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Convergent cross-sectional and longitudinal evidence for gaming-cue specific posterior parietal dysregulations in early stages of internet gaming disorder

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Abstract

Exaggerated reactivity to drug-cues and emotional dysregulations represent key symptoms of early stages of substance use disorders. The diagnostic criteria for (Internet) gaming disorder strongly resemble symptoms for substance-related addictions. However, previous cross-sections studies revealed inconsistent results with respect to neural cue reactivity and emotional dysregulations in these populations. To this end, the present fMRI study applied a combined cross-sectional and longitudinal design in regular online gamers (n = 37) and gaming-naïve controls (n = 67). To separate gaming-associated changes from predisposing factors, gaming-naive subjects were randomly assigned to 6 weeks of daily Internet gaming or a non-gaming condition. At baseline and after the training, subjects underwent an fMRI paradigm presenting gaming-related cues and non-gaming–related emotional stimuli. Cross-sectional comparisons revealed gaming-cue specific enhanced valence attribution and neural reactivity in a parietal network, including the posterior cingulate in regular gamers as compared to gaming naïve-controls. Longitudinal analysis revealed that 6 weeks of gaming elevated valence ratings as well as neural cue-reactivity in a similar parietal network, specifically the posterior cingulate in previously gaming-naïve controls. Together, the longitudinal design did not reveal supporting evidence for altered emotional processing of non-gaming associated stimuli in regular gamers whereas convergent evidence for increased emotional and neural reactivity to gaming-associated stimuli was observed. Findings suggest that exaggerated neural reactivity in posterior parietal regions engaged in default mode and automated information

The work was carried out at Institute of Psychology and Education, Ulm University, Ulm, Germany, and in the Department of Psychology, University of Bonn, Bonn, Germany.

processing already occur during early stages of regular gaming and probably promote continued engagement in gaming behavior.

KEYWORDS
addiction, cue reactivity, emotion, fMRI, internet gaming disorder, longitudinal design

1 | INTRODUCTION

In May 2019, the World Health Organization (WHO) included *Gaming Disorder* as distinct diagnosis (6C51) in the category *disorders due to addictive behaviors* in the International Classification of Diseases (ICD, 11th version). Previously, the American Psychiatric Association (APA) included *Internet Gaming Disorder* as an emerging disorder in the appendix of DSM-5.[1,2] Diagnostic criteria strongly resemble those for substance-related addictions and include (1) compulsive gaming and lack of control over gaming, (2) preoccupation with gaming at the expense of other activities, and (3) continued gaming despite negative consequences (see also Pontes et al[3]).

The inclusion in the diagnostic classification systems takes account of the growing concerns with respect to detrimental mental health effects of excessive and in some cases compulsive engagement in Internet gaming. Prevalence estimates of Internet Gaming Disorder (IGD) range from 0.3% to 27.5% worldwide[4] with a recent representative survey suggesting that 1.16% of adolescents in Germany meet the diagnostic criteria for IGD according to DSM-5 criteria[5] (prevalence estimates according to the WHO criteria, see Montag et al[6]). Accumulating evidence from cross-sectional and longitudinal surveys suggest detrimental effects on mental health which partly resemble those observed in substance addiction, with elevated emotional distress, anxiety, and depression being among the most commonly reported.[5,7]

In line with the symptomatic overlap between substance addictions and IGD, an increasing number of cross-sectional studies combined functional MRI with validated experimental paradigms from substance addiction research to determine IGD-associated neural alterations in the domains of cognition and reward-related processing, including exposure to gaming associated cues (cue reactivity). An early meta-analysis encompassing cognitive and reward-related fMRI studies reported that—compared to healthy controls—excessive gamers exhibited increased neural activation in fronto-cingulate regions, including anterior as well as posterior cingulate cortices (ACC, PCC) during cognitive and reward-related paradigms.[8] A subsequent meta-analysis[9] that incorporated a broader range of reward-related and executive functions confirmed generally exaggerated reactivity in fronto-cingulate circuits and additionally demonstrated increased reactivity in fronto-striatal circuits, particularly dorsal striatal and lateral prefrontal regions, with some evidence for domain-specific alterations in the latter regions depending on the motivational context of the cognitive domains assessed. Two recent meta-analyses specifically focused on cue-reactivity in IGD and reported increased neural reactivity in lateral prefrontal, cingulate and dorsal striatal regions in response to gaming cues within IGD individuals,[10] and exaggerated cue-reactivity in lateral prefrontal and posterior parietal regions, including the PPC and precuneus, as well as decreased insular activation in IGD individuals relative to controls.[11]

Notably, in contrast to convergent evidence for exaggerated ventral striatal reactivity in response to drug-associated cues across substance addicted populations,[12,13] previous studies revealed inconsistent evidence for ventral striatal drug cue-reactivity in IGD. The ventral striatum is strongly engaged in signaling reward expectancy, reinforcement behavior, and salience with convergent translational evidence suggesting that this region critically contributes to the initial development of addiction via mediating reinforcing effects of the drug as well as associated incentive salience and learning processes whereas the dorsal striatum mediates habitual and compulsive use during later stages of the disorder.[14,15] In line with animal models, ventral striatal cue reactivity has already been observed in regular, nondependent, drug users whereas dependent users during later stages of the disorder exhibit pronounced reactivity in the dorsal striatum engaged in habit formation.[16–18]

A recent framework by Brand et al[19] extended previous models on substance-related addictions to internet-related addictive behaviors, including gaming, and emphasized the importance to account for interactions of person-affect-cognition and execution variables (I-PACE). A recent update of this model emphasized the relevance to (1) consider predisposing vulnerability factors such as emotional dysregulations, for example, anxiety or deficient reward processing, as well as (2) to differentiate early and later stages in addiction development, suggesting that the initial stages of behavioral addictions are mediated by the ventral striatum dependent incentive urges and sensitization with progressive impairments in prefrontal stimulus-specific inhibitory control during later stages of the disorder.[20]

