Functional and Effective Connectivity Between Reward and Inhibitory Control Networks Underlying Subclinical Binge Eating

***Supplemental Information***

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# **Supplemental Methods**

## Self-Report Measures

All participants completed self-reported assessment related to dysregulated eating, body image, negative affect, impulsiveness, and sensitivity to punishment/reward, including:

**Eating Disorder Diagnosis Scale (EDDS; Stice et al., 2000)**: a 22-item self-report screen which is based on DSM-5 eating disorder criteria. A symptom composite, calculated by summing 18 standardized EDDS items, excluding height, weight, birth control pill use, and missed menstrual periods, is internally consistent, stable, and has excellent concordance with other self-report measures of disordered eating and diagnoses based on structured interviews (Stice et al., 2000). The higher composite scores reflected more eating disorder symptoms (Jackson & Chen, 2008; Chen et al., 2021; Luo et al., 2020). This study used the EDDS to assess the presence or absence of BE episodes (Lyu et al., 2017; Chen et al., 2023b).

**Binge Eating Scale (BES; Gormally et al., 1982)**: a 16-item questionnaire to assess key behavioural (e.g., rapid eating, eating large amounts of food), and affective/cognitive symptoms (e.g., guilt, feeling out of control or unable to stop eating) that precede or follow a binge. Each item contains 3 to 4 statements that are weighted response options, which reflect a range of severity for each measured characteristic. Participants are asked to select the statement that best describes their experience. The scale’s possible total scores range from 0 to 46, with higher total scores indicating more severe BE symptoms (Gormally et al., 1982; Duarte et al., 2015; Oliva et al., 2020).

**Food Preference Scale (Coletta et al., 2009)**: a 5-item scale to assess participants’ preference for sweet, salty, spicy, sour and bitter foods. Items are rated on a 7-point Likert scale ranging from 1 (*very dislike*) to 7 (*very like*), with a higher score reflecting the greater preference for certain foods.

**Satisfaction and Dissatisfaction with Body Parts Scale (Berscheid et al., 1973)**: a 9-item scale to measure personal dissatisfaction with body parts (e.g., waist, thighs). All items are rated on a 5-point Likert-type scale ranging from 1 (*extremely satisfied*) to 5 (*extremely dissatisfied*). We summed the ratings of all items to obtain the score for this scale, with higher total scores reflecting more body dissatisfaction. This scale has been used with Chinese samples and was found to have good construct validity and satisfactory internal consistency (Jackson & Chen, 2011; Mellor et al., 2013; Chen et al., 2020). In the current study, the Cronbach’s alpha for this scale was 0.85.

**Three-Factor Eating Questionnaire-R18 (Anglé et al., 2009)**: a 18-item questionnaire to evaluate participants’ disordered eating behaviors and includes six items about cognitive restraint eating (e.g., “I consciously control my eating to lose weight”), three items about emotional eating (e.g., “I comfort myself by eating when I feel lonely”), and nine items about uncontrolled eating (e.g., “Sometimes, once I have started eating, I cannot stop”). Seventeen items are rated on a 4-point Likert scale ranging from 1 (*strongly disagree*) to 4 (*strongly agree*), and the last item (i.e., “To what extent do you restrict own eating”) is rated on an 8-point scale ranging from 1 (*never restrict*) to 8 (*always restrict*). We first converted the 8-point rating of the last item to a 4-point rating, and then summed the ratings of all items for each scale to obtain the subscale scores for this measure, with higher total scores reflecting more cognitive restraint eating, emotional eating, and uncontrolled eating. In the current study, the subscales had acceptable internal consistency (αs = 0.86 [cognitive restraint eating], 0.70 [emotional eating], and 0.90 [uncontrolled eating]).

**The Center for Epidemiologic Studies Depression Scale (Radloff, 1977)**: a 20-item measure that assesses participants’ depression during the past week (e.g., “I felt sad”). All items are rated on a 4-point scale ranging from 1 (*never or rarely*) to 4 (*very often*). To obtain the score for this scale, we reverse-scored the negatively worded items (4 items) and then summed the ratings of all items, with higher total scores indicating a more depressed mood. This scale has been used with Chinese samples and was found to have good construct validity and high internal consistency (Cheng et al., 2012; Yang et al., 2018). The Cronbach’s alpha for this scale in the current study was 0.86.

