Current Biology 24, 699–704, March 17, 2014 http://dx.doi.org/10.1016/j.cub.2014.01.068

Report

Dissociation between Musical and Monetary Reward Responses in Specific Musical Anhedonia

Ernest Mas-Herrero,[1] Robert J. Zatorre,[2,3]
Antoni Rodriguez-Fornells,[1,4,5]
and Josep Marco-Pallarés[1,4,*]
[1]Cognition and Brain Plasticity Group, Bellvitge Biomedical Research Institute-IDIBELL, L'Hospitalet de Llobregat, 08097 Barcelona, Spain
[2]Montreal Neurological Institute, McGill University, Montreal, QC H3A 2B4, Canada
[3]International Laboratory for Brain, Music, and Sound Research, Montreal, QC H3C 3J7, Canada
[4]Department of Basic Psychology, University of Barcelona, L'Hospitalet de Llobregat, 08097 Barcelona, Spain
[5]Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain

Summary

Music has been present in all human cultures since prehistory [1, 2], although it is not associated with any apparent biological advantages (such as food, sex, etc.) or utility value (such as money). Nevertheless, music is ranked among the highest sources of pleasure [3], and its important role in our society and culture has led to the assumption that the ability of music to induce pleasure is universal. However, this assumption has never been empirically tested. In the present report, we identified a group of healthy individuals without depression or generalized anhedonia who showed reduced behavioral pleasure ratings and no autonomic responses to pleasurable music, despite having normal musical perception capacities. These persons showed preserved behavioral and physiological responses to monetary reward, indicating that the low sensitivity to music was not due to a global hypofunction of the reward network. These results point to the existence of specific musical anhedonia and suggest that there may be individual differences in access to the reward system.

Results

It is well established that some psychiatric disorders are associated with a loss in the capacity to experience pleasure from stimuli such as food, drink, touch, or music, a deficit known as anhedonia [4, 5]. Healthy populations also exhibit a wide range of individual differences in their hedonic capacity (anhedonia trait) [6, 7], which has been related to differences in the brain reward system [8, 9]. Anhedonia has generally been treated as a uniform factor, that is, a reduction in the rewarding aspects of all or most known pleasant stimuli (whether physical or abstract), but to our knowledge, no studies have examined whether dissociations in anhedonia for different types of reward exist.

Here, we sought to identify whether there exist healthy individuals with specific musical anhedonia, that is, with normal perceptual function and hedonic response to other types of reinforcements, but with no emotional response to music. Concretely, we studied whether pleasure induced by music can be specifically dissociated from monetary reward. Finding such people could be important in understanding the sources of rewarding experience associated with music. In addition, the existence of a specific anhedonia would also raise the question of common versus specific reinforcer-dependent brain circuits associated with reward processing and how individuals evaluate different rewarding stimuli.

We selected three groups of ten people each with high (hyperhedonic group, H-HDN), average (hedonic group, HDN), or low sensitivity to musical reward (anhedonic group, ANH), assessed using a previously developed psychometric instrument, the Barcelona Musical Reward Questionnaire (BMRQ) [10], which is known to be a reliable indicator of interindividual variability in music-induced reward. In addition, the three groups were chosen to have comparable overall sensitivity to reward, anhedonia trait, and music perception functions (Table 1).

Participants performed two different experiments in counterbalanced order: a music task in which they had to rate the degree of pleasure they were experiencing while listening to pleasant music [11], and a monetary incentive delay task (MID) [12] in which participants had to respond quickly to a target in order to win or not to lose real money. The two tasks have been shown to engage reward-related neural circuits in each domain (both music and money) and lead to releases of the dopamine neurotransmitter [13, 14]. In order to have objective physiological measures of emotional arousal, we recorded changes of skin conductance response (SCR) and heart rate (HR), which are reliable measures of autonomic nervous system expression of emotion (for further details, see the Supplemental Experimental Procedures available online). Additionally, 1 year later, we performed a second, follow-up session with 26 out of the 30 participants in order to study (1) the consistency of the behavioral effects reported on the first session and (2) whether those effects could be driven by differences among groups in familiarity or musical emotion recognition. Participants were also asked to evaluate the degree of pleasure they experience with different kind of reward (food, sex, music, money, exercise, and drugs) using a visual analog scale (VAS; Figure 1A). One-way ANOVA, applied for each category, showed no differences among groups in the ratings (evaluation of pleasure) for sex, food, money, exercise, and drugs (all p values >0.2), but a significant effect on the music scale ($F(2,23) = 19.14$, $p < 0.001$). These results support the idea that there are no differences among groups in other reward stimuli different than music.

