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Distinct Processing of Social and Monetary Rewards in Late Adolescents With Trait Anhedonia

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Objective: Anticipatory and consummatory dissociation of hedonic experience may manifest as trait anhedonia in healthy and clinical populations. It is still unclear whether the underlying neural mechanisms of the monetary-based and affect-based incentive delay paradigms are distinct from each other. The present study aimed to examine the similarities and differences between the Affect Incentive Delay (AID) and the Monetary Incentive Delay (MID) imaging paradigms in relation to brain activations. ***Method:*** We administered the AID and the MID imaging tasks to 28 adolescent participants. A cue signaling the type of forthcoming feedback (reward or punishment) was displayed to the participants, followed by a target-hit task with corresponding reward or punishment. ***Results:*** The striatal and limbic regions were activated during the anticipatory phase of MID, while there was no brain activation during the anticipatory phase of AID. In the consummatory phase, the MID task activated the medial frontal cortex, while the AID task activated the frontal and dorsal limbic regions. We further found that the anhedonic group exhibited significant hypoactivation than the nonanhedonic group at the left pulvinar, the left claustrum and the left insula to positive cues in the anticipatory phase of the AID task. ***Conclusions:*** The results suggest that the AID and the MID tasks have unique activation patterns. Our findings also suggest that the AID task may be more sensitive in detecting anhedonia in people with trait anhedonia.

Keywords: anhedonia, anticipatory pleasure, consummatory pleasure, neuroimaging

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Anhedonia refers to a reduced capacity to experience pleasure and is an important symptom of schizophrenia (Epstein et al., 2006) and major depression (Tremblay et al., 2005). Anhedonia also influences the functional outcome of schizophrenia patients (Alvarez-Jimenez et al., 2012; Brune et al., 2011). Altered hedonic capacity is likely the result of a basic neuropsychophysiological dysfunction and may be a vulnerability marker that precedes the onset of psychiatric disorders (Kring & Elis, 2013). Most previous

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studies have focused on patients with clinical symptoms (Blanchard & Cohen, 2006), used behavioral rating of anhedonia (Horan et al., 2006), and adopted a unitary concept in defining anhedonia (Brune et al., 2011), leaving several unresolved issues in hedonic processing and reward behavior (Galvan, 2010). First, the development of reward circuitry affecting the corresponding observed behavior in adolescence has not been examined. Second, the type of task design (e.g., reward magnitude vs. reward probability), the response parameters (e.g., reaction time [RT] vs. response accuracy) and the type of stimuli used (e.g., monetary vs. social and affective) may have significant impact on the results as different tasks may capture different aspects of the same neural mechanism.

Recent studies suggest that reduced hedonic capacity can also be measured as an enduring trait in nonclinical samples (Chan et al., 2012; Katsanis et al., 1990; Wang et al., 2014). Nonclinical samples, including individuals with schizotypy (Chan et al., 2012) and nonpsychotic first-degree relatives of schizophrenia patients (Katsanis et al., 1990), have been shown to exhibit significantly higher levels of social and physical anhedonia than healthy controls. Wang et al. (2014) further demonstrated that the level of physical anhedonia in individuals with schizotypy lies intermediate between patients with schizophrenia and healthy controls, but they did not differ significantly from patients with schizophrenia in social anhedonia.

Given the above, we argue that reduced hedonic capacity can also be measured as an enduring trait in nonclinical samples. However, most previous studies have focused exclusively on clinical populations (Epstein et al., 2006; Tremblay et al., 2005). Of the small number of studies focusing on healthy individuals, most investigated the problem with tasks involving monetary rewards (Knutson et al., 2003, 2000). Xie et al. (2014) designed a task which captures the affective rewards in a group of individuals with social anhedonia and compared their performances with the monetary incentive delay task (Knutson et al., 2000). They found that individuals with social anhedonia exhibited a domain-specific deficit toward social affective information but not toward monetary-based rewards. These findings also suggest that incentive types could confound the findings on the dissociation of anticipatory and consummatory hedonic capacities.

