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Edited by Bolling and WFB Emotion Awareness Predicts Body Mass Index Percentile Trajectories in Youth

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Abstract

Objective—To examine the rate of change in BMI percentile across three years in relation to emotion identification ability and brain-based reactivity in emotional processing regions.

Study design—A longitudinal sample of 202 youth completed three fMRI-based facial processing tasks and behavioral emotion differentiation tasks. We examined the rate of change in youth's BMI percentile as a function of reactivity in emotional processing brain regions and behavioral emotion identification tasks using multilevel modeling.

Results—Lower correct identification of both happiness and sadness measured behaviorally predicted increases in BMI percentiles across development whereas higher correct identification of both happiness and sadness predicted decreases in BMI percentiles, while controlling for children's pubertal status, gender, ethnicity, IQ score, exposure to antipsychotic medication, family income-to-needs ratio, externalizing, internalizing, and depressive symptoms. Greater neural activation in emotion reactivity regions to sad faces also predicted increases in BMI percentiles during development, also controlling for the above-mentioned covariates.

Conclusions—Findings provide longitudinal developmental data demonstrating a link between both emotion identification ability and greater neural reactivity in emotional processing regions with trajectories of BMI percentiles across childhood.

Keywords

obesity; children; longitudinal

Obesity plagues our nation's youth, with 31.7% of youth classified as overweight or obese (1). Obesity during childhood and adolescence represents a significant pathway toward premature mortality and physical morbidity in adulthood (2). As such, a better understanding of the psychological and related neurobiological correlates that may

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contribute to elevated BMI in youth is needed. Emotion dysregulation(3), the inability to effectively recognize and control intense emotional responses, represents one hypothesized mechanism that may contribute to the development of obesity in youth. Impairments in emotional awareness, one component of emotion dysregulation, may be evidenced by an inability to correctly label and identify emotions in self and others, leading to distressing and emotionally dysregulated psychological states. Emotional reactivity, another component of emotion dysregulation, may be evidenced by increased activation in emotion-related brain regions, such as the amygdala. Excessive or impulsive eating may become a maladaptive mechanism through which children relieve their distress or attempt to self regulate, leading to lack of attention to satiety(4) and weight gain.

Decreased emotional awareness, one component of emotion dysregulation has been shown to be related to obesity in youth and adults (5–7). In a sample of Italian youth, decreased ability to label others' emotions was associated with obesity status (5). In a sample of female adolescents, the relationship between increased self-reported negative affect and overeating was mediated by poor emotional awareness (4). Other work has shown a reduced ability to label visual and verbal signs of emotion in film clips in both obese children and their mothers (6). Obese women have also been shown to exhibit deficits in emotional awareness and report using eating as a strategy for regulating negative emotions more often than non-obese women (7). This work suggests that obesity is related to difficulty in accurately identifying facial expressions of emotion. However, there has been no evidence that has linked poor emotional awareness to changes in BMI or obesity across time. The studies reviewed above support the hypothesis that poor emotional awareness would predict increases in BMI across time, eventually leading to obesity.

Another component of emotion dysregulation, emotional reactivity has yet to be studied as a potential contributor to obesity in childhood. Emotional reactivity, which may present as an intense experience of negative emotions, could lead to maladaptive regulation strategies such as increased or loss of control eating. fMRI studies in this area have primarily investigated reactivity in reward circuitry to images of food (8). Findings from a recent meta-analysis indicate increased reactivity to food images in areas associated with explicit memory, such as the right parahippocampal gyrus, and reduced reactivity in regions linked to cognitive control, such as the dorsolateral prefrontal cortex, among individuals who are overweight or obese (9). However, there have been few attempts to connect reactivity to non-food related imagery to obesity or overweight status in childhood. In one study, overweight and obese girls with loss of control eating showed a failure to engage brain regions associated with emotion regulation in response to a peer social rejection task (10). Furthermore, heightened activation in the fusiform face area (associated with emotional processing) in overweight and obese girls with loss of control eating following a simulated peer rejection predicted subsequent food intake. Given these preliminary findings of heightened activation to socially salient stimuli, investigating additional neural responses to faces (a different type of socially salient stimuli) in overweight and obese children is particularly important. Past work has documented that brain regions involved in emotional reactivity, such as the amygdala, appear to be critical for the detection and processing of emotional faces (11). Alterations in activity in these brain areas among youth at-risk for

becoming obese may suggest unique emotional processing characteristics related to high BMI.

The current study investigated the relationship between neural reactivity to emotional faces during an emotional face-processing task and BMI percentile trajectories in youth. We also examined the relationships between behaviorally-based emotion identification abilities and the trajectory of BMI percentiles across childhood and early adolescence. It was hypothesized that youth with poor emotion identification ability and greater neural activation to emotional faces in brain regions within an emotional reactivity brain network would evidence steeper increases their BMI across time, as both are hypothesized to be indicators of greater emotion dysregulation. In this context, increased eating may serve as one maladaptive method of regulating the intense experiences of negative emotion (e.g., emotional reactivity) and/or decreased ability to label and process emotions (e.g. emotion recognition).

Methods

Participants were from the Preschool Depression Study (PDS), a prospective longitudinal investigation of preschoolers and their families conducted at the Washington University School of Medicine (WUSM)(12). The current study reports on 202 children from the PDS (N= 305 at baseline) who across a seven-year period, completed annual behavioral assessments and at least one (out of a possible three) MRI scans proximal to these annual assessments. Parental written consent and child assent were obtained prior to participation and the WUSM Institutional Review Board approved all procedures. Children who did not complete an fMRI scan reported more externalizing and internalizing symptoms than those who did complete an fMRI scan. There were no group differences in terms of BMI percentile, gender, puberty, ethnicity, IQ, family income-to-needs ratio and MDD symptoms.