**State-Trait Anxiety Inventory (STAI; Spielberger et al., 1970)**: consists of 20 items that assess an individual’s feelings over the past week (the state scale of STAI [STAI-S]) and 20 other items that assess an individual’s general feelings (the trait scale of STAI [STAI-T]) based on a 4-point Likert scale. The present study used the STAI-T to evaluate participants’ trait anxiety. The Cronbach’s alpha for this subscale in the current study was 0.90.

**Barratt Impulsiveness Scale (Patton et al., 1995)**: a 30-item questionnaire used to evaluate three facets of impulsivity: motor impulsivity (e.g., ‘‘I do things without thinking”), attentional impulsivity (e.g., ‘‘I am more interested in the present than the future”), and non-planning impulsivity (e.g., ‘‘I make up my mind quickly”). Items were rated on a 5-point Likert scale ranging from 1 (*never*) to 5 (*always*), with a higher score indicating a higher level of impulsivity. In the current study, the subscales had acceptable internal consistency (αs = 0.85 [motor impulsivity], 0.85 [attentional impulsivity], and 0.84 [non-planning impulsivity]).

**Visual Analog Scale (VAS)**: The current hunger level was rated on the 100-mm VAS, ranging from 0 (*not hungry at all*) to 100 (*very hungry*). Participants’ current thirst level, desire to eat, and pleasure level were measured in the same manner (Dong et al., 2016; Verdejo-Román et al., 2017; Zhang et al., 2023).

**Body Awareness Questionnaire (BAQ; Shields et al., 1989)**: an 18-item measurement assessing self-reported attentiveness to normal body processes (e.g., sensitivity to body cycles and rhythms and ability to detect small changes in normal functioning). This questionnaire requires participants to rate the awareness of body processes on a 7-point scoring scale from 1 (*not at all true for me*) to 7 (*very true for me*), and has been demonstrated to be a reliable tool for evaluating body awareness (Cramer et al., 2018). The Chinese version of the BAQ has been found to have good reliability and validity in measuring body awareness (Luo et al., 2022). The Cronbach’s alpha for this scale in the current study was 0.83.

**Perceived Sociocultural Pressure Scale (Stice & Agras, 1998)**: an 8-item scale that assesses perceived pressure from friends, media, dating partner(s), and family to change one’s physical appearance (e.g., “I’ve felt pressure from my friends to change my physical appearance”). Items were rated on a 5-point scale ranging from 1 (*none*) to 5 (*a lot*), with high scores indicative of increased appearance pressure. The Cronbach’s alpha for this scale in the current study was 0.77.

**Early Life Environmental Unpredictability Scale (Luo et al., 2023)**: a 13-item scale to measure early life environmental unpredictability, including six items from the Family Unpredictability Scale (e.g., “My parent often fails to keep their promises”; Ross & Hill, 2000), three items from the unpredictability measures (e.g., “Things are often chaotic in my house”; Mittal et al., 2015) and four items from the subjective socioeconomic status measures (reverse coded) (e.g., “My family usually has enough money for material possessions”; Mittal et al., 2015). Items were rated on a 5-point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Higher scores indicated perceptions that reflect environments that are less economically secure and more unpredictable. The Cronbach’s alpha for this scale in this study was 0.72.

**Sensitivity to Punishment and Sensitivity to Reward Questionnaire (Torrubia et al., 2001)**:consists of 48 yes-no response items that contain two independent 24-item subscales: sensitivity to punishment (SP) and sensitivity to reward (SR). Each item required a binary answer (yes or no) and the total number of odd- and even-numbered items answered yes were taken as the total SP and SR scores, respectively. In the current study, the subscales had acceptable internal consistency (αs = 0.88 [SP] and 0.73 [SR]).



