Electrophysiological evidence of enhanced early attentional bias toward sexual images in individuals with tendencies toward cybersex addiction

JIANFENG WANG[†*] ⓘ, YUANYUAN CHEN[†] ⓘ and HUI ZHANG[*] ⓘ

School of Psychology, Chengdu Medical College, Chengdu, 610500, China

ABSTRACT

Background and aims: Attentional bias is a key factor in addictive behavior maintenance. However, whether attentional bias has a similar effect on cybersex addiction is unclear. We investigated differences in the attentional processing of sexually explicit images between individuals with high tendencies toward cybersex addiction (TCA) versus low tendencies using behavioral and electrophysiological indices. *Methods:* Twenty-eight individuals with high TCA and 29 with low TCA performed an addiction Stroop task comprising sexual and neutral images in colored frames. Participants were asked to respond to the frame color and not the image contents, and behavioral and event-related potentials were recorded. *Results:* Behaviorally, an addiction Stroop interference effect was found in the high TCA group, as shown by the longer reaction times to judge the frame colors of sexual images. Electrophysiologically, a P200 (150–220 ms) enhancement was present in response to sexual images compared with neutral ones, which was absent in the low TCA group. The event-related potential correlates with the addiction Stroop interference effect, indicating that the attentional bias underlying the addiction Stroop interference operates at an automatic level. A general, sexually related bias was found in the late positive potential (300–700 ms) amplitude, although between-group differences were insignificant. *Discussion and conclusions:* These findings indicate that sexual stimuli grab the attentional resources of individuals with high TCA at early automatic stages of attentional processing. Increased cue reactivity to sexual stimuli may contribute to pornographic consumption and play a crucial role in sustaining problematic excessive use of online pornography.

INTRODUCTION

Internet addiction has received growing attention in the past few decades. Many scholars argue that generalized and specific forms of Internet addiction should be distinguished (Brand, Young, Laier, Wölfling, & Potenza, 2016; Davis, 2001). Cybersex addiction is a specific form of Internet addiction (Davis, 2001; Meerkerk, van den Eijnden & Garretsen, 2006).

The use of online sexual activities has drastically increased due to the emergence of cybersex (Kohut et al., 2019; Lewczuk, Wojcik, & Gola, 2019). Approximately 87% males view pornography monthly, while about 58% males view pornography weekly (Brem et al., 2018). To date, no consensus exists regarding the conceptualization and diagnosis of cybersex addiction. Researchers use different terms to describe the phenomenon (e.g., problematic Internet pornography use, Internet sex addiction, online porn addiction). Although these

[†]These authors have contributed equally to this work.

[*]Corresponding authors.
E-mail: wjfzy1985@163.com, zhanghui080402@126.com

terms are different, they all contain similar addiction symptoms such as loss of control, preoccupation, and compulsive use. Additionally, broadly, cybersex addiction includes not only pornography consumption but also other cybersex activities such as engaging in sex chats, using sex webcams, searching for sexual partners, or engaging in sexual role play (Döring, 2009). However, the most common form of cybersex is watching pornography, particularly for men (Ross, Månsson, & Daneback, 2012; Shaughnessy, Byers, & Walsh, 2011). Furthermore, the classification of cybersex addiction is still under debate (Gola & Potenza, 2018). Cybersex addiction has been considered a subtype of hypersexual disorder (HD; Kafka, 2010), or a manifestation of compulsive sexual behavior disorder (CSBD; Kraus et al., 2018). Many patients presenting with HD or CSBD will show cybersex addiction as their primary problematic sexual behavior. However, some studies emphasize that cybersex addiction is different from HD or CSBD, because it involves only online sexual activities and not physical sexual intercourse in real life (Snagowski & Brand, 2015).

Understanding the development of cybersex addiction is necessary to devise appropriate treatment strategies. Therefore, deeper insight into the regulation of responses to sexually related stimuli is required (Castro-Calvo, Cervigón-Carrasco, Ballester-Arnal, & Giménez-García, 2021). Brain imaging studies have revealed that important brain substrates regulate the perception of sexually related cues (Brand et al., 2016; Kühn & Gallinat, 2014; Voon et al., 2014). Increasing evidence shows that men addicted to pornography display neural activation toward sexually related stimuli in the reward circuit (e.g., orbitofrontal cortex, ventral striatum), possibly regulated by the mesolimbic dopamine reward pathway (Brand et al., 2016; Seok & Sohn, 2015; Voon et al., 2014). Evidence from studies based on neurocognitive models of addiction points to the link between abnormal dopamine release and cognitive and behavioral responses to drug-related stimuli (e.g., Field, Marhe, & Franken, 2014; Kluwe-Schiavon et al., 2020). Specifically, individuals with drug addiction show elevated cue reactivity accompanied by high attention toward drug-related stimuli. This mechanism underlies emerging addictive behaviors and leads to high relapse rates among drug addicts (Asmaro, Carolan, & Liotti, 2014; Marissen et al., 2006). Whether cybersex addiction shares a similar physiopathology needs further investigation. Because of the similarities in behavior and neurobiology between cybersex addiction and substance abuse (Laier, Schulte, & Brand, 2013; Seok & Sohn, 2020; Snagowski, Wegmann, Pekal, Laier, & Brand, 2015; Wang & Dai, 2020), excessive attentional bias toward sexually related stimuli may be an indication of cybersex addiction. This heightened sexual cue reactivity may also contribute to the emergence and maintenance of cybersex addiction.

Several behavioral paradigms for measuring attentional bias have been developed, such as the Stroop task (Stroop, 1935). In an addiction Stroop test, differences in reaction times (RTs) to the font color of addiction-related and neutral stimuli are thought to reflect attentional bias. The RTs to the colors of addiction-related stimuli have proven to be slower than those to neutral stimuli because the addiction-related content distracts the individual from concentrating on color judgment. The Stroop task, as an accurate measure of attentional bias, is thus widely applied to understand the attentional processing of stimuli linked to various psychopathologies (Albery et al., 2017; Asmaro et al., 2014; Field & Cox, 2008).

Event-related potentials (ERPs) can be used to directly measure the time course of neural activity and are ideal for investigating the attentional processing of sexually related stimuli. The ERPs are time-locked electroencephalography (EEG) waves produced in response to stimuli, and different components reflect different stages of cognitive processing and attention engagement for stimuli. Specifically, early ERPs reflect automatic attention orientation to stimuli, whereas late ERPs show more controlled and sustained attention. For instance, P200, with a peak latency of 100–200 ms after the appearance of the stimulus, reflects an early and preconscious attentional processing of stimuli (Nijs, Franken, & Muris, 2010; Pourtois, Grandjean, Sander, & Vuilleumier, 2004). Moreover, P300, or the late positive potential (LPP), usually reflects the conscious attentional processing of information that continues into the late processing stage (Hajcak & Foti, 2020; Nijs et al., 2010; Prause, Steele, Staley, Sabatinelli, & Hajcak, 2015; Schupp, Flaisch, Stockburger, & Junghöfer, 2006). The attentional processes underlying Stroop RTs are not well understood. Although the Stroop interference is thought to be automatic (Sass et al., 2010), more strategic processes may also exert an influence (Thomas, Gonsalvez, & Johnstone, 2013; Van Hooff, Dietz, Sharma, & Bowman, 2008). Using the Stroop task in combination with ERPs, previous studies have found that emotional stimuli elicit larger early ERP components (e.g., P200; Thomas, Johnstone, & Gonsalvez, 2007) and late components (e.g., P300; Thomas et al., 2013) than neutral stimuli. Moreover, using the addiction Stroop paradigm, some studies in other addiction fields found that addiction-related stimuli induced larger P200 and P300/LPP amplitudes than neutral stimuli (e.g., Dai, Ma, & Wang, 2011; Nijs et al., 2010). Thus, we recorded the EEG activity during an addiction Stroop task to determine whether early P200 and late LPP components respond to pornographic images. The association between RTs and ERP components was also investigated.

