Monetary Reward Processing in Obese Individuals With and Without Binge Eating Disorder

Supplemental Information

Supplemental Methods

Participants Continued

Eligibility criteria included that participants had no head injury or medical condition. Participants were excluded if they met any of the following criteria: pregnant, breast-feeding, color-blind, currently taking antidepressant medication or migraine medication, history of cardiovascular disease, blood pressure > 145/90, bipolar disorder, psychosis, current substance-use disorder, history of seizure or neurologic disease, uncontrolled hypertension or diabetes.

All participants were native English speakers (demographic measures are displayed in Table 1). Participants consisted of a community sample recruited through advertisements and flyering in the New Haven area. Co-occurring disorders were assessed via a Structured Clinical Interview for DSM-IV Disorders (SCID; (1)). Five individuals each in the binge eating disorder (BED) group and obese (OB) group and none in the lean control (LC) group identified as smokers. In the BED group, nine individuals met criteria for a past mood disorder and five for past anxiety disorder; of these, one individual met current criteria for mood and one for anxiety disorders. In the OB group, four individuals met criteria for past mood disorder, two for past anxiety disorder, and one for past alcohol abuse. In the LC group, one individual met criteria for past alcohol, marijuana and cocaine abuse. Only the BED group completed the Eating Disorders Examination Interview. This protocol was approved by the Yale University School of Medicine Human Investigations Committee, and all participants provided written informed consent.

Monetary Incentive Delay Task (MIDT) fMRI Task

Participants completed two runs of the MIDT task, each consisting of 55 trials, lasting 12 seconds each (2). Each trial consisted of two anticipatory periods (A1 and A2) and one outcome phase (OC). During the A1 phase, participants viewed a cue (duration: 1000 milliseconds) signaling the potential win or loss of a specific amount of money (either $1 or $5) and then fixated on a crosshair (variable delay of 3-5 seconds). In the A2 phase, a target appeared on the screen (variable duration) and participants pressed a button and then fixated on a crosshair (variable delay of 4-6 seconds). Finally, in the outcome phase, participants received feedback (duration: 1200 milliseconds) on the win or loss of money and also viewed their cumulative earnings on the task.

fMRI volume acquisitions were time-locked to the offset of each cue and trial types were pseudorandomly ordered within each session. Task difficulty was based on practice reaction times collected prior to the scanning session and set so that participants would experience a positive outcome on 66 of trials. All participants were informed that their compensation on the task was performance-based.

The current task has been adapted from the original MIDT (3) in several ways. First, the anticipatory phase was segregated into two periods, with A1 corresponding to the prospect of reward/loss and A2 associated with the anticipation of the reward/loss. Second, the abstract cues to signal the potential win or loss of money were replaced with the actual words (e.g. “Win $1” or “Lose $5”) in order to minimize working memory components of the task. Third, a neutral stimulus of “Win $0” or “Lose $0” was included to counterbalance conditions. Fourth, in order to separate each task phase, every period was extended by several seconds. Fifth, the motoric

demands associated with pressing a button were contained in the A2 phase, while the motor preparation was contained in the A1 phase.

Image Acquisition and Analysis

Images were obtained using 2 Siemens TIM Trio 3T MRI systems. To minimize potential cross-scanner differences, an equal number of individuals from each experimental group were collected across scanners. Additionally, to control for potential scanner effects, this variable was added as a covariate in all group contrast analyses. Localizer images were acquired aligning the eighth slice parallel to the plane transecting the anterior and posterior commissures. Functional images were acquired with a T2*-weighed blood oxygen level dependent sequence with a TR of 1500 ms, TE of 27 ms, flip angle of 60°, 64 x 64 in-plane matrix, field of view of 220 x 220 and 25 4-mm slices with 1 mm skip. High-resolution 3D MPRAGE structural images were also acquired with a TR of 2530 ms, TE of 3.34 ms, flip angle of 7°, 256 x 256 in-plane matrix, and 176 1-mm slices. Each MIDT fMRI run consisted of 486 volumes, including an initial rest period of 9 seconds for signal stability, which was subsequently removed from analyses. Statistical analyses used a robust general linear model approach and each phase of each trial type was separately modeled. Analyses combined “Win $1” and “Win $5” trials, “Lose $1” and “Lose $5” trials, and “Win $0” and “Lose $0” trials in reward, penalty and neutral conditions in order to increase power.

