Facing temptation: The neural correlates of gambling availability during sports picture exposure

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Abstract

Nowadays, sports betting has become increasingly available and easy to engage in. Here we examined the neural responses to stimuli that represent sporting events available for betting as compared to sporting events without a gambling opportunity. We used a cue exposure task in which football (soccer) fans ($N = 42$) viewed cues depicting scheduled football games that would occur shortly after the scanning session. In the “betting” condition, participants were instructed to choose, at the end of each block, the game (and the team) they wanted to bet on. In the “watching” condition, participants chose the game they would prefer to watch. After the scanning session, participants completed posttask rating questionnaires assessing, for each cue, their level of confidence about the team they believed would win and how much they would enjoy watching the game. We found that stimuli representing sport events available for betting elicited higher fronto-striatal activation, as well as higher insular cortex activity and functional connectivity, than sport events without a gambling opportunity. Moreover, games rated with more confidence towards the winning team resulted in greater brain activations within regions involved in affective decision-making (ventromedial prefrontal cortex), cognitive inhibitory control (medial and superior frontal gyri) and reward processing (ventral and dorsal striatum). Altogether, these novel findings offer a sensible simulation of how the high availability of sports betting in today’s environment impacts on the reward and cognitive control systems. Future studies are needed to extend the present findings to a sample of football fans that includes a similar proportion of female and male participants.

Keywords Sports betting · fMRI · Reward availability · Functional connectivity · Insular cortex

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There has been a rapid proliferation of both online and brick-and-mortar sports betting venues that are readily available and easy to engage with. This all-time gambling availability is likely to be a key environmental factor in triggering the need for or temptation to gamble (Shaffer et al., 2004). With an easy access from a computer, tablet or phone, it is possible to bet everywhere, at every moment, such as before or during a game in play, while simultaneously using different platforms (James, O’Malley, & Tunney, 2016). Since every sporting event is available to bet on, merely viewing cues related to sporting events (e.g., advertisements featuring betting odds) has the potential to drastically increase gambling temptation (e.g., Dwyer, Shapiro, & Drayer, 2017; Dwyer & Weiner, 2018; Hing, Li, Vitartas, & Russell, 2017a; Hing, Russell, & Browne, 2017b; Hing, Russell, Lamont, & Vitartas, 2017c). In other words, exposure to sports betting stimuli might not simply involve perceiving salient cues, but should also trigger more advanced motivational and (monetary) decision-making processes.

The impact of reward availability on neural processes has been previously examined in neuroimaging studies on tobacco

and food (for reviews, see Jasinska, Stein, Kaiser, Naumer, & Yalachkov, 2014; Wilson & Sayette, 2015; Yalachkov, Kaiser, & Naumer, 2012). Hayashi, Ko, Strafella, and Dagher (2013) found that when cigarettes were immediately available, subjective craving was higher and was associated with increased activation within the dorsolateral prefrontal cortex (DLPFC). This region is activated during experimental tasks that involve strategic decision-making and high-order cognitive functions, such as working memory, planning, and inhibitory control (Bechara, 2005; Bickel et al., 2007; McClure & Bickel, 2014; Metcalfe & Mischel, 1999). Consistent with Hayashi et al., smokers who expected imminent access to cigarettes showed greater activation in bilateral DLPFC to smoking-related cues over neutral cues, as compared to those who did not expect such access (McBride, Barrett, Kelly, Aw, & Dagher, 2006; Wilson, Sayette, Delgado, & Fiez, 2005; Wilcox, Teshiba, Merideth, Ling, & Mayer, 2011; Zelle, Gates, Fiez, Sayette, & Wilson, 2017). In a recent study, Blechert, Klackl, Miedl, and Wilhelm (2016) showed that available foods, as compared to unavailable ones, elicited higher palatability ratings, as well as stronger neural activation in the orbitofrontal cortex, amygdala, caudate nucleus, and anterior cingulate cortex. These are all structures that are commonly activated during experimental paradigms that involve motivation and reward-related decision-making (e.g., Bechara, 2005).