Figure S1. Schematic illustration of the food reward Go/NoGo task. In the “GO NEUTRAL” run, neutral pictures served as target stimuli, therefore participants were asked to press the button with neutral stimuli (Go) and withhold their response to food stimuli (No-go). The instructional set of the “GO FOOD” run was the opposite. During each run, the trials began with a fixation cross (1,000 ms), followed by a neutral or a food stimulus presented for 1,000 ms. The time window to respond lasted 1,000 ms. Within a given run, trials were separated by a random inter-trial interval ranging from 1,000 to 3,000 ms.

## **Table S1.** Names and MNI coordinates of 15 regions of interest

|  |  |
| --- | --- |
| Region name |  Coordinates (in mm) |
| Executive control network (ECN) |
| 1 Dorsal medial PFC (dmPFC) | 0, 24, 46 |
| 2 Left anterior PFC (L\_aPFC) | −44, 45, 0 |
| 3 Right anterior PFC (R\_aPFC) |  44, 45, 0 |
| 4 Left superior parietal lobule (L\_sPar) | −50, −51, 45 |
| 5 Right superior parietal lobule (R\_sPar) |  50, −51, 45 |
| Reward network (RN) |
| 1 Left medial orbitofrontal cortex (L\_mOFC) | −14, 35, −22 |
| 2 Right medial orbitofrontal cortex (R\_mOFC) | 17, 37, −22 |
| 3 Left thalamus (L\_THA) | −10, −19, 6 |
| 4 Right thalamus (R\_THA) | 11, −18, 7 |
| 5 Left caudate (L\_CAU) | −13, 9, 10 |
| 6 Right caudate (R\_CAU) | 13, 10, 11 |
| 7 Left putamen (L\_PUT) | −26, 0, 0 |
| 8 Right putamen (R\_PUT) | 26, 2, 0 |
| 9 Left accumbens (L\_NAc) | −9, 12, −7 |
| 10 Right accumbens (R\_NAc) | 9, 12, −7 |

*Note.* The first letter in region name abbreviations (if available) indicates left or right hemisphere. MNI = Montreal Neurological Institute.



**Figure S2.** Reward-inhibition dual-system hypothetical model (fully connected model). In dynamic causal modelling, matrix A contains the parameters independent of experimental conditions, including matrices AI and AE. Matrix AI represents the intrinsic coupling of the brain region to itself. Matrix AE represents the intrinsic connections between brain regions. Matrix B represents the modulatory effect exerted by specific inputs (i.e., experimental conditions) on the connectivity between regions. CAU = caudate; mOFC = medial orbitofrontal cortex; IFG = inferior frontal gyrus; SPG = superior parietal gyrus.

# **Supplemental Results**

## Food Reward Stimuli

**Preliminary screening and rating of picture materials.** The food reward pictures were selected from the Chinese Food Image Database for Eating and Appetite Studies (Li et al., 2022b), given the cultural and geographical aspects of food preferences (for a review, see Labonté & Nielsen, 2023). A total of 508 food pictures were visually screened by two doctoral students, with the inclusion criteria being high image clarity and generalizability (in line with the Chinese cultural context). After two rounds of preliminary screening, 154 food pictures were included in the first round of the food picture Set 1. Meanwhile, 80 pictures of daily necessities (such as scissors and cups) were selected from the standardized picture library of daily necessities compiled by our team (Leng et al., 2021). Through randomly repeating 20 pictures, we obtained the first round of neutral picture Set 2, totaling 100 pictures. An additional 53 participants**[[[1]](#footnote-0)]** were recruited for this study and asked to rate the arousal, pleasantness and familiarity of 154 food pictures and 100 neutral pictures on a 7-point scale ranging from 1 (e.g., “I am very unfamiliar with this food/daily necessity”) to 7 (e.g., “I am very familiar with this food/daily necessity”). There were significant differences between the food and neutral pictures in arousal and pleasantness, and no significant differences in familiarity (food > neutral; arousal: *t* = 13.61, *p* < 0.001; pleasantness: *t* = 9.54, *p* < 0.001; familiarity: *t* = –0.35, *p =* 0.726). Since the purpose of this study was to construct a library of the most rewarding food pictures for binge eaters, we deleted 44 food pictures that scored low on both arousal and pleasantness, resulting a total of 110 food pictures.