Details of recruitment have been previously reported (12,13). In brief, from 2003-2005, 3-6 year olds were recruited from primary care practices and preschools/daycares throughout the Saint Louis metropolitan region using a screening checklist to oversample preschoolers with symptoms of depression. The final sample consisted of preschoolers with varying levels of depressive symptoms and healthy control preschoolers without psychiatric symptoms. In 2010, additional children (aged 10-15) with no prior psychiatric diagnosis were recruited from local schools to enhance the sample of healthy subjects. Children with neurological or chronic medical problems or those with significant developmental delays were excluded. All PDS participants without contraindication for MRI were eligible for an MRI scan session. In the present report, 157 children (77%) were participants in the original PDS study and 45 (23%) were recruited as additional healthy subjects in 2010.

Measures

Mothers reported family income at each annual assessment. The income-to-needs ratio was computed as the total family income at baseline divided by the federal poverty level, based on family size, at the time of data collection (14).

The Kaufman Brief Intelligence test (second edition,15) was used to assess verbal and nonverbal intelligence at the behavioral assessment wave closest to scan 2. The KBIT has a mean score of 100, standard deviation of 15, and has shown to be a reliable and valid measure of IQ in youth (16).

Exposure to medications was ascertained at each behavioral assessment closest to each scan using the MacArthur Health and Behavior Questionnaire (17). The child's lifetime exposure to antipsychotic medications was deemed particularly important given the known association between these medications and weight gain (18). For the purpose of the present report, exposure to medication was coded as 0 'no' and 1 'yes.'

Dimensional scores for externalizing (including attention deficit disorder, conduct disorder, oppositional defiant disorder), internalizing (including generalized anxiety disorder, separation anxiety disorder, post-traumatic stress disorder), and depressive symptoms were calculated at each behavioral assessment closest to each scan using the Preschool Age Psychiatric Assessment (PAPA(19,20)) and the Child and Adolescent Psychiatric Assessment (CAPA, 21,22). Dimensional scores were created by summing all symptoms endorsed in each category. The PAPA and CAPA consist of a series of developmentally appropriate questions covering the DSM-IV criteria for disorders of childhood. During the PAPA and/or CAPA interview, parents and children also identified their ethnicity. For the purpose of the present report ethnicity was coded as, '0' White and '1' African American or Biracial.

Pubertal development of each child was assessed at each behavioral assessment closest to each scan using the Pubertal Development Scale (PDS, 23), a self-report instrument measuring various aspects of children's pubertal development on a 5-point Likert scale.

BMI percentile

Trained research assistants obtained children's height and weight (measured without shoes) at each behavioral assessment closest to each scan using a standardized procedure and calibrated medical scale. BMI was calculated according to the CDC growth charts (24) using the standard formula (weight in kilograms divided by height in meters squared rounded to one decimal place). Age and gender adjusted BMI percentiles were created using the formula and syntax available on the CDC website (24).

Emotion Identification

The 40-item version of the Penn Emotion Differentiation Test (KIDSEDF, 25,26) was used at each behavioral assessment closest to each scan session to measure emotion identification of happy and sad faces. Each child viewed, via a computerized self-paced program, 40 pairs of faces, 1 pair at a time, and decided which face expressed the given emotion more intensely. This task has shown to be reliable and valid in youth (27). This variable was operationalized as the raw value of correct identification, with higher scores indicating more correct identification.

Neural Activation to Emotional Faces

Functional Task and Stimuli—PDS participants completed at least one scanning session (range = 1–3) that included task based functional activation to emotional faces (28), using an event-related facial emotion processing task similar to that used in previous research (29–31). This report focuses on the sad and neutral faces, drawn from the MacArthur Network Face Stimuli Set (32), viewed by each child. This task did not explicitly focus children's attention on the emotional content of each face; children were simply asked to decide whether each face was male or female. Each sad expression was presented from 10 individuals at full- and half-intensity (full expression morphed with neutral, 28,33), with the primary focus being on brain response to sad versus neutral faces (average functional activation to both the 100% and 50% intensity faces). Analysis of fMRI data was performed using in-house software (FIDL analysis package, <http://www.nil.wustl.edu/~fidl>, 34). We obtained each subject's blood oxygen level dependent (BOLD) response to sad faces using fixed effects general linear models incorporating regressors for linear trend and baseline shifts. A hemodynamic response shape was assumed (SPM canonical function) and used to derive magnitude estimates relative to fixation baseline. Each scan run consisted of 45 stimuli, 5 from each of the 9 conditions. Each stimulus was presented for 2500ms, followed by an intertrial interval (ITI) ranging between 500 and 6500ms (28).