However, in contrast to accumulating evidence for altered emotional processing in regular and dependent substance, users emotional dysregulations in IGD have not been examined.[21–23] Furthermore, based on extensive translational animal models,[15,24] the important role of ventral striatal cue reactivity during early as well as later stages of substance use disorders in humans has been established, such that ventral striatal cue reactivity has been consistently observed in fMRI studies in both dependent and recreational substance users.[16,25,26] In contrast, previous studies on cue-reactivity in subjects with IGD revealed inconsistent findings such that some studies found exaggerated ventral striatal reactivity in response to gaming-associated stimuli whereas others did not.[27–29] Moreover, findings from cross-sectional retrospective designs in individuals with an established IGD remain

limited with respect to determining cue-associated changes during the early stages of regular gaming.

To this end, the present study applied a combined cross-sectional longitudinal design in regular gamers of the massively multiplayer online role-playing game (MMORPG) World of Warcraft (WoW) and gaming-naïve controls (n= 131). Following the baseline (T1) assessment, non-gaming controls were randomly assigned to 6 weeks of daily WoW gaming (training group, TRG) or no gaming (training control group, TCG) (for detailed protocols, see also Zhou et al[30]). An MMORPG was employed due to the high popularity and particular high risk of escalation of use of these games.[31,32] At both timepoints, subjects underwent fMRI while they were presented WoW-associated as well as non-gaming–associated positive and negative visual stimuli to asses both neural cue reactivity and emotional processing. To additionally examine alterations on the level of subjective experience, behavioral ratings of valence and arousal were assessed following the fMRI assessments. Based on the previous literature, we expected (1) altered emotional processing in gamers versus non-gamers at baseline reflecting predisposing alterations or changes related to regular gaming and (2) exaggerated gaming cue-reactivity in fronto-striatal and fronto-cingulate regions in regular gamers relative to controls at baseline, as well as increases in fronto-striatal (particularly ventral striatal) cue reactivity in gaming naïve subjects who underwent the daily training as compared to the group who remained gaming naïve.

2 | MATERIALS AND METHODS

2.1 | Participants

The study was part of a larger cross-sectional and longitudinal project examining the effects of regular Internet gaming on brain structure and function. The sample was identical to our previous study examining effects of Internet gaming on brain structure[30] *N* = 131 healthy participants—either experienced WoW gamers or WoW-gaming naïve controls (71 males, 60 females; mean age = 23.80, SD = 3.97)—were enrolled in the project and underwent MRI assessments twice, at T1 (baseline) and after an interval of 6 weeks (T2). During the interval, subjects from the WoW naïve group were randomly assigned to either play WoW at least 1 h per day or to not engage in the game. All participants were free of a history of, or current psychiatric/neurological disorders, drug abuse or apparent brain structural abnormalities. Participants recruited for the group of regular WoW gaming (WoW group) had to fulfill the following inclusion criteria: (1) WoW gaming >7 h a week (years of WoW gaming M = 6.28, SD = 2.10), (2) play other multiplayer game <7h a week, and (3) no first-person shooter gaming to control for potential adaptive changes in prefrontal emotion regulation during exposure to negative emotional stimuli.[33] Participants in the WoW gaming naïve control group were WoW gaming naïve at enrollment and reported generally low online video gaming addiction tendencies (Table 1). Based on the study, exclusion criteria and MRI brain structural quality assessments *n* = 12 subjects were excluded (for details, see Zhou et al[30]). From the remaining 119 subjects, additional *n* = 15 subjects were excluded from the present study due to excessive head motion or technical issues during functional fMRI (for details, see flow diagram presented in Figure S1) leading to a final sample size of *N* = 104 participants (54 males and 50 females, mean age = 23.51, SD = 3.91; WOW, *n* = 37; control group, *n* = 34; training group, *n* = 33). For avoiding duplicate analysis with the previous study[30] and consistency within the image analysis, questionnaire data assessing levels of Internet addiction and behavior data during fMRI were analyzed from present sample (*n* = 104). To determine cue-reactivity and emotional alterations associated with regular WOW gaming on the neural level cross-sectional and longitudinal analyses were applied to the functional MRI data. For the cross-sectional comparison, data from the initial fMRI assessment (T1) of the WoW group (*n* = 37; 23 males and 14 females, mean age = 24.84, SD = 4.27) were compared to the non-gaming group (*n* = 67; 31 males and 36 females, mean age = 22.78, SD = 3.52). To determine WoW-gaming associated alterations in a longitudinal fashion, the non-gaming group was randomly assigned to two different 6-week interventions following T1 data acquisition: The training group was required to play WoW at least 1 h per day (TRG, *n* = 33), whereas the training control group (TCG, *n* = 34) did not engage in the game. All participants provided written informed consent and received monetary compensation. Addiction severity was assessed using previously validated self-report scales. WOW gaming addiction in the gamers was assessed using the WOW gaming addiction scale.[34] General online video gaming addiction (OVGA) at T1 and training associated changes between T1 and T2 in this domain were assessed on the behavioral level using a modified version of the video game addiction questionnaire.[35] The OVGA was administered to all subjects at both timepoints (T1, T2). For details on the gaming addiction assessments, see also Zhou et al (reference 30)[29]

The study and procedures were in accordance with the latest Declaration of Helsinki and had full ethical approval of the local ethic committee at the University of Bonn, Bonn, Germany.