**Re-rating and determination of picture materials.** Prior to the scanning, a total of 59 participants (*n*BE = 30, *n*non-BE = 29) further rated 110 food pictures and 100 neutral pictures on a 9-point scale ranging from 1 (*very unpalatable*) to 9 (*very palatable*) in terms of arousal, pleasantness, familiarity, palatability (food pictures only), and favoritism (food pictures only). For the food pictures, we selected the TOP 30, 50, and 100 pictures that had the highest scores on favoritism for the two groups, and tested the between-group differences in favoritism (i.e., eating tendency in daily life), and then examined the between-group differences in favoritism to REPEATED food pictures. Specifically, 20/43/95 of the TOP 30/50/100 food pictures in the favoritism ranking of each of the two groups were duplicates (i.e., REPEATED food pictures). We found that for REPEATED food pictures, the BE group had a significantly higher eating tendency than non-BE group (Table S2), suggesting that the same food pictures had a higher reward value for the BE group, and that they had a higher eating tendency in daily life. Meanwhile, the TOP 30 and TOP 50 food pictures differed significantly in eating tendency, but not the TOP 100 pictures. Accordingly, we chose 43 of the TOP 50 pictures duplicated in each group as the formal food reward stimuli (Table S2).

After two rounds of material rating, we finally included 43 food picture stimuli and 37 daily necessities (randomly matched based on familiarity) as neutral picture stimuli for formal scanning. All pictures had the same background and were included in the scanning task at a similar resolution and image size. These picture stimuli not only maximized the reward value of the food stimulus for the BE group (Labonté & Nielsen, 2023; Wang et al., 2011) but also ensured, to the largest extent possible, that the neural response differences were driven by the grouping conditions.

## Table S2. Group comparison of food favoritism (eating tendency)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Food favoritism | BE (*n* = 30) | Non-BE (*n* = 29) | *t*-value | *p*-value | *F*-value | *p*-value |
|
| Top 30 pictures | 6.41 ± 0.90 | 5.82 ± 1.02 | 2.39 | 0.02\* | 4.77 | 0.03\* |
| **Repeated 20 pictures** | 6.52 ± 0.88 | 6.01 ± 0.95 | 2.18 | 0.03\* | 3.22 | 0.08 |
| Non-repeated 10 pictures | 6.18 ± 1.20 | 5.45 ± 1.32 | 2.29 | 0.03\* | 5.71 | 0.02\* |
| Top 50 pictures | 6.08 ± 0.92 | 5.53 ± 0.10 | 2.25 | 0.03\* | 4.53 | 0.04\* |
| **Repeated 43 pictures** | 6.16 ± 0.89 | 5.60 ± 0.10 | 2.32 | **0.02\*** | 5.00 | **0.03\*** |
| Non-repeated 7 pictures | 5.64 ± 1.28 | 5.18 ± 1.25 | 1.43 | 0.16 | 1.29 | 0.26 |
| Top 100 pictures | 5.48 ± 1.01 | 5.04 ± 1.03 | 1.70 | 0.10 | 2.63 | 0.11 |
| **Repeated 95 pictures** | 5.52 ± 1.01 | 5.07 ± 1.03 | 1.75 | 0.09 | 2.67 | 0.11 |
| Non-repeated 5 pictures | 4.68 ± 1.48 | 4.52 ± 1.45 | 0.44 | 0.67 | 1.04 | 0.31 |

*Note.* Age and sex were controlled as covariates in the *F* test. Significance is indicated by the asterisks (\**p* < 0.05). BE = binge eating.



**Figure S3.** Group comparison of food preferences. The bar plots represent, in order, the preference for sweet (orange), salty (blue), spicy (red), sour (yellow), and bitter (green) foods. The darker bars represent food preferences of the BE group and the lighter bars represent food preferences of the non-BE group. BE = binge eating.