MRI Data Acquisition—Structural and functional scanning was performed on a 3.0 Tesla TIM TRIO Siemens whole body system. BOLD images during face processing were acquired with a T2*-weighted asymmetric spin-echo echo-planar sequence (TR = 3000 ms, TE = 27 ms, flip angle = 90°, FOV = 256 mm, voxel size = 4×4×4 mm) in the axial plane paralleling to the anterior-posterior commissure, with a 12-channel head coil. During each functional run, 99 sets of 36 contiguous axial images with isotropic voxels (4mm³) were acquired parallel to the anterior-posterior commissure plane.

fMRI Data Processing—We preprocessed fMRI data using standard steps including: (1) compensation for slice-dependent time shifts, (2) removal of first 5 images of each run to allow BOLD signal to reach steady state, (3) elimination of odd/even slice intensity differences due to interpolated acquisition, (4) realignment of data acquired in each subject within and across runs to compensate for rigid body motion, (5) intensity normalization to a whole brain mode value of 1,000, (6) registration of the 3D structural volume (T1) to the atlas representative template in the Talairach coordinate system (35) using a 12-parameter affine transform and re-sampling to 1mm cubic representation (36,37), (7) coregistration of the 3D fMRI volume to the T2, and the T2 to the participants structural image, (8) transformation of the fMRI volumes to atlas space using a single affine 12-parameter transform, and (9) spatial smoothing using a 6mm full-width half-maximum Gaussian filter. The common atlas template was optimized for children in our age range; the use of co-registration to this type of common template space has been validated in several prior studies (38,39).

Previously validated “motion scrubbing” procedures adapted for fMRI data were used to remove artifacts due to head motion (40,41). As discussed and validated previously for use in this sample (42), the motion-scrubbing procedure assesses frame-wise displacement based

on the parameters used in preprocessing step 4. This represents the differential head motion from one acquisition frame to the next summing across linear (x, y, z) and rotational displacements (yaw, pitch, and roll, where degrees of rotation are converted to millimeters of movement by calculating displacement on the surface of a sphere with a radius of 50 mm). Any frame with a sum displacement greater than 0.9 mm was masked out of the analysis.

A Priori Region of Interest Definitions—As a measure of activation to emotional faces, we examined responses to sad faces versus neutral faces in a previously identified network of brain regions (43,44) associated with emotion responsivity. This network of regions included the bilateral amygdala and other regions that show positive resting-state functional connectivity with the amygdala, including hippocampal, parahippocampal, striatal, and temporal regions (emotion reactivity network; Table I, available at www.jpeds.com). For each region, we created a spherical region of interest, 12mm in diameter, around its centroid, listed in Table I. Magnitude estimates of the response to sad versus neutral faces were averaged across all of the ROIs within the emotional reactivity network to create an overall estimate of responses in those regions.

Statistical analyses

Analyses were conducted using SPSS version 21 (SPSS Inc., Chicago, IL). Repeated data on all covariates, main predictors (e.g. emotion identification ability), and the outcome variable (BMI percentile) were available; therefore, we analyzed change in BMI percentile across time (i.e. using all three scan assessments) using multilevel linear mixed (MLM) models (45) to account for dependencies due to repeated measurements. Each model looked at the ability of happiness identification, sadness identification, or activation in emotional reactivity brain regions to sadness and happiness as predictors (i.e., each were assessed at three time points) of both the main effect and slope (rate of change) in BMI percentile across time. Fixed effects were included in each MLM for time (i.e., within-individual change over time in BMI percentile across the three scan assessments), correct happiness identification, correct sadness identification, or emotional reactivity to sadness and happiness, and the interactions between time and emotion identification or emotional reactivity to examine the influence of these factors on changes in BMI percentile over time. All models included puberty, gender, ethnicity, IQ score, exposure to antipsychotic medication, family income-to-needs ratio, externalizing dimensional symptoms, internalizing dimensional symptoms, and depressive symptoms as covariates. Prior to conducting analyses with the predictors of interest (e.g. emotion identification and activation in brain regions), we ran a model that included only the covariates above to determine which exerted significant influence on BMI percentiles. None of the covariates had a significant effect on BMI percentile. However, given the theoretical and empirical support for both puberty and ethnicity being associated with differences in the rates of increase in BMI/BMI percentiles, we chose to include interactions between these predictors and time in our final model. All continuous predictors were mean-centered. Random effects for the BMI percentile intercept and slope for time were included to account for individual variability in mean levels of BMI percentile and rate of change in BMI percentile.

Results

Descriptive statistics for all variables at each scan are presented in Table II (available at www.jpeds.com). At Scan 1, participants were between the ages of 7-13. 108 participants were white and 94 participants were African American or Biracial.

Performance Based Measures of Emotion Identification of Faces in Relation to BMI

We examined correct happiness and sadness identification as predictors of the level and change in BMI percentile across time in two separate MLMs, controlling for the covariates above. We also conducted MLM's removing children with extremely low (e.g. $\leq 3^{\text{rd}}$ percentile) or extremely high (e.g. $\geq 99^{\text{th}}$ percentile) BMI's and with age as covariate instead of pubertal status. Substantive interpretations of the estimates of interest (all p 's below .05) and model fit did not change (Table IV and Table V; available at www.jpeds.com). Therefore, to maintain statistical power, we chose to retain participants with extremely low or high BMI percentiles in the final analyses. We also chose to retain puberty in our analyses, as this has been shown to be more associated with increases in BMI (e.g., 46) and brain alterations (e.g., 47) than age. There were main effects for correct happiness and sadness identification indicating an association with average BMI percentiles at Scan 1 (Table III; available at www.jpeds.com). These main effects were qualified by interactions between emotion identification and time in predicting BMI percentile. The negative coefficient associated with each interaction term indicates that the changes in BMI percentile over time tends to be more strongly negative for individuals with more correct happiness and sadness identification. In addition, these interactions suggest that youths who had lower correct identification of either happiness or sadness showed increases in their in BMI percentiles across time (Figure 1, A and B).

