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Original Research

Neuroanatomical correlates of trait gambling-related cognitive distortions

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Abundant evidence suggests that gambling-related cognitive distortions play a crucial role in disruptive gambling behavior. However, to date, there have been few efforts to address the neuroanatomical basis of inter-individual differences in trait gambling-related cognitive distortions. We applied voxel-based morphometry to explore the neuroanatomical correlates of trait gambling-related cognitive distortions by correlating regional gray matter volume with behavioral scores tested by the gambling attitudes and beliefs survey. The results show that individuals with a higher degree of gambling-related cognitive distortion present greater gray matter volume in the frontal orbital cortex, insula cortex, temporal fusiform cortex and precentral gyrus/superior frontal gyrus in the right hemisphere. In contrast, these individuals present reduced gray matter volume in the left putamen, left lateral occipital cortex, right lateral occipital cortex, and right cuneal cortex. These results suggest that trait gambling-related cognitive distortions are influenced by brain regions involved in subjective reward value, interoception, and risk prediction, and explain how gambling-related cognitive distortions lead to persistent involvement in gambling.

Keywords

Gambling-related cognitive distortions; voxel-based morphometry; neuroanatomical correlates; brain mapping

1. Introduction

Gambling-related cognitive distortions refer to the biased processing of chance, probability, and skill in gambling behavior (Ladouceur, 2004; Raylu and Oei, 2002, 2004; Steenbergh et al., 2002; Toneatto, 1999). Examples of cognitive distortions include an illusion of control (the belief that one can influence the outcome of a chance-determined event) (Langer, 1975), and gambler's fallacy, (the belief that future outcomes can be predicted based on past outcomes) (Sundali and Croson, 2006). Thus, individuals with high gambling-related cognitive distortions believe that gambling outcomes can be controlled by luck, personal skill, and past gambling experiences (Breen and Zuckerman, 1999; Raylu and Oei, 2004; Toneatto, 1999). Interestingly, cognitive distortions are observed not only in problem gamblers but also in non-problem gamblers (Ciccarelli et al., 2016; Grant and Bowling, 2015; Joukhador et al., 2004). The term 'problem gamblers' refers to people who have developed disordered gambling behaviors which often cause harm to themselves, their family, and potentially their community (Blaszczynski and Nower, 2002). Non-problem gamblers are individuals who have not been harmed by gambling (Blaszczynski and Nower, 2002). Previous research has argued that gambling-related cognitive distortions are associated with disruptive gambling practices (Oei et al., 2008; Raylu and Oei, 2002, 2004; Steenbergh et al., 2002). Moreover, players with higher levels of irrational gambling cognition tend to engage in riskier gambling practices (Miller and Currie, 2008). Besides, intervention studies have revealed a reduction in pathological gambling after treatment of gambling-related cognitive distortions (Oei et al., 2010; Toneatto and Ladoceur, 2003; Toneatto and Millar, 2004).

Existing studies exploring the neural correlates of gambling-related cognitive distortions have focused mainly on state cognitive distortions (Clark et al., 2009, 2014). Using an established laboratory gambling task, researchers found that a near-miss event--"*a special kind of failure to reach a goal, one that comes close to being successful*" --evoked anterior insula bilaterally and the ventral striatum (Breiter et al., 2001; Chase and Clark, 2010; Clark et al., 2009; Habib and Dixon, 2013; Joutsa et al., 2012; Reuter et al., 2005; Shao et al., 2013). Intriguingly, damage to the insula abolished the near-miss effect (Clark et al., 2014). Additional studies have also found that the effect of state cognitive distortions on responses in a card-guessing task correlates with stronger activation of the lateral prefrontal cortex and greater volume of gray matter (GM) in the striatum and orbitofrontal cortex (OFC) (Gui et al., 2012; Huang et al., 2018).

However, few efforts have been directed to investigate the association between brain function and trait gambling-related cognitive distortions (Clark et al., 2009; Dymond et al., 2014; Lara et al., 2018). One functional MRI (fMRI) study indicated that activation of the anterior insula was associated with non-problem gamblers' trait gambling-related cognitive distortions (Clark et al., 2009). Using magnetoencephalography (MEG) Dymond et al. (2014) showed that trait gambling-related cognitive distortions were related to theta power changes in the right OFC and the anterior insula in both problem gambler and non-problem gambler subjects. It is worth mentioning that only one study to date has examined the neuroanatomical correlates of trait gambling-related cognitive distortions in a sample of 25 adults (Lara et al., 2018). It only explored the relationship between interpretative bias (the *ad hoc* attribution of gambling successes to ability and losses to bad luck) and GM volume in the dorsal anterior cingulate (ACC). In addition to interpretative bias, there is a class of errors that can be identified as trait gambling-related cognitive distortions, including the illusion of control, superstitious beliefs, overconfidence, and gambler's fallacy. Therefore, it is necessary to examine the relationship between trait gambling-related cognitive distortions and brain structure.