**Table S3.** Group comparison of behavioral performance

|  |  |  |  |
| --- | --- | --- | --- |
| Measures | BE (*n* = 29) | Non-BE (*n* = 29) | *p*-values |
| Mean ± *SD* | Mean ± *SD* |
| Reaction times (correct Go trials, ms) |  |  |  |
| food | 502.26 (62.17) | 492.24 (58.16) | 0.529 |
| neutral | 538.13 (51.29) | 523.42 (70.67) | 0.368 |
| overall | 520.19 (54.53) | 507.83 (61.08) | 0.420 |
| Commission errors (No-go trials, %) |  |  |  |
| food | 4.86 (4.14) | 5.10 (5.09) | 0.844 |
| neutral | 8.34 (5.33) | 7.55 (6.16) | 0.602 |
| overall | 6.60 (3.54) | 6.33 (4.84) | 0.805 |
| Omission errors (Go trials, %) |  |  |  |
| food | 4.97 (7.78) | 2.72 (3.70) | 0.169 |
| neutral | 3.38 (6.49) | 1.97 (2.93) | 0.290 |
| overall | 4.17 (6.57) | 2.34 (3.10) | 0.183 |

*Note.* BE = binge eating; *SD* = standard deviation.

## Table S4. Group comparison of functional connectivity (BE > non-BE)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Condition of interest | MNI coordinates (x, y, z) | Voxel size | Statistics | *p*FDR |
| ROI-to-ROI connectivity |
| *food reward\_nogo condition* |
| left mOFC–right mOFC | - a | - a | 6.41 | 0.043 |
| right sPar–left aPFC | - a | - a | 5.58 | 0.043 |
| right sPar–right IFG | - a | - a | 5.58 | 0.043 |
| Seed-to-voxel connectivity |
| *food reward\_nogo condition* |
| left aPFC (seed)–right angular gyrus | 46, −54, 14 | 130 | 4.50 | 0.033 |
| right mOFC (seed)–right mOFC | 8, 46, −12 | 100 | 4.76 | 0.043 |
| right mOFC (seed)–right LOC | 34, −96, −10 | 377 | −4.70 | **0.00005** |
| right mOFC (seed)–right SPG | 32, −42, 70 | 230 | −4.64 | **0.0010** |
| *food reward\_nogo−neutral\_nogo condition* |
| left sPar (seed)–left LOC | −40, −78, 4 | 158 | −4.45 | 0.011 |
| left sPar (seed)–left superior occipital gyrus | −16, −90, −6 | 165 | −4.76 | 0.011 |
| right CAU (seed)–left LG | 0, −74, 4 | 187 | −4.21 | **0.0028** |
| *food reward\_nogo−food reward\_go condition* |
| right aPFC (seed)–right calcarine gyrus | 8, −92, 4 | 152 | −4.99 | 0.040 |
| right mOFC (seed)–left calcarine gyrus | 2, −88, 2 | 151 | −4.22 | 0.041 |
| right THA (seed)–brain-stem | −4, −38, −58 | 108 | −4.45 | 0.030 |
| left NAc (seed)–left SFG 1 | −4, 56, 34 | 125 | 4.91 | 0.013 |
| left NAc (seed)–left SFG 2 | −16, 60, 20 | 119 | 4.29 | 0.013 |

*Note.* In the ROI-to-ROI analysis, statistical significance was set at *p* < 0.05 with FDR correction (Jafri et al., 2008). In the seed-to-voxel analysis, statistical significance was set at voxel-wise threshold *p* < 0.001 threshold and cluster-size FDR corrected significance of *p* < 0.05 (Worsley et al., 1996). Connections that survived a stringent Bonferroni correction for multiple comparisons are indicated in bold (*p*FDR < 0.05/16 = 0.003). BE = binge eating; MNI = Montreal Neurological Institute; ROI = region of interest; mOFC = medial orbitofrontal cortex; sPar = superior parietal lobule; aPFC = anterior prefrontal cortex; IFG = inferior frontal gyrus; LOC = lateral occipital cortex; SPG = superior parietal gyrus; CAU = caudate; LG = lingual gyrus; THA = thalamus; NAc = accumbens; SFG = superior frontal gyrus; FDR = false discovery rate.

a See Table S1 for the initial ROI information.