Experimental Procedure

Participants completed a practice version of the MIDT before entering the scanner in order to familiarize individuals with the task and minimize learning effects. Additionally, the

practice session served to calibrate the computerized task so that in the scanner each individual would win on approximately 66% of trials. All participants were informed that their reimbursement would be influenced by their in-scanner performance. In the scanner, individuals completed the MIDT in two 10-minute sessions. Following each session, participants rated, on a 4-point Likert scale, specific emotions associated with each of the cue presentations (e.g. 'Happy' or 'Sad').

Supplemental Results

Main Effects

Main effects of the MIDT related to specific task phases are reported across all three groups in Table S1.

Affective Responses

A diagnostic-group-by-trial-type repeated-measures analysis of variance (ANOVA) examining affective responses to the incentive value of different trial types (winning, neutral, losing) showed a main effect of trial type [$F_{(2,108)} = 298.98$, $p < 0.001$]. Pairwise comparisons revealed that, in a stepwise fashion, participants reported significantly greater cue-elicited "happiness" when winning, during neutral or losing trials ($p < 0.01$). There was no significant difference in affective ratings between the experimental groups [$F_{(2,54)} = 0.52$, $p > 0.05$] and no diagnostic-group-by-trial-type interaction [$F_{(4,108)} = 0.76$, $p > 0.05$].

In-Scanner Behavior

Multiple one-way ANOVAs examining behavioral responses in-scanner showed no significant group differences between experimental groups on earnings [$F_{(2,111)} = 3.02$, $p > 0.05$] or mean hit rate for win/loss trials [$F_{(2,111)} = 2.71$, $p > 0.05$]. There was, however, a significant between-group difference in mean reaction time on win/loss trials [$F_{(2,111)} = 4.75$, $p < 0.05$], whereby the LC group had significantly shorter reaction times than the BED group ($p < 0.05$), but did not differ from the OB group ($p > 0.05$).

Group Differences

While the findings listed in the text of the manuscript focus on brain regions implicated in reward processing and hypothesized to differ between groups, additional findings are listed below (as well as in accompanying tables).

Group Differences: BED vs OB

A1Win

Between-group BED-OB contrasts of neural activity during the A1Win phase showed significantly increased activity in the BED, relative to the OB group, in the left IFG extending to the insula, the right middle frontal gyrus extending to the inferior frontal gyrus, the caudate and putamen; right precentral gyrus extending to the postcentral gyrus and insula (Table 2A).

A1Loss

In the A1Loss phase BED-OB contrasts demonstrated significantly increased activity in the left IFG extending to the insula and prefrontal gyrus (Table 2A).

Group Differences: BED vs LC

A1Win

No significant differences between BED and LC groups were observed during this phase (Table 2B).

A1Loss

Between-group contrasts of neural activity in the BED group, relative to the LC group, showed significantly increased activity in the right IFG extending to the middle frontal gyrus (Table 2B).

Group Differences: OB vs LC

A1Win

Group differences in the OB group, relative to the LC group, during the A1 winning phase showed diminished activity in the left posterior insula extending to the inferior parietal lobule; in the right precentral gyrus extending to the postcentral gyrus and insula; in the left precentral gyrus extending to the superior temporal gyrus, postcentral gyrus and insula; in the left cingulate gyrus extending bilaterally (Table 2C).

A1Loss

During the A1Loss phase, the OB group, relative to the LC group, demonstrated significantly increased activity in the right middle frontal gyrus in the OFC. The OB group demonstrated relatively decreased activity in the right insula extending to the postcentral gyrus; in the left medial frontal gyrus extending to the anterior cingulate and paracentral lobule; in the left precentral gyrus extending to the postcentral gyrus (Table 2C).