We also tested differences among groups in music emotion recognition during this follow-up session. Participants performed a musical emotion recognition task [15] in which they had to rate the absence or presence of four emotion domains (happy, sad, scary, and peaceful) on 56 excerpts (14 excerpts each expressing these emotions; see Supplemental Experimental Procedures). Overall, participants recognized at above-chance levels the emotion expressed on the four different categories (p values <0.002). There were no significant differences among groups in any of the four emotion

*Correspondence: josepmarco@gmail.com

Table 1. Psychometric Scores in Anhedonia, Sensitivity to Reward and Punishment, Amusia, and the BMRQ of the Three Groups

	Anhedonics	Hedonics	Hyperhedonics	p Value
n	10	10	10	
Age	24.7 (5.2)	20.6 (1.8)	23.0 (5.8)	0.16
BMRQ				
Emotion evocation	11.6 (3.7)	16.7 (2.3)	18.9 (1.4)	<0.001
Mood regulation	12.4 (2.9)	16 (2.3)	18.3 (1.4)	<0.001
Sensory-motor	14.3 (2.3)	15.7 (2.5)	17.6 (2.0)	0.01
Social reward	11.2 (2.9)	12.4 (3.6)	17.3 (1.9)	<0.001
Musical seeking	8.8 (2.4)	10.7 (2.8)	16.8 (2.0)	<0.001
Overall	58.3 (5.9)	72.4 (5.9)	89.8 (3.2)	<0.001
Anhedonia				
PAS	14.3 (5.7)	13.6 (5.6)	11.4 (5.3)	0.50
SPSR				
Sensitivity to punishment	10.7 (6.0)	10.7 (5.8)	11.5 (5.1)	0.94
Sensitivity to reward	8.0 (3.9)	7.0 (4.2)	8.9 (3.6)	0.57
BIS BAS				
BAS drive	10.2 (2.3)	10.9 (2.1)	11.3 (1.8)	0.45
Fun seeking	12.1 (1.6)	10.6(2.4)	11.0 (2.5)	0.56
Reward responsiveness	14.9 (2.2)	15.2 (2.3)	15.8 (2.9)	0.64
BIS	21.2 (2.7)	20.5 (3.9)	20.9 (4.8)	0.92
Amusia				
MBEA	83.3 (4.9)	85.7 (4.9)	86.4 (5.8)	0.47

SDs are reported between parentheses. p value indicates the significance of the group effect in a one-way ANOVA. PAS, Physical Anhedonia Scale; SPSR, Sensitivity to Punishment and Sensitivity to Reward Questionnaire; BIS, Behavioral Inhibition System; BAS, Behavioral Activation System; MBEA, Montreal Battery of Evaluation of Amusia.

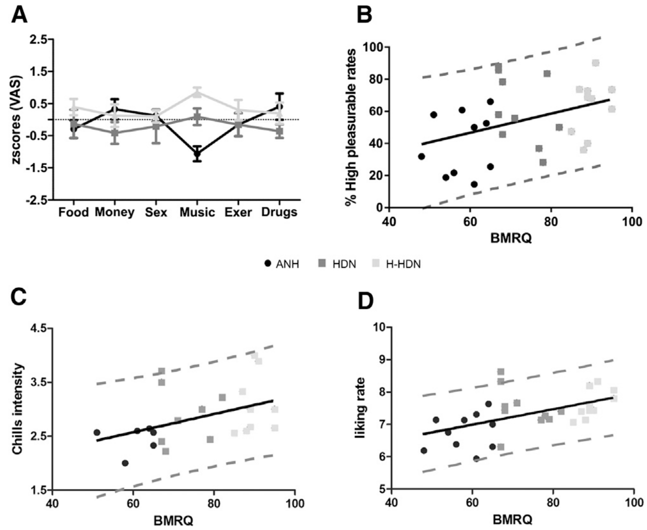

Figure 1. Behavioral Correlates of Sensitivity to Music Reward

(A) Average score for different reward types assessed by a visual analog scale. Note that the groups present similar scores in all domains except in the music scale. Error bars indicate the SEM. Exer, exercise. Groups showed no significant differences in music emotion recognition either (Figure S1).

(B–D) Scatter plot of (B) the proportion of responses associated to chills and high pleasurable rates, (C) the reported intensity, and (D) the average liking rate with overall scores of the BMRQ in the music task. Black circles represent ANH participants; dark gray squares, HDN; and light gray, H-HDN. The solid black line represents the slope of the linear fit, and the dashed gray line represents the 95% confidence interval (the stimuli selected for the music task are available in the Table S1).