Voxel-based morphometry (VBM) was used to explore the neuroanatomical correlates of trait gambling-related cognitive distortions by studying the correlation between GM volume and individual differences in cognitive distortions among participants. The gambling attitudes and beliefs survey (GABS) was used to measure trait gambling-related cognitive distortions (Breen and Zuckerman, 1999). GABS has been designed to "*capture a wide range of cognitive biases, irrational beliefs, and positively valued attitudes to gambling*", and has been validated by many studies as a measure of trait gambling-related cognitive distortions (see, e.g. Goodie and Fortune, 2013; Strong et al., 2004). We hypothesize a correlation between individual behavioral differences and GM volume within multiple brain regions which is in accordance with previous fMRI and MEG studies, including the striatum, insula, OFC, and ACC (Clark et al., 2009; Dymond et al., 2014; Lara et al., 2018).

2. Material and methods

2.1 Participants

All data were obtained from the OpenfMRI database (https://openfmri.org/), accession number: ds000009. Twenty-four participants (10 females, 14 males; mean age: 20.8 years; right-handed) were included in the data analysis. Each participant's behavioral scores from GABS (see below) and T1-weighted MRI images were collected. No participants reported mental and neurological disorders.

2.2 Assessment of gambling-related cognitive distortions

Gambling-related cognitive distortions were assessed using GABS, which contains 35 queries such as, "*If I have not won any of my bets for a while, I am probably due for a big win*", and "*No matter what the game is, there are betting strategies that will help you win*" (Breen and Zuckerman, 1999). Participants were asked to use a four-point Likert scale (from '*strongly agree*' to '*strongly disagree*') to indicate the extent to which they agree with each query. Total scores falling in the range between 35 and 140 are considered to be valid. A higher score indicates the perception of gambling as a positive, exciting experience in which luck and strategy are important. Thus, the higher the score, the greater the cognitive bias toward gambling, and the more likely the participant is to gamble frequently. Previous studies have proved the high reliability, convergent validity and discriminative success of GABS (Breen et al., 2001; Grant and Bowling, 2015; Strong et al., 2004; Tanner and Mazmanian, 2016).

2.3 MRI data acquisition

Structural MRI scans were carried out on a Siemens 3T Trio scanner located at the Ahmanson-Lovelace Brain Mapping Center at the University of California, Los Angeles. A magnetization-prepared rapid-acquisition gradient echo (TR = 1900 ms, TE = 2.26 ms, matrix 256 $\times$ 256, eld of view 250) was applied to obtain 3D T1-weighted whole-brain structural images. As well 176 contiguous sagittal slices were produced, with 1 mm slice thickness, for whole-brain coverage.

2.4 Voxel-based morphometry (VBM) analysis

VBM was used to determine GM volume for every voxel at the whole-brain level (Ashburner and Friston, 2000). MRI data were processed using SPM8 (Statistical Parametric Mapping, Wellcome Department of Imaging Neuroscience, London, UK). First, a primary evaluation of image quality was conducted by manual visual examination. Second, the origin of the brain was set to the anterior commissure for better registration. Third, a unified segmentation approach was employed to classify images into GM, white matter, cerebrospinal fluid, and everything else (e.g., skull and scalp) (Ashburner and Friston, 2005). Fourth, diffeomorphic anatomical registration through exponential lie algebra (DARTEL) was used for registration (Ashburner, 2007). A study-specific template was created based on average tissue probability maps from all participants, following which all participants' GM images were normalized to this template in MNI152 space. Fifth, GM voxel values were modulated by multiplying the Jacobian determinants to conserve regional differences in the GM volume. The modulated GM images were then smoothed with a Gaussian kernel of 8-mm full width at half maximum (FWHM). Lastly, the threshold for absolute masking was set to 0.2, to mask the modulated images to exclude noise. GM images modulated through this masking process were sent for downstream statistical analyses.

