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Neural correlates of the impact of control on decision making in pathological gambling

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ABSTRACT

Perceived control over a gambling outcome leads individuals to accept more and larger bets, increased risk-taking. Pathological gamblers, however, do not diminish risk-taking when control is absent, suggesting an illusion of control. To evaluate neural correlates of perceived control in gamblers, this study compared magnetoencephalography responses of 36 pathological (PG) and 36 non-pathological gamblers (NPG) during the Georgia Gambling Task.

PGs exhibited greater activity in bilateral primary sensory regions. An interaction between pathology and control over the gambling task was observed bilaterally throughout dorsal and ventral visual processing streams, and lateral PFC. NPGs showed decreased activity when control was absent. Groups did not differ in response to potential bet cost. These findings provide neurophysiological evidence that PGs suffer from the pattern of risk-taking associated with perceived control, even when no control exists. They suggest that gambling pathology contributes to differential processing of gambling stimuli other than potential costs or rewards.

1. Introduction

When individuals perceive an element of control over a gambling situation (i.e., believe actions increase chance of success), they accept more gambling bets at all levels of confidence (Dixon, 2000; Goodie, 2003; Kweitel and Allen, 1998; Moore and Ohtsuka, 1999), even difficult bets (Davis et al., 2000). These findings have implications for pathological gambling (PG), a disorder associated with an illusion of control (Breen and Frank, 1993; Cantinotti et al., 2004; Dickerson, 1993; Fortune and Goodie, 2012; Ladouceur and Gaboury, 1988; Ladouceur et al., 1991; Ladouceur and Walker, 1998; Steenbergh et al., 2002; Toneatto, 1999) and an exaggerated belief in one's ability to determine the outcome of uncertain events (Langer, 1975). Problem gamblers have fewer symptoms than pathological gamblers but also are willing to accept bets as if they have control, even when the relevant control does not exist. Non-problem gamblers abate risky behavior when control is reduced (Goodie, 2005).

Gambling disorder is set to join other addictive disorders in the forthcoming DSM version (APA, 2012), with all members of the category sharing diminished cognitive control as an important clinical feature (Goudriaan et al., 2006). These shared cognitive features imply prefrontal cortex (PFC) circuitry deviations (van den Heuvel et al., 2003; Monchi et al., 2001; MacDonald et al., 2000), including orbitofrontal (OFC), dorsolateral (DL) PFC, and ventromedial (VM) PFC regions (see Fineberg et al., 2009). Indeed, PGs have deficits on risky judgment tasks similar to persons with DLPFC, OFC, and VMPFC lesions (Bechara et al., 1997, 1998; Brand et al., 2005; Cavedini et al., 2002). In addition, PGs' PFC-mediated deficits on response inhibition (Potenza et al., 2003a,b) and hypersensitivity to infrequent rewards (Hewig et al., 2010) could make them more prone to risky behaviors. Hypoactivity in the VMPFC–ventral striatal reward system (Blum et al., 1996) also is negatively correlated with gambling pathology (Reuter et al., 2005), and high-risk choices are known to activate VMPFC circuitry (Van Leijenhorst et al., 2010).

Data implicating PFC in problem gambling-related behaviors is consistent with the top-down regulation requirements of the relevant cognitive operations. It is likely, however, that these regulation requirements begin their influence earlier in the stimulus processing stream. The idea that top-down bias signals (Desimone and Duncan, 1995) begin their influence at the sensory-perceptual stage is well known (Clementz et al., 2010; Desimone and Duncan, 1995; Kastner and Ungerleider, 2000; Maunsell and Treue, 2006).

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Showing how sensory registration differs as a function of task demands and pathological conditions is important for discerning how top-down control supports flexible behavioral regulation and for understanding how such flexibility is limited by pathology.