To date, few studies have investigated sexually related attentional bias in individuals with cybersex addiction or hypersexual behavior. In comparing patterns of attention engagement between participants with compulsive sexual behavior and healthy controls using the dot probe paradigm, Mechelmans et al. (2014) found that the compulsive group showed attentional bias toward sexually explicit material. Using the same paradigm, Pekal, Laier, Snagowski, Stark, and Brand (2018) reported a close association between attentional bias toward sexually related stimuli and the severity of Internet Pornography Use Disorder in both men and women. However, Doornwaard, van den Eijnden, Johnson, and ter Bogt (2014) found that participants who

consumed pornography on a regular basis were faster at answering the dot probe task (independently of whether the dot appeared next to a neutral or sexually explicit image). In another study, Albery et al. (2017) used a modified Stroop task to examine attentional bias among sexually active participants and found a Stroop interference effect for sexually related words compared with neutral words. However, these behavioral studies only assess biases accompanied by measurable behavioral changes, whereas attentional bias can occur independent of behavioral interference. Behavioral measures also fail to distinguish between sensory and cognitive processes related to attentional bias.

Using ERPs as an indicator of attentional resource allocation, Prause et al. (2015) compared the EEG activity of heavy Internet porn viewers versus healthy controls viewers while viewing pornographic and non-sexual images. They found that the LPP amplitude increased for pornographic images compared to non-sexual images in both groups, but the amplitude increase was less for frequent viewers of Internet pornography. However, the passive viewing paradigm was used by Prause et al. (2015), therefore behavioral measures of attentional bias could not be obtained. In addition, the study did not assess whether sexually related stimuli automatically captured the attention of frequent viewers of Internet pornography during early processing stages (preceding P300 or LPP). Hence, consensus on sexually related attentional bias in relation to cybersex addiction is lacking.

To gain greater insight into the specific processes underlying attention measures (e.g., the Stroop task), it is important to combine behavioral measures with more sensitive, attention-related parameters (e.g., ERPs) to further examine the relationship between results. To overcome the limitations of the aforementioned studies, we explored the attentional bias of individuals with high tendencies of cybersex addiction (TCA) versus low TCA when presented with sexually related stimuli. To the best of our knowledge, this is the first study to combine behavioral and ERP measures to examine attentional bias toward sexually related stimuli in the cybersex addiction field.

We hypothesized that there would be differences in the attentional processing of sexually related cues between the high and low TCA groups. Specifically, the core assumption was that high TCA individuals display heightened automatic and sustained attentional bias toward sexually related stimuli compared with the low TCA group, as reflected by RTs and P200/LPP amplitudes.

METHODS

Participants

In total, 263 male college students completed the Problematic Internet Pornography Use Scale (PIPUS; Chen & Jiang, 2020; Kor et al., 2014). Female students did not participate in the research because cybersex addiction is more commonly identified in men (Ballester-Arnal, Castro-Calvo, García-Barba, Ruiz-Palomino, & Gil-Llario, 2021; Pekal et al., 2018). As cybersex addiction is not a quantifiable phenomenon, there was no threshold for the empirical classification of cybersex addiction. Therefore, we identified participants by using the highest and lowest quartiles of PIPUS scores. Based on this criterion, 30 individuals with high TCA and 30 with low TCA were invited to voluntarily participate in the electrophysiological study. Exclusion criteria included being under 18 years, having a history of drug addiction, and having serious psychiatric disorders including depression and obsessive-compulsive disorder. Three participants (two from the high TCA group and one from the low TCA group) were excluded due to excessive eye movement artifacts.

Measures and procedure

The Chinese version of the PIPUS was used to assess cybersex addiction (Chen & Jiang, 2020). The scale consisted of 12 items divided into four dimensions: distress and functional problems, overuse, difficulty in self-control, and avoidance of negative emotions. Items were rated on a six-point scale from 0 (never) to 5 (always). The Cronbach's alpha for this sample was 0.95.

Participants completed the PIPUS assessment first. Based on the abovementioned screening criteria, 60 individuals were invited to participate in the Stroop task, wherein EEG activity was recorded. After completing the task, participants completed the Barratt Impulsiveness Scale-11 (BIS-11; Patton, Stanford, & Barratt, 1995), Obsessive-Compulsive Inventory-R (Foa et al., 2002), Self-Rated Depression Scale (Zung, Richards, & Short, 1965), and Self-Rated Anxiety Scale (Zung, 1971) to assess impulsivity, obsessive-compulsive features, depression, and anxiety, respectively. All participants received RMB 100 for their participation.

Stimuli and experimental task

The stimuli consisted of 20 pornographic (explicit images of vaginal intercourse between one man and one woman) and 20 neutral images (e.g., portraits, walking, and shopping). In previous studies examining sexual-related cognitive processing, neutral stimuli have been selected in a variety of ways, including one person (e.g., Prause et al., 2015), two persons (e.g., Antons & Matthias, 2020), and other objects such as furniture or animals (Mechelmans et al., 2014; Seok & Sohn, 2020). In this study, each neutral stimulus included one or two people, without controlling for gender, age, or body size. The pornographic images were downloaded from publicly available pornographic websites. The neutral images were collected from the Chinese Affective Picture System (Bai, Ma, Huang, & Luo, 2005). All images were rated in a pilot study, ranking from 1 (not pleasant/not arousing/not sexually arousing) to 9 (very pleasant/very arousing/very sexually arousing) regarding their valence, arousal, and sexual arousal. Regarding valence ratings, the difference between pornographic and neutral images was not significant (5.27 ± 1.42 vs. 4.45 ± 1.33, $t(29) = 1.91$, $P = 0.07$). However, there was a significant difference in pornographic and neutral
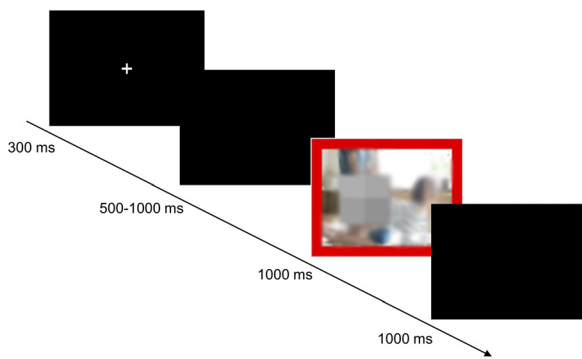
Fig. 1. Schematic flow of the experimental procedure

images regarding arousal (5.38 ± 1.40 vs. 3.99 ± 1.55, $t(29) = 3.45$, $P = 0.002$) and sexual arousal (5.35 ± 1.65 vs. 1.48 ± 0.80, $t(29) = 11.67$, $P < 0.001$).

The Stroop task was performed using E-Prime 2.0. The task consisted of two blocks, each containing 30 sexually related stimuli and 30 neutral stimuli (each image was presented three times with a differently colored frame). Participants had a 2-min break in each block. Each trial began with the display of a small white cross for 300 ms. Thereafter, a blank screen was shown for 500–1,000 ms before the stimulus image was displayed. The images were randomly displayed. Participants were required to name the color of the frames surrounding the images as quickly and accurately as possible using number keys (1, 2, and 3) on a keyboard (Zhao, Liu, & Maes, 2017). The keys were color-coded red, yellow, and blue, which corresponded to the index, middle, and ring fingers of the right hand, respectively. The image disappeared after a key was pressed or 1,000 ms, followed by a blank screen for 1,000 ms. Figure 1 shows the diagrammatic flow of the test.

Electrophysiological recording and analysis

EEG activity was recorded from 64 scalp sites using an elastic cap containing active tin electrodes. EEG activity was amplified by BrainAmp amplifier (Brain Products GmbH, München, Germany). Reference electrodes were placed on the left and right mastoids and a ground electrode was placed on the medial frontal aspect. Vertical electrooculograms (EOGs) were recorded in the right eye. All electrode impedances were less than 5 kΩ. The EEG and EOG channels were digitized at a sampling rate of 500 Hz. Offline analysis was performed using Brain Vision Analyzer 2.0. Filtering settings included a bandpass of 0.01–30 Hz (24 dB/oct). Independent component analysis based on EEG channels was used to eliminate the ocular artifacts.