Table S1. Main Effects during MIDT (*n* = 57)

MIDT Phase	Structure	BA	Left/ Right	MNI Coordinates x	y	z	k	*t*-value
A1 Winning> A1 Neutral	Cingulate Gyrus/ Lentiform Nucleus/ Medial Frontal Gyrus/ Postcentral Gyrus/ Superior Temporal Gyrus/ Thalamus/ Insula/ Caudate/ Precentral Gyrus/ Precuneus/ Inferior Parietal Lobule/ Claustrum/ Midbrain Red Nucleus/ Superior Frontal Gyrus/ Culmen/ Superior Parietal Lobule/ Inferior Frontal Gyrus/ Posterior Cingulate/ Middle Frontal Gyrus/ Middle Temporal Gyrus/ Transverse Temporal Gyrus/ Anterior Cingulate/ Superior Occipital Gyrus/ Parahippocampal Gyrus/ Lingual Gyrus	40	R	6	15	36	24730	7.18
	Precentral Gyrus/ Middle Frontal Gyrus/ Inferior Frontal Gyrus/ Superior Frontal Gyrus	6	L	-39	6	33	1248	-5.52
	Middle Temporal Gyrus/ Superior Temporal Gyrus	22	L	-54	-36	-6	253	-5.39
	Inferior Parietal Lobule/ Supramarginal Gyrus	7	L	-39	-63	54	620	-4.68
A1 Losing> A1 Neutral	Precentral Gyrus/ Medial Frontal Gyrus/ Lentiform Nucleus/ Thalamus/ Inferior Parietal Lobule/ Superior Frontal Gyrus/ Cingulate Gyrus/ Culmen/ Precuneus/ Culmen/ Declive/ Superior Temporal Gyrus/ Midbrain Red Nucleus/ Inferior Frontal Gyrus/ Middle Temporal Gyrus/ Paracentral Lobule/ Insula/ Posterior Cingulate/ Cuneus/ Lingual Gyrus/ Parahippocampal Gyrus/ Middle Frontal Gyrus/ Anterior Cingulate/ Middle Occipital Gyrus	4	L	-33	-21	57	40024	7.96
A2 Winning> A2 Neutral	Caudate/ Middle Temporal Gyrus/ Thalamus/ Cingulate Gyrus/ Precentral Gyrus/ Anterior Cingulate		L	-24	-48	18	2604	5.74
	Insula	13	R	42	15	-6	99	4.74

	Lentiform Nucleus/ Cingulate/ Orbital Gyrus/ Middle Frontal Gyrus/ Superior Frontal Gyrus/ Middle Temporal Gyrus/ Cuneus/ Parahippocampal Gyrus/ Precuneus/ Posterior Cingulate/ Thalamus/ Uncus/ Insula/ Middle Occipital Gyrus/ Postcentral Gyrus	39	L	-24	6	-15	16826	-6.27
	Declive/ Pyramis	-	R	12	-78	-27	290	-4.05
A2 Losing> A2 Neutral	Thalamus/ Insula/ Cingulate Gyrus/ Superior Temporal Gyrus/ Caudate/ Precentral Gyrus/ Anterior Cingulate	-	L	-15	-39	12	2459	6.20
	Declive	-	L	-6	-90	-30	133	4.47
	Lingual Gyrus/ Middle Temporal Gyrus/ Precuneus/ Superior Frontal Gyrus/ Posterior Cingulate/ Middle Frontal Gyrus/ Lentiform Nucleus/ Middle Occipital Gyrus/ Parahippocampal Gyrus/ Superior Temporal Gyrus/ Insula/ Precentral Gyrus/ Thalamus/ Medial Frontal Gyrus/ Inferior Temporal Gyrus/ Midbrain Red Nucleus	18	R	15	-51	3	15172	-6.10
	Middle Temporal Gyrus/ Superior Temporal Gyrus/ Inferior Temporal Gyrus	21	L	-66	-12	-12	283	-4.56
Winning Outcome> Neutral Outcome	Middle Occipital Gyrus/ Medial Frontal Gyrus/ Parahippocampal Gyrus/ Middle Frontal Gyrus/ Precuneus/ Posterior Cingulate/ Cingulate Gyrus/ Middle Temporal Gyrus/ Superior Frontal Gyrus/ Angular Gyrus/ Superior Occipital Gyrus/ Postcentral Gyrus/ Lentiform Nucleus/ Inferior Frontal Gyrus/ Superior Temporal Gyrus/ Fusiform Gyrus/ Insula/ Thalamus/ Cuneus/ Inferior Temporal Gyrus	19	R	42	-87	21	9639	5.99
	Postcentral Gyrus/ Insula	43	L	-54	-6	15	351	4.84
	Culmen	-	L	-9	-60	-24	92	3.84
	Middle Temporal Gyrus	21	L	-63	-6	-15	94	3.70
	Caudate/ Inferior Frontal Gyrus/ Anterior Cingulate/ Thalamus/	-	R	24	-21	33	1087	-4.84