Comparable patterns of activations have been observed by previous neuroimaging studies on problem gambling—that is, when samples of problem gamblers viewed casino-related or gambling-related pictures (Crockford, Goodyear, Edwards, Quickfall, & el-Guebaly, 2005; Goudriaan, de Ruiter, van den Brink, Oosterlaan, & Veltman, 2010; Limbrick-Oldfield et al., 2017). Nevertheless, viewing gambling pictures in these studies was not directly linked to an opportunity to gamble during or after the experiment. In some cases, the neural responses associated with cue exposure may have also been mixed with unrelated motor processes, (e.g., such as in Goudriaan et al., 2010, in which subjects pressed a response button when a face appeared on a picture). Hence, although these studies have laid important groundwork for understanding the brain systems underlying gambling cue responding, they did not explicitly model the impact of availability during gambling picture viewing. Moreover, these studies recruited problem gamblers from addiction treatment centers. This could have lowered the motivational saliency of gambling cues in these populations (e.g., Brevers et al., 2017; Jasinska et al., 2014; van Holst, van Holstein, van den Brink, Veltman, & Goudriaan, 2012a). Specifically, it is possible that both the nonavailability of gambling cues and the quitting motivation of abstinent gamblers could lower the motivational salience of gambling cues during cue exposure tasks.

Sescousse, Barbalat, Domenech, and Dreher (2013) explicitly examined the impact of gambling availability on neural

processes. This fMRI study highlighted that (non-treatment-following) problem gamblers, as compared to nongambler healthy controls, exhibited higher ventral–striatal activation when viewing cues that signal the probabilistic occurrence of an upcoming monetary rewards. Importantly, problem gamblers exhibit blunted neural responses when viewing cues that signal the occurrence of another type of rewards (i.e., erotic content pictures). These findings further outline the importance of examining the impact of gambling availability, as well as the relative attractiveness of the gambling cue on the neural response (see also Limbrick-Oldfield et al., 2017).

Therefore, the main goal of this study was to evaluate the availability of gambling cues on neural cue reactivity in football fans. Specifically, we reasoned that making gambling cues available for participants to bet on would represent a sensible simulation of the high availability of ready-to-gamble offers in today's environments. Through this experimental manipulation we aimed to identify the neural correlates of sports betting availability by football fans. Moreover, we also wanted to examine how brain activation was modulated by participants' level of interest (i.e., degree of confidence toward the winning team; and degree of enjoyment directed toward a game) toward each cue presented during the experiment.

Another aim of the present study was to examine the effect of sports betting availability on insular-cortex-centered psycho-physiological interaction. Indeed, activation of the insula has been shown to vary according to the levels of uncertainty or saliency attached to a stimulus (e.g., Burke & Tobler, 2011; Grosenick, Greer, & Knutson, 2008; Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Paulus & Frank, 2006; B. W. Smith et al., 2009; Symmonds, Wright, Bach, & Dolan, 2011; Wu, Bossaerts, & Knutson, 2011; Wu, Sacchet, & Knutson, 2012). The insula has also been identified as an integrative interoceptive site connecting autonomic, affective, and cognitive processing (for reviews, see Craig, 2009; Droutman, Bechara, & Read, 2015a; Droutman, Read, & Bechara, 2015b). Specifically, a growing body of research has indicated that the insula plays a key role in altering the balance between the automatic and deliberative systems (Addicott, Sweitzer, Froeliger, Rose, & McClernon, 2015; Janes et al., 2010; Naqvi & Bechara, 2009, 2010; Naqvi, Gaznick, Tranel, & Bechara, 2014; Noël, Brevers, & Bechara, 2013a, 2013b) and could initiate network switching between the default (ventromedial prefrontal cortex [VMPFC] and posterior cingulate cortex) and central executive (DLPFC and posterior parietal cortex) modes during the identification of salient stimuli (Addicott et al., 2015; Chang, Yarkoni, Khaw, & Sanfey, 2013; Droutman et al., 2015a, b; Menon & Uddin, 2010). Hence, examining insular-centered psycho-physiological interaction should offer a fine-grained analysis of the neural processes triggered by cues that signal gambling availability.

Method

Participants

Forty-two football (i.e., soccer) fans participated in this study (38 males and four females, mean age 23.42 years). All participants gave written informed consent to the experimental procedure, which was approved by the Ghent University Institutional Review Board. This study was performed strictly in accordance with the approved guidelines. All participants were right-handed and had normal or corrected-to-normal vision. They were advised to avoid alcoholic drinks in the 24 h prior to testing.