The EEG activity for correct responses during either condition was superimposed and averaged. ERPs were time-locked to the stimulus onset and the epoch was set to 1,000 ms, including a 200 ms pre-stimulus baseline. Based on a visual inspection of the aggregate grand average ERP (see Appendix) and literature (e.g., Nijs et al., 2010; Prause et al., 2015), P200 was defined as an average amplitude between 150 and 220 ms and LPP as an average amplitude between

300 and 700 ms. The following 15 electrode sites were chosen for analysis: F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, and P4. This was consistent with electrodes averaged for P200 and LPP in other studies (e.g., Dai, Ma, & Wang, 2011; Prause et al., 2015; Wang & Dai, 2020).

Statistical analysis

Independent sample t-tests were used to explore the between-group differences in terms of questionnaire data. For the behavioral measurements (accuracy and RTs), a 2×2 repeated measures analysis of variance (ANOVA) was conducted with groups (high TCA vs. low TCA) as the between-subject factor, and stimulus type (sexual vs. neutral) as the within-subject factor. For the P200 and LPP amplitudes, a $2 \times 2 \times 15$ repeated measures ANOVA was performed with electrode site and stimulus type as the within-subject factors and group as the between-subject factor. In case the interaction between group and stimulus type was statistically significant, we computed two paired t-tests comparing sexual vs neutral images, separately for high and low TCA groups. For these two planned comparisons, the threshold alpha was set at 0.025 (Bonferroni-corrected for two planned tests with an uncorrected alpha of 0.05). Moreover, in case of simple main effect analyses that were motivated by an interaction effect involving the electrode site factor, we adopted an alpha value of 0.05/15 = 0.003. In all analyses, statistical values were subjected to Greenhouse–Geisser corrections. Effect sizes were reported as partial eta square (η_p^2).

Ethics

All study procedures were conducted in accordance with the Declaration of Helsinki. All participants were informed about the nature of the study, and they provided informed consent to participate in the study. The protocol for this research was approved by the local Ethical Review Board.

RESULTS

Self-reported results

The mean and standard deviation (SD) of each questionnaire is shown in Table 1. The PIPUS score for the high TCA group (36.21 ± 14.73) was higher than that of the low TCA group (12.34 ± 0.55, $t(55) = 8.57$, $P < 0.001$). A significant difference was also observed for SDS ($t(55) = 2.18$, $P = 0.003$), SAS ($t(55) = 2.96$, $P = 0.004$), and BIS-11 ($t(53) = 2.88$, $P = 0.006$), all of which were higher in the high TCA group than the low TCA group.

Behavioral results

The mean RTs of the correct responses for each stimulus type were calculated (Fig. 2). Outlier scores (>2 SD from the mean) were excluded. Regarding accuracy, the high TCA group scored significantly lower (94.3%) than the low TCA

Table 1. Descriptive statistics of the high TCA and low TCA groups on questionnaires

Variable (M ± SD)	High TCA (n = 28)	Low TCA (n = 29)	t	P
Age (years)	18.64 ± 0.99	19.03 ± 1.66	1.08	0.283
PIPUS	36.21 ± 14.73	12.34 ± 0.55	8.57	<0.001
SDS	37.79 ± 7.54	32.72 ± 9.78	2.18	0.033
SAS	36.75 ± 9.75	30.00 ± 7.31	2.96	0.004
BIS-11	78.12 ± 9.79	69.55 ± 11.97	2.88	0.006
OCI-R	39.31 ± 10.75	35.48 ± 11.97	1.24	0.220

Abbreviations: PIPUS, Problematic Internet Pornography Use Scale; SDS, Self-Rated Depression Scale; SAS, Self-Rated Anxiety Scale; BIS-11, Barratt Impulsiveness Scale-11; OCI-R, Obsessive-Compulsive Inventory-R; TCA, tendencies toward cybersex addiction.
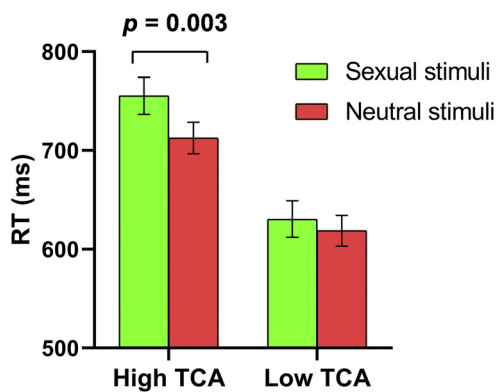

Fig. 2. RTs for the sexual and neutral stimuli in the high TCA and low TCA groups. The error bars represent one standard error

group (96.9%; $F_{(1, 55)} = 6.33$, $P = 0.015$, $\eta_p^2 = 0.10$). However, there was no significant main effect of stimulus type or their interaction of stimuli type and group ($ps > 0.26$). The RTs of sexually related stimuli were longer than those of neutral stimuli ($F_{(1, 55)} = 15.04$, $P < 0.001$, $\eta_p^2 = 0.22$). The main effect of group ($F_{(1, 55)} = 21.80$, $P < 0.001$, $\eta_p^2 = 0.28$) demonstrated that the RTs were significantly longer in the high TCA group than in the low TCA group. More importantly, there was a significant group × stimulus type interaction ($F_{(1, 55)} = 4.88$, $P = 0.031$, $\eta_p^2 = 0.08$). The interaction was explored with two planned comparisons using paired *t*-tests (Bonferroni corrected $P = 0.05/2 = 0.025$). The simple effect of stimulus type revealed that the RT of sexually related stimuli (755.38 ± 119.97 ms) was longer than that of neutral stimuli (712.59 ± 98.99 ms) for the high TCA group ($t_{(27)} = 3.31$, $P = 0.003$, Cohen's $d = 0.63$). However, there was no significant difference between the RTs of sexually related stimuli (630.49 ± 74.40 ms) and neutral stimuli (618.77 ± 67.83 ms) for the low TCA group ($t_{(28)} = 1.99$, $P = 0.056$, Cohen's $d = 0.37$). Thus, the high TCA group displayed a greater Stroop interference effect, demonstrating a greater attentional bias toward explicit images.

ERP results

P200. For the P200 amplitudes, we observed significant main effects of stimulus type ($F_{(1, 55)} = 23.27$, $P < 0.001$, $\eta_p^2 = 0.30$) and electrode site ($F_{(14, 770)} = 14.52$, $P < 0.001$, $\eta_p^2 = 0.21$) and the stimulus type × electrode site interaction ($F_{(14, 770)} = 8.72$, $P < 0.001$, $\eta_p^2 = 0.14$). Post-hoc analyses (Bonferroni corrected $P = 0.05/15 = 0.003$) revealed that sexual stimuli induced greater amplitudes than neutral stimuli, especially at the frontal, fronto-central, and central electrodes ($ps < 0.001$). No significant main effect of group was found ($F < 1$). However, there was a significant group-× stimulus type interaction ($F_{(1, 55)} = 6.50$, $P = 0.014$, $\eta_p^2 = 0.11$). Post-hoc *t*-tests (Bonferroni corrected $P = 0.025$) revealed that sexual stimuli elicited greater amplitudes than neutral stimuli for the high TCA group, ($t_{(27)} = 5.03$, $P < 0.001$, Cohen's $d = 0.95$), but there was no significant difference in amplitude between stimuli for the low TCA group ($t_{(28)} = 1.67$, $P = 0.106$, Cohen's $d = 0.31$; see Figs 3 and 4). This result suggests that in an early latency window, individuals with high TCA tend to automatically allocate more attention to sexually explicit images than neutral ones. This was not observed in the low TCA group.