See also Figure S1 and Table S1.

dimensions (p values >0.11; Figure S1). Thus, the presence of musical anhedonia is not related to difficulty with music emotion recognition.

Music Task

The participants listened to music excerpts selected as being highly pleasing by an independent group of healthy persons of similar demographics, and to self-selected excerpts (Table S1), and were asked to rate in real time the degree of pleasure they were experiencing by pressing one of four different buttons on a keyboard (1, neutral; 2, low pleasure; 3, high pleasure; 4, chill; adapted from [11]). At the end of each excerpt, they were asked to rate the overall degree of pleasure (from 1 to 10) and to report the number and the intensity of chills they experienced (from 1 to 5) (see the Supplemental Experimental Procedures for further details).

The proportion of real-time responses associated with chills and high-pleasure ratings compared to low and neutral ratings was predicted only by the overall BMRQ score when all the psychometric scores available (BMRQ, BIS/BAS, SPSRQ, and MBEA) were included in a stepwise regression analysis (R^2 = 0.11, F(1,28) = 4.71, p = 0.04; Figure 1B), such that those with low BMRQ scores had the fewest high-pleasure or chill responses. Similarly, participants with higher BMRQ scores experienced more-intense chills (R^2 = 0.30, F(1,22) = 10.66, p = 0.004) and reported higher liking rates (R^2 = 0.29, F(1,28) = 10.32, p = 0.003; Figures 1C and 1D) on the ratings given at the end of each excerpt. Similar results were obtained during the follow-up session (see the Supplemental Experimental Procedures), indicating that these behavioral effects were consistent across time.

During the second session, participants also rated the degree of familiarity of each excerpt. The three groups reported similar mean familiarity rate on those excerpts selected for the SCR and HR analysis (F(2,25) = 0.45, p = 0.64) and on 16 new musical pieces that were not previously used in the experiment (see the Supplemental Experimental Procedures). These findings discard the possibility of some sort of bias because of differences in familiarity among groups.

Figure 2 shows SCR responses associated with the four different degrees of pleasure experienced by the three groups. Visually, the H-HDN and HDN groups presented increases of SCR amplitude as the rate of pleasure increases. However, the ANH group only showed a small peak while reporting chills. Individual SCR curves revealed that this peak was due only to one of the anhedonic participants, who presented a significant increase of the SCR (Figure S2A) and could be considered an outlier in this group. To test the relationship between the degree of pleasure experienced and SCR amplitude on a trial-by-trial basis, we performed a regression analysis for each individual, using SCR amplitude as dependent variable and pleasure rating as independent measure. If SCR amplitude scales with the degree of pleasure rated by the participants, then the slope of this relationship should be positive and significantly different from 0 (see Figure S3 for the distribution of the slopes obtained). This was the case for HDN (t(9) = 5.43, p < 0.001) and H-HDN (t(9) = 5.99, p < 0.001) participants. Higher ratings were associated with larger SCR amplitude in these two groups. However, ANH participants showed no