2.2 | Experimental paradigm

Cue-reactivity and emotional processing was assessed using a modified version of an fMRI block-design paradigm that has been previously demonstrated to be sensitive to substance dependence and gaming associated neural changes.[16,21,33] During the paradigm, visual stimuli from four categories were presented: negative, positive, neutral, and WoW pictures. The negative, positive, and neutral pictures were selected from the International Affective Picture System (IAPS) database whereas the WoW stimuli were screenshots from the game. Negative and positive stimuli were selected with respect to matched arousal ratings from the IAPS database. During fMRI, the stimuli were presented in condition-specific blocks with six blocks per condition each encompassing five stimuli presented for 4 s. The blocks were presented in a pseudorandomized order while ensuring that each block was followed by a block of a different category. To ensure attentive processing, all of the blocks were followed by the

TABLE 1 Group characteristics: Demographics and internet gaming

Sample (n = 104)	TCG M (SD)	TRG M (SD)	WoW Gamer M (SD)	F(χ^2/t)	p
Age (years)	22.4 (3.00)	23.2 (3.99)	24.8 (4.27)	3.93	0.023*
Gender (male/female)	18/16	13/20	23/14	3.61	0.165
OVGA T1	7.85 (1.86)	7.52 (1.48)	15.10 (5.23)	55.40	<0.001***a
OVGA T2	8.09 (3.10)	8.85 (2.65)	14.80 (4.79)	5.68	<0.02*b
WoW addiction T1	-	-	86.70 (24.00)	-	-
WoW addiction_T2	-	53.80 (17.20)	82.90 (21.90)	-	-

Abbreviations: OVGA_T1, measured on-line computer game addiction scores at T1; OVGA_T2, measured on-line computer game addiction scores at T2; WoW addiction_T1, measured WoW addiction questionnaire at T1; WoW addiction_T2, measured WoW addiction questionnaire at T2.
[a]Cross-sectional analysis.
[b]Longitudinal analysis.
*p < 0.05.
**p < 0.01.
***p < 0.001.

presentation of an additional picture following a 1.5 s (on average, randomized between 1000 and 2000 ms) black screen and subjects had to indicate via button press whether the picture had been shown during the preceding block (see Figure S2). Blocks were separated by a fixation cross period (randomized between 3000 and 6000 ms) during which a fixation cross was displayed that served as low level baseline. Total duration of the paradigm was approximately 12 min.

2.3 | Behavioral assessments—Emotional processing

To further assess differences in subjective emotional experience, participants were asked to rate arousal and valence of stimuli following the MRI acquisition. For each participant, the rating pictures were randomly selected from all pictures in the paradigm. Rating was conducted by displaying rating scales ranging from 1 to 7 (indicating arousal, 1 very low–7 very high, valence, 1 very negative–7 very positive).

2.4 | MRI data acquisition

Functional MRI data were acquired using the following acquisition parameters: (T2*-weighted echo-planar images [EPI]) was acquired on a 1.5 T Siemens Magnetom Avanto Siemens Scanner (Siemens, Erlangen, Germany), using 12 channel standard matrix head coil (31 axial slices; 3 mm slice-thickness; 3 × 3 × 3.3 mm voxel size; TR was 2.5 s; TE was 45 ms; FoV = 192 mm × 192 mm; Flip angle = 90°; matrix size = 64 × 64; axial orientation, applied filter prescan normalization, PAT modus GRAPPA 2 with 32 reference lines). T1-weighted structural image was acquired before T2*-weighted image and used to improve normalization of the functional images (acquisition parameters: 160 sagittal slices; TR = 1.660 s; TE = 3.09 ms; Flip angle 15°; FoV = 256 × 256, matrix size = 256 × 256; 1 × 1 × 1 mm resolution; sagittally oriented 3D sequence, magnetization preparation non-selective inversion recovery with TI = 850 ms). The paradigm was presented using Presentation software (https://www.neurobs.com/index_html) in combination with an in-house developed template for paradigm programming.

2.5 | MRI data preprocessing

Data were preprocessed using the DPABI toolbox[36] (version V4.3_171210, http://rfmri.org/DPARSF). The first 10 functional volumes were discarded to allow for MRI equilibration. Preprocessing included standardized preprocessing procedures including realignment to correct for head motion, coregistration of the mean functional image to the brain structural image, and normalization using a two-step procedure including segmentation of the structural image and subsequent application of the corresponding normalization parameters to the functional time series (Montreal Neurological Institute standard space, MNI, resampled at 3 × 3 × 3 mm). To account for inverse consistent deformations in image registration, a fast diffeomorphic registration algorithm (Diffeomorphic Anatomical Registration using Exponentiated Lie Algebra, DARTEL[37]) was applied for both segmentation and smoothing. The normalized images were smoothed using a full width at half maximum (FWHM) Gaussian filter with 6 mm.

2.6 | fMRI data analysis

To determine effects of WOW gaming on cue reactivity and emotional processing, second-level random effects general linear model (GLM) analyses were conducted in SPM12b (https://www.fil.ion.ucl.ac.uk/spm) On the first level, the GLM was applied to model the condition-specific blocks and the attention test phase following each block. To further control for motion-related artifacts, the six head motion parameters were included in the design matrix as additional regressors. The first level matrix was convolved with the standard hemodynamic response function (HRF). Contrasts of interest from the first level analyses were subjected to second level voxel-wise ANOVA models as implemented in SPM12b.

In line with the cross-sectional longitudinal design of the study, 2-s level whole brain voxel-wise analyses were conducted. To examine cue-reactivity and emotion processing in regular gamers, a voxel-wise whole brain mixed ANOVA analyses including group as between-subject factor (WoW vs. non-gamer) and condition as between-subject factor (Neg, Neu, Pos, WoW) were calculated on the baseline (T1) data. Second, to determine cue-reactivity changes during the early stages of gaming, a voxel-wise whole brain mixed ANOVA was conducted including training group (TCG vs. TRG) as between subject factor and timepoint (T1 vs. T2) as within subject factor. For all analyses a cluster-based threshold with False Discovery Rate (FDR) of $p > 0.05$ and an initial cluster forming threshold of $p < 0.001$ was applied to correct for multiple comparisons. To disentangle significant interaction effects parameter estimates were subsequently extracted from the regions that exhibited significant interaction effects on the whole brain level and subjected to post-hoc analyses. To this end, condition-specific parameter estimates were extracted from 6-mm-radius spheres centered at the significant peak coordinates using marsbar 0.44 (http://marsbar.sourceforge.net/) and subjected to SPSS for post hoc *t* tests.