To aid in the interpretation of this effect, we tested the significance of the simple slopes at 1SD below the mean, mean, and 1SD above the mean of happiness and sadness identification. For happiness, the simple slope was 1.16 at -1SD ($p = 0.56$), -1.95 at the mean of happiness identification ($p = 0.35$), and -5.05 at +1SD ($p = .06$). Thus, as happiness identification ability increases, the slope of BMI across time becomes more strongly negative. The region of significance for happiness identification ranges from -12.69 to 4.79; Approximately 14% of our sample had values of happiness identification (*centered*) falling outside of this range indicating a simple slope that is significantly different from zero. This suggests that the rate of decrease in BMI percentile would be significant for relatively high levels of correct happiness identification.

For sadness, the simple slope was 1.43 at -1SD ($p = 0.51$), -2.04 at the mean of sadness identification ($p = 0.31$), and -5.51 at +1SD ($p = .03$). Thus, as sadness identification ability increases, the slope of BMI across time becomes more strongly negative. The region of significance for sadness identification ranges from -7.26 to 2.22; Approximately 34% of our sample had values of sadness identification (*centered*) falling outside of this range indicating a simple slope that is significantly different from zero. This suggests that the rate of decrease in BMI percentile would be significant for relatively high levels of correct sadness identification.

Neural Activation in Emotional Reactivity Regions to Sad and Happy Faces

Next, we examined functional brain activation in emotional reactivity regions to sad and happy faces as predictors of the level and change in BMI percentile across time, again controlling for the same variables above (Table III). No significant effects were found for reactivity to happiness on BMI percentile (Figure 1, D). There was a significant main effect for sadness reactivity on BMI percentile, indicating an association with BMI at Scan 1. This main effect was qualified by an interaction between sadness reactivity and time. The negative coefficient associated with each interaction term indicates that the changes in BMI percentile over time tends to be more strongly negative for individuals with less reactivity to sad faces. In addition, this interaction suggests that youths with greater brain activation in emotional reactivity regions to sad faces had increases in BMI percentile over time (Figure 1, C).

To aid in the interpretation of this effect, we tested the significance of the simple slopes at 1SD below the mean, mean, and 1SD above the mean of reactivity to sadness. The simple slope was -1.34 at -1SD ($p = 0.47$), 1.03 at the mean of reactivity to sadness ($p = 0.50$), and 3.16 at +1SD ($p = .08$). Thus, as reactivity to sadness increases, the slope of BMI across time becomes more strongly positive. The region of significance for reactivity to sadness ranges from -1.52 to 0.27; Approximately 8% of our sample had values of sadness reactivity (*centered*) falling outside of this range indicating a simple slope that is significantly different from zero. This suggests that the rate of increase in BMI percentile would be significant for relatively high levels of sadness reactivity.

Exploratory Analyses

Based on BMI percentile at Scan 1, we grouped children as being healthy '0' (e.g. BMI percentiles ≤ 84.99) or overweight/obese '1' (e.g. BMI percentiles ≥ 85) at the time of scan 1. In order to determine whether these findings were driven by healthy or overweight/obese children, we ran our MLM models separately for each group. Group differences emerged for sadness identification, such that the interaction between sadness identification and time was only significant for children in the overweight/obese group at Scan 1 ($B = -1.55$, $t = -2.84$, $p < .01$). Among children who were overweight/obese at Scan 1, those who were able to accurately identify sad faces showed a decline in their BMI percentile across time, whereas those who were worse at identifying sad faces showed an increase in their BMI percentile across time (Figure 2).

To aid in the interpretation of this effect, we tested the significance of the simple slopes at 1SD below the mean, mean, and 1SD above the mean of sadness identification among children who were overweight/obese. The simple slope was 0.74 at -1SD ($p = 0.79$), -3.69 at the mean of identification to sadness ($p = 0.07$), and -8.12 at +1SD ($p < .001$). Thus, as sadness identification ability increases, the slope of BMI across time becomes more strongly negative. The region of significance for sadness identification ranges from -11.29 to 0.19; Approximately 30% of obese children in our sample had values of sadness identification (*centered*) falling outside of this range indicating a simple slope that is significantly different from zero. This suggests that the rate of decrease in BMI percentile would be significantly faster for high levels of correct sadness identification.

Discussion

This study used both neural measures of emotion reactivity and performance based measures of emotion identification to predict changes in the developmental trajectories of BMI percentiles in youth. These findings suggest that decreased ability to accurately recognize happiness and sadness in others and increased reactivity to sad faces are related to increases in BMI percentiles throughout childhood. Conversely, increased ability to accurately recognize happiness and sadness in others and decreased reactivity to sad faces are related to decreases in BMI percentiles throughout childhood. Among the children who were overweight or obese, increased ability to recognize sad faces also led to a faster rate of decline in their BMI across time. These findings emerged even when dimensional measures of psychopathology and other key factors that could contribute to BMI percentiles were accounted for in the analyses. Such findings provide data that could meaningfully inform intervention efforts aimed at stabilizing the rate of increase or even enhancing the rate of decrease in the trajectories of BMI in youth on pathways toward obesity.