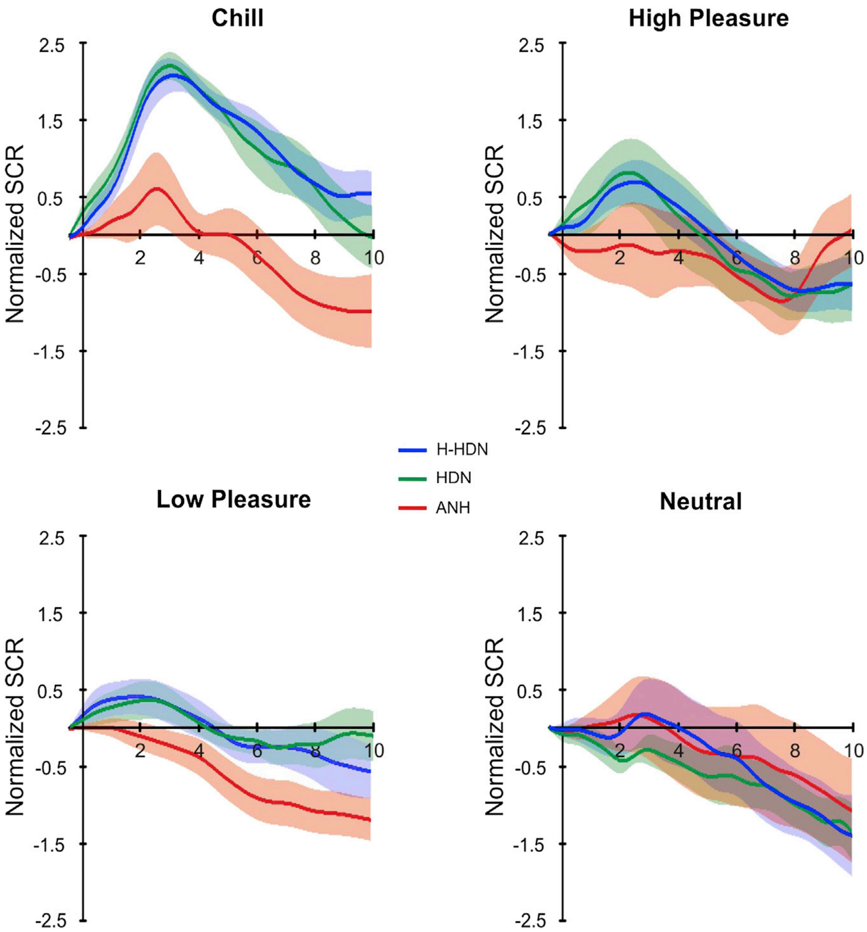

Figure 2. SCR to Different Degrees of Music Pleasure

Normalized skin conductance response associated with the four different pleasure rates (chill, high pleasure, low pleasure, and neutral) for the three groups in the music task. Note the increase of SCR in both H-HDN and HDN groups (but not in the ANH group) as a function of increasing pleasure rate. Solid lines indicate the averaged SCR with the corresponding SEM. See also Figure S2 for individual plots (Figure S2A) and same analysis excluding self-selected pieces (Figure S2B).

relationship between the behavioral ratings and the SCR responses ($t(9) = 0.88$, $p < 0.4$).

We applied the same regression analysis with the HR data as dependent measure. Consistently with the SCR, there was a positive relationship between the HR and the behavioral ratings of pleasure in the H-HDN ($t(9) = 5.24$, $p = 0.001$) and HDN ($t(9) = 3.3$, $p = 0.009$) groups, but not in the ANH ($t(9) = 0.24$, $p = 0.80$; Figures 3B and 3D). Similar results were obtained when we performed the same SCR and HR analyses without including the self-selected excerpts (see the Supplemental Experimental Procedures and Figure S2B).

Finally, we performed stepwise linear regression analysis to assess the relationship between the individual's slope and the psychometric measures evaluated. The BMRQ was the only variable that significantly predicted each individual's slope in the SCR ($R^2 = 0.32$, $F(1,28) = 13.37$, $p = 0.001$) and HR ($R^2 = 0.16$, $F(1,28) = 5.34$, $p = 0.03$) analysis (Figures 3B and 3D).

These results indicate that although some ANH participants reported chills and high-pleasure ratings behaviorally, they were not accompanied by a significant increase of physiological responses (Figures 3A and 3C). Those individuals may have been responding to a demand characteristic (as experimental instructions indicated that four different buttons were available), rather than reporting a true physiological response. Therefore, they could assume that the experimenter was expecting them to press all four during the session, and thus they may have altered their behavior to conform to these expectations.

Monetary Task

In this task, the participants had to respond quickly to a target in order to win or not to lose real money. Magnitude (€2 or €0.2) and valence (gain or loss) of the potential outcome was indicated by a cue at the beginning of each trial. In gain trials, if participants responded on time, they obtained the corresponding amount of money. In loss trials, they avoided losing that amount (see the Supplemental Experimental Procedures). The participants achieved an average hit rate of 61.8% (SD = 7.9). No differences in performance were observed among groups ($F(1,27) = 0.09$, $p = 0.91$). Reaction time (RT) analysis showed that the participants tended to respond faster to the target in trials with higher magnitude ($F(1,27) = 3.85$, $p = 0.06$). There was no significant effect of valence ($F(1,27) = 0.56$, $p = 0.46$) or the interaction between the two factors ($F(1,27) = 0.89$, $p = 0.35$). These effects were not affected by group in any condition (Fs < 1), suggesting that the three groups were equally motivated to seek and avoid monetary reward and punishment, respectively.

Figure 4 shows SCR response to the four different monetary reward cues. SCR amplitude was greater in trials with high-magnitude outcomes ($F(1,27) = 69.37$, $p < 0.001$). No differences were observed between gains and losses ($F(1,27) = 0.23$, $p = 0.64$). Moreover, there were no significant interaction effects between group and conditions (valence × group: $F(2,27) = 1.67$, $p = 0.20$; magnitude × group: $F(1,27) = 0.15$, $p = 0.60$) (Figure 4). No significant effects were observed with the HR (Fs < 1).