3 | RESULTS

3.1 | Demographics and gaming behavior

In the present sample ($n = 104$), there was no differences in gender distribution between the three groups ($\chi_{(2)}^2 = 3.61$, $p = 0.165$). However, WoW gamers were slightly older that than TCG (mean difference [MD] $_{\text{WoW-TCG}} = 2.5$, $t_{101} = 2.75$, $p_{\text{Bonferroni}} = 0.021$), whereas there was no age difference between TCR and TRG ($MD_{\text{TRG-TCG}} = 0.9$, $t_{101} = 0.92$, $p_{\text{Bonferroni}} = 1.000$), or WoW group and TRG ($MD_{\text{WoW-TRG}} = 1.6$, $t_{101} = 1.78$, $p_{\text{Bonferroni}} = 0.232$) (for details, see Table 1). This pattern was consistent with the larger sample reported in our previous study (for details, see Zhou et al[30]) and consequently age was controlled for in analyses including comparisons of the WOW group with the gaming-naïve controls.

3.2 | Addiction severity- Cross-sectional comparison at time point 1 (T1)

A one-way ANOVA of online video game addiction (OVGA) scores at T1 (see Table 1) ($n = 104$) including three groups (TCG, TRG, and WoW) as between-group factor revealed a significant main effect of group ($F_2 = 55.40$, $p < 0.01$, $\eta^2 = 0.526$). The post hoc tests revealed that the WoW group had higher OVGA scores than both, TCG ($MD_{(\text{WoW-TCG})} = 7.21$, $t_{100} = 8.82$, $p_{\text{Bonferroni}} < 0.001$) and TRG ($MD_{(\text{WoW-TRG})} = 7.54$, $t_{106} = 9.23$, $p_{\text{Bonferroni}} < 0.001$) at baseline assessment. There was no difference between TCG and TRG ($MD_{(\text{TRG-TCG})} = 0.33$, $t_{100} = 0.4$, $p_{\text{Bonferroni}} = 1.000$). These results were consistent with the original sample (for details, see Zhou et al (reference 30)

3.3 | Cross-sectional analysis - Subjective emotional experience

Cross-sectional examination of valence ratings (T1) by means of a mixed ANOVA revealed a significant interaction effect between groups (non-gamer and WoW gamers) and emotion (Neg, Neu, Pos, WoW; $F_{3,255} = 8.88$, $p < 0.001$, $\eta^2 = 0.014$) with post hoc analyses demonstrating specifically higher valence ratings for WOW-associated stimuli in the gamers (mean [SE]: WoW gamer = 5.74[0.14], non-gamer = 4.97[0.11], $t_{55} = 4.72$, $p_{\text{Bonferroni}} < 0.001$) yet no differences in the other conditions ($p > 0.05$, Figure 1A). For arousal ratings, a mixed ANOVA revealed no significant interaction effects between the factor group and the factor of emotion category ($F_{3,255} = 1.09$, $p = 0.352$, $\eta^2 = 0.003$, Figure 1B). Findings remained stable after including age as covariate in the analyses (for details, see Tables S1–S3).

3.4 | Cross-sectional analysis—Functional MRI

In line with the analyses of the behavioral data, a mixed ANOVA with the between-subject factor group (non-gamer vs. WoW gamer) and the within-subject factor condition (Neg, Pos, Neu, and WoW) was computed. On the whole brain level, a significant interaction effect was observed in four clusters located in the posterior cingulate cortex (PCC), and right middle occipital gyrus (rMOG), right inferior parietal lobule (rIPL), and left inferior parietal lobule (lIPL) ($p < 0.05$ FDR-corrected, see Table 2 and Figure 2A). Post hoc analyses that directly compared the two groups on the condition-specific extracted parameter estimates revealed that regular gamers demonstrated exaggerated reactivity in these regions in response to WOW stimuli, whereas no between-group differences for the emotional stimuli were observed (all p values > 0.05 after Bonferroni correction, Figure 2B). These results remained stable after controlling for age (Tables S4–S7). Given that the analyses of the behavioral and neural cross-sectional data convergently revealed WoW stimuli specific differences between the WoW group and gaming-naïve group, the longitudinal analyses focused on the WoW condition.

3.5 | Longitudinal analysis of online gaming addiction changes during training

Self-reported WoW gaming behavior confirmed that the TRG group spent >1 h per day playing WoW. Additional analysis of tracking data revealed that the TRG group spent a mean cumulative time of 53.4 h (SD 23.9) gaming WoW during the training interval ($n = 31$, data from $n = 2$ lost due to technical issues). For the longitudinal analysis of gaming addiction scores (as assessed by the OVGA), we conducted a 2×2 mixed ANOVA including timepoints (T1 vs. T2) as within subject factor and groups (TCG, TRG) as between subject factor. Results revealed a significant interaction effect between timepoint and group ($F_{1,64} = 5.68$, $p = 0.020$, $\eta^2 = 0.013$) with the TRG exhibiting an