We found that in children, poor ability to correctly identify sad and happy faces predicted increases in BMI percentiles across time and above average ability to correctly identify sad and happy faces predicted decreases in BMI percentiles across time, while controlling for symptoms of psychopathology and relevant demographic variables. Of note, the significance of these interactions occurred primarily at the extremes of happiness and sadness identification (eg, very high and low values) indicating that for most youth who are average on emotion identification ability, there is not a significant association with BMI percentile changes across time. This finding in a sample youth with varying BMI is consistent what has been shown in obese children and adults who show reduced awareness of their own and others emotions (6,7,48) and adds to the growing body of literature linking social-emotional processing deficits with eating disorders (49,50). The current findings advance our understanding of the dynamic interplay between social-emotional development and physical well-being by showing that poor facial emotion recognition ability may be one pathway toward accelerated weight gain across childhood, possibly contributing to obesity in adolescence or early adulthood. Furthermore, these findings offer an alternative approach to weight management or loss among children at-risk for developing obesity, namely, focusing on the accurate recognition of emotions.

Additional fMRI results indicate that greater neural activation to sad, but not happy faces in brain regions within the emotional reactivity brain network predicted increases in BMI percentiles across time, whereas less neural activation to sad faces in the same brain regions predicted decreases in BMI percentiles across time, again controlling for clinical and other relevant variables. The significance of this interaction also occurred at the extreme values of sadness reactivity and there was not a significant relation between BMI percentile changes and sadness reactivity for youth who evidence average sadness reactivity. Differences in the brain function of youth with more rapidly increasing BMI percentile trajectories, as evidenced by greater neural responses to sad faces in the emotional reactivity network, may indicate difficulty with regulation of negative emotion arising from top-down brain regions thought to modulate activation of emotion reactivity regions. Past work indicates greater reactivity to food-related imagery among obese individuals (8), but this is one of the first

study to link BMI trajectories across development in youth to neural responses to non-food related emotional stimuli.. Thus, obese youth and those at-risk for obesity as a function of rapidly increasing BMI may show deficits in emotion awareness, particularly sadness, not restricted to food.

Taken together, these findings suggest that reduced emotion identification ability, particularly within the context of increased neural reactivity in the emotional processing brain regions may place youth at risk for increasing BMI. Youth may be experiencing heightened brain-based reactivity to emotional faces and at the same time be unable to accurately label facial affect, a combination that places an individual at high risk for distress and impairment. Furthermore, results from this study suggest that among youth who are already overweight or obese, those who exhibit increased ability to identify facial emotions show a faster rate of decline in their BMI percentiles over time. Additional longitudinal research linking responses in these brain regions to emotion identification performance and BMI throughout childhood that accounts for other key psychosocial, genetic and metabolic risk factors, such as physical activity and family history of obesity is warranted.

This study could not assess more broad family-level factors that have been shown to be associated with childhood obesity, such as parental obesity. Despite this limitation, it is unlikely that such family-level factors would entirely account for the relationships found in this study. Although evidence exists for substantial heritability in both obesity (51) and facial affect processing (52), environmental factors also make significant contributions. It is crucial that future work continue to explore the unique and shared contributions of family- and child-level factors that influence changes in BMI over time. Genetic contributions to BMI were not measured in this study and additional work is needed on the genetic contributions to obesity and how family- and child-level factors may influence heritability. Although the number of participants in this study is large for neuroimaging work, the sample is relatively small for assessing obesity. In addition, the study sample contains a high proportion of children with psychopathology, however this was accounted for in the analysis. Furthermore, given the relatively small number of children with extremely low BMI percentiles, these data cannot inform whether similar patterns may be exhibited among youth at-risk for other eating pathology, such as anorexia.

This study significantly adds to the limited research on developmental trajectories of emotion awareness, emotional reactivity, and BMI percentiles in youth using a racially and socioeconomically diverse sample. One strength of this study is the use of two objective emotion paradigms that were repeated across time: one that is behavioral/performance based and another that captures neural reactivity to sad faces through fMRI. Consistent findings were shown for both tasks indicating that both emotion recognition and greater neural responses to faces in emotional reactivity brain regions were related to changes in BMI percentiles over time.

Taken together, these findings have implications for the treatment and/or prevention of obesity in youth. Given that youth experienced increases in BMI percentiles when correct emotion identification ability was low, interventions targeting this aspect of emotional competence may be a particularly useful for youth who are overweight or obese. Further

supporting such an approach, youth who were overweight or obese actually showed the fastest rate of decline in their BMI percentiles when their performance on these tasks was high. The ability to accurately label emotions in others may increase awareness of one's own emotions, lessening physiological feelings of distress. Over time, enhanced emotion awareness may decrease episodes of emotionally driven or uncontrolled eating and as a result, stop significant weight gain (4).

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Abbreviations

BOLD	Blood oxygen level dependent
BMI	Body mass index
fMRI	Functional magnetic resonance imaging
MLM	Multi-level model
PDS	Preschool Depression Study

Figure 1.

- a.** Model-implied trajectories of BMI percentiles at low, medium, and high levels of correct happiness identification
- b.** Model-implied trajectories of BMI percentiles at low, medium, and high levels of: correct sadness identification
- c.** Model-implied trajectories of BMI percentiles at low, medium, and high levels of activation to sadness in emotional reactivity regions
- d.** Model-implied trajectories of BMI percentiles at low, medium, and high levels of activation to happiness in emotional reactivity regions across time

Note. Time indicates the scan number such that 1= each child's first scan, 3= child's third scan.