In this study, we examined trait anhedonia in a nonclinical sample of community-dwelling individuals toward affective or social rewards in addition to monetary rewards. Based on the previous findings from Xie et al. (2014), we developed imaging paradigms and recruited an independent sample to further examine the distinct neural mechanisms of these two types of stimuli. Previous evidence has demonstrated that both monetary and social stimuli activate the ventral striatum (Izuma, Saito, & Sadato, 2008). Moreover, trait anhedonia correlated significantly with behavioral reward processing (Xie et al., 2014). Based on these findings we hypothesized that elevated trait anhedonia would be associated with deactivation of the ventral striatum during anticipation of reward. Moreover, there would be distinct neural processing of monetary and affective incentives. Finally, given the behavioral findings of domain-specific deficits in social but not monetary incentives in social anhedonia (Xie et al., 2014), we also hypothesized that there would be specific impairments of brain activations in individuals with anhedonia when compared with individuals without anhedonia.

Method

Participants

Twenty-eight participants (eight males and 20 females) with a mean age of 18.88 years ($SD = 1.81$, range = 17 to 21) and a mean education of 11.86 years ($SD = 1.43$) were recruited from the community based on a sample pool of an extensive project on trait anhedonia. They were all screened by questionnaires and interviews that were conducted by trained research assistants. Participants with a personal or family history of neuropsychiatric disorders, neurological disorders, and head trauma were excluded from this study. The study was approved by the ethics committee of the Institute of Psychology, the Chinese Academy of Sciences. Written informed consent was obtained from the participants after the study was explained to them.

AID and MID Tasks

The participants were administered two incentive delay tasks, namely the Monetary Incentive Delay Task (MID; Knutson et al., 2000) and the Affective Delay Task (AID; Xie et al., 2014). The details of these two tasks have been described elsewhere (Knutson et al., 2000; Xie et al., 2014). In brief, these two tasks are designed to capture the same construct (the anticipatory and consummatory components of hedonic capacity) but differ in terms of the type of stimulus (monetary vs. affective) used. Participants were instructed to make a quick response after a delayed period preceding a cue, which indicated what type of feedback (i.e., a reward, punishment, or neutral) they might receive if they won.

In the MID task, monetary incentive consisted of gaining and losing monetary points which could be exchanged for cash after the experiment. In the beginning of each trial, a cue which could be a circle, a triangle, or a square lasting for 250 ms was displayed at the center of the computer screen. Each cue meant different conditions. The participants were then asked to fixate at a white cross while waiting for 2,000 ms to 2,500 ms (anticipation). Participants were then required to press a button with their right index finger as soon as possible to respond to a target. The duration of the target was determined based on the performance of participants, ranging from 150 ms to 350 ms. In the first trial, the duration of the target was 300 ms. The variable duration of the target was to ensure that the accuracy of each participant could be maintained at about 66.7%. Following the target hitting stage was the incentive which lasted 1,650 ms. Before the experiment, each participant was told the meaning of each cue and the final points which the participants won would be exchanged into RMB (Chinese currency). A triangular cue meant a positive condition, in which if the participants successfully hit the target, the incentive that followed would show that the participants could win 5 points, or nothing. A square cue meant a negative condition, in which if the participants missed the target, the incentive that followed would show that the participants could loss 5 points, or not lose anything. A circular cue meant a neutral condition, which entailed no reward or punishment whether the participants hit the target or not. Each trial continued for 12 s. The MID task contained two runs, each consisting of 30 trials, with 10 positive, negative, and neutral conditions each. The order of all the trials in each run was pseudorandomized.

In the AID task, participants received emotional pictures as reward or loss based on their RT to the target (Xie et al., 2014). These emotional images were drawn from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1997) and have been tested and validated in several previous studies (Xie et al., 2014). Under the reward condition, participants were presented with a positive image when their RTs were sufficiently short or otherwise a neutral image. Under the punishment condition, participants would see a negative image as feedback when they were too slow. However, they could receive a neutral feedback to avoid this if their response were fast enough. Under the neutral condition, participants would see a neutral image regardless of RTs.

The basic architecture of trial timings was similar to the MID task, except that the feedback period was longer (3,000 ms) to ensure the emotion-eliciting effect of the images. Therefore, the random intertrial interval ranged from 2,500 ms–5,500 ms to guarantee a total of 12 s in each trial. Participants completed 10 trials under each condition. Experiment conditions were randomly presented in each run of scanning. There were 30 trials per run, with a total of two runs for the task. Participants were required to assess how much pleasure they felt after scanning.

Trait Anhedonia Measures

The Chapman Physical Anhedonia Scale (CPAS; Chapman & Chapman, 1978; Chinese version Chan et al., 2012) was used to assess the inability to experience pleasure from typically pleasurable physical stimuli such as food, sex, and settings. A higher score indicates more severe physical anhedonia.