LPP. Regarding the LPP amplitudes, we observed significant main effects of stimulus type ($F_{(1, 55)} = 221.24$, $P < 0.001$, $\eta_p^2 = 0.80$) and electrode site ($F_{(14, 770)} = 68.98$, $P < 0.001$, $\eta_p^2 = 0.56$) and the stimulus type × electrode site interaction ($F_{(14, 770)} = 10.88$, $P < 0.001$, $\eta_p^2 = 0.17$). Post-hoc analyses (Bonferroni corrected $P = 0.003$) revealed that sexual stimuli elicited greater amplitudes than neutral stimuli, particularly at the central, centro-parietal and parietal electrodes ($ps < 0.001$). A significant main effect of group was also observed ($F_{(1, 55)} = 6.02$, $P = 0.017$, $\eta_p^2 = 0.10$). The average amplitudes across conditions were greater in the low TCA group than in the high TCA group. However, there was no significant group × stimulus type interaction ($F_{(1, 55)} = 2.88$, $P = 0.10$, $\eta_p^2 = 0.05$), suggesting that the LPP bias toward sexual stimuli was similar in both groups.

ERP correlates of the addiction Stroop interference

To evaluate the correlation between ERPs and Stroop interference, we conducted a further analysis with interference status as a between-subjects variable. Interference scores were calculated by subtracting the mean RTs of color-naming neutral images from those of sexually explicit images. Participants with positive (negative) interference scores were classified into the interference (non-interference) group (Pérez-Edgar & Fox, 2003). Overall, 36 (18 high TCA and 18 low TCA) and 21 (10 high TCA and 11 low TCA) participants were classified into the interference and non-interference groups, respectively.

ERPs were analyzed using ANOVA, with interference as the between-subject factor and stimulus type and electrode site as the within-subject factors. For the P200 amplitudes,
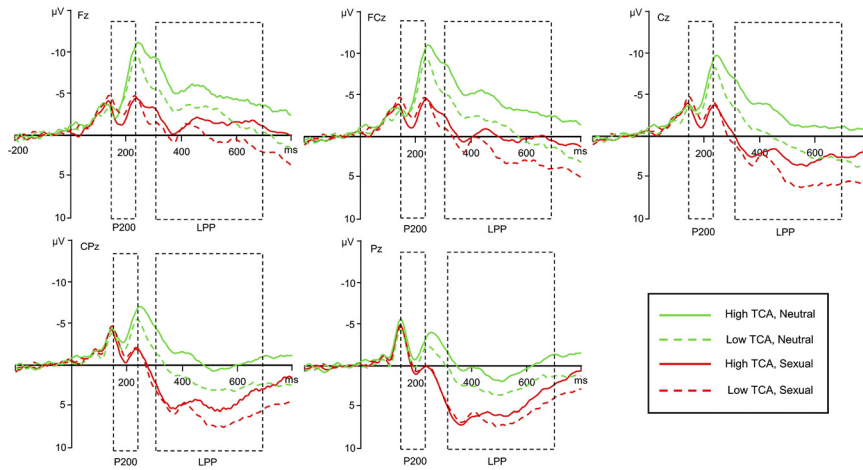
Fig. 3. Grand average ERPs for the high TCA and low TCA groups under the sexual and neutral conditions for electrodes sites at Fz, FCz, Cz, CPz, and Pz
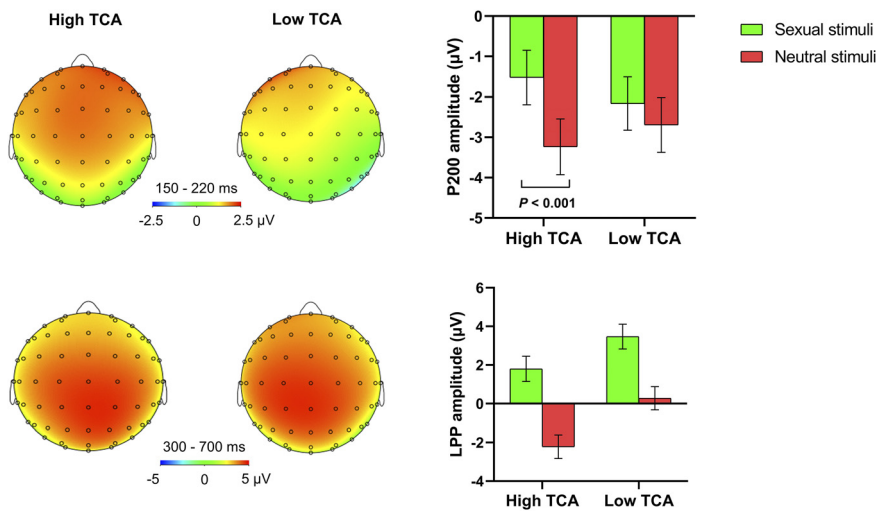

Fig. 4. (Left) Topographical maps of the amplitude differences between the sexual and neutral stimuli in the high TCA and low TCA groups. (Right) The mean amplitudes of P200 and the LPP in the sexual and neutral conditions for the high TCA and low TCA groups. The error bars represent one standard error

we found a significant interaction between interference and stimulus type (F (1, 55) = 4.18, $P = 0.046$, $\eta_p^2 = 0.07$). This interaction was driven by the more positive P200 amplitudes elicited by sexual images than neutral ones in the interference group ($P < 0.001$), while in the non-interference group, there were no such differences between the two stimuli conditions ($P = 0.36$). With respect to the LPP amplitudes, the interference × stimulus type interaction was not significant.

DISCUSSION

This study investigated the differences in the attentional processing of sexually explicit images between individuals with high versus low TCA, using an addiction Stroop task

based on behavioral (RTs) and electrophysiological (P200 and LPP amplitude) indices. We found significant effects for the behavioral component of the task as well as a significant ERP effect within the 150–220 ms time window (i.e., the P200 effect). These findings indicate that in the early stages of attentional processing, high TCA individuals are more attentive to sexually related cues. To the best of our knowledge, this is the first electrophysiological evidence of early attentional bias toward sexually related cues in the cybersex addiction field.

Behavioral evidence suggests robust Stroop interference effects in which the RTs elicited by sexual stimuli were significantly longer than those of neutral stimuli in the high TCA group. Specifically, sexually explicit images distracted participants from the color-judging task in the high TCA group. This result is consistent with Albery et al. (2017), who reported a Stroop interference effect for pornographic words

compared with neutral stimuli in a cohort of sexually active individuals. This finding is also consistent with the results of previous studies that have shown increased attentional bias toward sexual stimuli than neutral stimuli, using a visual dot probe task for compulsive sexual behaviors or Internet Pornography Use Disorder (Mechelmans et al., 2014; Pekal et al., 2018). Incentive sensitization theory has been employed to explain attentional bias toward addiction-related cues in individuals with certain addiction disorders (Field & Cox, 2008; Robinson & Berridge, 1993). This theory proposes that repeated substance use increases the dopaminergic response, making it more sensitive and motivationally salient. This triggers the characteristic behavior of addicted individuals through the urge to feel the experiences elicited in response to addiction-related cues (Robinson & Berridge, 1993). After the repeated experience of a given stimulus, related cues become salient and attractive, thus garnering attention. The findings of this study showed that individuals with high TCA did in fact present stronger interference in the color judging of sexually explicit images relative to neutral ones. This evidence is similar to results reported for substance-related (Asmaro et al., 2014; Della Libera et al., 2019) and non-substance-related behavior, including sexual behavior (Pekal et al., 2018; Sklenarik, Potenza, Gola, Kor, Kraus, & Astur, 2019; Wegmann & Brand, 2020).

However, behavioral measurements were unable to shed light on the time course and nature of information-processing mechanisms contributing to the addiction Stroop interference. It is thought that sensory capture during the early automatic stage (e.g., Sass et al., 2010) or cognitive elaboration during later strategic stage (e.g., Thomas et al., 2013; Van Hooff et al., 2008) contributes to Stroop interference. Although one study has investigated the ERPs related to cue reactivity to sexual stimuli in individuals reporting hypersexual behavior problems (Prause et al., 2015), only the LPP component was analyzed, ignoring the possibility of early or late effects.