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Figure 2. Model-implied trajectories of BMI percentiles at low, medium, and high levels of correct sadness identification across time among overweight/obese youth

Table 1
Regions included as part of emotion reactivity network

Region	X	Y	Z
Emotion Reactivity Network			
Left Amygdala	-23	-8	-16
Left Hippocampus	-27	-26	-12
Left Inferior Temporal Gyrus	-41	-9	-29
Left Superior Temporal Gyrus	-27	6	-32
Right Amygdala	18	-8	-20
Right Hippocampus	34	-26	-14
Right Parahippocampal Gyrus	18	-23	-14
Right Putamen	25	2	-7
Right Superior Temporal Gyrus	33	10	-28

Table 2

Descriptive Statistics at each Scan

	Scan 1 (n = 172)			Scan 2 (n = 154)			Scan 3 (n = 150)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Age (in years)	10.28	1.27	7-13	11.74	1.20	9-15	12.86	1.16	10-16
Sex (% female)	49			49			49		
Puberty	1.74	0.98	1-4	2.43	1.02	1-4	2.99	0.96	1-5
Ethnicity (% white)	52			52			52		
Externalizing Dimensional Symptoms	4.59	6.03	0-29	3.58	4.89	0-24	2.90	4.83	0-29
Internalizing Dimensional Symptoms	2.29	2.62	0-17	1.71	1.87	0-13	1.38	1.62	0-10
MDD Dimensional Symptoms	2.54	2.13	0-9	1.89	1.71	0-8	1.94	1.62	0-6
Antipsychotic Med (% use)	7			7			7		
Correct Happiness Identification	8.96	4.26	2-17	9.23	3.77	2-18	10.07	3.55	2-18
Correct Sadness Identification	10.63	3.64	3-18	10.80	2.80	4-17	11.43	2.56	5-16
BMI	19.29	4.53	12-38	20.04	4.66	13-41	21.26	5.19	14-43
BMI percentile	60.10	31.23	1.47-99.59	59.56	31.71	1.03-99.62	62.44	30.79	1.29-99.63

Notes: Puberty coded as '1', prepubertal, '2', early puberty, '3', mid-pubertal, '4', late puberty, '5', postpubertal; Gender coded as '1' male, '0' female; Ethnicity coded as '0' White, '1' African American; Happiness and Sadness identification indicates the number of correct trials; BMI = body mass index

Table 3
Fixed Effect Estimates from the Multilevel Models Predicting Change in BMI Percentile from Emotion Identification and Emotional Reactivity

Effect	B	SE	t	df	p
<i>Happiness</i>					
Intercept	76.80	9.72	7.90	305.15	<.001
Scan	-1.95	2.06	-0.94	172.73	ns
Sex	1.11	4.61	0.24	185.68	ns
Puberty	-2.35	2.79	-0.84	174.36	ns
Ethnicity	-21.25	7.92	-2.68	237.35	.01
IQ	0.23	0.18	1.29	183.13	ns
Income-to-Needs	0.36	2.02	0.18	314.61	ns
Externalizing Dimensional Symptoms	0.42	0.30	1.40	210.06	ns
Internalizing Dimensional Symptoms	-0.29	0.75	-0.39	188.90	ns
MDD symptoms	0.80	0.68	1.17	183.86	ns
Antipsychotic use	-4.88	8.25	-0.59	283.50	ns
Correct Happiness ID	1.42	0.79	1.80	168.48	.07
Puberty*Scan	1.40	1.17	1.19	159.56	ns
Ethnicity*Scan	2.63	2.67	0.99	156.71	ns
Happiness ID*Scan	-0.82	0.34	-2.39	161.75	.02
<i>Sadness</i>					
Intercept	77.14	9.57	8.06	304.01	<.001
Scan	-2.04	2.00	-1.02	173.85	ns
Sex	1.22	4.63	0.26	186.96	ns
Puberty	-2.81	2.78	-1.01	172.48	ns
Ethnicity	-20.71	7.60	-2.72	237.72	.01
IQ	0.19	0.18	1.05	184.79	ns
Income-to-Needs	0.47	2.02	0.23	316.83	ns
Externalizing Dimensional Symptoms	0.49	0.30	1.64	205.50	ns
Internalizing Dimensional Symptoms	-0.44	0.74	-0.60	185.69	ns
MDD symptoms	0.93	0.68	1.37	180.86	ns

Effect	B	SE	t	df	p
Antipsychotic use	-4.71	8.25	-0.57	289.31	ns
Correct Sadness ID	2.85	0.98	2.92	169.13	.00
Puberty*Scan	1.51	1.17	1.29	158.47	ns
Ethnicity*Scan	2.08	2.52	0.83	154.87	ns
Sadness ID*Scan	-1.21	0.44	-2.78	162.27	.01
<u>Emotional Reactivity to Sadness</u>					
Intercept	64.89	8.68	7.48	268.44	<.001
Scan	0.91	1.52	0.60	173.31	ns
Sex	3.47	4.52	0.77	187.17	ns
Puberty	-0.10	2.07	-0.05	186.30	ns
Ethnicity	-7.96	6.38	-1.25	190.26	ns
IQ	0.19	0.18	1.05	187.19	ns
Income-to-Needs	-0.08	1.80	-0.05	369.10	ns
Externalizing Dimensional Symptoms	0.53	0.30	1.80	299.26	.07
Internalizing Dimensional Symptoms	-0.57	0.60	-0.95	239.94	ns
MDD symptoms	0.46	0.63	0.73	246.68	ns
Antipsychotic use	-1.73	7.59	-0.23	264.09	ns
Sadness reactivity	-26.36	12.10	-2.18	213.89	.03
Puberty*Scan	0.39	0.91	0.43	186.34	ns
Ethnicity*Scan	-3.20	1.85	-1.74	129.69	.09
Sadness reactivity*Scan	12.99	6.16	2.11	210.69	.04
<u>Emotional Reactivity to Happiness</u>					
Intercept	66.66	8.66	7.70	267.54	<.001
Scan	0.87	1.53	0.57	172.61	ns
Gender	3.59	4.50	0.80	187.05	ns
Puberty	-0.10	2.09	-0.05	186.21	ns
Ethnicity	-8.64	6.32	-1.37	191.80	ns
IQ	0.20	0.18	1.09	188.24	ns
Income-to-Needs	-0.32	1.81	-0.17	370.25	ns
Externalizing Dimensional Symptoms	0.46	0.30	1.55	301.74	ns
Internalizing Dimensional Symptoms	-0.49	0.60	-0.81	242.00	ns