The Chapman Social Anhedonia Scale (CSAS; Eckblad et al., 1982; Chinese version Chan et al., 2012) was used to assess the inability to experience pleasure from nonphysical stimuli such as other people, talking, or exchanging expressions of feelings. A higher score indicates more severe social anhedonia.

The Temporal Experience of Pleasure Scale (TEPS; Gard, Kring, Gard, Horan, & Green, 2007; Chinese version Chan et al., 2010) was used to assess individual trait dispositions in both anticipatory (e.g., "I look forward to a lot of things in my life") and consummatory (e.g., "I enjoy taking a deep breath of fresh air when I walk outside") pleasure. Higher scores on this scale indicate a greater degree of pleasure.

fMRI Data Acquisition

Imaging acquisition was conducted on a 3-Tesla scanner system (MAGNETOM® Verio Siemens). A high-resolution T1-weighted structural image including 176 slices was acquired by a sequence with the parameters specified as: TR = 2,300 ms; TE = 3 ms; FOV = 256 mm; flip angle = 9 degree; image matrix = 256 × 256; voxel dimensions = 1 mm × 1 mm × 1 mm. After the T1-weighted structure imaging, a T2-weighted image was acquired to exclude participants with organic brain disease. Functional images were then acquired by an echo planar imaging sequence, with the parameters specified as: TR = 2,000 ms; TE = 30 ms; FOV = 210 mm; slices = 32; flip angle = 90 degree; image matrix = 64 × 64; voxel dimensions = 3.3 mm × 3.3 mm × 4 mm. The sequence of MID and AID tasks was counterbalanced across subjects. Head movement was minimized using a headholder pad.

Functional Imaging Data Analysis

All the acquired DICOM data were transformed into the NIFTI format which could be manipulated in the free software SPM8 for imaging data analysis. In preprocessing, the data of each participant underwent slice timing and were realigned to the 16th slice of each TR. Then the functional imaging files were coregistered to the structural image of each participant and were normalized and smoothed with 8-mm full-width at half maximum Gaussian kernel. All the functional images were resampled into 3 mm × 3 mm × 3 mm. Finally the smoothed imaging data were utilized to construct the hemodynamic response function with six head movement parameters involved as covariates that created nine conditions (neutral cue, negative cue, positive cue, neutral cue hit, neutral cue miss, negative cue hit, negative cue miss, positive cue hit, positive cue miss) based on the respective time points.

In the second-level analysis, the contrasts "positive cue > neutral cue" and "negative cue > neutral cue" were set to identify brain activation during the anticipation of the positive and negative incentives respectively. The contrasts "positive cue hit > neutral cue hit" and "negative cue miss > neutral cue miss" were set to identify brain activation during the consummation of positive and negative incentives respectively (to avoid confusion and complication, the two consummatory contrasts were renamed as "positive incentive > neutral incentive" and "negative incentive > neutral incentive" below). The contrast settings were similar to those in previous studies, that is, subtract the neutral hit or miss could rule out the influence from the hit or miss on the affect to cue per se (Knutson et al., 2008; Knutson et al., 2000). The significance level of the anticipatory contrasts were set as $p < .0001$ (uncorrected), while the significance level of the consummatory contrasts were set as $p < .001$ (uncorrected). The uncorrected $p < .0001$ was suggested to be more sensitive in detecting activation in the nucleus accumbens while performing the MID task (Knutson et al., 2003). The minimum cluster size was set as 100 or more voxels with $p < .001$ (corrected in multiple comparisons). Furthermore, we utilized a parcellation and labeling method suggested by Tzourio-Mazoyer et al. (2002) based on the automated anatomical labeling template (AAL). The local maximum radius was set at 10 mm which meant that the activated areas around the coordinates of peaks with a 10 mm radius were analyzed. To further identify brain activation at the nucleus accumbens during anticipation of incentives, a mask ranged from (x: ± 4 to 10; y: +6 to + 18; 0 to −10) which contained the nucleus accumbens proper was adopted in accordance with previous studies (David et al., 2005).

Comparison of Anhedonia Group and Control Group

To explore the effect of anhedonia on task performance, all the participants were classified with the K-Means cluster analysis in the PASW 18.0 based on the score of CSAS and CPAS into two subgroups: the anhedonia group in which participants had high scores on the CSAS (10.13 ± 4.29) and the CPAS (31.00 ± 6.02); and the healthy control group in which participants had low scores on the two scales (CSAS: 7.75 ± 4.08; CPAS: 16.65 ± 3.66; Table 4 in Supplementary Materials). The two groups differed significantly in the CSAS but not the CPAS score such that the anhedonia group was mainly characterized by social but not physical anhedonia, $t(26) = -7.76$, $p < .001$ (Table 4 in Supplementary Materials).

