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FULL-LENGTH REPORT

Event-related potentials in a two-choice oddball task of impaired behavioral inhibitory control among males with tendencies towards cybersex addiction

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ABSTRACT

Background and aims: Impaired behavioral inhibitory control (BIC) is known to play a crucial role in addictive behavior. However, research has been inconclusive as to whether this is also the case for cybersex addiction. This study aimed to investigate the time course of BIC in male individuals with tendencies towards cybersex addiction (TCA) using event-related potentials (ERPs) and to provide neurophysiological evidence of their deficient BIC. *Methods:* Thirty-six individuals with TCA and 36 healthy controls (HCs) were given a Two-Choice Oddball task that required them to respond differently to frequent standard stimuli (images of people) and infrequent deviant stimuli (pornographic images) within 1,000 ms. Electroencephalography (EEG) was recorded as the participants performed the task. *Results:* Despite the similarity of standard stimuli between the groups in terms of reaction times (RTs), the RTs of the TCA group to deviant stimuli were much slower than those of the HC group. The behavioral difference was accompanied by group differences in the averaged amplitudes of N2 (200–300 ms) and P3 (300–500 ms) components in the deviant-standard difference wave. More specifically, compared to the HC group, the TCA group demonstrated smaller N2 and P3 amplitude differences for deviant than standard stimuli. *Discussion and conclusions:* Individuals with TCA were more impulsive than HC participants and shared neuropsychological and ERP characteristics of substance use disorder or behavioral addictions, which supports the view that cybersex addiction can be conceptualized as a behavioral addiction.

KEYWORDS

cybersex addiction, behavioral inhibitory control, event-related potentials, N2, P3

INTRODUCTION

Cybersex addiction

Internet addiction has received increasing attention worldwide over the past two decades (Sussman, Harper, Stahl, & Weigle, 2018). Many researchers believe that a distinction should be made between general Internet addiction and specific Internet addiction (e.g., Brand, Young, Laier, Wölfling, & Potenza, 2016; Davis, 2001). Particularly, addiction to cybersex is often considered a specific form of Internet addiction (e.g., Brand, Young, & Laier, 2014; de Alarcón, de la Iglesia, Casado & Montejo, 2019). With the development of the Internet, the availability of pornographic materials has greatly increased. A study shows that among all kinds of online activities, watching pornography is the most likely to be addictive (Meerkerk, Eijnden, & Garretsen, 2006).

There has been a long debate about whether cybersex addiction should be defined as a behavioral addiction (e.g., de Alarcón et al., 2019). However, there is increasing evidence regarding the similarity between cybersex addiction and substance use disorder or other

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behavioral addictions (Kowalewska et al., 2018; Stark, Klucken, Potenza, Brand, & Strahler, 2018). Previous studies have revealed the association between cybersex addiction and cue reactivity and craving (Laier, Pawlikowski, Pekal, Schulte, & Brand, 2013; Brand et al., 2011); such mechanisms also result in the development and maintenance of substance use disorder (Drummond, 2001; Tiffany & Wray, 2012). The craving and cue reactivity concepts are derived from studies of substance use disorder and applied to research concerning specific Internet addiction (e.g., Potenza, 2008). For example, some studies have examined the neural correlations between craving and cue reactivity in individuals with specific Internet addiction and have discovered that the ventral striatum is involved in craving experiences in the face of addiction-related cues (Kober et al., 2016; Miedl, Büchel, & Peters, 2014). Research on subjects who have hypersexual behaviors or those who suffer from cybersex addiction also provides consistent results (Brand, Snagowski, Laier, & Maderwald, 2016; Klucken, Wehrum-Osinsky, Schweckendiek, Kruse, & Stark, 2016; Voon et al., 2014). Moreover, Laier and Brand (2014) developed a theoretically driven model for cybersex addiction. The model assumes a similarity between cybersex addiction and substance use disorder by stressing the role of positive and negative reinforcement. People can utilize cybersex to achieve gratification and reduce adverse emotional states (Laier & Brand, 2014). Such mechanisms of reinforcements have been widely recognized in other substance use disorders and addiction forms, where the negative (associated with withdrawal and tolerance) and positive (wanting and liking) reinforcements represent vital motivational processes (Robinson & Berridge, 2008).

Impulsivity

According to addiction theories, the weakened control of the specific behavior in behavioral addiction and substance use disorder may be related to the disturbance between the impulsive and reflective systems (Brand et al., 2019; Dong & Potenza, 2014; Wiers et al., 2007; Zilverstand & Goldstein, 2020). For example, it is suggested that in the Interaction of Person-Affect-Cognition-Execution (I-PACE) model (Brand et al., 2019), the dysregulation between the neural systems for early addictive behaviors is particularly related to the hyperactive impulsive system. Moreover, the cognitive and affective bias mechanisms, craving and cue reactivity, and incentive sensitization are related to such hyperactivity, which are mutually reinforced during the addiction process (Brand et al., 2019). For late addictive behaviors, it is possible that the reflective system loses its control of the impulsive system continuously, and certain behaviors can thus become habitual, even though such addictive behaviors lead to adverse consequences (Brand et al., 2019). Neuroimaging studies suggest that subjects experiencing problematic hypersexual behavior or cybersex addiction have elevated activities in the dorsolateral prefrontal cortex (one portion of reflective system) and ventral striatum (one portion of impulsive system) in the case of cue reactivity (Brand et al., 2016; Gola et al., 2017; Seok & Sohn, 2015). Reflective system hyperactivity is suggested to be the increased effort required by subjects to maintain the control of temptations, which are primarily triggered via an impulsive system. Therefore, the altered brain function and structure involved in impulsivity indicate the potential role of impulsivity in the cybersex addiction mechanism.