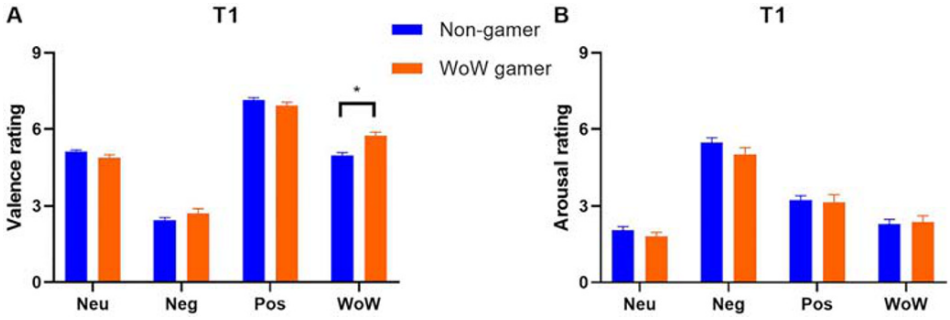

FIGURE 1 Cross-sectional analysis of subjective emotional experience in terms of valence and arousal. (A) Excessive gamers reported higher positive valence for the WOW related stimuli as compared to the non-gamers; (B) with respect to arousal no significant group differences were observed. Neu, neutral stimuli; Neg, negative stimuli; Pos, positive stimuli; WoW, world of Warcraft (gaming) stimuli; T1, timepoint 1 (baseline) assessment

TABLE 2 Group differences in brain activation—Cross-sectional analysis

Region	Peak MNI Coordinate (x, y, z)	Peak Intensity	Number of Voxels	Brodmann's Area
PCC	12, −54, 15	29.6239	305	29/30
rMOG	33, −75, 33	10.4264	83	19
rIPL	51, −54, 45	7.8967	39	40
lIPL	−54, −57, 42	10.4944	41	40

Abbreviations: PCC, posterior cingulate cortex; rMOG, right middle occipital gyrus; rIPL, right inferior parietal lobule; lIPL, left inferior parietal lobule. FDR $p < 0.05$ for multiple correction on the cluster level and cluster size >40.

increase in OVGA scores over the six-week training ($MD_{TRG(T2-T1)} = 1.33$, $t_{32} = 4.30$, $p < 0.001$), whereas no significant changes in the TRG were observed ($p > 0.05$) (see Table 1).

3.6 | Longitudinal analyses—Effects of training on subjective emotional experience

Examining the effects of training on the subjective emotional experience by means of mixed ANOVAs that focused on the WoW stimuli including group as between subject factor (TRG, TCG) and timepoint (T1, T2) as within subject factor revealed a significant interaction effect ($F_{1,55} = 6.26$, $p = 0.015$, $\eta^2 = 0.017$) for valence ratings. Post hoc analyses revealed that valence ratings significantly increased in the TRG (mean [SE]:TRG_{T1} = 4.95[0.15], TRG_{T2} = 5.34[0.16], $t_{55} = 3.02$, $p_{Bonferroni} = 0.022$, Figure 3A–C) but not in the TCG. An additional ANOVA on the arousal ratings also revealed a significant group by timepoint interaction effect ($F_{1,55} = 6.36$, $p = 0.015$, $\eta^2 = 0.025$), with post hoc analysis indicating that the training group reported higher arousal ratings after the training as compared to the TCG for WOW stimuli (mean [SE]: TCG_{T1} = 2.26[0.24], TRG_{T2} = 2.81[0.27], $t_{85.9} = 2.73$, $p_{Bonferroni} = 0.046$, Figure 3B,C).

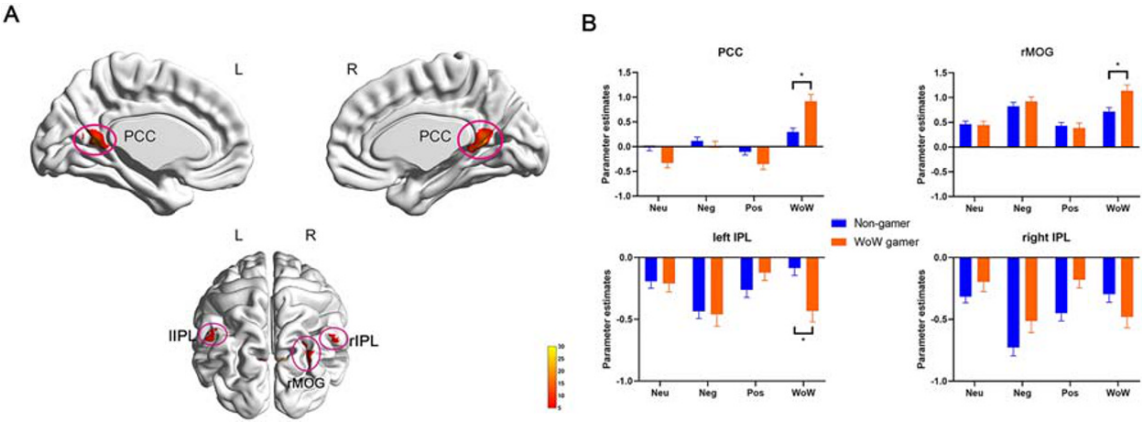

FIGURE 2 Cross-sectional analysis of the fMRI paradigm including positive, negative, neutral, and WoW gaming related stimuli. (A) Voxel-wise mixed ANOVA model including group and emotional condition revealed a significant interaction effect in four clusters located in the PCC, lIPL, rIPL, and rMOG (FDR $p < 0.05$, cluster size $k > 39$, color bar represents peak intensity); (B) post hoc analysis revealed that excessive gamers exhibited stronger neural cue-reactivity in response to gaming-related pictures compared to non-gamer (Bonferroni-corrected $p < 0.05$). TCG, training control group; TRG, training group; WoW, World of Warcraft; Neu, neutral stimuli; Neg, negative stimuli; Pos, positive stimuli; WoW, world of Warcraft (gaming) stimuli; T1, timepoint 1 (baseline) assessment; PCC, posterior cingulate cortex; IPL, inferior parietal lobule; lIPL, left inferior parietal lobe; rIPL, right inferior parietal lobe; rMOG, right middle occipital gyrus. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