2.5 Statistical analyses

A general linear model (GLM) was implemented for statistical analysis. To analyze the correlation between neuroanatomical structure and individual differences in gambling-related cognitive distortions, self-reported GABS scores were used as variables of interest, while the GM volume in each voxel was considered the dependent variable, with age and gender as confounding covariates. Monte Carlo simulation with a corrected significance threshold of $p < 0.05$ was used to correct for multiple comparisons of the results. Specifically, a combination of the voxel-wise threshold, $p < 0.01$, and a cluster size of > 129 voxels was used to determine the threshold. As smaller clusters within small subcortical structures could be missed, we examined statistical maps before applying the cluster size threshold but did not find any other clusters. Finally, to see how the combined GM volume of multiple regions predicted GABS scores, we used support vector regression and leave-one-out cross-validation test. To measure the performance of the prediction, a correlation between predicted and actual GABS scores was applied.

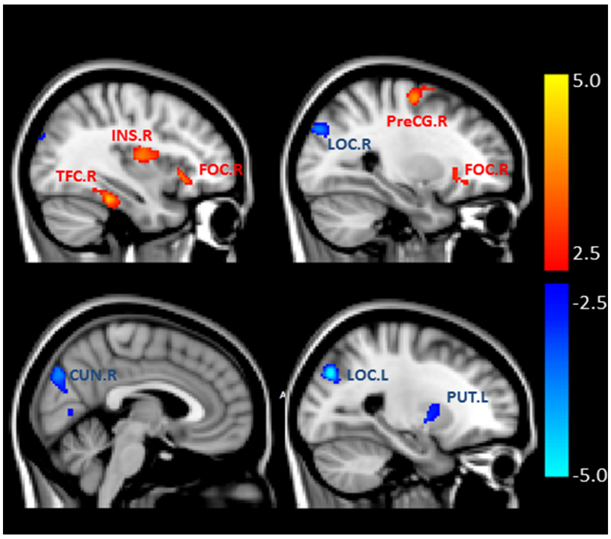

Figure 1. Specific brain regions displayed a positive correlation between GM volume and GABS score (corrected $p < 0.05$). These regions are labeled as follows: TFC.R: the right temporal fusiform cortex, posterior division; INS.R: the right insular cortex; OFC.R: the right frontal orbital cortex; PreCG.R: the right precentral gyrus/superior frontal gyrus; CUN.R: the right cuneal cortex; LOC.L: the left lateral occipital cortex, superior division; LOC.R: the right lateral occipital cortex, superior division; PUT.L: the left putamen.

3. Results

GABS scores of each participant were taken as an index of their trait gambling-related cognitive distortions -- the higher the score, the greater the cognitive bias toward gambling, and the greater likelihood of gambling frequently. The normality of data was determined by kurtosis (0.93) and skewness (0.04) of the GABS scores. The GABS scores ranged from 63 to 105 (mean = 83.22; SD = 9.03), suggesting a high degree of individual differences. No significant differences were detected in GABS scores between male and female participants (t (22) = -1.56, $p = 0.13$, $BF_{10} = 0.84$).

Next, we explored the potential relationship between brain structures and observed individual differences in GABS scores. We determined the correlation between participants' GABS scores and the GM volume of each voxel at the whole-brain scale, with age and gender as confounding covariates. The results, corrected for multiple comparisons, are shown in Fig. 1. Importantly, GABS scores correlated positively with GM volume of specific clusters in the right OFC (OFC.R; 610 voxels; Peak MNI coordinate: 42, 24, -8; Z = 4.39;), right insula cortex (INS.R; 268 voxels; Peak MNI coordinate: 34, -8, 12; Z = 3.71), right temporal fusiform cortex, posterior division (TFC.R; Peak MNI coordinate: 36, -34, -22; Z = 4.43), and right precentral gyrus/superior frontal gyrus (PreCG.R; Peak MNI coordinate:28, -8, 60; Z = 3.95). Thus, individuals with a high degree of gambling-related cognitive distortions displayed higher GM volume in these regions of the right hemisphere.

Additionally, GABS scores were found to be negatively correlated with GM volume in a statistically significant manner in multiple regions, including the left putamen (PUT.L; 174 voxels; Peak MNI coordinate:-24, -2, 0; Z = 3.17), bilateral lateral occipital cortex, superior division (LOC.L: 241 voxels; -24, -78, 36; Z = 5.17; LOC.R: 308 voxels; 30, -84, 34; Z = 4.03) and right cuneal cortex (CUN.R; 481 voxels; 2, -80, 34; Z = 4.18). These regions tended to have reduced GM volume in individuals with high levels of gambling-related cognitive distortions.

