; and [b]Rotman Research Institute, Baycrest Centre, University of Toronto, Toronto, ON, Canada M6A 2E1

Music has existed in human societies since prehistory, perhaps because it allows expression and regulation of emotion and evokes pleasure. In this review, we present findings from cognitive neuroscience that bear on the question of how we get from perception of sound patterns to pleasurable responses. First, we identify some of the auditory cortical circuits that are responsible for encoding and storing tonal patterns and discuss evidence that cortical loops between auditory and frontal cortices are important for maintaining musical information in working memory and for the recognition of structural regularities in musical patterns, which then lead to expectancies. Second, we review evidence concerning the mesolimbic striatal system and its involvement in reward, motivation, and pleasure in other domains. Recent data indicate that this dopaminergic system mediates pleasure associated with music; specifically, reward value for music can be coded by activity levels in the nucleus accumbens, whose functional connectivity with auditory and frontal areas increases as a function of increasing musical reward. We propose that pleasure in music arises from interactions between cortical loops that enable predictions and expectancies to emerge from sound patterns and subcortical systems responsible for reward and valuation.



Interactions Between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value

Valorie N. Salimpoor,[1,2,3]* Iris van den Bosch,[4] Natasa Kovacevic,[2] Anthony Randal McIntosh,[2] Alain Dagher,[1] Robert J. Zatorre[1,3]

We used functional magnetic resonance imaging to investigate neural processes when music gains reward value the first time it is heard. The degree of activity in the mesolimbic striatal regions, especially the nucleus accumbens, during music listening was the best predictor of the amount listeners were willing to spend on previously unheard music in an auction paradigm. Importantly, the auditory cortices, amygdala, and ventromedial prefrontal regions showed increased activity during listening conditions requiring valuation, but did not predict reward value, which was instead predicted by increasing functional connectivity of these regions with the nucleus accumbens as the reward value increased. Thus, aesthetic rewards arise from the interaction between mesolimbic reward circuitry and cortical networks involved in perceptual analysis and valuation.

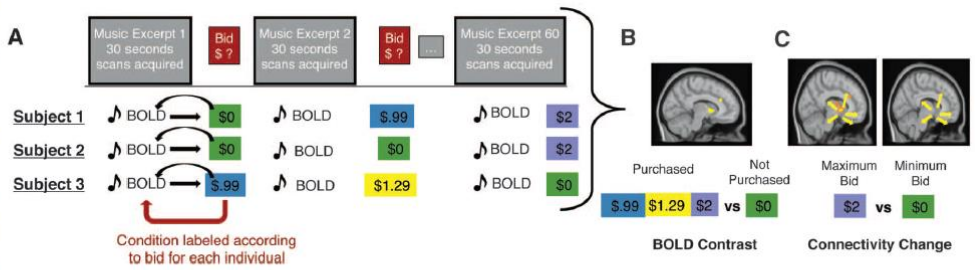


Fig. 1. Experimental paradigm. (**A**) Blood-oxygenation level–dependent (BOLD) activity was collected while participants listened to 60 30-s clips of new music (matched to their preferences by music-recommendation software, such as Pandora and Last.fm). Participants then placed bids with their own money that were used to categorize each excerpt according to desirability ($0, $0.99, $1.29, and $2) for the purposes of analysis. (**B**) Contrast analysis revealed regions associated with purchasing (Fig. 2A). (**C**) Multivariate connectivity methods allowed us to examine neural interactions associated with increased reward value of music (Fig. 3).

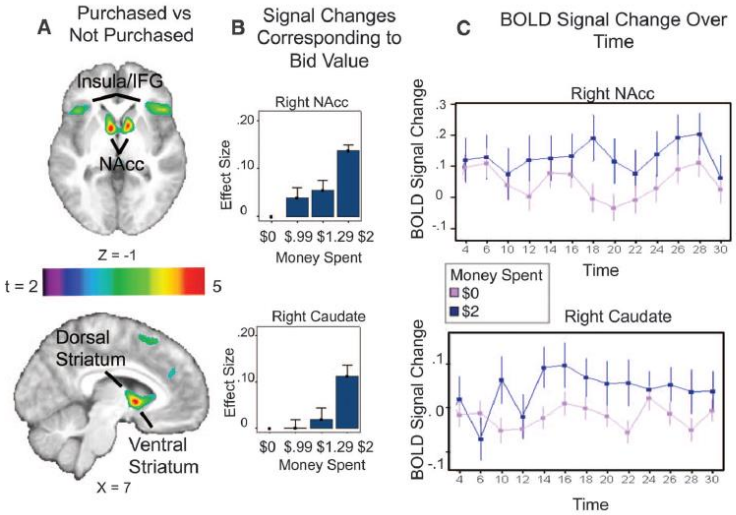


Fig. 2. Neural activity associated with reward value of music. (**A**) A whole-brain contrast revealed areas, including the dorsal and ventral striatum, that are active during the processing of desirable (bids > $0) as opposed to undesirable ($0 bids) music (table S2A). Z, plane of horizontal section (millimeters); t, value of *t* statistic; X, plane of vertical section (millimeters). (**B**) Among individuals who made sufficient bids in all categories (*13*), multiple linear regression allowed us to determine which purchasing-related regions (table S2B) corresponded to increasing reward value. Among the clusters from Fig. 1A, signal change in the right NAcc accounted for 33% of the variability in the amount spent, and the caudate accounted for an additional 10%; other regions did not contribute directly to reward value. Error bars indicate 1 SEM. (**C**) Average BOLD signal time course for the right NAcc and right caudate during the 30-s excerpts.