In the present study, we examined differences in the early P200 and late LPP components in response to pornographic and neutral stimuli when performing the Stroop task. Our novel result is that individuals with high TCA displayed the early modulation of P200 relative to neutral stimuli in response to sexual stimuli. This result is consistent with that of Mechelmans et al. (2014), who reported participants with compulsive sexual behavior showing greater attentional bias toward sexually explicit than neutral stimuli, especially during early stimuli latency (i.e., an early orienting attentional response). P200 is associated with lower processing of stimuli (Crowley & Colrain, 2004). Thus, our P200 findings demonstrate that the differences between sexual and neutral stimuli may be discriminated by individuals with high TCA at relatively early stages of attention during the low-level processing of stimuli. Enhanced P200 amplitudes to sexual stimuli in the high TCA group manifest as an amplified early attentional engagement because the salience of these stimuli increases. Other addiction ERP studies have revealed comparable findings, namely that the discrimination in addiction-related cues begins in the early stages of stimuli processing

(e.g., Nijs et al., 2010; Versace, Minnix, Robinson, Lam, Brown, & Cinciripini, 2011; Yang, Zhang, & Zhao, 2015). Furthermore, investigating neural changes resulting from Stroop interference revealed that such interference manifests through the enhanced sensory processing of sexual stimuli relative to neutral stimuli. This indicates that the attentional bias underlying the addiction Stroop interference operates at an automatic level. Based on our findings, sensory bias toward sexual stimuli may be a core feature of cybersex addiction. The P200 ERP indications of the preferential processing of sexual stimuli in cybersex addicts may represent attentional processes that contribute to the automatic and uncontrollable nature of symptoms in addiction disorders.

The LPP occurs later and reflects conscious, voluntary, and motivation-related attention than P200. In this study, a larger LPP amplitude for sexually explicit images relative to neutral images was identified for both groups. Our finding agrees with those of previous studies that reported a greater LPP amplitude in individuals with and without sexual problems to sexual cues relative to neutral stimuli (Prause et al., 2015; Steele, Staley, Fong, & Prause, 2013). This LPP pattern has also been observed in drug addiction and other behavioral addictions (e.g., Dunning et al., 2011; Wölfling et al., 2011). In general, the LPP amplitude is influenced by the meaning or motivational value of a stimulus, with stimuli perceived to be more important generating higher amplitudes (Hajcak & Foti, 2020; Johnson, 1993). Thus, the higher amplitudes of sexually explicit images result from enhanced salience to pornographic material.

However, contrary to our expectations, the LPP augmentation to sexual stimuli relative to neutral stimuli was not larger in the high than the low TCA group. Specifically, only a significant main effect of group was observed, with the high TCA group eliciting a lower LPP amplitude than the low TCA group across the stimuli conditions. In substance addiction studies, the addiction group generally produces a larger LPP amplitude than the control group in response to addiction cues. However, the results of this study replicate a previous ERP study that also found the LPP amplitude lower in frequent users of online pornography than in controls (Prause et al., 2015). Similarly, Kühn and Gallinat (2014) found that frequent pornography consumption was related to weaker brain activation in response to sexual images. This can be explained in several ways. First, cybersex addicts may experience habituation to still images. With the proliferation of pornographic content on the Internet, frequent users of online pornography are more likely to watch pornographic movies and short videos than still images. Given that pornographic videos generate higher physiological and subjective arousal than sexually explicit images, static pictures result in less sexual responsiveness (Both, Spiering, Everaerd, & Laan, 2004). Second, intense stimulation may cause significant neuroplastic changes (Kühn & Gallinat, 2014). Specifically, regularly viewing pornographic materials reduces the volume of gray matter in the dorsal striatum, a region related to sexual arousal (Arnow et al., 2002). Third, the high TCA group may have deliberately suppressed its emotional response to sexual

stimuli during the experiment. Watching pornographic material is usually accompanied with masturbation, which could not occur in the laboratory setting. LPP amplitudes can be suppressed by intentional down-regulation. Emotion regulation may moderate the components of attentional bias in the late stages of processing (e.g., Hajcak, MacNamara, & Olvet, 2010). For example, Moser, Hajcak, Bukay, and Simons (2006) found that the intentional suppression of emotion to arousing stimuli substantially reduced the LPP. In summary, the LPP results indicated that the attentional bias toward sexual stimuli was similar in both groups during a later, more controlled stage of attentional processing.

The present findings have theoretical and clinical implications. Theoretically, these findings show that cybersex addiction resembles substance addiction in terms of attentional bias at the behavioral and electrophysiological levels. These findings may fuel the persistent controversy on the view that cybersex addiction is a mental disorder. Clinically, attentional biases to addiction-related stimuli may be causally related to addiction disorders (Brand et al., 2019). However, as attentional biases can be modified with successful interventions (Heitmann, Bennik, Hemel-Ruiter, & Jong, 2018; Wen et al., 2020), the findings provide a new avenue for the treatment of cybersex addiction. Psychological interventions may preferentially target early sensory attentional resource allocation to sexual stimuli. In addition, future research is needed to determine whether an individual's distribution of attention to sexual stimuli predicts specific treatment outcomes.

This study has several limitations. First, female participants were not included in the study based on differences in brain activation across genders as well as the higher prevalence of cybersex addiction in men than in women. Thus, it is important to examine whether similar electrophysiological markers of cybersex addiction are present in women. Second, the current study included only sexually explicit and neutral images. Future studies should add an additional category of images (e.g., another type of reward) to determine if the attentional bias occurs specifically for sexual stimuli or arousing stimuli in general. Third, as self-reported sexual desire was not assessed in this study, we did not examine the relationship between sexual desire and behavioral or electrophysiological indicators. According to the incentive sensitization model of addiction (Robinson & Berridge, 1993), future research could explore the relationship between the P200 and LPP components and *wanting* versus *liking* aspects of the model (e.g., Voon et al., 2014).

CONCLUSION

In summary, this study suggests that heightened attentional bias for sexual stimuli in individuals with high TCA can be measured in a neurophysiological manner. Specifically, our findings provide initial evidence that individuals with high TCA may show a specific automatic attentional bias toward sexually related cues. This enhanced early attentional bias

can be considered as an important cognitive component of sexually related cue reactivity and its neural origins may lie in the brain's reward circuitry. Increased cue reactivity to sexual stimuli may contribute to pornographic consumption and play a crucial role in the maintenance of problematic excessive use of online pornography.

Authors' contribution: JW, YC, and HZ involved in study concept and design. JW and YC involved in data preparation, statistical analysis, and wrote the manuscript. JW and HZ involved in study supervision and edited the manuscript. All authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES

Albery, I. P., Lowry, J., Frings, D., Johnson, H. L., Hogan, C., & Moss, A. C. (2017). Exploring the relationship between sexual compulsivity and attentional bias to sex-related words in a cohort of sexually active individuals. *European Addiction Research*, *23*(1), 1–6. https://doi.org/10.1159/000448732.

Antons, S., & Matthias, B. (2020). Inhibitory control and problematic Internet-pornography use–The important balancing role of the insula. *Journal of Behavioral Addictions*, *9*(1), 58–70. https://doi.org/10.1556/2006.2020.00010.

Arnow, B. A., Desmond, J. E., Banner, L. L., Glover, G. H., Solomon, A., Polan, M. L., . . . Atlas, S. W. (2002). Brain activation and sexual arousal in healthy, heterosexual males. *Brain*, *125*(5), 1014–1023. https://doi.org/10.1093/brain/awf108.

Asmaro, D., Carolan, P. L., & Liotti, M. (2014). Electrophysiological evidence of early attentional bias to drug-related pictures in chronic cannabis users. *Addictive Behaviors*, *39*(1), 114–121. https://doi.org/10.1016/j.addbeh.2013.09.012.

Bai, L., Ma, H., Huang, Y., & Luo, Y. (2005). The development of native Chinese affective picture system-A pretest in 46 college students. *Chinese Mental Health Journal*, *19*, 719–722. https://doi.org/10.1016/j.molcatb.2005.02.001.