Impulsivity has been recognized as a complicated multidimensional concept that integrates biological, behavioral, and personality elements. The different impulsivity dimensions can be evaluated by imaging, behavioral, and self-report measures, respectively. Regarding the behavior dimension, impulsivity is used to describe maladaptive behaviors, including deficits in behavioral inhibitory control (BIC), that is, the ability to adaptively suppress behavior when environmental contingencies demand this (Groman, James, & Jentsch, 2009). With regard to impulsive behaviors, such as substance use disorder, the weakened BIC makes it more difficult to resist substance consumption and behavioral continuation regardless of the adverse effects (Spechler et al., 2016). For the biological dimension, studies have been conducted to examine the brain reactivity related to the diminished BIC. Typically, event-related potentials (ERPs) measurements are usually adopted to measure such a process.

Two ERPs components have been suggested in prior research to reflect BIC-related brain activity: One is N2, which is the maximum negative component in the frontal-central scalp when the stimulus lasts for approximately 200 ms. It represents the top-down mechanism, which inhibits the wrong propensity for automatic response and operates at the processing stage prior to motor execution (Falkenstein, 2006). Some studies have also indicated that N2 corresponds to conflict detection at the early inhibition stage (Donkers & Van Boxtel, 2004; Falkenstein, 2006; Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003). Therefore, N2 is identified as an indicator of cognitive process at the early stage, which is required for BIC implementation, but not real inhibitory braking. The second component of ERP is P3, which represents the maximal positive component within the central-parietal scalp when the stimulus lasts for approximately 300–500 ms. P3 is usually identified as an electrophysiological manifestation of the subsequent BIC tightly related to the real motor system inhibition within the premotor cortex (Donkers & Van Boxtel, 2004; Nieuwenhuis, Aston-Jones, & Cohen, 2005). Collectively, many studies indicate that both N2 and P3 are indicative of BIC-related processes with different functions. Therefore, the low N2 or P3 amplitudes among people with addiction compared with controls may serve as markers to predict neural deficits in the context of BIC.

Previous studies concerning BIC mostly apply classical paradigms such as Go/NoGo, Stop-Signal, and Two-Choice Oddball. In the Stop-Signal paradigm, participants need to stop their response when they see the stop signal. To maintain a high rate of successful inhibition, they must pay more attention to the stop signal and consciously wait for it. Consequently, the measurement of reaction time (RT) to Go stimuli may be inaccurate (Verbruggen & Logan, 2008). In the Go/NoGo paradigm, participants must make a button press response to stimuli of one type (Go stimuli) and withhold that response to stimuli of another type (NoGo stimuli). However, because Go trials require motor responses and NoGo trials do not, the BIC effects observed are likely to be contaminated by response-related processes (Kok, 1988). For this, the research adopts the Two-Choice Oddball paradigm. In previous studies, this paradigm has been successfully used to examine BIC associated with substance use disorders (e.g., Su et al., 2017; Zhao, Liu, & Maes, 2017).

In this task, respondents are requested to react to a frequent standard stimulus and infrequent deviant stimuli. For this reason, deviant stimuli comprise the detection of response conflict, suppression of prepotent responses, and choice of alternative reactions. Consequently, RTs to deviant stimuli are often longer than those to standard stimuli. Compared with the classical Go/NoGo task, this task reduces the possible influence of motor potential contamination on BIC and provides an extra RT indicator for BIC. It is argued that such a task may increase ecological validity compared with the Go/NoGo task. Inhibiting one specific behavior in daily life is usually accompanied by the substitution of one behavior with another expected behavior (such as suppressing the pornography watching habit and replacing it with additional entertainment). This is enrolled in the Two-Choice Oddball task, rather than the standard Go/NoGo task.

Impulsivity in cybersex addicts

Recent studies using self-report measures have found trait impulsivity to be positively correlated with higher symptom severity of cybersex addiction (Antons & Brand, 2018; Antons et al., 2019). However, studies examining BIC in the context of cybersex addiction using a Stop-Signal Task have provided mixed results. Antons and Brand (2018) found that higher symptom severity of cybersex addiction was related to higher trait impulsivity interaction with more impulsive actions. However, another study found that individuals with more symptoms of cybersex addiction exhibited better BIC performance (Antons & Matthias, 2020).

No existing study has examined the electrophysiological correlations between BIC and cybersex addiction, although ERP measurements have been adopted for years in exploring substance use disorder (Campanella, Pogarell, & Boutros, 2014; Littel, Euser, Munafo, & Franken, 2012) and different types of behavioral addiction (Luijten et al., 2014). ERP has been identified as a creditable approach for determining neural correlations of addictive disorders, and has been extensively applied in experiments and clinical practice (Campanella, Schroder, Kajosch, Noel, & Kornreich, 2019).