Results

Image Results

In the anticipatory phase of the MID task, the contrast "positive cue > neutral cue" activated the right caudate body, the right thalamus and the left medial globus pallidus; while the contrast "negative cue > neutral cue" activated the bilateral thalamus and the right substantia nigra. Both contrasts did not cause any activation in the anticipatory phase of the AID task (Figure 1 in Supplementary Materials).

The parcellation results of each activated peak points during anticipation of the monetary incentives showed that the thalamus, the caudate and the medial globus pallidus were activated to varying degrees by both the "positive > neutral cue" and the "negative cue > neutral cue" contrast (Table 1 in Supplementary Materials).

The results with mask and small volume correction (SVC) showed the bilateral nucleus accumbens to be activated by both the contrast "positive cue > neutral cue" and "negative cue > neutral cue". In the consummatory phase of the MID task, the contrast "positive incentive > neutral incentive" activated the left anterior cingulate cortex, the left medial frontal cortex and the right cingulate cortex, while the contrast "negative incentive > neutral incentive" did not elicit any brain activation (Figure 2 in Supplementary Materials). In the consummatory phase of the AID task, the contrast "positive incentive > neutral incentive" activated the bilateral middle temporal cortex, the bilateral superior frontal cortex, the bilateral anterior cingulate cortex, the right superior temporal cortex (the pole) and the right orbitofrontal cortex; while the contrast "negative incentive > neutral incentive" activated the bilateral middle temporal cortex, the bilateral medial frontal cortex, the bilateral superior temporal cortex (the pole) and the left orbitofrontal cortex (Table 2 in Supplementary Materials).

Comparison Between Anhedonia Individuals and Controls

The demographic data are summarized in Table 3 (Supplementary materials). Table 4 (Supplementary materials) shows that the anhedonia group scored higher on the CPAS and the SPQ interpersonal subscale, and lower on the TEPS as well as the TEPS anticipatory and consummatory subcomponents than the healthy control group.

A 2 (Group, anhedonia vs. healthy controls) × 2 (Task, MID vs. AID) × 3 (Valence, neutral vs. negative vs. positive cue) repeated measure ANOVA to the RT demonstrated that the main effect of valence, $F(2, 52) = 7.59$, $p = .001$,$\eta^2 = 0.226$, was significant. No other main effect or interaction was found. The difference between the two groups by their RT to negative cues in the AID task was nearly significant ($p = .055$).

A 2 (Group, anhedonia vs. healthy control) × 2 (Task, MID vs. AID) × 3 (Valence, neutral vs. negative vs. positive cue) repeated measure ANOVA to the posttrial assessment of cues demonstrated a main effect for valence, $F(2, 52) = 11.19$, $p < .001$, $\eta^2 = 0.301$, and an interaction effect of Valence × Task, $F(2, 52) = 8.59$, $p = .001$, $\eta^2 = 0.248$. The post hoc analysis revealed that anhedonia participants rated the neutral ($p = .047$) and positive cues ($p = .037$) lower than the healthy controls. The repeated measure ANOVA to the posttrial assessment of incentives failed to reveal any significant difference between the two groups (Figure 3 in Supplementary Materials).

Participants with low anhedonia scores showed more brain activation at the left thalamus, the left pulvinar and the right insula to the contrast "positive cue > neutral cue" in the AID task than participants with high anhedonia scores (see Figure 1). There was no difference in brain activation to other contrasts in the AID and the MID task between the two groups (see Table 1).