	Precentral Gyrus/ Insula							
	Thalamus/ Cingulate Gyrus/ Caudate	-	L	-24	-33	9	462	-4.19
	Inferior Frontal Gyrus/ Insula	9	L	-57	33	-6	321	-4.11
Losing Outcome> Neutral Outcome	Medial Frontal Gyrus/ Superior Frontal Gyrus/ Anterior Cingulate	9	R	3	51	21	2080	5.69
	Middle Occipital Gyrus	19	R	42	-84	18	177	5.45
	Inferior Frontal Gyrus	13	L	-30	15	-15	748	5.31
	Insula/ Superior Temporal Gyrus/ Inferior Frontal Gyrus/ Middle Frontal Gyrus	13	R	33	15	-9	543	4.95
	Superior Temporal Gyrus/ Middle Temple Gyrus	39	L	-63	-60	27	396	3.86
	Cerebellum	-	R	3	-57	-36	156	4.41
	Middle Frontal Gyrus/ Precentral Gyrus	8	R	45	27	45	190	4.39
	Cerebellum	-	L	-27	-78	-39	186	4.27
	Superior Temporal Gyrus/ Middle Temporal Gyrus	39	R	66	-54	30	166	3.84
	Precuneus	31	R	9	-51	36	201	3.93
	Superior Temporal Gyrus/ Supramarginal Gyrus/ Middle Temporal Gyrus	39	R	66	-54	30	188	3.70
	Middle Temporal Gyrus/ Superior Temporal Gyrus	21	R	51	-24	-12	183	3.70
	Cuneus	30	R	3	-63	3	111	3.30
	Caudate/ Thalamus/ Inferior Frontal Gyrus/ Parahippocampal Gyrus/ Middle Temporal Gyrus/ Paracentral Lobule/ Posterior Cingulate/ Precentral Gyrus/ Medial Frontal Gyrus/ Superior Parietal Lobule/ Lingual Gyrus/ Postcentral Gyrus	-	R	24	-24	33	4360	-6.53

BA, Brodmann's area; L, left; MIDT, Monetary Incentive Delay Task; MNI, Montreal Neurological Institute; R, right.
k = voxel cluster size (each voxel = 3 mm^3).