Participants were recruited on the Internet through advertisements displayed on social media. The ads asked for football fans (i.e., individuals who like watching European Football) to participate in a neuroimaging study on sports betting. Individuals who were interested then had to complete an online survey. This online prescreening tool aimed to assess individuals' (1) frequency of football game watching, (2) frequency of football game betting, (3) knowledge of teams from the main European Football League, and (4) level of interest attached to each main European Football League. All participants were judged to be physically healthy on the basis of their answers on an MRI screening form, enclosed to the online survey. The prescreening tool was also used to exclude any participant who reported having used mood stabilizers, antidepressants, antipsychotics, sleep medications, morphine, cocaine, or heroine or having regularly used cannabis in the past 12 months. The online prescreening tool is accessible through the following link: www.panlablimesurvey.ugent.be/PAN200/index.php/477436/lang-nl.

The screening procedure identified participants who watched football frequently and who maintained a high level of knowledge and interest in European Football Leagues. With regard to the frequency of football betting, the participants ranged from nonbettors to high-frequent bettors. Specifically, six participants reported having “not previously” bet on football, three participants reported their frequency of football betting as “very seldom,” three participants reported it as “seldom,” 13 participants reported betting “sometimes” on football, 12 participants reported betting “frequently” on football, and four participants reported betting “very frequently” on football. Importantly, the participants with no experience in sports betting reported that they could be potentially interested by betting on football. This additional question was added to the online screening tool in order to avoid recruiting individuals with some reluctance to bet on football.

Severity of problem gambling (Problem Gambling Severity Index; PGSI; Ferris & Wynne, 2001), and of alcohol use (Alcohol Use Disorders Identification Test; AUDIT; Saunders, Aasland, Babor, de la Fuente, & Grant, 1993) was screened on the day of the study. On the PGSI, 27 participants

reported no gambling problem; ten participants reported a moderate problem (score of 3 to 7); and five participants reported a high level of gambling problems (score of 8 or more). On the AUDIT, 18 participants reported no or low risk of alcohol use disorders (score between 0 and 7), 16 participants reported a medium risk (score between 8 and 15), and nine reported high risk (score between 16 and 19).

Financial compensation

Participants received a fixed amount of €50 for their participation, plus the money won with the sports betting game (up to €20).

Experimental task and MRI procedure

We used a cue exposure task (adapted from Blechert et al., 2016; see Fig. 1) in which cues depicting football games appeared on a screen (stimulus presentation length = 5 s, jittered intertrial interval [ITI] = 1.8 to 3 s, task length $\approx$ 16 min 45 s). More specifically, each cue depicted a football game from a European league (i.e., English Premiere League, German Bundesliga, Italian Calcio, French Ligue 1, Spanish Liga, Portuguese Primeira Liga, Nederlandse Eredivisie, and Belgian Pro League) that would occur either the day of (but after the scanning session) or the day following the scanning session. This procedure was adopted in order to reinforce the perceived availability of the event that appeared during the cue exposure task. This also required that different games be displayed as stimuli for each separate day of scanning. As a result, all participants were scanned on a Saturday (from 9 a.m. to 5 p.m.; seven to ten participants were scanned on the same day). Five Saturday sessions were undertaken in total (weekly from August 19 to September 23, 2017).

Prior to positioning in the scanner, participants received task instructions. They were asked to look attentively at each cue and were informed that there were two types of blocks of trials: a betting and a watching block. Each block consisted of ten football games (i.e., ten trials). In the “betting” block, each football game (showing the logos of the teams that would be playing against each other) was displayed on the screen for 5 s each (jittered ITI = 1.8 to 3 s). Participants were informed that when ten games were shown, they could bet on their chosen game and team at the end of the block. Specifically, an overview slide appeared for 10 s, after the betting block, displaying all ten cues (games) that had just been presented. During this phase, participants orally reported the number of the game and the team that they wanted to bet on (e.g., “One, FC Barcelona”) via intercom to the experimenter. Participants were also informed that they would receive the betting money once the sports event that he or she had bet on had taken place (€4 in case of a win, €2 in case of a draw, €0 in case of a loss). In the “watching” block, participants viewed the game cues as before;

Fig. 1 An illustration of some sports cues and of one overview slide for each condition during the cue exposure task.

however, they were instructed to identify the game they would enjoy watching the most and the team they thought would win the game. This implied that the cue exposure attached to the watching condition was not associated with the prospect of getting a monetary reward. Finally, participants were informed that there were five "betting" and five "watching" blocks displaying the same 50 games (but presented in a different pseudorandom order; 100 trials in total); that they could win an amount ranging from €0 (i.e., in the case of five losing bets) to €20 (i.e., in the case of five winning bets); that the two types of conditions would be presented in an alternating order; that there would be a 10-s interval (white screen) between blocks; that the task could start with either a "betting" or a "watching" block; and that all the games depicted during the experiment would occur the same weekend as the scanning session.