Ballester-Arnal, R., Castro-Calvo, J., García-Barba, M., Ruiz-Palomino, E., & Gil-Llario, M. D. (2021). Problematic and non-problematic engagement in online sexual activities across the lifespan. *Computers in Human Behavior*, *120*, 106774. https://doi.org/10.1016/j.chb.2021.106774.

Both, S., Spiering, M., Everaerd, W., & Laan, E. (2004). Sexual behavior and responsiveness to sexual stimuli following laboratory-induced sexual arousal. *Journal of Sex Research*, *41*(3), 242–258. https://doi.org/10.1080/00224490409552232.

Brand, M., Snagowski, J., Laier, C., & Maderwald, S. (2016). Ventral striatum activity when watching preferred pornographic pictures is correlated with symptoms of Internet pornography addiction. *Neuroimage, 129*, 224–232. https://doi.org/10.1016/j.neuroimage.2016.01.033.

Brand, M., Wegmann, E., Stark, R., Müller, A., Wölfling, K., Robbins, T. W., & Potenza, M. N. (2019). The Interaction of Person-Affect-Cognition-Execution (I-PACE) model for addictive behaviors: Update, generalization to addictive behaviors beyond internet-use disorders, and specification of the process character of addictive behaviors. *Neuroscience and Biobehavioral Reviews, 104*, 1–10. https://doi.org/10.1016/j.neubiorev.2019.06.032.

Brand, M., Young, K. S., Laier, C., Wölfling, K., & Potenza, M. N. (2016). Integrating psychological and neurobiological considerations regarding the development and maintenance of specific Internet-use disorders: An Interaction of Person-Affect-Cognition-Execution (I-PACE) model. *Neuroscience and Behavioral Reviews, 71*, 252–266. https://doi.org/10.1016/j.neubiorev.2016.08.033.

Brem, M. J., Garner, A. R., Grigorian, H. L., Florimbio, A. R., Wolford-Clevenger, C., Shorey, R., & Stuart, G. (2018). Problematic pornography use and physical and sexual intimate partner violence perpetration among men in batterer intervention programs. *Journal of Interpersonal Violence, 36*, NP6085–NP6105. https://doi.org/10.1177/0886260518812806.

Castro-Calvo, J., Cervigón-Carrasco, V., Ballester-Arnal, R., & Giménez-García, C. (2021). Cognitive processes related to problematic pornography use (PPU): A systematic review of experimental studies. *Addictive Behaviors Reports, 13*, 100345. https://doi.org/10.1016/j.abrep.2021.100345.

Chen, L., & Jiang, X. (2020). The assessment of problematic internet pornography use: A comparison of three scales with mixed methods. *International Journal of Environmental Research and Public Health, 17*, 488. https://doi.org/10.3390/ijerph17020488.

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: Age, sleep and modality. *Clinical Neurophysiology, 115*(4), 732–744. https://doi.org/10.1016/j.clinph.2003.11.021.

Dai, S. Y., Ma, Q. G., & Wang, X. Y. (2011). Attentional bias to addiction-related stimuli in internet addiction patients: An ERP study. *Journal of Psychological Science, 34*(6): 1302–1307. https://doi.org/10.16719/j.cnki.1671-6981.2011.06.006.

Davis, R. A. (2001). A cognitive-behavioral model of pathological Internet use. *Computers in Human Behavior, 17*(2), 187–195. https://doi.org/10.1016/S0747-5632(00)00041-8.

Della Libera, C., Zandonai, T., Zamboni, L., Santandrea, E., Sandri, M., Lugoboni, F., . . . Chelazzi, L. (2019). Revealing dissociable attention biases in chronic smokers through an individual-differences approach. *Scientific Reports, 9*(1), 4930. https://doi.org/10.1038/s41598-019-40957-0.

Doornwaard, S. M., van den Eijnden, R. J., Johnson, A., & ter Bogt, T. F. (2014). Exposure to sexualized media content and selective attention for sexual cues: An experimental study. *Computers in Human Behavior, 41*, 357–364. https://doi.org/10.1016/j.chb.2014.10.037.

Döring, N. M. (2009). The internet's impact on sexuality: A critical review of 15 years of research. *Computers in Human Behavior, 25*, 1089–1101. http://dx.doi.org/10.1016/j.chb.2009.04.003.

Dunning, J. P., Parvaz, M. A., Hajcak, G., Maloney, T., Alia-Klein, N., Woicik, P. A., . . . Goldstein, R. Z. (2011). Motivated attention to cocaine and emotional cues in abstinent and current cocaine users - an ERP study. *European Journal of Neuroscience, 33*(9), 1716–1723. https://doi.org/10.1111/j.1460-9568.2011.07663.x.

Field, M., & Cox, W. M. (2008). Attentional bias in addictive behaviors: A review of its development, causes, and consequences. *Drug and Alcohol Dependence, 97*(1–2), 1–20. https://doi.org/10.1016/j.drugalcdep.2008.03.030.

Field, M., Marhe, R., & Franken, I. H. (2014). The clinical relevance of attentional bias in substance use disorders. *CNS Spectrums, 19*(3), 225–230. https://doi.org/10.1017/S1092852913000321.

Foa, E. B., Huppert, J. D., Leiberg, S., Langner, R., Kichic, R., Hajcak, G., & Salkovskis, P. M. (2002). The obsessive-compulsive inventory: Development and validation of a short version. *Psychological Assessment, 14*(4), 485–496. https://doi.org/10.1037/1040-3590.14.4.485.

Gola, M., & Potenza, M. N. (2018). Promoting educational, classification, treatment, and policy initiatives. *Journal of Behavioral Addictions, 7*, 208–210. https://doi.org/10.1556/2006.7.2018.51.

Hajcak, G., & Foti, D. (2020). Significance?. . . Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review. *Psychophysiology*, e13570. https://doi.org/10.1111/psyp.13570.

Hajcak, G., MacNamara, A., & Olvet, D. (2010). Event-related potentials, emotion, and emotion regulation: An integrative review. Developmental *Neuropsychology, 35*, 129–155. https://doi.org/10.1080/87565640903526504.

Heitmann, J., Bennik, E. C., van Hemel-Ruiter, M. E., & de Jong, P. J. (2018). The effectiveness of attentional bias modification for substance use disorder symptoms in adults: A systematic review. *Systematic Reviews, 7*(1), 1–21. https://doi.org/10.1186/s13643-018-0822-6.

Johnson, Jr, R. A. Y. (1993). On the neural generators of the P300 component of the event-related potential. *Psychophysiology, 30*(1), 90–97. https://doi.org/10.1111/j.1469-8986.1993.tb03208.x.

Kafka, M. P. (2010). Hypersexual disorder: A proposed diagnosis for DSM-V. *Archives of Sexual Behavior, 39*(2), 377–400. https://doi.org/10.1007/s10508-009-9574-7.

Kluwe-Schiavon, B., Viola, T. W., Sanvicente-Vieira, B., Lumertz, F. S., Salum, G. A., Grassi-Oliveira, R., & Quednow, B. B. (2020). Substance related disorders are associated with impaired valuation of delayed gratification and feedback processing: A multilevel meta-analysis and meta-regression. *Neuroscience and Biobehavioral Reviews, 108*, 295–307. https://doi.org/10.1016/j.neubiorev.2019.11.016.

Kohut, T., Balzarini, R., Fisher, W., Grubbs, J. B., Campbell, L., & Prause, N. (2019). Surveying pornography use: A shaky science resting on poor measurement foundations. *The Journal of Sex Research, 57*, 722–742. https://doi.org/10.1080/00224499.2019.1695244.

Kor, A., Zilcha-Mano, S., Fogel, Y. A., Mikulincer, M., Reid, R. C., & Potenza, M. N. (2014). Psychometric development of the problematic pornography use scale. *Addictive Behaviors*, *39*(5), 861–868. https://doi.org/10.1016/j.addbeh.2014.01.027.