Currently, only gambling and gaming disorders are included in the main nomenclature systems for psychological disorders (i.e., DSM-5 and ICD-11). Cybersex addiction has been proposed as a type of behavioral addiction that has similar neurobiological and neurocognitive features as substance use disorders (Kowalewska et al., 2018; Stark et al., 2018). More empirical research is needed to determine the extent to which cybersex addiction exhibits similarities or differences with other addictive behaviors. It is of vital importance to identify the underlying mechanisms of cybersex addiction to better understand behaviors, and it can be quite useful to identify high-risk subjects and develop individualized interventions. Moreover, it facilitates ongoing discussion on comparability with other forms of addictive disorders.

The present study

This study aimed to explore the impact of pornographic material processing on BIC. BIC was investigated in individuals with tendencies towards cybersex addiction (TCA) and healthy controls (HCs) using a Two-Choice Oddball task. ERPs were measured in response to frequent standard stimuli (images of people) and infrequent deviant stimuli (pornographic images). Based on existing research on substance use disorder and behavioral addiction, we hypothesized that cybersex addiction is associated with impaired BIC. Specifically, we hypothesized that (1) individuals with TCA would exhibit significantly lower accuracy and longer RTs in response to pornography related deviant cues as compared to HC, and (2) individuals with TCA would exhibit attenuated ERP effects (N2 and P3 components) compared with HC.

METHODS

Participants

We gathered 303 questionnaires from male college students to ascertain their scores on the Problematic Internet Pornography Use Scale (PIPUS; Chen, Wang, Chen, Jiang, & Wang, 2018). Women were excluded from the research, because men more easily encounter such problems due to their frequent contact with pornographic materials (Ross, Månsson, & Daneback, 2012). As cybersex addiction is not a codified diagnosis, no thresholds could be used to empirically identify problematic Internet pornography users. Therefore, respondents whose scores were in the top 20th percentile were classified into the TCA group, while those whose scores fell in the bottom 20th percentile were classified into the HC group. According to the classification criterion, 36 participants with TCA and 36 HC were invited to voluntarily participate in the electrophysiological study. Two participants were excluded due to excessive eye movement artifacts. All participants were heterosexual, right-handed, had normal or corrected vision, had no history of mental illness, and had no medication history of the central nervous system (see Table 1).

Measurement instruments and procedure

To assess TCA, a Chinese version of the PIPUS was used. The PIPUS is a self-report scale developed based on the

Table 1. Participant characteristics of the TCA and HC groups

Variables (mean ± SD)	TCA (n = 36)	HC (n = 34)	t
Age (years)	19.75	19.76	−0.05
Weekly frequency of viewing pornography [a]	3.92 ± 1.54	1.09 ± 0.87	9.55***
Weekly frequency of masturbation [a]	2.81 ± 1.22	1.12 ± 0.91	6.54***
PIPUS score	19.78 ± 6.40	1.65 ± 1.28	16.65***
SDS score	28.00 ± 2.62	26.62 ± 3.36	1.93
SAS score	27.56 ± 3.12	26.29 ± 3.90	1.50
BIS-11 score	58.81 ± 9.37	55.03 ± 11.35	1.52

Abbreviations: BIS-11, Barratt Impulsiveness Scale-11; HC, healthy controls; PIPUS, Problematic Internet Pornography Use Scale; SAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale; TCA, tendencies towards cybersex addiction.
***$P < 0.001$.
[a]During the last 6 months.

Problematic Pornography Use Scale (Kor et al., 2014). The scale comprises 12 items grouped into four dimensions: (a) distress and functional problems, (b) excessive use, (c) self-control difficulties, and (d) use in order to escape or avoid negative emotions. Here, we replaced the term "pornography" with "Internet pornography." Participants were asked to report their use of Internet pornography in the past six months using a 6-point Likert scale, where 0 means "never" and 5 means "all the time"; the higher the score, the more severe the PIPU. The scale has good reliability and validity among Chinese college students (Chen et al., 2018). Cronbach's α in this study was 0.93.

Participants first completed the PIPUS. According to the above selection criteria, a sample of individuals with TCA and HC participants were invited to participate in the second stage of the experiment. They performed a Two-Choice Oddball task while Electroencephalography (EEG) was recorded. To assess trait impulsivity and a marker of psychiatric disease, participants completed the Barratt Impulsiveness Scale-11 (BIS-11; Patton, Stanford, & Barratt, 1995), the Self-Rating Depression Scale (SDS; Zung, Richards, & Short, 1965), and the Self-Rating Anxiety Scale (SAS; Zung, 1971). Further, demographic data and basic information related to cybersex use (frequency of viewing pornography and masturbation) were assessed. Finally, participants were debriefed and received a payment of RMB 100. The whole experiment took approximately 80 min.

Stimuli and experimental task

The assessment of BIC capacity was performed using the Two-Choice Oddball paradigm. Two types of stimuli were available: standard stimuli (person pictures) and deviant stimuli (pornographic pictures). The pornographic pictures were collected from free pornography websites; they included 40 picture sets comprising four different heterosexual sex categories (vaginal, anal sex, cunnilingus, and fellatio). Each category comprised 10 pornographic pictures. The person pictures, which were obtained from websites, included 40 pictures of a man and a woman taking a walk or jogging. They were matched to the number and sex of individuals in the pornographic pictures. These pictures were rated in a pilot study on the dimensions of valence, arousal, and sexual arousal (see Supplementary materials). No significant differences were found with respect to valence ratings. However, pornographic images elicited higher arousal and sexual arousal than the person images. To conceal the real objective of the experiment, these pictures were shown to respondents with colored frames, with a red frame for person pictures and blue frame for pornographic pictures. The participants were instructed to judge the color of the frames as quickly and accurately as possible by pressing different keys.