Finally, we determined whether the combined GM volume of 8 regions could predict GABS scores, using support vector regression and leave-one-out cross-validation tests. Remarkably, a significant correlation was found between predicted and actual GABS scores (r = 0.76, $p < 0.0001$ Fig. 2), indicating that variability in gambling-related cognitive distortions can largely be predicted using the brain structural images.

4. Discussion

The relationship between neuroanatomical structure differences and trait gambling-related cognitive distortions in individuals was explored. VBM analysis was performed to correlate the GM volume of each voxel from whole-brain MRI scans with GABS scores of 24 participants. Our results revealed that individuals with higher GABS scores (i.e., higher susceptibility to gambling-related cognitive distortions) showed greater GM volume in right OFC and right insula, but reduced GM volume in left putamen.

Our finding that reduced GM volume in the left putamen correlates with greater GABS scores is in accordance with recent findings that problem gamblers display GM volume reductions in left putamen compared with healthy controls (Fuentes et al., 2015). fMRI studies have also shown an association between the activity of the left putamen and gambling behavior (Fauthbühler et al., 2014; Habib and Dixon, 2013; Reuter et al., 2005). A number of studies have revealed that the putamen participates in the evaluation of action options, guiding the selection of higher-value actions (Balleine et al., 2007; Balleine and O'Doherty, 2010; Corbit and Janak, 2010; Haber et al., 2006; Haber and Knutson, 2010; Lau and Glimcher, 2008; Muranishi et al., 2011; Samejima et al., 2005). Thus, the left putamen may be associated with trait gambling-related cognitive distortions through its involvement in the value assessment of gambling. It is possible that individuals with greater gambling-related cognitive distortions tend to overestimate the value of gambling (e.g., overestimating the likelihood of winning or the positive effects of gambling), leading to continuous involvement in gambling.

As well, our results showed that GABS scores correlate with greater GM volume in the right insula. Activation and theta power changes in the anterior insula have also been implicated previously in trait gambling distortions (Clark et al., 2009; Dymond et al., 2014). The insula is known for its interoceptive functions; it can integrate interceptive states into conscious feelings. Many fMRI studies have demonstrated the involvement of insula in craving and drug urges (Brody et al., 2002; Delgado et al., 2000; Mcbride et al., 2006; Naqvi and Bechara, 2009; Paulus et al., 2003). In addition to brain function abnormalities, GM volume alterations in the insula have also been detected in addicts as compared with healthy controls (Lin et al., 2015; Weng et al., 2013). Intriguingly, neuropsychological research has shown that smokers with damage in the insula were more likely to quit smoking as a result of losing their urges for cigarettes (Naqvi et al., 2007). Similarly, individuals with damage in the insula abolished their gambling-