## Table S5. Correlations of behavioral performance with trait impulsiveness and connections within each group

|  |  |  |  |
| --- | --- | --- | --- |
| Variables | Reaction times(correct Go trials) | Commission errors(No-go trials) | Omission errors(Go trials) |
| BE group (*n* = 29) |
| Trait impulsiveness | 0.03 | 0.14 | −0.23 |
| motor subscale | 0.03 | −0.09 | −0.08 |
| attentional subscale | −0.01 | 0.12 | −0.32 |
| non-planning subscale | 0.07 | 0.20 | −0.11 |
| mOFC-LOC connection a | **−0.41\*** | 0.06 | **−0.59\*\*** |
| mOFC-SPG connection a | 0.26 | 0.05 | 0.21 |
| CAU-LG connection b | −0.32 | −0.08 | **−0.44\*** |
| mOFC→SPG connection a | 0.28 | −0.17 | 0.14 |
| Non-BE group (*n* = 29) |
| Trait impulsiveness | −0.14 | 0.33 | 0.05 |
| motor subscale | 0.01 | 0.36 | 0.19 |
| attentional subscale | −0.21 | 0.26 | −0.11 |
| non-planning subscale | −0.14 | 0.26 | 0.08 |
| mOFC-LOC connection a | −0.10 | 0.44**\*** | 0.14 |
| mOFC-SPG connection a | 0.16 | −0.002 | −0.03 |
| CAU-LG connection b | −0.11 | 0.23 | −0.04 |
| mOFC→SPG connection a | 0.15 | 0.07 | −0.08 |

*Note.* Significance is indicated by the asterisks (\**p* < 0.05; \*\**p* < 0.01). BE = binge eating; mOFC = medial orbitofrontal cortex; LOC = lateral occipital cortex; SPG = superior parietal gyrus; CAU = caudate; LG = lingual gyrus.

a Food reward\_nogo condition.

b Food reward\_nogo−neutral\_nogo condition.

## Table S6. Correlations of psychological factors with binge eating and neural indices (*n* = 58)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variables | Body awareness | Body dissatisfaction | Perceived appearance pressure | Environmental unpredictability | Depression | Anxiety | Trait impulsiveness  | Reward sensitivity | Punishment sensitivity |
| BE behaviors | –0.14 | **0.40\*\*** | **0.28\*** | **0.33\*** | **0.41\*\*** | **0.33\*** | **0.55\*\*\*** | **0.28\*** | 0.18 |
| *Regional activation and functional connectivity* |
| IFG activation a | 0.03 | –0.21 | –0.05 | –0.13 | –0.12 | –0.14 | –0.16 | –0.24 | 0.11 |
| mOFC-LOC connection a | 0.01 | 0.01 | –0.17 | **–0.34\*\*** | **–0.37\*\*** | **–0.31\*** | –0.25 | –0.12 | –0.06 |
| mOFC-SPG connection a | 0.05 | –0.13 | –0.13 | **–0.31\*** | –0.15 | –0.21 | **–0.39\*\*** | –0.24 | –0.03 |
| CAU-LG connection b | –0.20 | –0.13 | –0.18 | –0.13 | –0.04 | 0.06 | 0.001 | 0.04 | 0.02 |
| *Effective connectivity* |
| Matrix B: mOFC→SPG connection c | –0.05 | 0.00 | –0.03 | –0.11 | –0.06 | –0.13 | –0.12 | 0.05 | **–0.39\*\*** |
| Matrix AI: SPG→SPG connection d | 0.07 | 0.01 | 0.10 | –0.11 | –0.17 | –0.14 | –0.06 | **0.30\*** | –0.18 |
| Matrix AE: IFG→SPG connection d | 0.06 | –0.09 | –0.05 | 0.06 | 0.12 | 0.19 | –0.04 | –0.15 | 0.19 |
| Matrix AE: IFG→LG connection d | –0.15 | 0.12 | 0.13 | 0.17 | 0.22 | 0.22 | 0.14 | –0.10 | **0.33\*** |
| Matrix AE: LOC→SPG connection d | 0.04 | 0.05 | –0.13 | –0.05 | –0.07 | –0.10 | –0.20 | 0.26 | 0.06 |
| Matrix B: mOFC→LG connection d | 0.01 | –0.25 | –0.08 | –0.23 | –0.23 | –0.24 | –0.23 | **–0.33\*** | 0.07 |
| Matrix B: IFG→LG connection d | 0.09 | –0.19 | –0.15 | **–0.26\*** | –0.09 | –0.02 | –0.15 | –0.12 | **–0.35\*\*** |
| Matrix B: LG→LOC connection d | **0.33\*** | –0.02 | –0.18 | **–0.48\*\*\*** | **–0.38\*\*** | **–0.35\*\*** | –0.22 | 0.04 | **–0.26\*** |