The task consisted of four blocks of 100 trials. Every block presented 70 standard stimuli and 30 deviant stimuli. Participants were required to sit in front of the monitor, approximately 150 cm away from the screen, with a horizontal and vertical viewing angle of less than 6°. Participants had a two-minute break in each block; they also gained accuracy rate feedback to assess their performance at the end of each block. The stimuli were presented using E-prime 2.0 (Psychology Software Tools). Each trial began with a small white cross for 300 ms. Thereafter, a blank screen with a random duration of 500–1,000 ms appeared, followed by the onset of the image stimulus. When the standard picture appeared, the participants needed to quickly and accurately press the "F" key on the keyboard with their left index finger, and when the deviation picture appeared, they needed to press the "J" key with their right index finger (keyboard keys were balanced between participants). The stimulus picture disappeared after the key press or as it elapsed for 1,000 ms. Every response had been followed by a blank screen with a duration of 1,000 ms. The sequence of standard and deviant stimuli was randomized. Please refer to Fig. 1 for specific experimental procedures.

Electrophysiological recording and analysis

Tin electrodes installed in an elastic cap were employed to record the brain electrical activities from 32 scalp sites (Brain Products, Germany). The electrode FCz was used as the online reference, and the AFz electrode was used as the grounding electrode. Vertical electrooculogram (VEOG) was recorded by an electrode placed under the right eye, while the horizontal electrooculogram (HEOG) was recorded by an electrode placed 1 cm outside the left eye. The resistance of all electrodes was less than 5 kΩ. EEG and EOG were amplified with a DC ~100 Hz bandpass and digitized at 500 Hz/channel. The EEG data were analyzed offline using Brain Vision Analyzer 2.0. First, we reset the reference to the mean amplitude of the bilateral mastoid. Then, a bandpass of 0.01–30 Hz and an attenuation of 24 dB were used for filtering. The EOG artifacts were eliminated using independent component analysis.

The EEG that responded correctly under each condition was superimposed and averaged. The ERP waveform is locked

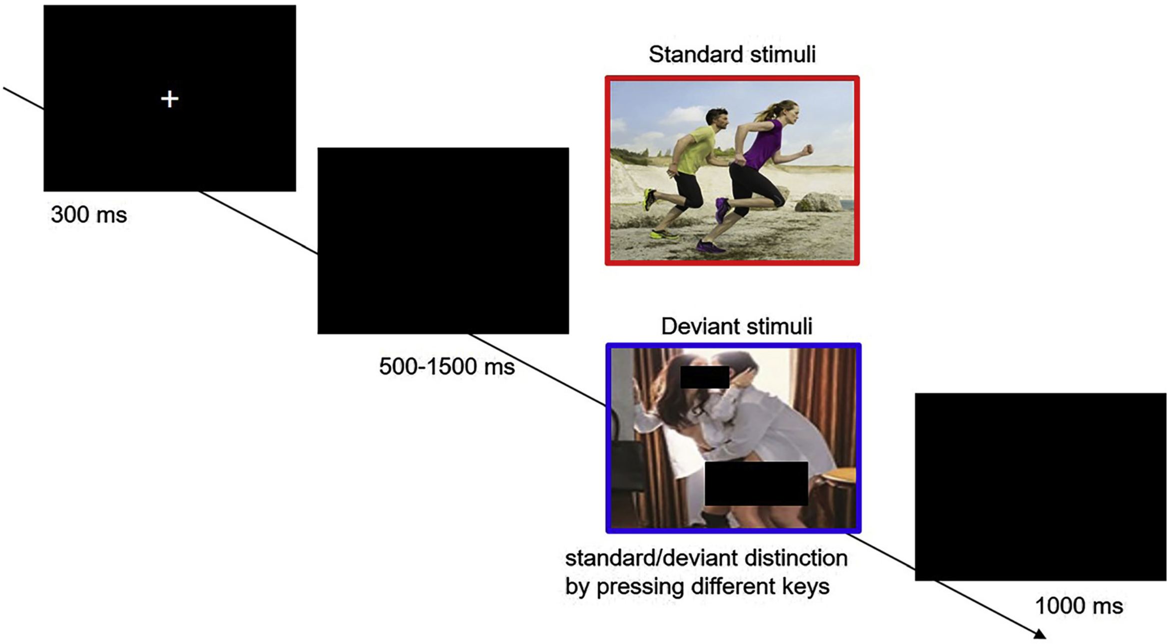

Fig. 1. Schematic illustration of the experimental procedure and the stimuli examples. Each trial presented a single stimulus. In a session, a standard stimulus (person pictures) was presented in 70% of the trials, while deviant stimuli (pornographic pictures) were presented in 30% of the trials