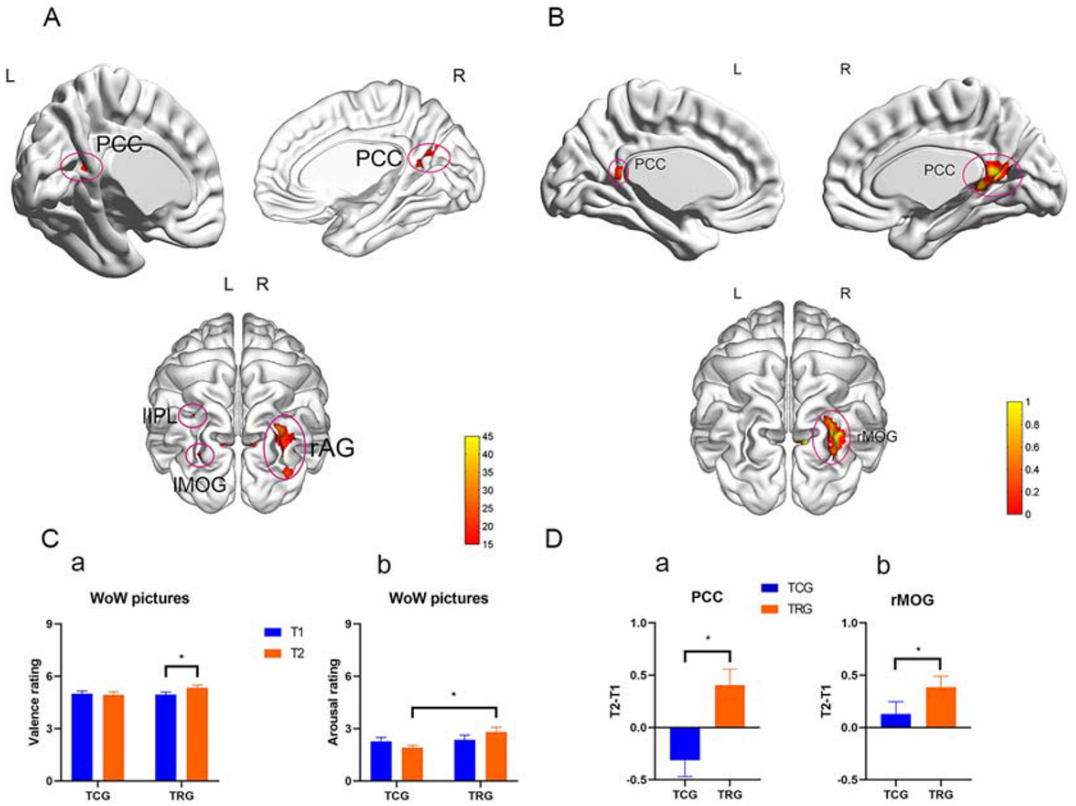

FIGURE 3 Longitudinal analysis of gaming effects on neural cue-reactivity. (A) Voxel-wise mixed ANOVA model including group and timepoint revealed an interaction effect in four clusters located in the PCC, rAG, lIPL, and lMOG (FDR $p < 0.05$, cluster size $k > 39$, color bar represents peak intensity); (B) overlaying changes observed in the cross-sectional and longitudinal analysis revealed that the PCC and rMOG demonstrated convergent alterations across the analyses; (C) results from the longitudinal analysis of emotional experience ratings. Results from post hoc tests demonstrating that the training group (TRG) reported increased valence ratings after the training relative to the baseline ratings, and higher arousal ratings after the training as compared to the non-training (TCG) control group at T2. (D) Post hoc examination of change scores (T2 > T1) in these regions revealed that the training group exhibited significantly increased reactivity to the gaming related stimuli after the training ($p < 0.05$). TCG, training control group; TRG, training group; WoW, world of Warcraft; PCC, posterior cingulate cortex; rMOG, right middle occipital gyrus; lIPL, left inferior parietal lobe; lMOG, left middle occipital gyrus, rAG, right angular gyrus. $^{*}p < 0.05$

Together with the increase in the OVGA scores, the changes in the subjective perception of the WoW stimuli indicate that the training intervention was efficient in terms of inducing an initial tendency for addictive gaming behavior/habit formation.

3.7 | Longitudinal analyses—Effects of training on neural cue reactivity

Examination of training-related neural changes for WoW-associated stimuli by means of a voxel-wise whole brain ANOVA including the between-subject factor group (TRG vs. TCG) and the within-subject factor timepoint (T1 vs. T2) revealed significantly larger changes in the PCC, bilateral middle occipital gyrus (lMOG, rMOG), and lIPL ($p < 0.05$, FDR corrected) in the training group (see Table 3 and Figure 3A). To determine the overlap between changes associated with long-term regular WoW gaming (cross-sectional analysis) and short-term WoW-training, the networks from both analysis approaches were overlaid. Results revealed common alterations in two regions encompassing the PCC and rMOG (Table 4 and Figure 3B). Subsequent extraction of parameter estimates from these regions revealed that WoW-related neural reactivity increased in both regions in the training relative to the control group over the course of the 6 weeks intervention period (two sample t test, for PCC, mean [SE]: $TCG_{(T2\text{-}T1)} = -0.32[0.15]$, $TRG_{(T2\text{-}T1)} = 0.41[0.15]$, $t_{65} = 3.33$, $p = 0.001$; for rMOG, mean [SE]: $TCG_{(T2\text{-}T1)} = -0.03[0.11]$, $TRG_{(T2\text{-}T1)} = 0.63[12]$, $t_{65)} = 4.11$, $p < 0.001$; Figure 3D). Additional

TABLE 3 Group differences in brain activation—Longitudinal analysis

Region	Peak MNI Coordinate (x, y, z)	Peak Intensity	Number of Voxels
rAG	30, −63, 39	42.1885	362
PCC	12, −57, 15	29.5285	164
lMOG	−30, −84, 30	19.6949	46
lIPL	−30, −54, 45	19.234	39

Abbreviations: rAG, right angular gyrus; PCC, posterior cingulate cortex; lMOG, left middle occipital gyrus; lIPL, left inferior parietal lobule. FDR $p < 0.05$ for multiple correction on the cluster level and cluster size >39.