Directly after the scanning session, participants completed posttask rating questionnaires. Specifically, for all 50 games that had been depicted during the cue exposure task, participants were asked to indicate which team they thought would win the game (by circling the team) and how sure they were that this team would win (1 = *not at all*, 2 = *very little*, 3 = *somewhat*, 4 = *to a great extent*). Next, they were asked to report, for the same 50 games, how much they would enjoy watching the game (1 = *not at all*, 2 = *very little*, 3 = *somewhat*, 4 = *to a great extent*). Then participants completed the AUDIT and PGSI and wrote down their bank account number for receiving the payment attached to their betting

choices (i.e., we had to wait until the games were played before being able to remunerate the participant).

Data acquisition

The stimulus presentation and timing of all events were achieved using Python 2.7.13 and Pygame 1.9.3 on an IBM-compatible PC.

All fMRI imaging was conducted in a 3-T Siemens MAGNETOM Prisma scanner at the GhfMI Center, UZ Gent, Gent University. Functional scanning used a z -shim gradient-echo echoplanar imaging (EPI) sequence with prospective acquisition correction (PACE). This specific sequence is dedicated to reducing signal loss in the prefrontal and orbitofrontal areas. The PACE option can help reduce the impact of head motion during data acquisition. The parameters were: TR = 2,000 ms; TE = 25 ms; flip angle = 90°; 64 × 64 matrix size with resolution 3 × 3 mm². Thirty-one 3.5-mm axial slices were used to cover the whole cerebral cortex and most of the cerebellum with no gap. The slices were tilted about 30 deg clockwise along the AC–PC plane in order to obtain better signals in the orbitofrontal cortex. A 180-slice MPAGE structural sequence was acquired (TI = 800 ms; TR = 2,530 ms; TE = 3.1 ms; flip angle 10°; 208 sagittal slices; 256 × 256 matrix size with spatial resolution as 1 × 1 × 1 mm³) for registering each participant's functional data to standard space. Prior to the EPI sequence, standard Siemens magnetic field maps were collected with the same slice

prescription as the functional scans using a multi-echo gradient-echo acquisition (effective EPI echo spacing = 0.5 ms, EPI TE = 25 ms, percent signal loss threshold = 10). This field map was used for correction of geometric distortions in the EPI data caused by magnetic field inhomogeneity.

Image preprocessing

The functional data for each participant were motion-corrected using rigid-body registration, implemented in FSL's linear registration tool, MCFLIRT (Jenkinson, Bannister, Brady, & Smith, 2002). Image preprocessing was carried out using the FMRI Expert Analysis Tool (version 6.00), part of the FSL package (FMRIB Software Library, version 5.0.9; www.fmrib.ox.ac.uk/fsl). All participants demonstrated less than 1.0 mm of either absolute or relative motion. Hence, no participant was excluded due to head motion. After motion correction and temporal low-pass filtering, each time series was corrected for geometric distortions caused by magnetic field inhomogeneity (Jenkinson, 2004). The first three volumes of each participant's functional data were discarded in order to allow the magnetic resonance signal to reach a steady state. The data were spatially smoothed using a 5-mm full-width-at-half-maximum (FWHM) Gaussian kernel. The data were filtered in the temporal domain using a nonlinear high-pass filter with a 116-s cutoff. A three-step registration procedure was used, whereby the EPI images were registered first to the matched-bandwidth high-resolution scan, then to the MPRAGE structural image, and finally into standard MNI space, using FLIRT (Jenkinson et al., 2002; Jenkinson & Smith, 2001). The registration from MPRAGE structural image to standard space was further refined using FNIRT nonlinear registration (Andersson, Jenkinson, & Smith, 2007a, b). Statistical analyses were performed in the native image space, with the statistical maps normalized to the standard space prior to higher-level analysis.