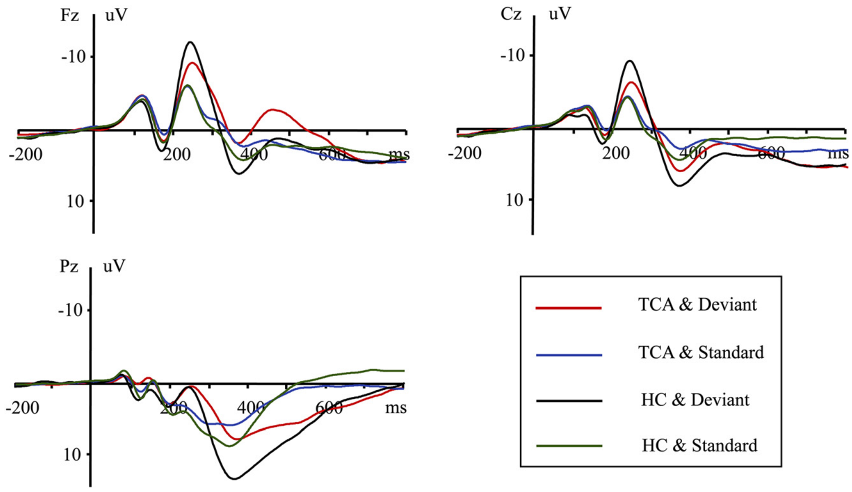

Fig. 2. Grand average ERPs for TCA and HC groups during standard and deviant conditions at Fz, Cz, and Pz electrode sites

at the beginning of the stimulus, with an average epoch of 1,000 ms, including the baseline of 200 ms before the stimulus. From the grand average waveforms of ERP in Figs. 3 and 4, it can be seen that the amplitude difference under standard and deviant conditions began at approximately 200 ms. These differences were manifested as N2 (200–300 ms) in the frontal-central scalp and P3 (300–500 ms) in the central-parietal scalp in the deviant-standard difference wave. Therefore, this study analyzed the average amplitudes and latencies of the N2 and P3 components at nine electrode sites, namely, F3, Fz, F4 (three frontal sites), C3, Cz, C4 (three central sites), P3, Pz, and P4 (three parietal sites).

Statistical analysis

Questionnaire data were analyzed using independent t-tests. Repeated measures analysis of variance (ANOVA) was applied to analyze the ERP indices of BIC (N2 and P3) and behavioral

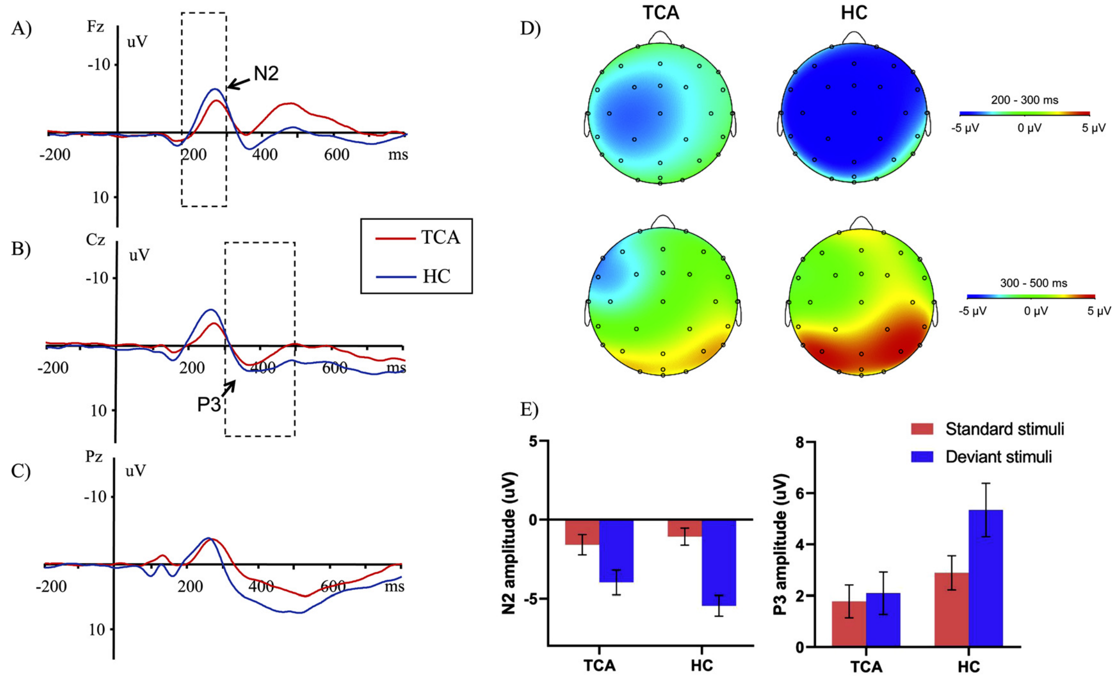

Fig. 3. (A, B, C) The averaged deviant minus standard difference ERPs in TCA and HC groups at the scalp midline electrode sites (Fz, Cz, and Pz). (D) Topographical maps of the amplitudes difference between deviant and standard conditions (across 200–500 ms) in TCA (left) and HC (right) groups. (E) The mean amplitudes of N2 and P3 in standard and deviant conditions for TCA and HC groups. The error bars represent one standard error