PGs and NPGs differentially activate dorsal and ventral visual processing streams, with PGs preferentially processing the visual components of gambling cues (Crockford et al., 2005). In response to visual gambling cues, PGs show greater activation in dorsal and ventral visual processing streams, which support identification of cues using spatial processing, visuo-spatial attention, action preparation, and object identification (Kravitz et al., 2011). Increased occipito-parietal activation during decision-making may reflect greater visual attention or resource allocation (Banich, 2004). Findings that PGs exhibit poor task-appropriate hemispheric differentiation (Goldstein et al., 1985) and have right inferior-occipital temporal cortex hypoactivity when responding to stimulus relevance in judgment tasks (Camchong et al., 2007) suggest alterations in the right hemisphere attention system, which may contribute to deficits in proper level of control in cognitive judgment tasks (Goodie, 2005).

Identifying neural correlates of PG would facilitate understanding of the disorder, its relation to other disorders, and possibilities for treatments. Identification of temporal abnormalities in neural activity in PG has been limited by the use of functional magnetic resonance imaging (fMRI) in most PG neuroimaging studies. The temporal resolution of fMRI, with a sampling rate slower than the visual processing pathway's neural transmission time, limits determination of when abnormalities occur in the visual processing stream and whether abnormalities might be a cause or a result of other abnormalities. For investigating the time course and neural correlates of atypical response to conditions of control and non-control in PGs (Goodie, 2005), we had two goals: (1) to describe the neural circuitry underlying perceived control, and (2) to study differences in neural activation associated with perception of control in problem and non-problem gamblers. To accomplish these goals, we used magnetoencephalography (MEG), a functional neuroimaging tool directly measuring neural activity with a temporal resolution in the millisecond range (Wang and Kaufman, 2003).

Two variants of the Georgia Gambling Task (Goodie, 2003) were used to investigate the perception of control. Perceived control existed in one task, as participants' knowledge and reasoning abilities could increase their chances of winning (e.g., like in a game of poker). A second task lacked the element of control, as participants were presented with an uncontrollable probability of winning (e.g., like in roulette). It was hypothesized that the neural activity of NPGs would discriminate between the two conditions, while the neural activity of PGs would not.

2. Methods

2.1. Participants

Participants were 72 University of Georgia undergraduate students (29 females, 43 males) who self-identified as gambling at least once weekly. They received either course credit or monetary compensation for their participation. Participants were right-handed, absent of known neurological disorders, and free of any substance use disorder within the last 6 months. None of the subjects were receiving medication at the time of testing. Participants were administered the Diagnostic Interview for Gambling Severity (DIGS; Winters et al., 2002) and South Oaks Gambling Screen (SOGS; Lesieur and Blume, 1987), measures of gambling pathology which have score ranges of 1–10 and 1–20, respectively. Participants were divided evenly into two groups, non-pathological gamblers (DIGS $\leq$ 1; SOGS $\leq$ 1; N = 36; 23 females) and pathological gamblers (DIGS $\geq$ 5; SOGS $\geq$ 5; N = 36; 6 females). Eight hundred twelve individuals meeting all other criteria were administered the DIGS and SOGS in order to find 82 meeting the diagnostic criteria. Of the latter, 10 completed the entire study but had data that was not used either because of technical issues or an insufficient number of acceptable MEG trials. This project was approved by the University of Georgia Institutional Review Board. All participants provided informed consent.

2.2. Stimuli and procedure

The remainder of the study included behavioral and MEG testing sessions, using variations of the Georgia Gambling Task (Goodie, 2003), which combines overconfidence (an unrealistically optimistic belief about the probability of a favorable outcome) with risk attitude. The behavioral session consisted of a confidence calibration task comprised of a series of U.S. state pairs, which were initially selected at random and then presented in the same order to all participants. Participants sat in front of a data collection computer, running software developed in the Delphi™ environment, and were presented with 180 pairs of states to be compared on the dimension of population. Participants clicked with a mouse on the state that they thought had the larger population, and then assessed their confidence in their answer being correct, by clicking the mouse on one of seven confidence intervals: 50–52%, 53–60%, 61–70%, 71–80%, 80–89%, 90–97% or 98–100%. These methods have been used successfully in our laboratory (Campbell et al., 2004; Goodie, 2003, 2005; Schaefer et al., 2004).