Brain-imaging analyses

Betting versus watching trials To identify brain regions involved in the cue exposure of football games available for betting, we examined the neural activity during stimulus presentation. Specifically, we compared blood oxygen level-dependent (BOLD) activity, during the onset of “betting” trials, in which participants viewed football games available for betting, with activity during the onset of “watching trials,” in which participants viewed games when reflecting on whether they would be interested in potentially watching it. The brain-imaging data were modeled using an event-related general linear model (GLM) within FSL's FILM module using FEAT. First-level statistical analysis included the “betting” trials and the “watching” trials as regressors (i.e., two conditions of interest). The event onsets (duration of each event = 5

s) were convolved with a canonical hemodynamic response function (HRF, double-gamma) to generate regressors used in the GLM. Null events were not explicitly modeled and therefore constituted an implicit baseline. An additional 24 motion regressors were added (six motion parameters, the derivatives of these motion parameters, the squares of the motion parameters, and the squares of the derivatives; comprising FSL's standard + extended set of motion parameters). For each participant, we computed the following contrast images: (1) betting trials minus watching trials and (2) watching trials minus betting trials. These were then input into a random-effect model for group analysis using nonparametric permutation analyses (FSL Randomize, with 10,000 random permutations of the data), with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, family-wise error [FWE] corrected for multiple comparisons across the whole brain.

Brain activation as a function of parametric increases of confidence and enjoyment The event-related whole-brain GLM analyses were also used to perform parametric contrasts based on the scores obtained through the posttask rating questionnaires (level confidence and enjoyment associated to each game). Specifically, (i) “betting” events were weighted according to the level of confidence ($-3 = \text{not at all}$, $-1 = \text{very little}$, $1 = \text{somewhat}$, $3 = \text{to a great extent}$), and (ii) “watching” events were weighted according to the level of enjoyment ($-3 = \text{not at all}$, $-1 = \text{very little}$, $1 = \text{somewhat}$, $3 = \text{to a great extent}$). For each participant, we computed the following parametric contrast images: (i) confidence about “betting” trials and (ii) enjoyment about “watching” trials. These were then input into a random-effect model for group analysis using nonparametric permutation analyses (FSL Randomize with 10,000 random permutations of the data), with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, FWE corrected for multiple comparisons across the whole brain.

Insula-centered functional connectivity analyses Psychophysiological interaction (PPI) analyses were performed on the “betting cues versus watching cues” contrasts, as well as on the parametric contrasts (i.e., level of confidence for the “betting” trials, level of enjoyment for the “watching” trials). We created an insular seed regressor by computing individual average time series within a 10-mm sphere surrounding the individual subject's peaks within the functional mask of right anterior insula ($x = 34$, $y = 20$, $z = -4$; see also Fig. 2 and Table 1). The locations of the peak voxels were based on the “betting cues minus watching cues” contrast.

The insular seed mask was first transformed into individual space using FLIRT. Next, the time course of each seed was extracted. For each participant, a first-level PPI model was set up using FSL, including the following user-specified regressors: (1) the time course of the seed region, (2) four regressor codings for the task contrasts,

and (3) the four regressor coding interaction terms—that is, the multiplication of time course and each of the task contrasts. The single-subject contrast images for each of these nine regressors were created. Each participant's PPI contrast image for the interaction regressor was then centered into a second-level random-effect analysis to test for group effects using nonparametric permutation analyses (FSL Randomize with 10,000 random permutations of the data), with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, FWE corrected for multiple comparisons across the whole brain.

Results

Brain activation when viewing cues available for betting versus cues available for watching

Figure 2A and Table 1 show the brain regions in which activation increased for the “betting cues minus watching cues” contrast. This analysis revealed significant activation in the right hippocampus, frontal orbital cortex, anterior insula, medial frontal gyrus, and caudate nucleus. For the “watching cues minus betting cues” contrast (Fig. 2B), significant activation was observed in the left superior gyrus (voxel cluster size = 328, peak = $-68, -36, 14$), extending into the left supramarginal gyrus (peak = $-62, -46, 26$) and the lateral occipital cortex (peak = $-68, -36, 14$).

Fig. 2 (A) Whole-brain activation for the “betting cues minus watching cues” contrast. (B) Whole-brain activation for the “watching cues minus betting cues” contrast. These contrast maps were thresholded using cluster detection statistics, with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, family-wise error corrected for multiple comparisons. The right side of the brain is on the right.

Brain activation in function of parametric increases

Figure 3A and Table 2 show brain activation increases for the parametric contrast on the level of confidence toward “betting” trials. This analysis revealed clusters of activation in bilateral superior frontal gyrus (BA8), the anterior aspect of right middle frontal gyrus (BA10) or frontal pole, paracingulate gyrus and medial frontal gyrus (BA6), left inferior frontal gyrus, bilateral anterior insula, bilateral hippocampus, bilateral caudate, and lateral occipital cortex.

Figure 3B and Table 2 show brain activation increases for the parametric contrast on the level of enjoyment toward “watching” trials. This analysis revealed clusters of activation in bilateral inferior frontal gyrus, middle frontal gyrus, left frontal orbital cortex, left anterior insula, bilateral caudate nucleus, and lateral occipital cortex.