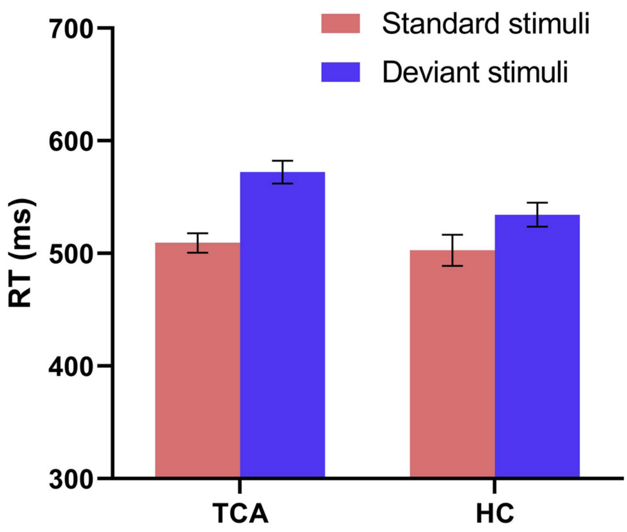

Fig. 4. RTs for TCA and HC groups for standard and deviant stimuli. The error bars represent one standard error

measurements (accuracy and RTs). This resulted in a Group (TCA, HC) × Stimulus (standard and deviant conditions) × Electrode sites (9 sites) ANOVA for N2 and P3 amplitudes and latencies related to BIC, and a Group × Stimulus ANOVA for behavioral measures. The RT data were based on trials with a correct response. Trials where RTs were less than 150 ms, reflecting anticipation, were not considered (Meule, Lutz, Vögele, & Kübler, 2012). Stimulus and Electrode sites were within-subject factors, and Group was the between-subject factor. Post-hoc analyses using pairwise comparisons with Bonferroni adjustments were applied. All statistical values were reported with Greenhouse–Geisser corrections, and the partial eta-square (η^2_p) value was reported to have significant effects. An alpha level of 0.05 was used for all statistical tests.

Ethics

Informed consent was signed by all study participants. The research was approved by the Chengdu Medical College Institutional Review Board.

RESULTS

Self-reported results

As expected, TCA group showed higher PIPUS score (19.78 ± 6.40) than HC group (1.65 ± 1.28), $t(68) = 16.65$, $P < 0.001$. In addition, TCA group scored higher than HC group on the weekly frequency of viewing pornography (3.92 ± 1.54 vs. 1.09 ± 0.87), $t(68) = 9.55$, $P < 0.001$, and masturbation (2.81 ± 1.22 vs. 1.12 ± 0.91), $t(68) = 6.54$, $P < 0.001$. However, TCA and HC groups did not differ on depression as measured by the SDS, on anxiety as measured by the SAS, and on trait impulsivity as measured by the BIS-11, indicating that these factors were not an area of concern in the present study. This makes any behavioral and ERP differences directly attributable to measures related to cybersex.

Behavioral results

The repeated measures ANOVA of the accuracy, with Group as a between-subject factor and Stimulus as a within-subject factor, revealed a significantly lower accuracy for the deviant (96.27%) than for the standard stimuli (98.44%), $F(1, 68) = 15.67$, $P < 0.001$, $\eta^2_p = 0.19$. There were no significant effects involving the Group factors, $Fs < 1$. With respect to RTs, deviant stimuli gave rise to longer RTs compared with standard stimuli, $F(1, 68) = 41.58$, $P < 0.001$, $\eta^2_p = 0.38$ (see Fig. 2). No main effect for Group was found, $F(1, 68) = 2.65$, $P = 0.108$, $\eta^2_p = 0.04$. More importantly, the Group × Stimulus interaction was significant, $F(1, 68) = 4.54$, $P = 0.037$, $\eta^2_p = 0.06$. The simple-effect of Stimulus showed that deviant stimuli elicited longer RTs compare with standard stimuli in both the TCA and HC groups, $F(1, 35) = 46.28$, $P < 0.001$, $\eta^2_p = 0.57$, $F(1, 33) = 7.60$, $P = 0.009$, $\eta^2_p = 0.19$. Moreover, the simple-effect of Group showed that although the two groups exhibited analogous RTs for standard stimuli, $F(1, 68) = 0.16$, $P > 0.68$, the TCA group exhibited longer RTs than the HC group for deviant stimuli, $F(1, 68) = 6.68$, $P = 0.012$, $\eta^2_p = 0.09$.

ERP results

N2. The repeated measures ANOVA on the mean amplitudes of N2, with Stimulus and Electrode sites as the repeated factors and Group as the between-subject factor, displayed significant main effects of Stimulus, $F(1, 68) = 72.72$, $P < 0.001$, $\eta^2_p = 0.52$, and Electrode sites, $F(8, 544) = 130.08$, $P < 0.001$, $\eta^2_p = 0.66$, and a significant Stimulus × Electrode sites interaction, $F(8, 544) = 8.46$, $P < 0.001$, $\eta^2_p = 0.11$. Compared with standard stimuli, deviant stimuli induced greater amplitudes at frontal and central electrodes. No significant main effect was found for Group, $F < 1$. Moreover, there was a significant Group × Stimulus interaction, $F(1, 68) = 6.27$, $P = 0.015$, $\eta^2_p = 0.08$. The amplitude difference between deviant and standard stimuli was larger in HC group (−4.38 μV) than the TCA group (−2.39 μV).

Additionally, significant main effects of Stimulus, $F(1, 68) = 28.51$, $P < 0.001$, $\eta^2_p = 0.30$, and Electrode sites, $F(8, 544) = 3.52$, $P = 0.023$, $\eta^2_p = 0.05$, were observed for N2 latencies. In comparison with standard stimuli, deviant stimuli elicited longer latencies. N2 latency in frontal sites was longer than that in parietal sites.