Kraus, S. W., Krueger, R. B., Briken, P., First, M. B., Stein, D. J., Kaplan, M. S., ... Reed, G. M. (2018). Compulsive sexual behaviour disorder in the ICD-11. *World Psychiatry*, *17*(1), 109–110. https://doi.org/10.1002/wps.20499.

Kühn, S., & Gallinat, J. (2014). Brain structure and functional connectivity associated with pornography consumption: The brain on porn. *JAMA Psychiatry*, *71*(7), 827–834. https://doi.org/10.1001/jamapsychiatry.2014.93.

Laier, C., Schulte, F. P., & Brand, M. (2013). Pornographic picture processing interferes with working memory performance. *Journal of Sex Research*, *50*(7), 642–652. https://doi.org/10.1080/00224499.2012.716873.

Lewczuk, K., Wojcik, A. D., & Gola, M. (2019). Increase in the prevalence of online pornography use – objective data analysis from the period between 2004 and 2016 in Poland. *PsyArxiv Preprints: PsyArXiv.* https://doi.org/10.31234/osf.io/tmn4r.

Marissen, M. A., Franken, I. H., Waters, A. J., Blanken, P., van den Brink, W., & Hendriks, V. M. (2006). Attentional bias predicts heroin relapse following treatment. *Addiction*, *101*(9), 1306–1312. https://doi.org/10.1111/j.1360-0443.2006.01498.x.

Mechelmans, D. J., Irvine, M., Banca, P., Porter, L., Mitchell, S., Mole, T. B., ... Voon, V. (2014). Enhanced attentional bias towards sexually explicit cues in individuals with and without compulsive sexual. *PLoS ONE*, *9*(8): e105476. https://doi.org/10.1371/journal.pone.0105476.

Meerkerk, G. J., Eijnden, R. J. V. D., & Garretsen, H. F. (2006). Predicting compulsive internet use: It's all about sex!. *CyberPsychology & Behavior*, *9*(1), 95–103. https://doi.org/10.1089/cpb.2006.9.95.

Moser, J. S., Hajcak, G., Bukay, E., & Simons, R. F. (2006). Intentional modulation of emotional responding to unpleasant pictures: An ERP study. *Psychophysiology*, *43*(3), 292–296. https://doi.org/10.1111/j.1469-8986.2006.00402.x.

Nijs, I. M., Franken, I. H., & Muris, P. (2010). Food-related Stroop interference in obese and normal-weight individuals: Behavioral and electrophysiological indices. *Eating Behaviors*, *11*(4), 258–265. https://doi.org/10.1016/j.eatbeh.2010.07.002.

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt impulsiveness scale. *Journal of Clinical Psychology*, *51*(6), 768–774. https://doi.org/10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1.

Pekal, J., Laier, C., Snagowski, J., Stark, R., & Brand, M. (2018). Tendencies toward Internet-pornography-use disorder: Differences in men and women regarding attentional biases to pornographic stimuli. *Journal of Behavioral Addictions*, *7*(3), 574–583. https://doi.org/10.1556/2006.7.2018.70.

Pérez-Edgar, K., & Fox, N. A. (2003). Individual differences in children's performance during an emotional Stroop task: A behavioral and electrophysiological study. *Brain and Cognition*, *52*(1), 33–51. https://doi.org/10.1016/S0278-2626(03)00007-1.

Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex*, *14*(6), 619–633. https://doi.org/10.1093/cercor/bhh023.

Prause, N., Steele, V. R., Staley, C., Sabatinelli, D., & Hajcak, G. (2015). Modulation of late positive potentials by sexual images in problem users and controls inconsistent with "porn addiction". *Biological Psychology*, *109*, 192–199. https://doi.org/10.1016/j.biopsycho.2015.06.005.

Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: An incentive-sensitization theory of addiction. *Brain Research Reviews*, *18*(3), 247–291. https://doi.org/10.1016/0165-0173(93)90013-P.

Ross, M., Månsson, S., & Daneback, K. (2012). Prevalence, severity, and correlates of problematic sexual internet use in Swedish men and women. *Archives of Sexual Behavior*, *41*, 459–466. https://doi.org/10.1007/s10508-011-9762-0.

Sass, S. M., Heller, W., Stewart, J. L., Silton, R. L., Edgar, J. C., Fisher, J. E., & Miller, G. A. (2010). Time course of attentional bias in anxiety: Emotion and gender specificity. *Psychophysiology*, *47*(2), 247–259. https://doi.org/10.1111/j.1469-8986.2009.00926.x.

Schupp, H. T., Flaisch, T., Stockburger, J., & Junghöfer, M. (2006). Emotion and attention: Event-related brain potential studies. *Progress in Brain Research*, *156*, 31–51. https://doi.org/10.1016/S0079-6123(06)56002-9.

Seok, J. W., & Sohn, J. H. (2015). Neural substrates of sexual desire in individuals with problematic hypersexual behavior. *Frontiers in Behavioral Neuroscience*, *9*, 321. https://doi.org/10.3389/fnbeh.2015.00321.

Seok, J. W., & Sohn, J. H. (2020). Response inhibition during processing of sexual stimuli in males with problematic hypersexual behavior. *Journal of Behavioral Addictions*, *9*(1), 71–82. https://doi.org/10.1556/2006.2020.00003.

Shaughnessy, K., Byers, E., & Walsh, L. P. (2011). Online sexual activity experience of heterosexual students: Gender similarities and differences. *Archives of Sexual Behavior*, *40*, 419–427. https://doi.org/10.1007/s10508-010-9629-9.

Sklenarik, S., Potenza, M. N., Gola, M., Kor, A., Kraus, S. W., & Astur, R. S. (2019). Approach bias for erotic stimuli in heterosexual male college students who use pornography. *Journal of Behavioral Addictions*, *8*(2), 234–241. https://doi.org/10.1556/2006.8.2019.31.

Snagowski, J., & Brand, M. (2015). Symptoms of cybersex addiction can be linked to both approaching and avoiding pornographic stimuli: Results from an analog sample of regular cybersex users. *Frontiers in Psychology*, *6*, 653. https://doi.org/10.3389/fpsyg.2015.00653.

Snagowski, J., Wegmann, E., Pekal, J., Laier, C., & Brand, M. (2015). Implicit associations in cybersex addiction: Adaption of an Implicit Association Test with pornographic pictures. *Addictive Behaviors*, *49*, 7–12. https://doi.org/10.1016/j.addbeh.2015.05.009.

Steele, V. R., Staley, C., Fong, T., & Prause, N. (2013). Sexual desire, not hypersexuality, is related to neurophysiological responses elicited by sexual images. *Socioaffective Neuroscience & Psychology*, *3*(1), 20770. https://doi.org/10.3402/snp.v3i0.20770.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *19*, 643−662.

Thomas, S. J., Gonsalvez, C. J., & Johnstone, S. J. (2013). Neural time course of threat-related attentional bias and interference in panic and obsessive–compulsive disorders. *Biological Psychology*, *94*(1), 116–129. https://doi.org/10.1016/j.biopsycho.2013.05.012.

Thomas, S. J., Johnstone, S. J., & Gonsalvez, C. J. (2007). Event-related potentials during an emotional Stroop task. *International Journal of Psychophysiology*, *63*(3), 221–231. https://doi.org/10.1016/j.ijpsycho.2006.10.002.

Van Hooff, J. C., Dietz, K. C., Sharma, D., & Bowman, H. (2008). Neural correlates of intrusion of emotion words in a modified Stroop task. *International Journal of Psychophysiology*, *67*(1), 23–34. https://doi.org/10.1016/j.ijpsycho.2007.09.002.

Versace, F., Minnix, J. A., Robinson, J. D., Lam, C. Y., Brown, V. L., & Cinciripini, P. M. (2011). Brain reactivity to emotional, neutral and cigarette-related stimuli in smokers. *Addiction Biology*, *16*(2), 296–307. https://doi.org/10.1111/j.1369-1600.2010.00273.x.