Discussion

The main aims of the present study were to examine whether there were distinct neural processing of monetary and affective incentives in healthy late adolescents, and if so, to determine

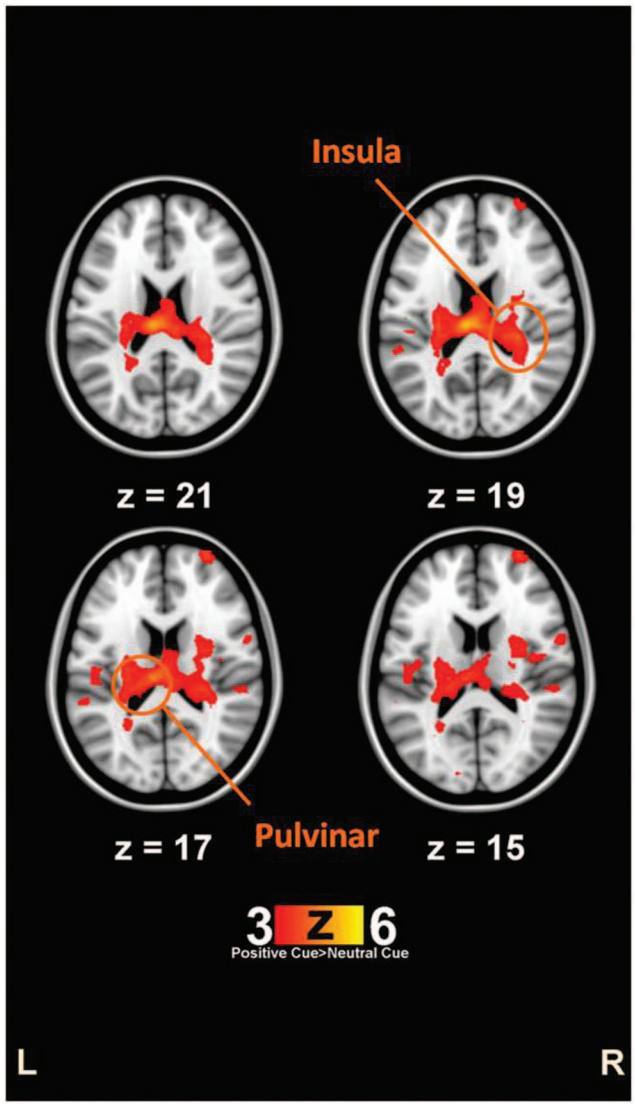

Figure 1. Group difference in brain activation in relation to positive affective cues. Positive affective cues elicited more brain activities in the left thalamus, the left pulvinar and the right insula in the healthy control group than the anhedonia group.

Table 1
The Brain Activation to the Positive Monetary Cue (Healthy Control > Anhedonia Group)[a]

Areas/Positive cue > Neutral cue	Cluster size	Side	Peak Z (x,y,z)
Thalamus	128	Left	4.57 (−8,−24,20)
Insula/BA13		Right	3.92 (29,−30,20)
Thalamus/Pulvinar		Left	3.68 (−17,−27,16)

Note. Coordinates of maximal activation points and correlated Z-value displayed in MNI spaces.
[a] Uncorrected $p < .001$ with FWE cluster correction $p < .005$, volume clusters > 100.

whether there were specific impairments in brain activations in individuals with high levels of anhedonia. Our findings showed that there were similarities in the brain regions recruited by both affective and monetary incentives in healthy late adolescents. However, our data also demonstrated that affective incentives may elicit specific activation at the left thalamus, the left pulvinar and the right insula in healthy individuals but not in individuals with high levels of anhedonia.

When performing the MID task, both the anticipation to gain monetary incentives and the anticipation to avoid monetary loss activated the bilateral thalamus and the left medial globus pallidus. Moreover, the anticipation to gain monetary incentives also activated the right caudate, while the anticipation to avoid monetary loss activated the right substantia nigra. These findings are consistent with the general imaging findings of the MID task in healthy adult samples (Knutson et al., 2000, 2003). Although the whole brain analysis of our participants failed to identify any activation at the nucleus accumbens, the regions of interest analysis with small volume correction revealed that the bilateral nucleus accumbens were activated by the anticipation of gain and the anticipation to avoid monetary loss. The discrepancy of the MID task imaging findings may be due to the recruitment of late adolescents instead of adults in our study (Knutson et al., 2000). Our findings are consistent with Bjork et al.'s findings that there was ventral striatal activation deficit rather than a ventral striatal activation surfeit in late adolescents (Bjork et al., 2004). Millstein (1993) also found that adolescents are less optimistically biased about obtaining future rewards compared to their adult counterparts and thus may lead to decreased brain activation in the MID task.

Consummation of monetary gain activated the left ventral medial frontal cortex, the left anterior cortex and the right cingulate cortex, while monetary loss failed to elicit any significant brain activations. These findings are consistent with previous studies (Knutson et al., 2008; Knutson et al., 2003). The ventral medial frontal cortex has been suggested to be responsible for the evaluation of rewards and value representation (Knutson et al., 2005). The anterior cingulate cortex, however, plays an important role in conflict monitoring (Haber & Knutson, 2010; Knutson et al., 2008). The coordination of the medial frontal cortex and the anterior cingulate cortex may optimize decision making to approach reward in future similar circumstances.