P3. Similarly, the repeated measures ANOVA on the mean amplitudes of P3 showed significant main effects of Group, $F(1, 68) = 4.45$, $P = 0.039$, $\eta^2_p = 0.06$, Stimulus, $F(1, 68) = 8.31$, $P = 0.005$, $\eta^2_p = 0.11$, and Electrode sites, $F(8, 544) = 76.03$, $P < 0.001$, $\eta^2_p = 0.53$, and a significant Stimulus × Electrode sites interaction, $F(8, 544) = 43.91$, $P < 0.001$, $\eta^2_p = 0.39$. The averaged amplitudes across conditions were larger for the HC group (4.12 μV) than for the TCA group (1.94 μV). Deviant stimuli induced larger amplitudes compared to standard stimuli at central and parietal sites. More importantly, the interaction effect between Group and Stimulus was significant, $F(1, 68) = 4.94$, $P = 0.03$, $\eta^2_p = 0.07$. Although the HC group exhibited enhanced P3 amplitudes for deviant stimuli (5.34 μV) than for standard stimuli (2.89 μV), $F(1, 33) = 11.63$, $P = 0.002$, $\eta^2_p = 0.26$, the TCA group did not show a significant P3 amplitude differences between deviant (2.10 μV) and standard (1.78 μV) conditions, $F < 1$.

Analysis of P3 latencies revealed a significant main effect of Electrode sites, $F(8, 544) = 17.13$, $P < 0.001$, $\eta^2_p = 0.20$, reflecting longer latencies in the frontal and central sites than the parietal sites. The interaction between Stimulus × Electrode sites was significant as well, $F(8, 544) = 16.71$, $P < 0.001$, $\eta^2_p = 0.20$, reflects that longer latencies triggered by deviant stimuli than standard stimuli at parietal sites.

DISCUSSION

This study aimed to explore the effect of pornographic stimuli on BIC among individuals with TCA compared to HC, both at the behavioral and electrophysiological levels, using a modified Two-Choice Oddball task combined with ERPs recordings. This is the first study to investigate the electrophysiological correlates of BIC in the context of cybersex addiction with ERPs. Although previous studies have found a link between trait impulsivity and symptoms of cybersex addiction (Antos & Brand, 2018; Antos et al., 2019), this study did not find a significant difference in BIS-11 scores between the TCA and HC groups. Similarly, Gola et al. (2017) found no significant differences in trait impulsivity between diagnosed problematic pornography users and control participants. Future research will therefore need to examine this link in greater depth.

Although BIS-11 is considered a trait measure of impulsivity, the modified Two-Choice Oddball task pertains to an operational measure of impulsivity. In the domain of neuropsychology and cognitive neuroscience, impulsivity is often equal to BIC, meaning the top-down control mechanism, which inhibits inappropriate automatic or reward-related responses against current requirements (Groman et al., 2009). Although both groups exhibited effects of BIC during the deviant condition, the response of the TCA group to the deviant stimuli was slower than that of the HC group, indicating poorer BIC capacity. Behavioral differences were accompanied by group differences in the average amplitudes of N2 and P3 in the deviant-standard difference wave. More specifically, the TCA group demonstrated smaller N2 and P3 amplitude differences for deviant than standard stimuli compared to the HC group. The results prove that task-irrelevant pornographic stimuli interfere with the BIC of individuals with TCA.

In this study, participants experienced response conflict when they responded to infrequent deviant stimuli in the context of frequent standard stimuli that elicit a prepotent response. This response conflict induced a prominent N2 component in the deviant-standard difference wave, with the largest amplitudes at the frontal and central sites. Previous studies have shown that a fronto-central oddball N2 evoked by deviant stimuli, which is similar to NoGo N2 elicited in the Go/NoGo task, was accepted as an index of conflict monitoring (Donkers & Van Boxtel, 2004; Nieuwenhuis et al., 2003). The N2 amplitude with conflict detection was greater than that without conflict detection (Donkers & Van Boxtel, 2004). Here, both the TCA and HC groups exhibited significantly deviant-related N2 components. This shows that both groups could detect response conflict during the deviant condition. However, the TCA group showed smaller amplitude differences for deviant than standard conditions compared to the HC group. This shows that reduced attention engagement was yielded in the TCA group versus the HC group, leading to poor preparation for later BIC (Eimer, 1993). Therefore, during the processing phase before motor execution, the TCA group exhibited deficient early cognitive processes necessary to implement BIC.

Furthermore, a significant P3 component, with the largest amplitudes at parietal sites, was found in the 300–500 ms range of the deviant-standard difference wave. Previous studies have shown that P3 caused by nogo stimuli (reflecting later BIC) has been found to be more significant than that caused by go stimuli in the Go/NoGo task (Donkers & Van Boxtel, 2004; Nieuwenhuis et al., 2005). The amplitude of P3 increases with the growth of cognitive resources. Consistent with those of previous studies, deviant stimuli involving BIC in this study resulted in greater P3 amplitudes than standard stimuli. More importantly, the amplitude of deviant-related P3 in the TCA group was much smaller than that in the HC group. It revealed a deficient BIC process under deviant conditions in the TCA group.