Discussion

In the present study, we explored the differences in physiological responses associated with two different types of reward (music and money) in three groups of participants classified independently according to their sensitivity to music reward [10]. We found, to our knowledge for the first time, the existence of a group of healthy people for whom music is not rewarding (ANH). This result was reflected not only by their self-reported scores, but also by their relative lack of physiological responses (SCR and HR) to music. However, increases of both SCR and HR as a function of increasing degree of reported pleasure to music were systematically observed in the other two groups. These differences could not be

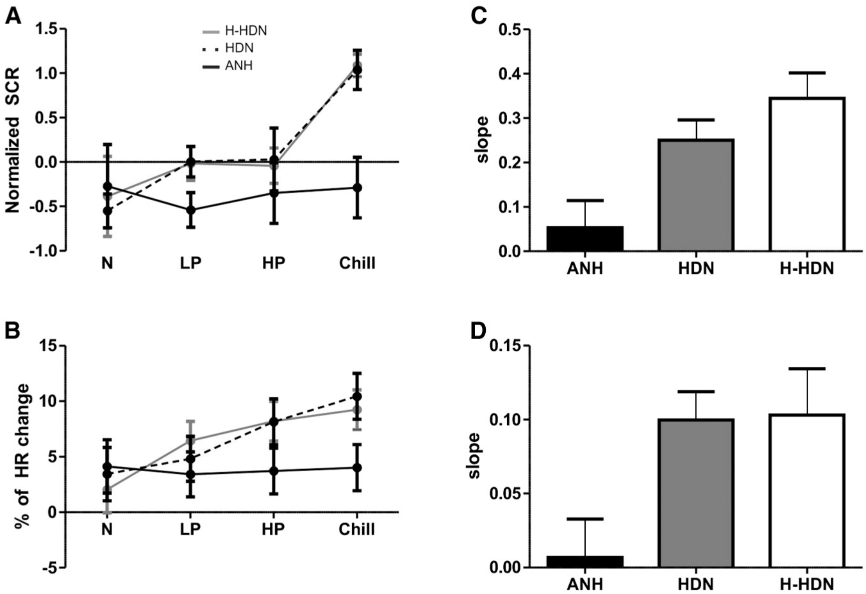

Figure 3. Physiological Responses to Music Reward

Average of (A) the normalized SCR and (B) the proportion of change of HR in comparison to baseline levels while participants report different levels of pleasure in the music listening task. The three groups are plotted separately: H-HDN and HDN groups (but not the ANH group) presented a clear increase in both measures while increasing pleasure rates. This is reflected on the mean slope for each group from the regression analysis performed with pleasure rating as independent variable and the (C) normalized SCR and (D) HR as dependent measures. The mean slope of the ANH group, in contrast to HDN and H-HDN, is close to 0 in both measures, suggesting no relationship between physiological responses and the reported degree of pleasure. Error bars indicate the SEM. See also Figure S3 for the slope's distribution.

explained by a generalized abnormal functioning of the reward system: psychometrically, the three groups were matched according to their overall sensitivity to reward and anhedonia trait using reliable psychometric measures [6, 16, 17]. Behaviorally, the three groups presented similar RT when trying to seek or avoid potential monetary reward or punishments, respectively; and physiologically, the three groups presented similar SCR and HR to monetary reward-predicting cues. In addition, these differences could not be explained by (1) deficits in music perception (amusia), as the three groups were matched according to their scores in a widely used battery to assess amusia [18]; (2) deficits in familiarity, as ANH individuals recognized excerpts at the same level as the other groups; or (3) deficits in recognizing emotion in music, as the three groups showed similar accuracy scores for recognizing different emotional dimensions in music [15].

