Background and Aims

- Obesity affects more than 850 million adults worldwide and is one of the leading causes of death in first-world countries.

- There are also well-established associations between higher adiposity, elevated impulsivity, and decreased cognitive performance.

- Previous studies have investigated the neural correlates of these obesity-related cognitive effects, and have included studies of gray and white matter volumes; white matter microstructure; or metabolic/functional activity. However, to the best of our knowledge, none have investigated all of these factors in a single cohort.

- Therefore, the primary aim of this study was to identify differences in brain structure and function related to normal individual variability in body composition.

- This was achieved by:
  1. Acquiring two independent measures of body composition - i.e., body mass index (BMI) and body fat percentage (BFP); and
  2. Using these as magnetic resonance imaging measures of local gray matter volume, white matter volume, white matter microstructure, and functional connectivity using voxel-based morphometry (VBM), diffusion tensor imaging (DTI), and resting state functional MRI (rs-fMRI).

Body Composition (BMI and BFP)

- 32 healthy adults were recruited from the community at large and screened for prior neurological or psychiatric trauma or illness, alcohol or drug abuse, etc.

- Participants were recruited to span a broad range of age and weight, although sex was evenly balanced.

- BMI was calculated using height and weight, whereas BFP was measured using a Tanita BC-350 bioelectric impedance scale.

- As shown in both Figure 1 and Figure 2: Age was correlated with BMI (corrected for total intracranial volume, or TIV). BMI ranged from 18 to 37, and BFP ranged from 7.5 to 44.

- BFP, but not BMI, was significantly correlated with age (Figure 2C).

- BMI was significantly correlated with BFP (Figure 2D), but even after regressing out age and gender, there remained a significant correlation between BMI and BFP (Figure 2E).

- After body composition measurements were acquired for each participant, 27 MRI scans were performed.

Gray and White Matter Volumetric Analyses (VBM)

- Processing of whole brain T1-weighted images (1mm isotropic) was performed using SPM8 and the VBM toolbox, and included: unified segmentation; non-linear (DARTEL) normalization to MNI space; image modulation; and 5 mm 3D smoothing.

- By running separate cluster-level GLM analyses for gray and white matter images, we found:
  1. Several gray matter regions (i.e., the thalamus, insula, caudate, hippocampus, precuneus, as well as the prefrontal and parietal cortex) demonstrated significant volume reductions with higher BMI and/or BFP (Figure 3A).
  2. Several white matter regions (i.e., the cingulum, corpus callosum, inferior fronto-occipital fasciculus, inferior and superior longitudinal fasciculi, and regions proximal to the basal ganglia) also demonstrated volume reductions with higher BMI and/or BFP (Figure 3B).
  3. Neither gray nor white matter analyses (corrected for age, gender and intracranial volume) revealed volume increases.

White Matter Microstructural Analyses (DTI)

- Processing of diffusion-weighted images (100 directions; b = 700 – 1000 s/mm²) was performed using Catphan. After motion correction, SPM8, and included: co-registration; gradient orientation; skull stripping; linear (AIR) and non-linear (LDOCB) normalization to MNI space; calculation of fractional anisotropy (FA); mean diffusivity (MD) images; white-matter masking; and 6 mm 3D smoothing.

- By running separate cluster-level GLM analyses for FA and MD images, we found that:
  1. The corona radiata, inferior fronto-occipital fasciculus, inferior longitudinal fasciculus, as well as the orbital frontal and temporal white matter demonstrated significantly reduced FA with higher BMI and/or BFP. Only the left corona radiata showed increased FA (Figure 3A).
  2. The cingulum, corpus callosum, caudate, and precuneus, as well as middle and orbital frontal and paralimbic white matter demonstrated significant increases in MD with higher BMI and/or BFP. No regions exhibited significantly decreased MD (Figure 3B).

Functional Connectivity Analysis (rs-fMRI)

- Processing of resting state BOLD fMRI data (322 volumes; 7.4 minutes) was performed using the SPM8 Con trunk toolbox, and included: head motion correction; spatial normalization; 6 mm 3D smoothing; motion compensation; functional deconvolution; band-pass filtering (0.01–0.08 Hz); and CompCor (motion, white and grey matter, CSF, white and grey matter, and cerebrospinal fluid components.

- Each subject’s network connectivities were calculated by averaging bivariate correlations between all ROIs pairs (taken from a previously published atlas; Figure 5A), and these were plotted against BMI and BFP, correcting for age and gender (Figure 5B-D). Of the three networks investigated (i.e., the DMN, CIN, and SN), we observed:

  1. No significant relationships between DMN or CIN connectivity and either BMI or BFP (Figure 5B-C), and
  2. Significant increased SN connectivity among higher BMI and BFP individuals (Figure 5D).

Discussion and Conclusions

- Although the association between BMI and BFP was not perfect (r² = 0.72), both measures were in good agreement regarding the neural correlates of obesity.

- Total brain size, as well as global gray and white matter volumes were positively correlated with BMI and BFP in our sample (Figure 6). However, many structures exhibited significant volumetric decreases with higher BMI and BFP.

- Several white matter regions also showed decreased FA and/or increased MD (both markers of decreased white matter integrity) among higher BMI and BFP individuals.

- Despite relatively under-developed gray and white matter structures and reduced white matter connectivity proximal to several nodes of the Salience Network (SN), functional connectivity within this network was significantly increased as a function of BMI and BFP.

In summary, we have shown that:

1) two independent measures of body composition (i.e., BMI and BFP) are correlated with aberrant changes in brain structure and functional connectivity, and
2) many of the affected regions/networks offer a biologically plausible explanation for previously reported deficits in reward-processing and cognitive performance.

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Individual differences in brain structure and functional connectivity related to body mass index (BMI) and body fat percentage (BFP)

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