TABLE 4 Overlap between brain functional alterations in the cross-sectional and longitudinal analysis

Region	Peak MNI Coordinate (x, y, z)	Number of Voxels
PCC	6, −57, 6	108
rMOG	33, −78, 24	79

Abbreviations: PCC, posterior cingulate cortex; rMOG, right middle occipital gyrus.

control analysis on the condition-specific extracted parameter estimates from these regions revealed no changes in reactivity to the non-gaming related stimuli (neutral, positive, negative; all $p_{Bonferroni} > 0.05$) arguing against unspecific training-induced changes in these regions.

3.8 | Examination of neural cue-reactivity within the regular gamers

In contrast to our expectations and some previous studies, including one study using a comparable WoW sample and cue-reactivity paradigm,[38] neither the cross-sectional nor the longitudinal analysis revealed cue-induced striatal activation (on the whole brain level or using the striatal regions-of-interest as used in Zhou et al., (reference 16). To further delineate the cue-reactivity networks and the robustness of this response, we explored neural reactivity within the group of regular WoW gamers (WoW > neutral) separately at T1 and T2. At both time-points, the WoW cues elicited robust activation in a highly similar network engaging the default mode network (DMN) including the PCC and mPFC, cognitive control network (CCN) including MFG and IFG, and posterior parietal attention network including precuneus and IPL, whereas no reactivity in striatal regions was observed (Figure 4, details presented in Table S8).

3.9 | Mapping onto the large-scale networks of the brain

To further map the gaming-related changes on the large-scale functional networks of the brain and to determine whether the cross-sectional and longitudinal analyses mapped onto the same networks, the significant clusters were mapped onto the Yeo atlas.[39] Briefly, the majority of voxels across all analyses mapped onto the default mode network (DMN) and the visual network (for details, see Tables S9–S12).

4 | DISCUSSION

The present fMRI study used a combined cross-sectional longitudinal design to examine cue-reactivity and emotional processing during early stages of Internet Gaming Disorder. Cross-sectional comparisons revealed enhanced positive valence attribution and neural reactivity in a parietal network, including the PCC and bilateral IPL, as well as rMOG in regular gamers as compared to gaming naïve-controls. Alterations in regular gamers were specifically observed during processing of gaming-related stimuli whereas the gamers exhibited normal processing of non-gaming related emotional stimuli. The longitudinal analyses revealed that 6 weeks of gaming increased valence ratings as well as neural cue-reactivity in a similar network, specifically the PCC and rMOG, in previously gaming-naïve controls. Finally, further examination of gaming cue-reactivity within the regular gamers revealed robust neural cue-reactivity at both timepoints in the posterior and anterior DMN, visual network, dorsal attention, and fronto-parietal network (see also Tables S11–S12), whereas no neural cue-reactivity in striatal regions was observed.

In line with previous studies in behavioral addiction,[10] including IGD,[9,11] the gaming-related stimuli induced stronger behavioral and

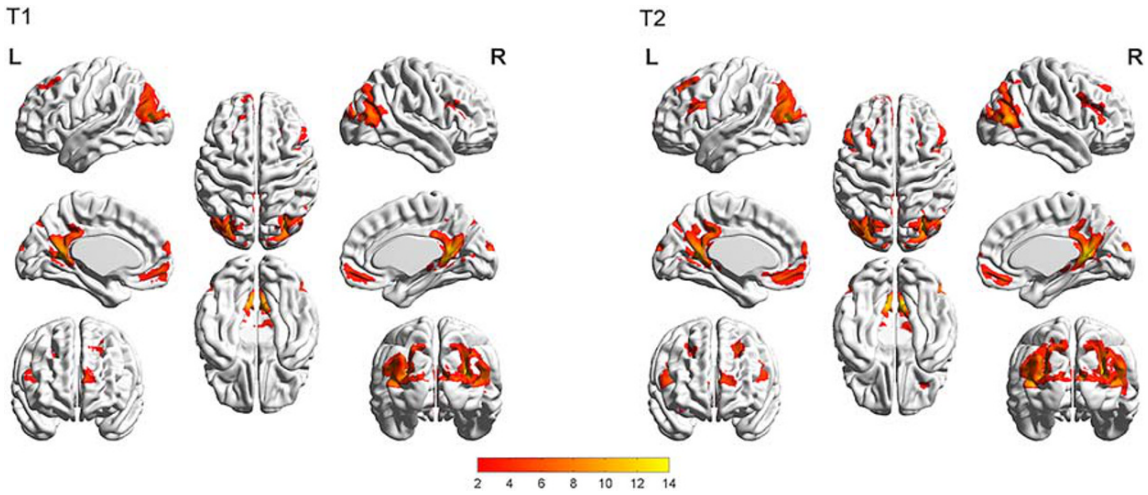

FIGURE 4 Examination of neural cue-reactivity (WoW pictures > neutral pictures) within the excessive gamers at both timepoints (T1 and T2). At both time-points, the gaming cues elicited robust activation in the bilateral posterior cingulate cortex (PCC), ventral medial prefrontal cortex (vmPFC), inferior prefrontal gyrus (IFG), middle prefrontal gyrus (MFG), superior prefrontal gyrus (SFG), parietal lobe, middle temporal gyrus (MTG), and occipital lobe (for details, see Table S12)