Traditionally, anhedonia and sensitivity to reward have been usually treated as indivisible constructs related to the integrity of the reward system. However, the identification of people with specific musical anhedonia might indicate the existence of different impact of reinforcers in the reward system. That is, although some individuals might have a disturbance of the reward system and therefore present a decrease of reward experience to all reinforcements, other individuals might have affected only some specific pathways that access this system, yielding specific forms of anhedonias. Both music and other primary reinforcers (those with a biological bases, such sex and food) and secondary reinforcers (those associated with primary reinforcers, such as money) engage reward-related brain circuits [12, 19–24] and lead to release of the dopamine neurotransmitter in certain subcortical pathways [13, 14]. However, given the complex and abstract nature of musical reward, emotions evoked by music might not be exclusively processed within the reward network, but might be influenced by other cortical areas such as those related to auditory perception [25] and integrative areas such as frontal cortices [20, 25]. In fact, some case studies with patients showing a loss of the capacity for feeling emotions when listening to music after brain damage have reported lesions not in reward-related structures, but in temporal, frontal, or parietal regions ([26, 27], but see [28]). Consistent with this line of reasoning, Salimpoor and colleagues [25] showed that the reward value of novel music was predicted not only by activation in reward-related regions (ventral striatum, amygdala, and ventromedial prefrontal cortex), but also by modulation of functional connectivity between ventral striatum and auditory cortices, as well as frontal regions. These results suggest that musical reward depends not only on the engagement of the mesolimbic structures, but also on how this network interacts with other cortical regions related to music.

In parallel to these results, a recent meta-analysis [21] has shown that although different reward types (food, sex, and money) engage a common brain network (orbitofrontal cortex, ventral striatum, amygdala, insula, and thalamus), the location of the activity within these regions varied somewhat across reward. In addition, each reward type activated specific regions depending on its properties. These recent findings suggest that assignment of reward value may not be associated only with a unique reward network, but rather may depend on the recruitment of specialized areas involved in the perceptual and cognitive processing of each reward type. Therefore, we hypothesize that the music-anhedonic participants identified in the present study, although they preserved sensitivity to other rewards and had intact music perception, might show an altered interaction between music processing regions and the reward network. Importantly, what our findings reveal is not a particular preference for one class of stimuli over another (one person may enjoy opera, while another may find it boring), but an inability to derive pleasure from an entire domain, music, which the vast majority of human populations do find pleasurable. Such domain-specific anhedonias may also exist in other forms. Studying this particular and rather encapsulated aspect of anhedonia may help shed light more generally on why the link between perception and pleasure can sometimes be broken.

Finally, an interesting result of the present study is that H-HDN and HDN did not differ in their physiological responses to music. Therefore, although H-HDN participants subjectively reported experiencing greater emotions with music, objective measures of emotions, like SCR and HR, did not reflect these differences. One plausible hypothesis is that although both groups experience similar emotional reactions to music, the

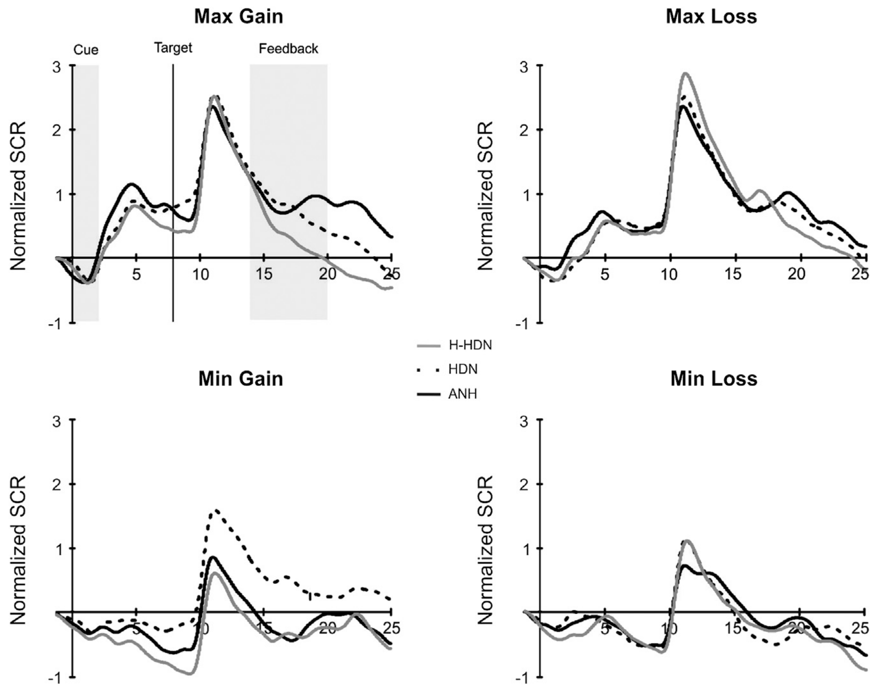

Figure 4. SCR to Monetary Reward

Normalized skin conductance response in the monetary task associated with anticipation of potential reward and punishment according to the magnitude of the outcome for the three groups. Anticipation of high-magnitude outcomes evoked higher SCR responses than did low-magnitude outcomes. However, no differences among groups were found.

same experience is more motivationally salient for the H-HDN group. In that sense, a recent study [29] with patients who developed musicophilia (specific pathological craving for music [30, 31]) showed that they presented differences in gray matter within the salience network, a system involved in reward anticipation and consummation. This could imply a double dissociation between ANH and H-HDN: while ANH participants might have altered interactions between auditory cortices and limbic regions, thus reducing the reward and pleasure induced by music (reduced liking experience), H-HDN participants might have an altered interaction among regions evaluating the motivational value of reward [32], specifically among subregions specialized in musical reward processing (increased wanting).