*Note.* In dynamic causal modelling, matrix A contains the parameters independent of experimental conditions, including matrices AI and AE. Matrix AI represents the intrinsic coupling of the brain region to itself. Matrix AE represents the intrinsic connections between brain regions. Matrix B represents the modulatory effect exerted by specific inputs (here, food reward\_nogo condition) on the connectivity between regions. *n*BE = 29 (males, 7, females, 22), *n*non-BE = 29 (males, 10, females, 19). Significance is indicated by the asterisks (\**p* < 0.05; \*\**p* < 0.01; \*\*\**p* < 0.001). BE = binge eating; IFG = inferior frontal gyrus; mOFC = medial orbitofrontal cortex; LOC = lateral occipital cortex; SPG = superior parietal gyrus; CAU = caudate; LG = lingual gyrus.

a Food reward\_nogo condition.

b Food reward\_nogo−neutral\_nogo condition.

c Reward-inhibition dual-system model.

d Reward-inhibition-vision triple-system model.

## Table S7. Correlations between mOFC–SPG connection and binge eating (timepoint 1)

|  |  |  |
| --- | --- | --- |
| Variables | Binge eating frequency | Binge eating behavior |
| BE group (*n* = 29) |
| mOFC-SPG connection a | −0.17 | −0.24 |
| Non-BE group (*n* = 29) |
| mOFC-SPG connection a | - b | - c |
| Full sample (*n* = 58) |
| mOFC-SPG connection a | −0.56\*\*\* | −0.50\*\*\* |

*Note.* Significance is indicated by the asterisks (\*\*\**p* < 0.001). mOFC = medial orbitofrontal cortex; SPG = superior parietal gyrus; BE = binge eating.

a Food reward\_nogo condition.

b The correlation coefficient was not available because the frequency of binge eating was 0 for each participant in the non-BE group.

c The correlation coefficient was not available because binge eating behavior scores (calculated by summing 10 standardized EDDS items) were not available in the non-BE group. Specifically, the scores for items 6, 8, 13 and 14 were 0 for each non-BE participant, so standardized scores for these items were not available.

Supplemental Discussion

At the behavioral level, we observed that the BE group reported higher levels of impulsivity than controls, while there were no significant between-group differences in GNG performance. Broadly, behavioral tasks may be less reliable than self-reported measures in capturing stable individual differences in personality traits (e.g., trait impulsiveness) (Oliva et al., 2019, 2020) because tasks appear to be more exposed to state-dependent variations (Meule, 2013). More specifically, most of the evidence for deficits in food-specific response inhibition stems from studies on individuals with obesity (e.g., Price et al., 2016; Liu et al., 2019; Gerdan & Kurt, 2020; Osimo et al., 2021; Wang et al., 2022; Wang et al., 2024). Despite deficits in inhibitory control in individuals with obesity compared to normal-weight individuals, such impairment appears to be independent of the presence of BE episodes, thus more related to the complex etiology of obesity (Lavagnino et al., 2016; Oliva et al., 2019). It is plausible that the altered neural responses in binge eaters during GNG task may not equate to behavioral impairments in their response inhibition, which is consistent with the results of previous neurocognitive studies that also reported non-significant differences in GNG performance between binge eaters/drinkers and controls (e.g., Watson et al., 2016; Blanco-Ramos et al., 2019; Oliva et al., 2019; Suárez-Suárez et al., 2020). Future studies could further investigate the behavioral control of binge eaters by including more diverse paradigms, such as food-related stop signal task and Stroop task. Despite the lack of behavioral differences between groups, significant inverse correlations between GNG indices and functional connections were further observed only in the BE group (Table S5), suggesting that individual variations of key connections may play a crucial role in inhibitory control in binge eaters.