Effect	B	SE	t	df	p
MDD symptoms	0.40	0.64	0.63	250.83	ns
Antipsychotic use	-3.68	7.59	-0.48	260.73	ns
Happiness reactivity	1.55	13.72	0.11	206.16	ns
Puberty*Scan	0.38	0.92	0.41	187.30	ns
Ethnicity*Scan	-2.87	1.86	-1.54	128.77	ns
Happiness reactivity*Scan	-2.70	6.68	-0.40	200.51	ns

Notes. Scan denotes scan number across time; Sex coded as '1' male, '0' female; Ethnicity coded as '0' White, '1' African American; Happiness and Sadness identification indicates the number of correct trials; BMI = body mass index.

Table 4
Fixed Effect Estimates from the Multilevel Models Predicting Change in BMI Percentile from Emotion Identification and Emotional Reactivity with Extremely Low and High BMI percentiles removed

Effect	B	SE	t	df	p
<i>Happiness</i>					
Intercept	77.97	9.76	7.98	301.29	.00
Scan	-2.37	2.13	-1.11	169.06	.27
Sex	.28	4.59	.06	182.23	.95
Puberty	-1.78	2.85	-.62	172.09	.53
Ethnicity	-21.00	7.93	-2.65	227.14	.01
IQ	.22	.18	1.22	178.16	.23
Income-to-Needs	.36	2.05	.17	310.56	.86
Externalizing Dimensional Symptoms	.43	.31	1.41	207.12	.16
Internalizing Dimensional Symptoms	-.47	.77	-.62	186.92	.54
MDD symptoms	.91	.70	1.30	182.00	.19
Antipsychotic use	-5.09	8.25	-.62	276.58	.54
Correct Happiness ID	1.42	.81	1.75	165.30	.08
Puberty*Scan	1.23	1.21	1.02	156.46	.31
Ethnicity*Scan	2.95	2.73	1.08	151.89	.28
Happiness ID*Scan	-.80	.36	-2.25	157.92	.03
<i>Sadness</i>					
Intercept	77.74	9.62	8.08	299.35	.00
Scan	-2.35	2.07	-1.14	169.78	.26
Sex	.35	4.62	.08	182.53	.94
Puberty	-2.29	2.87	-.80	170.18	.42
Ethnicity	-20.20	7.63	-2.65	227.23	.01
IQ	.17	.18	.97	179.07	.33
Income-to-Needs	.37	2.05	.18	311.55	.86
Externalizing Dimensional Symptoms	.48	.30	1.60	201.93	.11
Internalizing Dimensional Symptoms	-.62	.76	-.82	183.44	.42
MDD symptoms	1.04	.70	1.50	178.93	.14

Effect	B	SE	t	df	p
Antipsychotic use	-4.63	8.26	-.56	281.37	.57
Correct Sadness ID	2.81	1.01	2.79	165.50	.01
Puberty*Scan	1.34	1.22	1.09	154.91	.27
Ethnicity*Scan	2.35	2.578	.91	149.34	.36
Sadness ID*Scan	-1.14	.45	-2.52	159.12	.01
<u>Emotional Reactivity to Sadness</u>					
Intercept	65.01	8.63	7.53	263.32	.00
Scan	.65	1.53	.42	169.17	.67
Sex	2.43	4.51	.54	184.10	.59
Puberty	.27	2.10	.13	179.68	.90
Ethnicity	-7.07	6.36	-1.11	184.56	.27
IQ	.17	.18	.96	184.55	.34
Income-to-Needs	-.08	1.85	-.04	366.65	.97
Externalizing Dimensional Symptoms	.54	.30	1.80	295.08	.07
Internalizing Dimensional Symptoms	-.65	.62	-1.04	240.82	.30
MDD symptoms	.46	.64	.72	242.97	.47
Antipsychotic use	-1.21	7.56	-.16	259.97	.87
Sadness reactivity	-27.46	12.51	-2.20	212.66	.03
Puberty*Scan	.33	.92	.36	181.05	.72
Ethnicity*Scan	-3.13	1.87	-1.67	127.56	.09
Sadness reactivity*Scan	13.46	6.34	2.13	209.60	.04
<u>Emotional Reactivity to Happiness</u>					
Intercept	66.63	8.62	7.73	262.19	.00
Scan	.65	1.54	.42	167.95	.67
Gender	2.59	4.48	.58	183.89	.56
Puberty	.35	2.12	.17	180.31	.87
Ethnicity	-7.64	6.30	-1.21	186.09	.23
IQ	.18	.18	.99	185.74	.32
Income-to-Needs	-.23	1.86	-.12	366.50	.90
Externalizing Dimensional Symptoms	.48	.30	1.60	298.64	.11
Internalizing Dimensional Symptoms	-.61	.63	-.96	243.46	.34

Effect	B	SE	t	df	p
MDD symptoms	.38	.65	.59	247.53	.56
Antipsychotic use	-3.10	7.55	-.41	256.55	.68
Happiness reactivity	.78	13.85	.06	200.20	.96
Puberty*Scan	.30	.93	.33	182.20	.74
Ethnicity*Scan	-2.86	1.88	-1.52	126.16	.13
Happiness reactivity*Scan	-2.48	6.75	-.37	194.89	.71

Notes. Scan denotes scan number across time; Sex coded as '1' male, '0' female; Ethnicity coded as '0' White, '1' African American; Happiness and Sadness identification indicates the number of correct trials; BMI = body mass index.