In conclusion, in the present study, we described a group of healthy subjects with specific music anhedonia. We showed dissociations between monetary and musical reward, both psychometrically and physiologically, suggesting the existence of different access to the reward system. Further studies in these individuals might be important to understand the neural basis underlying emotion and music rewarding experiences, as well as reward processing more generally.

Experimental Procedures

The BMRQ [10] was used to assess the distribution of sensitivity to musical reward in a population of 1,029 university students (41% male; mean = 21 years, SD = 3.7). Three groups of ten participants with low (ANH group), medium (HDN group), and high (H-HDN group) BMRQ scores were selected (43% male; mean = 22.8 years, SD = 4.9 years). In addition, the three groups were matched in (1) global sensitivity to reward and punishment using the BIS/BAS [16] and SPSRQ [17], (2) hedonism trait using the PAS (excluding those items referring to musical rewarding experiences to assess the hedonic impact of other activities or stimulus outside the music domain) [6], and (3) amusia score using the MBEA [18] (Table 1; see the Supplemental Experimental Procedures). Twenty-six out of the original 30 (eight ANH, nine HDN, and nine H-HDN) were recruited for a second behavioral session 1 year later. Procedures were approved by the Ethical Committee of the Bellvitge Biomedical Research Institute (IDIBELL).

Supplemental Information

Supplemental Information includes Supplemental Experimental Procedures, three figures, and one table and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2014.01.068.

Acknowledgments

This work was supported by the Ramón y Cajal program (RYC-2007-01614 to J.M.-P.), the FPI (BES-2010-032702 to E.M.-H.), Spanish government grants (MICINN; PSI2011-29219 to A.R.-F.; PSI2009-09101 and PSI2012-37472 to J.M.-P.), and grants from the Catalan government (2009-SGR-93). R.J.Z. is supported by funding from the Canadian Institutes of Health Research. The authors thank Raquel Adaia for her help in data acquisition.

Received: August 29, 2013
Revised: December 24, 2013
Accepted: January 30, 2014
Published: March 6, 2014

References

1. Conard, N.J., Malina, M., and Münzel, S.C. (2009). New flutes document the earliest musical tradition in southwestern Germany. Nature *460*, 737–740.
2. Mithen, P.S. (2006). The Singing Neanderthals: The Origins of Music, Language, Mind and Body (London: Weidenfeld and Nicolson).
3. Dubé, L., and Le Bel, J. (2003). The content and structure of laypeople's concept of pleasure. Cogn. Emotion *17*, 263–295.
4. Der-Avakian, A., and Markou, A. (2012). The neurobiology of anhedonia and other reward-related deficits. Trends Neurosci. *35*, 68–77.
5. Olivares, J.M., and Berrios, G. (1998). The anhedonias: clinical and neurobiological aspects. Int. J. Psychiat. Clin. *2*, 157–171.
6. Chapman, L.J., Chapman, J.P., and Raulin, M.L. (1976). Scales for physical and social anhedonia. J. Abnorm. Psychol. *85*, 374–382.
7. Meehl, P.E. (1975). Hedonic capacity: some conjectures. Bull. Menninger Clin. *39*, 295–307.
8. Harvey, P.-O., Pruessner, J., Czechowska, Y., and Lepage, M. (2007). Individual differences in trait anhedonia: a structural and functional magnetic resonance imaging study in non-clinical subjects. Mol. Psychiatry *12*, 767–775.
9. Padrão, G., Mallorquí, A., Cucurell, D., Marco-Pallares, J., and Rodriguez-Fornells, A. (2013). Neurophysiological differences in reward processing in anhedonics. Cogn. Affect. Behav. Neurosci. *13*, 102–115.