Regarding the reward-inhibition-vision triple-system model, we observed three main effective connectivity results. First, the BE group displayed a stronger inhibitory self-connection in the right superior parietal gyrus (SPG) compared to controls (matrix AI, i.e., latent coupling of the brain region to itself independent of experimental condition). The neurofunctional and neurostructural alterations in the SPG implicated in executive functioning have been reported in individuals with eating disturbances (Fuglset et al., 2016; Zhong et al., 2023). In general, increased within-region endogenous connectivity indicates an increase in “self-inhibition” (e.g., Bencivenga et al., 2021; Randeniya et al., 2023). The enhanced inhibitory self-connection in the SPG may reflect the necessary engagement of inhibitory control in response inhibition task, but this does not mean a severe impairment of executive function in subclinical binge eaters (e.g., Oliva et al., 2019). This finding provides novel evidence for the neural vulnerability of BE-associated symptomatology from the perspective of endogenous self-connection in brain regions. Second, the left inferior frontal gyrus (IFG)→right SPG inhibitory connection, left IFG→lingual gyrus (LG) inhibitory connection, and right lateral occipital cortex (LOC)→SPG excitatory connection were significantly weakened in the BE group (matrix AE, i.e., intrinsic connections between regions independent of experimental condition). It has been suggested that the ventral striatal to hypothalamus directed connectivity was correlated with ventral striatal prediction error in eating disorders (Frank et al., 2021). Existing studies have demonstrated abnormalities in functional activation and morphological structure of the visual cortex (such as middle occipital gyrus and LG) in individuals with obesity (Gearhardt et al., 2014; Hermann et al., 2019; Syan et al., 2021). However, examinations of task-dependent directional connectivity between cognitive control and visual processing systems have rarely involved subclinical population. Our results may suggest that diminished bidirectional interaction between control and visual areas is an important neural response during food reward-based inhibition control in individuals with recurrent BE episodes. The present research contributes to the prior studies involving subclinical BE subjects (Chen et al., 2023b; Li et al., 2022a; Oliva et al., 2019, 2020) by identifying the directionality of abnormal influences of inhibitory control and visual perception regions during dual-system conflict processing in binge eaters. Finally and interestingly, during the food reward\_nogo condition, the BE group exhibited an opposite pattern in the valence of connections between the reward→visual nodes and inhibition→visual nodes; that is, the medial orbitofrontal cortex (mOFC)→LG inhibitory connection was enhanced while the IFG→LG excitatory connection was weakened (matrix B, i.e., modulatory connectivity). The reward reactivity information in the mOFC might suppress the conversion of visual processing information in the LG, while the response inhibition information in the IFG might facilitate the conversion of visual perception information in the LG. Furthermore, the strengthened mOFC→LG inhibitory effect and weakened IFG→LG excitatory effect indicated that the reward→visual system modulation may override the control→visual system modulation during inhibition of the food reward stimuli in adults with recurrent BE episodes. Given that neurobiological alterations in the LG have been demonstrated in patients with eating disorders (Barona er al., 2019; Phillipou et al., 2015; Wang et al., 2023), these novel findings suggested that, in addition to higher-order cognitive control and reward networks, the primary visual processing circuit (especially the LG) also play a key role in the neural hierarchical mechanisms of food reward-based response inhibition in binge eaters. Future studies could investigate these interesting possibilities.

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1. **[]** The additional 53 participants were recruited from the Southwest University in Chongqing, China (via advertisement online and offline). [↑](#footnote-ref-0)