neural responses in regular gamers as compared to gaming-naïve controls. In contrast to accumulating evidence for emotional alterations, particularly elevated negative affect and depressive symptom load,[6,40] in excessive gamers, as well as an increasing number of studies reporting altered behavioral and neural processing of non-drug associated emotional stimuli in individuals with regular drug use (e.g., Zilverstand et al[2]), regular gamers in the present study did not demonstrate altered emotional processing of non-gaming related stimuli. A previous cross-sectional study reported altered fronto-striatal processing of negative stimuli in IGD individuals,[41] suggesting that IGD partly resembles emotion-regulation deficits as previously observed in regular substance users.[21] Participants in the previous IGD study fulfilled the DSM-5 criteria for IGD and compared to the regular gamers in the present study may therefore represent a sample that already made the transition from regular to problematic and finally compulsive gaming. In the context of the previous findings, the present results may reflect that (1) in contrast to regular substance users regular gamers present intact emotional processing, (2) predisposing emotional alterations may render regular gamers vulnerable for the transition to IGD, or alternatively that (3) only during later stages of IGD emotional processes become progressively dysregulated.

In line with recent meta-analytic data suggesting exaggerated neural responses to gaming cues in IGD, regular gamers exhibited enhanced neural reactivity in response to gaming related pictures, in both cross-sectional comparison with gaming-naïve controls and relative to neutral pictures. Exaggerated reactivity to drug or behavioral addiction related cues has been consistently reported in the literature and documented across substance addictions,[12,13] pathological gambling,[42] and increasingly IGD.[9,11] The exaggerated neural reactivity to addiction-associated cues in these populations is considered to reflect an acquired dopamine-mediated reinforcement-based learning process that develops with repeated pairing of the stimuli with rewarding experience. Neural cue-reactivity thus reflects mechanisms related to the development of exaggerated reward and salience attribution as well as self-directed processes and habit formation. Neural cue reactivity accordingly engages several brain systems engaged in these processes, specifically the striatum engaged in reward processes and habit formation, frontal regions engaged in executive control, and parietal regions engaged in attention and self-referential processes.[43]

In substance-based addictions, neural cue-reactivity has been most consistently observed in striatal regions involved in reward processes and habit formation.[12,13,43] Ventral striatal cue reactivity has been already observed in non-addicted, regular substance users which is considered to reflect exaggerated incentive salience of drug-associated cues.[16,18] In contrast to some previous studies in IGD subjects,[29] the present study did not find robust evidence for exaggerated striatal cue-reactivity in regular gamers, suggesting that alterations in striatal reward processing regions may only occur during later stages of the disorder. In line with a recently proposed hypothesis in the context of pathological gambling, the different neuroimaging profiles of individuals with regular substance use and gaming may be explained by the different dopamine release profiles, such that drugs induce supra-physiological dopamine levels, whereas engagement in potentially addictive behaviors may lead to prolonged elevated dopamine levels in the normal physiological range.[42]

On the other hand, neural cue reactivity in posterior parietal and middle occipital regions was observed in the cross-sectional analysis as well as in the longitudinal analysis. The observation that 6 weeks of gaming increased valence perception as well as posterior parietal cue-reactivity in previously gaming-naïve individuals suggests that changes in this region are critically related to regular (daily) engagement in gaming and already occur following relatively short time-periods. Specifically, the PCC and rMOG demonstrated convergently increased reactivity towards gaming related cues. Mapping the regions on the large-scale brain networks further confirmed that these regions map onto the posterior DMN and visual networks which have been repeatedly reported in cue-reactivity studies in substance addiction[2,16,44] as well as in meta-analytic studies on cue-reactivity in IGD (e.g., Zheng et al[11]). In the context of recent overarching models on substance use disorders, the DMN and visual network have been suggested to reflect a stronger engagement of self-referential or attentional/salience processes.[2] On the other hand, the posterior DMN has been increasingly recognized for its role in learning, including the acquisition and application of automated information processing following both immediate and excessive training.[44,45] In the context of the focus on regular gamers and the short-term intervention in gaming naïve controls, the present findings thus may point to an important role of DMN-mediated learning processes that may mediate the formation of regular gaming behavior.

Findings from the present study need to be considered in the context of several limitations. (1) The inclusion criterion of >7 h gaming per week for the WoW group will have led to the inclusion of a group of recreational rather than addictive users and given the lack of strict IGD diagnostic criteria at the time of the study implementation the diagnostic status of this group remains unclear. (2) Given that the IAPS stimuli represent rather weak and outdated emotional probes, we cannot fully exclude that (a) interactions between the differential visual properties of the IAPS and WoW stimuli may have contributed to the results and that (b) stronger emotional probes may have revealed gaming-associated differences between the experimental groups. Finally, the use of a passive control condition (in the TCG) may not have accounted for additional effects of WoW gaming such as motor skill learning in the longitudinal design.

Together, the present combined cross-sectional and longitudinal design did not reveal supporting evidence for behavioral or neural alterations during the processing of *non-gaming* associated stimuli in (excessive) gamers whereas convergent evidence for increased emotional and neural reactivity to gaming-associated stimuli was observed. Findings suggest that exaggerated neural reactivity in posterior parietal regions engaged in self-referential processing already occurs during early stages of regular gaming probably promoting continued engagement in gaming behavior.

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AUTHORS CONTRIBUTION

CM designed the study. RS, BL, and PT contributed to the acquisition of the data. FY, BB, and CM analyzed the data, interpreted the results, and drafted the manuscript. MR, BW, QW, and SY provided critical revision of the manuscript for important intellectual content.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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