No significant activation was observed when comparing the level of confidence for the “betting” trials and the level of enjoyment for the “watching” trials (with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, FWE corrected for multiple comparisons across the whole brain).

Insula-centered functional connectivity

Betting cues versus watching cues For the “betting cues minus watching cues” contrast (see Fig. 4), the analyses identified positive PPI between the anterior insular seed, the right parahippocampal gyrus (voxel cluster size = 570, peak = $8, -34, -8$; $z > 3.72$), and the lateral occipital cortex (voxel cluster size = 433, peak = $-34, -88, -8$, $z > 3.72$). No significant PPI was found for the “watching cues minus betting cues” contrast.

Parametric contrasts No significant PPI was found for the parametric contrasts, either with the level of confidence in “betting” trials or the level of enjoyment in “watching” trials (using a threshold of either $z > 3.1$ or $z > 2.3$, respectively).

Assessment of possible moderators

When each of the variables was entered in the GLM as a covariate, we found no significant effect of sports betting frequency, problem gambling severity, or alcohol use severity. We also observed no significant correlation (Spearman's rho) between these scores and the parameter estimate values extracted from the significant clusters of activation obtained with each specific contrast (including the brain connectivity analyses).

Discussion

The aim of this study was to examine how gambling availability impacts on the neural response during sports cue exposure. We used a paradigm in which participants (all football fans)

Table 1 Significant peak of activations for the “betting minus watching” contrast

Structure	Left/Right	<i>k</i>	<i>x</i>	<i>y</i>	<i>z</i>
Hippocampus, Frontal orbital cortex, Insula, Medial frontal gyrus	R	3,531	36	− 24	− 12
			32	− 24	− 12
			34	20	− 4
			19	34	− 10
			20	42	− 10
			42	18	− 8
Caudate nucleus, Precuneus cortex	L	484	− 18	− 4	24
			− 26	− 4	24
			− 26	− 44	16
			− 18	− 26	18
			− 22	− 36	12
			− 24	− 52	16
Occipital pole, Lingual gyrus, Middle occipital gyrus	L	308	− 34	− 94	2
			− 30	− 94	4
			− 20	− 88	6
			− 24	− 84	6
			− 18	− 80	6
			− 18	− 92	8

Maps resulting from group analyses were thresholded using Randomize with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, family-wise error corrected for multiple comparisons across the whole brain. *k*, voxel cluster size (each voxel = 8 mm³); L, left; R, right; MNI, Montreal Neurological Institute.

viewed cues depicting games from European professional football leagues. Each of the cues represented games that were going to occur shortly after the scanning session. In the “betting” condition, the cues were available to bet on at the end of the block, whereas at the end of the block in the

“watching” condition, participants chose the game they would prefer to watch.

When contrasting “betting” cues against “watching” cues, we observed significant activations in the right middle frontal gyrus and right frontal orbital cortex. These regions are usually

Fig. 3 Whole-brain activation for (A) parametric increases of confidence on betting trials and (B) parametric increases of enjoyment on watching trials. These contrast maps were thresholded using cluster detection

statistics, with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, family-wise error corrected for multiple comparisons.

Table 2 Significant peak of activations for the parametric contrasts

Structure		Left/Right	<i>k</i>	<i>x</i>	<i>y</i>	<i>z</i>
Level of confidence “betting” trials	Lingual gyrus, Hippocampus, Temporal gyrus, Occipital fusiform cortex, Cingulate gyrus, extending into Caudate nucleus, Insula, and Frontal orbital cortex	L/R	40,936	– 24	– 66	– 2
				– 28	– 34	– 28
				– 48	– 52	– 26
				38	– 46	– 26
				– 4	2	24
				6	2	26
				18	28	48
	Superior frontal gyrus, Middle frontal gyrus, extending into Medial prefrontal gyrus	L	613	26	34	40
				14	34	42
				30	26	54
				22	26	60
				30	30	52
				– 18	– 14	– 30
				– 26	– 32	– 28
Level of enjoyment “watching” trials	Parahippocampal gyrus, Lateral occipital cortex	L/R	26,689	– 16	– 28	– 28
				– 8	– 26	– 28
				10	– 72	62
				– 20	– 18	– 28
				– 22	24	– 28
	Frontal orbital cortex, Inferior frontal gyrus, Middle frontal gyrus, Superior temporal gyrus, Frontal medial gyrus, extending into Caudate nucleus and Insula	L/R	15,709	– 36	24	– 26
				– 40	28	– 24
				– 32	6	64
				– 48	22	– 22
				2	40	– 22
	Middle frontal gyrus, Inferior frontal gyrus	R	3,208	52	28	22
				42	12	24
				42	6	24
				40	24	26
				56	20	30
	Middle temporal gyrus	R	355	36	6	34
				68	– 14	– 18
				66	– 12	– 22
				64	– 16	– 18
				72	– 18	– 8
				64	2	– 12
				58	– 10	– 18