Table S2. Overlapping activity during MIDT Trials in BED and OB groups

BED + OB								
MIDT Phase	**Structure**	**BA**	**Left/ Right**	**MNI Coordinates**			**k**	***t*-value**
				x	**y**	**z**		
A1Win	Lingual Gyrus/ Thalamus/ Cuneus/ Parahippocampal Gyrus/ Posterior Cingulate/ Culmen	18	L	-27	-57	3	1269	-4.32
	Superior Frontal Gyrus/ Medial Frontal Gyrus	10	L	-6	63	30	136	-3.98
	Insula	13	L	-39	-15	15	96	-3.62
A1Loss	Lingual Gyrus/ Parahippocampal Gyrus/ Cuneus/ Thalamus/ Posterior Cingulate	30	L	-27	-54	-3	978	-4.17
A2Win	Inferior Temporal Gyrus/ Middle Occipital Gyrus	18	L	-51	-78	-6	560	-4.40
	Cingulate Gyrus/ Middle Frontal Gyrus/ Precentral Gyrus/ Medial Frontal Gyrus/ Inferior Parietal Lobule/ Postcentral Gyrus/ Paracentral Lobule/ Precuneus/ Superior Frontal Gyrus	6	L	-18	-12	66	3077	-4.64
	Precentral Gyrus/ Middle Frontal Gyrus	6	L	-57	9	36	223	-4.10
	Culmen/ Fusiform Gyrus/ Parahippocampal Gyrus	-	R	21	-51	-15	345	-4.01
	Middle Temporal Gyrus	39	R	54	-69	30	135	-3.99
	Precuneus/ Cuneus	19	L	-12	-82	43	188	-3.76
	Precuneus/ Posterior Cingulate	31	R	3	-63	24	176	-3.76
	Insula/ Superior Temporal Gyrus	13	L	-51	-38	21	127	-3.27
A2Loss	Precentral Gyrus/ Medial Frontal Gyrus/ Superior Temporal Gyrus/ Postcentral Gyrus/ Cingulate Gyrus/	4	L	-24	-21	66	4775	-5.06

	Paracentral Lobule/ Inferior Parietal Lobule/ Middle Frontal Gyrus/ Parahippocampal Gyrus/ Fusiform Gyrus/ Superior Parietal Lobule/ Precuneus/ Thalamus/ Posterior Cingulate							
	Insula/ Superior Temporal Gyrus	13	L	-36	-15	15	161	-3.70
	Inferior Frontal Gyrus/ Middle Frontal Gyrus/ Superior Frontal Gyrus	9	L	-54	12	30	238	-3.56
OCWin	Inferior Occipital Gyrus/ Fusiform Gyrus/ Middle Occipital Gyrus/ Lingual Gyrus/ Cuneus/ Precuneus	18	L	-42	-84	-6	2599	5.28
	Inferior Frontal Gyrus	9	L	-45	9	30	160	5.26
	Posterior Cingulate/ Parahippocampal Gyrus/ Middle Temporal Gyrus/ Precentral Gyrus/ Postcentral Gyrus/ Inferior Parietal Lobule/ Insula/ Medial Frontal Gyrus/ Caudate/ Precuneus/ Anterior Cingulate/ Superior Temporal Gyrus	29	L	-18	-42	9	4761	-5.04
	Culmen of Vermis/ Culmen	-	R	3	-66	-15	710	-4.29
	Insula/ Superior Temporal Gyrus	13	R	42	6	-12	183	-3.12
OCLoss	Inferior Occipital Gyrus/ Lingual Gyrus/ Cuneus/ Middle Occipital Gyrus/ Fusiform Gyrus/ Superior Parietal Lobule/ Precuneus	18	L	-42	-84	-9	2161	4.87
	Paracentral Lobule/ Medial Frontal Gyrus/ Precentral Gyrus/ Postcentral Gyrus/ Precuneus/ Superior Temporal Gyrus/ Insula/ Cingulate Gyrus/	7	R	21	-42	63	9131	-6.35

Parahippocampal Gyrus/ Inferior Parietal Lobule							
Culmen of Vermis/ Culmen/ Declive	-	L	3	-66	-15	890	-4.23

BA, Brodmann's area; BED, binge eating disorder; L, left; MIDT, Monetary Incentive Delay Task; MNI, Montreal Neurological Institute; OB, obese; R, right.
k = voxel cluster size (each voxel = 3 mm^3).

Supplemental References

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