However, in the AID task, neither the anticipation to view positive pictures nor the anticipation to avoid negative pictures elicited any brain activation in our sample. These findings are inconsistent with a previous study adopting a nonmonetary incentive reward task (Izuma et al., 2008). Izuma, Saito, and Sadato (2008) adopted a social decision-making task and compared the brain activation to the MID task in a group of healthy adult participants. They found that both the social decision-making task and the MID task activated the ventral striatum. These authors thus concluded that there was a "common neural currency" for rewards. The discrepancies might have been due to the different methods and sample recruitment. In Izuma et al.'s (2008) study, they adopted a good reputation task to capture social reward which can be considered a highly relevant and salient higher cognitive reward in everyday life. Unlike the good reputation incentives, our study adopted a paradigm capturing more basic affective rewards which may have a different neural basis (Berridge, 2003). Moreover, such a difference in brain activation may also be complicated by the ventral striatal activation impairment observed in adolescents. Further studies adopting a comparable design and sample is warranted for direct comparison.

The consummation of positive pictures in the AID task activated the bilateral middle temporal cortex, the bilateral superior frontal cortex, the bilateral anterior cingulate cortex, the right orbitofrontal cortex, and the right temporal pole. The parcellation results demonstrated that 60.67% of the activated regions (6, 59, 24) labeled as the right superior frontal cortex were located in the right medial frontal cortex, and the other 33.71% were located in the left medial frontal cortex (due to limited space, the parcellation results of consummation of affective pictures were not shown). In other words, both the positive pictures and the monetary gain elicited activities in the medial frontal cortex and the anterior cingulate cortex. The medial frontal cortex has been shown to be sensitive to not only monetary rewards, but also social rewards (Lin, Adolphs, & Rangel, 2012). Apart from the evaluation of reward, the medial frontal cortex also plays an important role to represent the thinking of others (Frith, 2007; Izuma, 2012). The positive pictures elicited additional activations in the temporal cortex, particularly the temporal pole, which has been demonstrated to correlate with social functioning (Frith, 2007). The additional activations in the orbitofrontal cortex to affective incentives is consistent with a previous study by Izuma (2012) and suggests that the orbitofrontal cortex indeed plays an important role in the conversion between abstract and concrete reward in social circumstances.

Interestingly, when we compared individuals with anhedonia and healthy controls using the AID task, the anhedonia individuals felt more unpleasant than the healthy controls toward the positive and neutral affective cues in posttrial assessment. Behavioral data suggest that individuals with anhedonia reacted more slowly to negative affective cues than healthy controls. These behavioral results are consistent with the pattern of brain activations we found. Healthy controls showed more activation toward the positive affective cues than individuals with anhedonia in the left thalamus, the left pulvinar, and the right insula. These findings show that affective incentives may elicit specific activation in the brain and the AID task may be more sensitive in detecting anhedonia in people with trait anhedonia.

There are several limitations in the present study. First, the modest sample size, especially the anhedonia group, may limit the interpretability of the negative results. Second, the affective incentives utilized in this study were mainly based on pictures with positive, negative, and neural valences. These stimuli, as com-

mented above, may not be as effective as social incentives such as building good personal reputation in eliciting anticipation and consumption of pleasure. Moreover, the monetary incentives used in this study were tokens which may explain why the nucleus accumbens were not activated in the whole brain analysis. Third, it appears that the number of trials per condition was relatively low and may not be amenable to whole-brain analyses. The experimental time and the total number of trials were restricted to avoid fatigue of participants. However, there has been ample evidence suggesting that there was activation in the nucleus accumbens during the anticipation for monetary reward (Knutson et al., 2008; Knutson et al., 2000). Finally, the subgroup analyses for individuals with anhedonia included only males and therefore may be biased.

Notwithstanding these limitations, the present study represents an important extension of the extant literature on anticipation and consummation of affective and monetary incentive rewards. This is also the first study that examines functional brain responses to affective and monetary incentives in individuals with and without anhedonia. These data demonstrate that the AID and the MID tasks have unique activation patterns. Our findings also suggest that the AID task may be more sensitive in detecting anhedonia in people with trait anhedonia.

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