Maps resulting from group analyses were thresholded using Randomize with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, family-wise error corrected for multiple comparisons across the whole brain. *k*, voxel cluster size (each voxel = 8 mm³); L, left; R, right; MNI, Montreal Neurological Institute.

activated during tasks that engage emotion regulation, executive, and inhibitory control processes (e.g., Kober et al., 2010). We also observed significant whole-brain activations in the caudate nucleus and anterior insula. Accordingly, activations within the caudate nucleus have been reported during reward anticipation while gambling (Limbrick-Oldfield et al., 2017; van Holst, Veltman, Büchel, van den Brink, and Goudriaan, 2012b). Our present findings are also consistent with previous studies showing that the anterior insula is involved during the

processing of gambling (Goudriaan et al., 2010) and complex emotional cues (Deen, Pitskel, N. B., & Pelphrey, 2011). More specifically, we observed that the anterior insula is more strongly activated when individuals are viewing a sports event that is associated with a betting prospect. This result is in line with a theoretical account advancing that the anterior insula plays a key role in developing and updating motivational states with specific associated actions (Wager & Barrett, 2004), and most likely provides information necessary for goal-directed

Fig. 4 Significant PPI with the right anterior insula seed (10-mm sphere around peak = 34, 20, – 4) for the contrast on betting trials minus watching trials. The contrast maps were thresholded using cluster detection statistics, with a height threshold of $z > 3.1$ and a cluster probability of $p < .05$, family-wise error corrected for multiple comparisons.

behavior (Drouman et al. 2015a, b; Nelson et al., 2010). Interestingly, we observed significant supramarginal gyrus activation when contrasting “watching” cues against “betting” cues. Since this brain area is involved in heightened visual processing (Makino, Yokosawa, Takeda, & Kumada, 2004; Roland & Gulyás 1995; Servos, Osu, Santi, & Kawato, 2002) and recognition of familiar objects (Sugiura, Shah, Zilles, & Fink, 2005) and memories (Yonelinas, Otten, Shaw, & Rugg, 2005), the present results suggest that reflecting on a game to “watch” (when exposed to the teams’ names and logos) might have required a higher level of semantic–visual processing than reflecting on which game to bet on.

Parametric contrasts were also undertaken to examine how brain activation was modulated by participants’ level of confidence in their chosen team for each of the “betting” trials, or by the degree of watching enjoyment for each cue presented during the “watching” trials. We observed patterns of activations that, taken together, should offer a representative brain map of activations showing how the neural response is modulated by participants’ level of interest toward a sporting event (i.e., on either confidence or enjoyment). Specifically, for these two parametric contrasts, we observed significant clusters of activations that have previously been reported in experimental tasks that engaged (1) emotion regulation and cognitive control (superior, middle, medial prefrontal cortices, and paracingulate gyrus; Everitt & Robbins, 2005; Koob & Le Moal, 2001; Lebreton, Abitbol, Daunizeau, & Pessiglione, 2015; Volkow, Fowler, & Wang, 2003), (2) feelings of desire, reward anticipation, or urge (anterior insula and caudate nucleus; Naqvi & Bechara, 2009; Paulus & Stewart, 2014; Verdejo-Garcia, Clark, & Dunn, 2012), and (3) the processing of visual information (the lateral occipital cortex).