10. Mas-Herrero, E., Marco-Pallares, J., Lorenzo-Seva, U., Zatorre, R.J., and Rodriguez-Fornells, A. (2013). Individual differences in Music Reward experiences. Music Percept. *31*, 118–138.
11. Salimpoor, V.N., Benovoy, M., Longo, G., Cooperstock, J.R., and Zatorre, R.J. (2009). The rewarding aspects of music listening are related to degree of emotional arousal. PLoS ONE *4*, e7487.
12. Knutson, B., Adams, C.M., Fong, G.W., and Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. J. Neurosci. *21*, RC159.
13. Salimpoor, V.N., Benovoy, M., Larcher, K., Dagher, A., and Zatorre, R.J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. Nat. Neurosci. *14*, 257–262.
14. Schott, B.H., Minuzzi, L., Krebs, R.M., Elmenhorst, D., Lang, M., Winz, O.H., Seidenbecher, C.I., Coenen, H.H., Heinze, H.J., Zilles, K., et al. (2008). Mesolimbic functional magnetic resonance imaging activations during reward anticipation correlate with reward-related ventral striatal dopamine release. J. Neurosci. *28*, 14311–14319.
15. Vieillard, S., Peretz, I., Gosselin, N., Khalfa, S., Gagnon, L., and Bouchard, B. (2008). Happy, sad, scary and peaceful musical excerpts for research on emotions. Cogn. Emotion *22*, 720–752.
16. Carver, C.S., and White, T.L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: the BIS/BAS scales. J. Pers. Soc. Psychol. *67*, 319–333.
17. Torrubia, R., Ávila, C., Moltó, J., and Caseras, X. (2001). The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. Pers. Individ. Dif. *31*, 837–862.
18. Peretz, I., Champod, A.S., and Hyde, K. (2003). Varieties of musical disorders. The Montreal Battery of Evaluation of Amusia. Ann. N Y Acad. Sci. *999*, 58–75.
19. Blood, A.J., and Zatorre, R.J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. Proc. Natl. Acad. Sci. USA *98*, 11818–11823.
20. Koelsch, S. (2010). Towards a neural basis of music-evoked emotions. Trends Cogn. Sci. *14*, 131–137.
21. Sescousse, G., Caldú, X., Segura, B., and Dreher, J.-C. (2013). Processing of primary and secondary rewards: a quantitative meta-analysis and review of human functional neuroimaging studies. Neurosci. Biobehav. Rev. *37*, 681–696.
22. Camara, E., Rodriguez-Fornells, A., and Münte, T.F. (2010). Microstructural brain differences predict functional hemodynamic responses in a reward processing task. J. Neurosci. *30*, 11398–11402.
23. Menon, V., and Levitin, D.J. (2005). The rewards of music listening: response and physiological connectivity of the mesolimbic system. Neuroimage *28*, 175–184.
24. Yacubian, J., Gläscher, J., Schroeder, K., Sommer, T., Braus, D.F., and Büchel, C. (2006). Dissociable systems for gain- and loss-related value predictions and errors of prediction in the human brain. J. Neurosci. *26*, 9530–9537.
25. Salimpoor, V.N., van den Bosch, I., Kovacevic, N., McIntosh, A.R., Dagher, A., and Zatorre, R.J. (2013). Interactions between the nucleus accumbens and auditory cortices predict music reward value. Science *340*, 216–219.
26. Mazzoni, M., Moretti, P., Pardossi, L., Vista, M., Muratorio, A., and Puglioli, M. (1993). A case of music imperception. J. Neurol. Neurosurg. Psychiatry *56*, 322.
27. Satoh, M., Nakase, T., Nagata, K., and Tomimoto, H. (2011). Musical anhedonia: selective loss of emotional experience in listening to music. Neurocase *17*, 410–417.
28. Griffiths, T.D., Warren, J.D., Dean, J.L., and Howard, D. (2004). "When the feeling's gone": a selective loss of musical emotion. J. Neurol. Neurosurg. Psychiatry *75*, 344–345.
29. Fletcher, P.D., Downey, L.E., Witoonpanich, P., and Warren, J.D. (2013). The brain basis of musicophilia: evidence from frontotemporal lobar degeneration. Front. Psychol. *4*, 347.
30. Rohrer, J.D., Smith, S.J., and Warren, J.D. (2006). Craving for music after treatment for partial epilepsy. Epilepsia *47*, 939–940.
31. Jacome, D.E. (1984). Aphasia with elation, hypermusia, musicophilia and compulsive whistling. J. Neurol. Neurosurg. Psychiatry *47*, 308–310.
32. Sescousse, G., Barbalat, G., Domenech, P., and Dreher, J.C. (2013). Imbalance in the sensitivity to different types of rewards in pathological gambling. Brain *136*, 2527–2538.