Upon completing the confidence assessment phase, participants were taken to the MEG laboratory for the evaluation of neural activity during performance of a similar judgment task. After being familiarized with the environment and MEG equipment, participants were given instructions for the task. Each participant completed one of two conditions, to which they were assigned randomly (see Fig. 1). Participants in the "Knowledge" condition fixated on a cross at the center of the screen. While the fixation cross stayed on, a previously seen state pair appeared, with their previous answer above and the competing option below fixation (the "Judgment" task phase). Participants were then presented with the number of points that could be lost on that trial (the "Decision" task phase; based on the previously reported confidence level for this state pair population judgment), and then either accepted or rejected the bet with a button press. After bet acceptance or rejection, individuals received accuracy feedback, and then saw their cumulative point score (a higher number of points indicated better performance). The "Random" condition was similar in stimulus sequence except that, rather than state pairs, participants were presented matched uncontrollable probabilities of winning that bet on each trial. These probabilities and the potential point losses were based on trials in the confidence assessment phase, a fact of which the participants were unaware. The element of control exists in the Knowledge condition, as participants' knowledge and reasoning skills can improve their chances of winning. Although participants can choose whether or not to accept bets in the Random condition, they cannot improve their probability of winning, so the element of control is not present in this condition. Each MEG run consisted of 180 trials (the same series and order as in the confidence assessment session) displayed by Presentation software (Neurobehavioral Systems, Inc, Albany, CA). Stimuli were projected on a screen that was 35 cm in front of the participant. A break was provided after 90 trials.

2.3. MEG data acquisition

Three head localization coils (positioned at the nasion, and left and right preauricular points) and Ag–AgCl electrodes (positioned at the outer canthi of each eye, and above and below the left eye for recording of horizontal and vertical eye movements, respectively) were affixed prior to testing. MEG recordings were obtained using a 143 channel CTF OMEGA whole head system (CTF/VSMMedtech Ltd., Coquitlam, BC, Canada). MEG data were recorded continuously, sampled at 600 Hz, with an analog filter bandpass of 0.6–300 Hz. Head shape was digitized using a Polhemus Fastrak (Polhemus Inc., Colchester, VT, USA) for later co-registration of head position relative to MEG sensor locations. An inflatable air bladder was fitted to the subject's head (like a stocking cap) to encourage head stabilization throughout. Head position relative to sensor locations was measured at the beginning and end of testing, with no participant moving more than 3 mm in any plane.

2.4. MEG data preprocessing

Data were then pre-processed following recommendations (with minimal modification) made by Junghöfer et al. (2000). Raw data were visually inspected offline for bad sensor recordings. Bad sensors were interpolated (no more than 5% of sensors for any subject) using a spherical spline interpolation method as implemented in BESA 5.3 (MEGIS Software, Gräfelfing, Germany). Data were digitally filtered from 1 to 100 Hz (6 db/octave rolloff, zero-phase). Artifact adjustment was achieved by using the Independent Component Analysis (ICA) toolbox in EEGLAB 6.0b (Delorme and Makeig, 2004) running under Matlab (Version 7.10, MathWorks, Natick, MA, USA). ICA allows artifact adjustment without spatially distorting the data by using higher-order statistics to produce temporally independent signals in the data (Onton et al., 2006). Independent components with topographies representing saccades, blinks, and heart rate artifact were removed according to published guidelines (Jung et al., 2000).

2.5. Source localization and analysis

Individuals' event-related fields (ERFs) for the Judgment and Decision task phases were constructed by averaging all available trials (see Fig. 2). A three-compartment boundary element method (BEM) realistic head model was constructed in Curry 6 (Neuroscan). For this BEM model, the average triangle edge