PPI analyses were conducted using the right anterior insula as a seed. For the “betting trials minus watching trials” contrast, the PPI analyses highlighted significant positive couplings between the right anterior insula, parahippocampal gyrus, lingual gyrus, lateral occipital cortex, and occipital pole. One interpretation of these PPI results is that the exposure to “betting” trials elicited increased insular cortex coupling, as compared to the context of “watching” trials (i.e., a context-specific modulation of effective connectivity; Friston et al., 1997; see also Di, Huang, & Biswal, 2017; McLaren, Ries, Xu, & Johnson, 2012; D. V. Smith, Gseir, Speer, & Delgado, 2016). Another interpretation is that the insula modulated the parahippocampal, lingual, and occipital gyri’s responses to “betting” trials, as compared to the context of “watching” trials (i.e., a modulation of stimulus-specific responses; Friston et al., 1997; see also Di et al., 2017; McLaren et al., 2012; D. V. Smith et al., 2016). Interestingly, comparable insula-centered PPI with the parahippocampal and occipital gyri has been highlighted in the literature during tasks featuring emotional stimuli and face recognition (Dalglish et al., 2017; Denny et al., 2014). Hence, the PPI patterns observed in the present study might reflect a higher engagement of stimulus recognition and perceptual saliency processes for the football game stimuli that were associated with a gambling opportunity, as compared to those that were not (i.e., the “watching” condition of the cue exposure task). Importantly, the parametric contrasts did not lead to significant PPI activation. This suggests that the pattern of insula-centered PPI was significantly modulated by the type of condition (“betting” vs. “watching”), but not by the reported levels of winning confidence and enjoyment associated with the betting and “watching” conditions, respectively.

In the present study, the exposure to stimuli during the “watching” and “betting” conditions did not simply involve watching cues (as it would in a pure test of cue reactivity; Jasinska et al., 2014), but also decision-making (i.e., reflecting on whether to select the game for betting or watching). This procedure was adopted in order to mimic the current offer of sports betting, which is highly accessible (e.g., betting is available simply by using a smartphone app) and also features a ubiquity of cues (e.g., advertisements) reminding you of this fact. Nevertheless, one limitation of this study is that the decision demands might have differed between the betting and watching trials of the cue exposure task. More specifically, exposure to betting trials was associated with the prospect of winning money, whereas exposure to the watching trials was not associated with any reward. Therefore, in the present study, deciding which game to bet on might have been more likely to elicit stronger activation of neural valuation and instrumental choice circuits than was deciding which game to watch. One possible direction for future studies could be to associate the exposure to watching trials with a concrete incentive, such as Internet or television access that would allow the participant to view the games he or she selected for watching. Another option would be to

compare a condition associated with money (e.g., the “betting” condition from the present study) to a condition that was similar but did not involve monetary reward (e.g., participants might just have to select the team with the highest chance to win the game). This procedure would allow us to further advance our understanding on how sports betting impacts on the experience of watching sports. It would be also interesting to contrast different types of “betting” conditions (i.e., to include only “betting” trials within the cue exposure task). For instance, previous neuroimaging studies have shown that insular cortex activity is triggered by “frustration,” such as when individuals are being denied (or “blocked”) gambling opportunities (Weiss, Sullivan, & Tull, 2015; Xue, Lu, Levin, & Bechara, 2010; Yu, Mobbs, Seymour, Rowe, & Calder, 2014; see also Bierzynska et al., 2016). Through this procedure, we would also expect to obtain higher insula-centered connectivity for the “blocked” trials (as compared to trials available for betting), especially with the amygdala, which is a brain structure that has been implicated in the processing of frustration (Yu et al. 2014).

Another caveat of this study is that our sample was essentially constituted of male participants, which hampers generalization of the present results to the population of female football fans. It will also certainly be important to extend this research to a sample of individual with problem sports-bettors in which both extreme ends of the spectrum of gambling dependence will be well represented. Specifically, the results from the present study could be used as functional masks by future studies when assessing group activation differences in predefined regions of interest. This should be especially helpful for increasing the statistical power of studies that involve specific types of populations—that is, those that are difficult to recruit, usually resulting in small samples.

In summary, the present study extends previous neuroimaging work on reward availability by highlighting how the prospect of a gambling-related choice impacts on brain activations and on insula-centered functional connectivity. Specifically, the results from the present study demonstrate that sports betting cues trigger neural networks commonly observed in brain research on cognition and emotion. In addition, functional connectivity analyses further confirmed that the insula is a region that serves as a key hub for interactions among the brain networks involved in the processing of salient and motivational cues. Further research should build on the present findings in order to further examine how the high availability of ready-to-consume rewards in today’s environments exploits human hedonic tendencies.

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[betting_study](https://github.com/dbrevers/sports_betting_study). The raw data are available at [openneuro.org: https://openneuro.org/datasets/ds001247/versions/00001](https://openneuro.org/datasets/ds001247/versions/00001). The unthresholded statistical maps are available at Neurovault.org: <https://neurovault.org/collections/3517/>.

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