Accordingly, less pronounced N2 and P3 amplitudes in the TCA group relative to the HC group can be considered markers for neural deficits in BIC. Our study supports the idea that impulsivity is a risk factor for the development of cybersex addiction (Antons & Brand, 2018; Antons et al., 2019). This is consistent with the results of most studies on substance use disorder (e.g., Sokhadze, Stewart, Hollifield, & Tasman, 2008; Zhao et al., 2017), gambling disorder (e.g., Kertzman et al., 2008), and Internet addiction (e.g., Zhou, Yuan, Yao, Li, & Cheng, 2010). These studies confirmed that deficits in BIC in individuals with substance use disorder and behavioral addictions were associated with attenuated N2 and/or P3 amplitudes. Thus, the behavioral and electrophysiological results of this study demonstrate that cybersex addiction might share neuropsychological and ERP characteristics of substance use disorder or behavioral addictions.

One potential mechanism leading to impaired BIC in individuals with TCA is that cue reactivity and craving while watching pornographic cues induce them to automatically attend to pornographic materials. Therefore, the occupation of cognitive resources affects the performance of the TCA group in cognitive tasks. According to the dual-process model of addiction (Brand et al., 2019; Dong & Potenza, 2014; Wiers et al., 2007; Zilverstand & Goldstein, 2020), addictive behaviors are subject to the influence of mutually competing impulsive and reflective systems. In addictive behavior, however, the reflective system is suppressed by the impulsive system. This relationship makes it increasingly harder for individuals with TCA to cognitively control cybersex activities despite negative consequences. Since pornographic stimuli processing is associated with brain structures related to attention and arousal (Paul et al., 2008), the pornographic pictures in the Two-Choice Oddball task seem to attract more attention to the TCA group than the HC group. Thus, as shown by the worse BIC performance, pornographic cues result in individuals with TCA being distracted more strongly from task demands. Theoretically, craving and cue reactivity should correlate with deficits in BIC in the case of Internet gaming disorder as well as other types of Internet addiction (Brand et al., 2019; Dong and Potenza, 2014). In future research, the potential interaction between neural correlates of cue reactivity and reductions in BIC should be examined to better understand the underlying mechanisms of the loss of control over cybersex consumption. For example, future studies could assess participants' levels of sexual arousal and craving before and after presentation of pornographic images to determine whether they interfere with participants' BIC capacity (Laier et al., 2013).

Our findings here are theoretically and clinically significant. Theoretically, our results indicate that cybersex addiction resembles substance use disorder and impulse control disorder in terms of impulsivity at electrophysiological and behavioral levels. Our findings may fuel the persistent controversy about the possibility of cybersex addiction as a novel type of psychiatric disorder. Clinically, our results suggest that ERPs can be employed to investigate neurocognitive functions (such as BIC), thus highlighting which cognitive processes should be addressed in cybersex addiction treatment (Campanella et al., 2019). Besides the usefulness of ERPs in identifying patient impairments, studies have been conducted to examine the ERPs effect on psychiatric disorder treatment (Campanella, 2013). In the field of Internet addiction, several studies have utilized ERPs recordings to assess potential clinical benefits (Ge et al., 2011; Zhu et al., 2012). These studies indicate that ERPs measurement may be a potential approach for assessing the efficiency and brain correlations of cognitive correction for addictive disorders.

There are several limitations to this study. First, we investigated only male participants because cybersex addiction seems to be primarily a male problem. For example, previous studies have found that men are exposed to pornography at a younger age, consume more pornography (Hald, 2006), and are more likely to encounter problems compared with women (Ballester-Arnal, Castro Calvo, Gil-Llario, & GilJulia, 2017). However, studies comparing men's and women's activation patterns in processing pornography have shown that certain brain areas are more activated in men than in women (e.g., Wehrum et al., 2013). Thus, future studies should examine the sex differences in BIC during the processing of pornographic cues. Second, this study did not consider any definite clinical sample. This is because there is no consensus regarding the clinical definition of cybersex addiction. Future studies should perform a comparative analysis of respondents with cybersex addiction and respondents without cybersex addiction to determine whether there is a common response mode. Third, this is the first study to apply the Two-Choice Oddball task in the context of cybersex addiction. Consequently, these preliminary research results should be compared with other tasks such as the Go/Nogo and Stop-Signal paradigms. A recent study showed that individuals with higher symptom severity of cybersex addiction performed better in the Stop-Signal task (Antons & Brand, 2020). This suggests that studies on BIC in cybersex addiction are rare and inconsistent; thus, more research is needed to further demonstrate this. Finally, there is still debate among scholars as to whether pornographic images are cues (Prause, Steele, Staley, Sabatinelli, & Hajcak, 2016) or rewards (Gola, Wordecha, Marchewka, & Sescousse, 2016). Incentive salience theory distinguishes two basic components of "wanting" and "liking," and addiction is characterized by increased cue-related "wanting" and decreased reward-related "liking" (Robinson, Fischer, Ahuja, Lesser, & Maniates, 2015). More advanced experimental paradigms, disentangling cues, and rewards are required in future studies. It is also useful to assess sexual desire and liking for pornographic stimuli and to examine their relationship to electrophysiological signals.

In summary, we expanded upon previous findings to show that individuals with TCA exhibit neural deficits specifically for pornographic cues during both the early and late stages of the inhibition process. The behavioral and electrophysiological data of this study demonstrate that cybersex addiction may share the neuropsychological and ERPs characteristics of substance use disorder or behavioral addictions, which supports the view that cybersex addiction can be conceptualized as a behavioral addiction.

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SUPPLEMENTARY MATERIAL

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