Table 5
Fixed Effect Estimates from the Multilevel Models Predicting Change in BMI Percentile from Emotion Identification and Emotional Reactivity with Age as a Covariate Instead of Puberty

Effect	B	SE	t	df	p
<i>Happiness</i>					
Intercept	78.25	9.80	7.99	298.65	.000
Scan	-2.01	2.69	-.75	299.12	.46
Sex	2.56	4.53	.56	181.39	.57
Age	-.12	2.82	-.04	209.47	.97
Ethnicity	-19.81	7.84	-2.53	235.50	.01
IQ	.24	.18	1.33	185.48	.19
Income-to-Needs	.48	2.03	.24	317.11	.81
Externalizing Dimensional Symptoms	.39	.30	1.32	205.81	.19
Internalizing Dimensional Symptoms	-.37	.75	-.50	190.88	.62
MDD symptoms	.94	.67	1.41	183.66	.16
Antipsychotic use	-7.04	8.03	-.88	282.68	.38
Correct Happiness ID	1.24	.78	1.59	170.15	.11
Age*Scan	.44	.97	.45	152.88	.65
Ethnicity*Scan	1.80	2.58	.70	158.75	.49
Happiness ID*Scan	-.73	.34	-2.17	164.75	.03
<i>Sadness</i>					
Intercept	78.93	9.68	8.15	296.49	.00
Scan	-2.20	2.68	-.82	300.18	.41
Sex	2.48	4.55	.55	181.17	.59
Age	-1.31	2.82	-.46	207.65	.64
Ethnicity	-19.66	7.55	-2.60	234.21	.01
IQ	.20	.18	1.09	186.14	.28
Income-to-Needs	.64	2.03	.32	318.36	.75
Externalizing Dimensional Symptoms	.45	.30	1.54	199.99	.13
Internalizing Dimensional Symptoms	-.50	.74	-.67	186.81	.50
MDD symptoms	1.05	.66	1.58	179.70	.12

Effect	B	SE	t	df	p
Antipsychotic use	-7.00	8.02	-.87	286.89	.38
Correct Sadness ID	2.67	.97	2.75	170.94	.01
Age*Scan	.86	.99	.87	152.83	.38
Ethnicity*Scan	1.45	2.46	.59	157.12	.56
Sadness ID*Scan	-1.14	.43	-2.64	166.71	.01
<u>Emotional Reactivity to Sadness</u>					
Intercept	65.28	9.00	7.26	267.16	.00
Scan	.69	2.31	.30	319.99	.77
Sex	4.05	4.50	.90	183.93	.37
Age	1.36	1.95	.70	265.40	.49
Ethnicity	-7.74	6.36	-1.22	191.84	.22
IQ	.19	.18	1.06	188.28	.29
Income-to-Needs	-.07	1.79	-.04	369.19	.97
Externalizing Dimensional Symptoms	.53	.29	1.82	297.41	.07
Internalizing Dimensional Symptoms	-.61	.59	-1.03	244.36	.31
MDD symptoms	.54	.61	.89	243.41	.38
Antipsychotic use	-1.49	7.59	-.20	264.55	.84
Sadness reactivity	-26.25	12.00	-2.19	213.86	.03
Age*Scan	-.33	.68	-.48	190.33	.63
Ethnicity*Scan	-3.48	1.80	-1.93	127.96	.06
Sadness reactivity*Scan	12.83	6.11	2.10	211.06	.04
<u>Emotional Reactivity to Happiness</u>					
Intercept	67.13	8.99	7.47	266.31	.00
Scan	.55	2.33	.24	319.42	.81
Gender	4.18	4.48	.93	184.25	.35
Age	1.30	1.96	.66	262.27	.51
Ethnicity	-8.39	6.31	-1.33	193.29	.18
IQ	.20	.18	1.10	189.58	.27
Income-to-Needs	-.30	1.80	-.17	370.76	.87
Externalizing Dimensional Symptoms	.46	.29	1.58	299.05	.12
Internalizing Dimensional Symptoms	-.52	.60	-.87	246.40	.38

Effect	B	SE	t	df	p
MDD symptoms	.46	.62	.75	246.44	.45
Antipsychotic use	-3.40	7.59	-.45	261.39	.65
Happiness reactivity	1.03	13.57	.08	206.28	.94
Age*Scan	-.26	.69	-.38	191.49	.71
Ethnicity*Scan	-3.15	1.82	-1.73	128.92	.09
Happiness reactivity*Scan	-2.23	6.63	-.34	202.29	.74

Notes. Scan denotes scan number across time; Sex coded as '1' male, '0' female; Ethnicity coded as '0' White, '1' African American; Happiness and Sadness identification indicates the number of correct trials; BMI = body mass index.