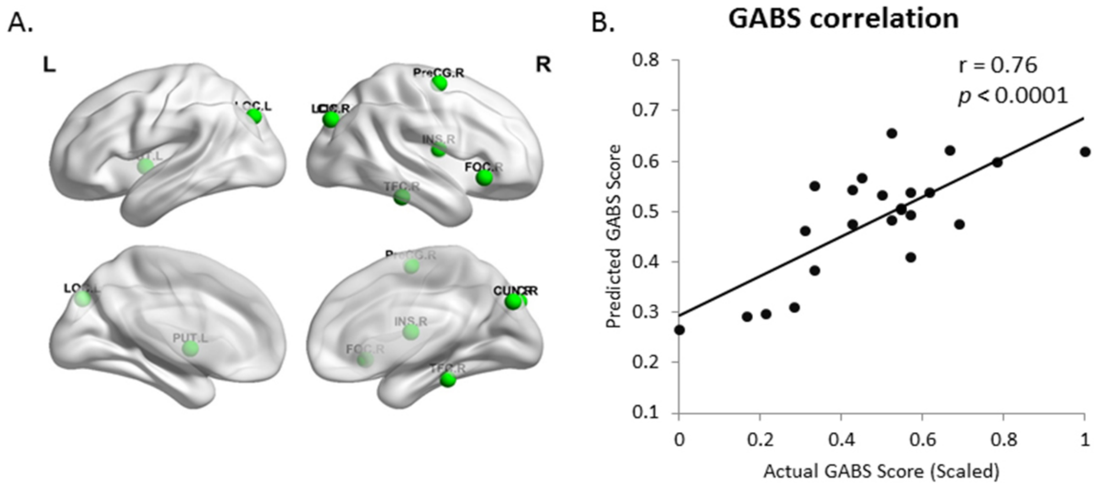

Figure 2. Prediction of GABS scores based on the GM volume of eight regions. (A) Locations of eight regions showing correlation with GABS score. TFC.R: the right temporal fusiform cortex, posterior division; INS.R: the right insular cortex; FOC.R: the right frontal orbital cortex; PreCG.R: the right precentral gyrus/superior frontal gyrus; CUN.R: the right cuneal cortex; LOC.R: the left lateral occipital cortex, superior division; LOC.R: the right lateral occipital cortex, superior division; PUT.L: the left putamen. (B) A scatter plot showing the correlation between actual GABS scores and predicted GABS scores.

related cognitive distortions (Clark et al., 2014). Given that participants reporting higher GABS scores experience more excitement in gambling, it is possible that an increase in GM volume supports the interoceptive functions of insula.

In uncertain environments, the insula is suggested to participate in risk prediction based on the prior outcome. In previous studies, individuals with insula damage displayed difficulty in discriminating risk gains from risk losses and failed to modify their risk behavior based on prior outcome (Clark et al., 2008; Weller et al., 2009). Risk prediction about the uncertainty of environments is relevant to gambler's fallacy (the belief that future outcomes can be predicted based on past outcomes) (Gui et al., 2012). Thus, our study suggests that individuals with higher GABS scores may be more susceptible to gambler's fallacy, as an increase in insula GM volume may impact its role in risk prediction.

Finally, our study showed a positive correlation between GM volume of OFC and GABS scores, in accordance with a prior MEG study demonstrating that theta power changes in the right OFC are associated with trait gambling-related cognitive distortions (Dymond et al., 2014). A VBM study similarly found the increased volume in the right prefrontal cortex in pathological gamblers as compared to controls (Koehler et al., 2015). Previous studies have also provided evidence that OFC-mediated subjective value attribution and was an essential component in adaptive decision making (Breiter et al., 2001; Elliott et al., 2003; Knutson et al., 2000; Tremblay and Schultz, 1999; Valentin et al., 2007). Moreover, neuroimaging studies have demonstrated that problem gamblers show exaggerated activation in OFC because they assigned a greater reward value to gambling outcomes (van Holst et al., 2012). It has been suggested that problem gambling stems partially from impaired competency of the OFC when confronted with negative consequences (Van et al., 2009). Additionally, investigation of drug addiction has implicated lateral OFC in deficient attribution of feedback values (Dom et al., 2005; Goldstein et al., 2007). Together, our results link GM volume in the OFC to trait gambling-related cognitive distortions which cause individuals to overestimate the reward value of gambling, confirming the role of OFC in encoding subjective reward value and predicting subsequent decisions and actions.

In conclusion, trait gambling-related cognitive distortions measured by GABS were associated with increased GM volume in the right OFC, right insula, and left putamen, components of the brain reward system. The right OFC and left putamen to represent subjective value evaluation mechanisms and guide subsequent decisions and actions, while the insula represents risk predictions according to the prior outcome and is known for its interoceptive functions. Therefore, our results suggest that individuals with greater gambling-related cognitive distortions as measured by GABS, tended to overestimate the reward value of gambling (including overestimating the likelihood of winning or the positive effects of gambling) and underestimate its risks. This may explain why gambling-related cognitive distortions may cause gamblers to continue their involvement.

However, given the sample size is relatively small, the results should be considered with caution and must be replicated with a larger sample size (Button et al., 2013) or with multi-site collaboration approaches (Kong et al., 2018). Moreover, as our prediction analysis was based on significant regions from the same dataset, this data interdependence may cause overestimation of prediction performance, though cross-validation tests were applied. Also, our study was based on correlative analyses which do not allow for inferences about causal relationships. Finally, our study did not distinguish between different brain structures underlying various gambling-related cognitive distortions (i.e., the illusion of control and gambler's fallacy) and further investigation is needed to elucidate these details.

Author contributions

H.H.L. conceived the idea and wrote the manuscript. X.Z.K. carried out the statistical analysis. H.H.L., X.Z.K., and F.K revised the paper. All authors reviewed and approved the final manuscript.

Ethics approval and consent to participate

The UCLA Institutional Review Board approved the behavioral and MRI protocols. All subjects gave informed written consent before their participation.

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Conflict of interest

The authors declare no conflict of interest.

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