Voon V., Mole T. B., Banca P., Porter L., Morris L., Mitchell S., . . ., Irvine M. (2014) Neural correlates of sexual cue reactivity in individuals with and without compulsive sexual behaviours. *PLoS ONE*, *9*(7), e102419. https://doi.org/10.1371/journal.pone.0102419.

Wang, J., & Dai, B. (2020). Event-related potentials in a two-choice oddball task of impaired behavioral inhibitory control among males with tendencies towards cybersex addiction. *Journal of Behavioral Addictions*, *9*(3), 785–796. https://doi.org/10.1556/2006.2020.00059.

Wegmann, E., & Brand, M. (2020). Cognitive correlates in gaming disorder and social networks use disorder: A comparison. *Current Addiction Reports*, *7*, 356–364. https://doi.org/10.1007/s40429-020-00314-y.

Wen, S., Larsen, H., Boffo, M., Grasman, R. P., Pronk, T., Van Wijngaarden, J. B., & Wiers, R. W. (2020). Combining web-based attentional bias modification and approach bias modification as a self-help smoking intervention for adult smokers seeking online help: Double-blind randomized controlled trial. *JMIR Mental Health*, *7*(5), e16342. https://doi.org/10.2196/16342.

Wölfling, K., Mörsen, C. P., Duven, E., Albrecht, U., Grüsser, S. M., & Flor, H. (2011). To gamble or not to gamble: At risk for craving and relapse – learned motivated attention in pathological gambling. *Biological Psychology*, *87*(2), 275–281. https://doi.org/10.1016/j.biopsycho.2011.03.010.

Yang, L., Zhang, J., & Zhao, X. (2015). Implicit processing of heroin and emotional cues in abstinent heroin users: Early and late event-related potential effects. *The American Journal of Drug and Alcohol Abuse*, *41*(3), 237–245. https://doi.org/10.3109/00952990.2015.1020383.

Zhao, X., Liu, X., & Maes, J. H. (2017). Male smokers' behavioral and brain responses to deviant cigarette-related stimuli in a Two-choice oddball paradigm. *Journal of Psychophysiology*, *32*(4): 172–181. https://doi.org/10.1027/0269-8803/a000195.

Zung, W. W. (1971). A rating instrument for anxiety disorders. *Psychosomatics*, *12*(6), 371–379. https://doi.org/10.1016/S0033-3182(71)71479-0.

Zung, W. W., Richards, C. B., & Short, M. J. (1965). Self-rating depression scale in an outpatient clinic: Further validation of the SDS. *Archives of General Psychiatry*, *13*(6), 508–515. https://doi.org/10.1001/archpsyc.1965.01730060026004.

APPENDIX
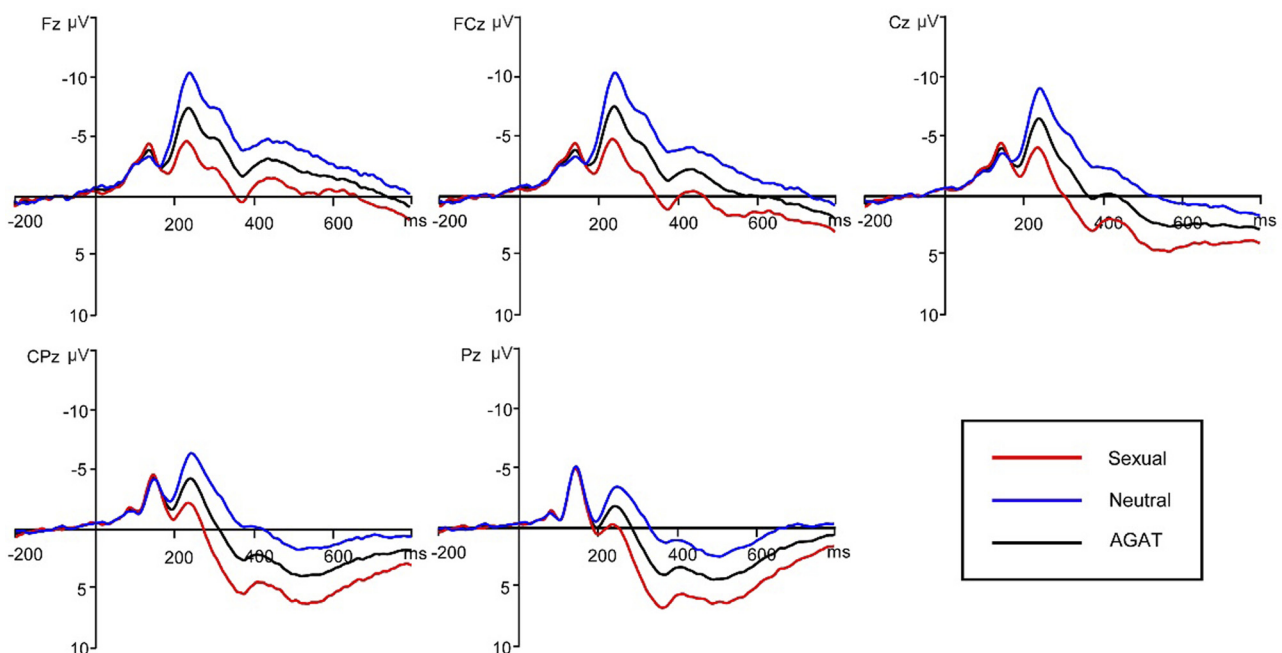
Supplementary Fig. 1. The aggregate grand average from trials (AGAT) was created by aggregating all the individual trials, from all participants and both conditions, into one group and then averaging them. The AGAT waveform (black line) is plotted along with grand averages for the two conditions (red line and blue line)
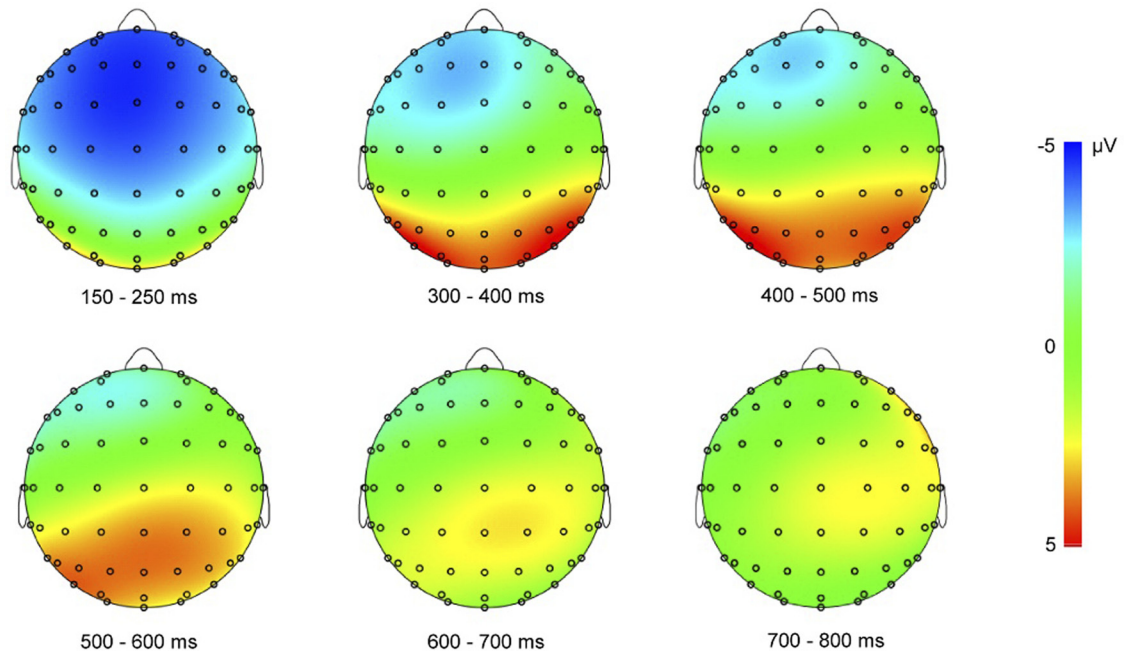
Supplementary Fig. 2. The topographic map for the AGAT waveform