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The role of emotional inhibitory control in specific internet addiction – an fMRI study

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HIGHLIGHTS

- Higher social anxiety & reduced emotional competence in specific internet addicts.
- Longer reaction times in EST for socially anxious words in internet gaming addicts.
- Left middle and superior temporal gyrus hypoactivation in internet gaming addicts.
- Social words may be less retrievable in semantic storage of internet gaming addicts.

Keywords:
Specific internet addiction
Emotional Stroop Task
Affective Go/No-Go task
emotional inhibitory control
fMRI

ABSTRACT

Background: Addicts to specific internet applications involving communication features showed increased social anxiety, emotional competence deficits and impaired prefrontal-related inhibitory control. The dorsal Anterior Cingulate Cortex (dACC) likely plays an important role in cognitive control and negative affect (such as social exclusion, pain or anxiety).
Aim: To assess (social) anxiety-related inhibitory control in specific internet addiction (addicted use of games and social networks) and its relation to altered dACC activation.
Methods: N = 44 controls and n = 51 specific internet addicts completed an anxious words-based Affective Go/No-Go task (AGN). A subsample of n = 23 healthy controls and n = 25 specific internet addicts underwent functional Magnetic Resonance Imaging (fMRI) while completing an Emotional Stroop Task (EST) with socially anxious, positive, negative and neutral words. Subgroups of internet gaming and social network addicts were exploratively assessed. Psychometric measures of social anxiety, emotional competence and impulsivity were additionally explored.
Results: Specific internet addicts showed higher impulsivity, social anxiety and reduced emotional competence. Between-group differences in AGN and EST behavioral measures were not detected. No group differences were found in the dACC, but explorative analyses revealed decreased left middle and superior temporal gyrus activation during interference of socially anxious words in internet gaming and relative to social network addicts.

Abbreviations: AGN, Affective Go/No-Go task; AICA, checklist for the Assessment of Internet and Computer game Addiction; AICA_30, checklist for the Assessment of Internet and Computer game Addiction referring to the previous 30 days; AICA_lifetime, Assessment of Internet and Computer game Addiction: Lifetime maximum; EKF, emotional competence questionnaire (EKF; German designation, Emotionale-Kompetenz-Fragebogen); EST, Emotional Stroop Task; IGA, Internet Gaming Addiction; OSVe-S, scale for online addictive behavior in adults self-report (German designation: Skala zum Onlinesuchtverhalten bei Erwachsenen); SASKO, questionnaire for Social Anxiety and Social Competence deficits (German designation: Fragebogen zu Sozialer Angst und Sozialen Kompetenzdefiziten).

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Conclusion: Given the function of the left middle temporal gyrus in the retrieval of words or expressions during communication, our findings give a first hint that social words might be less retrievable in the semantic storage of internet gaming addicts, possibly indicating deficiencies in handling speech in social situations.

1. Introduction

Internet addiction currently is the fastest growing addiction and gains worldwide attention due to its' rising prevalence [1]. Internet games and social networks (subsuming the excessive use of chats, forums and social networks such as Facebook) are the two most commonly used applications by internet addicts [2,3]. Both involve communication and social cognitions [4], but have never been explored in this specific combination before.

The 5th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, [5]) refers only to the condition of problematic internet game use termed as "Internet Gaming Disorder", while it is often designated as "Internet Gaming Addiction" (IGA) in the current literature. For reasons of uniformity as well as to underline the condition's addictive character, the terms "IGA" and "social network addiction" are applied in this manuscript and both are summarized under the designation of "specific internet addiction".

Similar to substance addictions [6,7], IGA has been associated with increased social and general anxiety [8,9], impulsivity [10] and emotional competence deficits [11], the latter potentially impairing addicts in the recognition, control, regulation and expression of their own emotions as well as in the recognition of other's emotions.

Furthermore, the few existing psychometric studies on social network use reported pathological Facebook use to be associated with poor emotion regulation skills, comprising a lack of acceptance of own emotional responses, limited access to emotion regulation strategies, poor impulse control and, similar to IGA, increased social and general anxiety [12–14]. Games and social networks might especially capture their users by facilitating the experience of positive social emotions (e.g. via social contacts in a game [15] or positive social feedback in social networks [12]), which socially anxious individuals might not be able to gain in real life.

Brand et al. [4] considered these aspects in their 'Interaction of Person-Affect-Cognition-Execution' (I-PACE) model of internet use. The authors suggest that gratification (e.g. social recognition), leading to positive and negative reinforcement, is one of the core motives in the early stages of specific internet use disorders. With repeated use, gratification decreases and the compensation for negative feelings (e.g. loneliness) and cognitions (e.g. "I am nobody without the internet") gains increasing importance: The addicted use of specific internet applications which include communication features might compensate for the perceived lack of social support, social distrust, feelings of isolation, and loneliness in the real world [16–19]. These negative emotional conditions might be induced by increased social anxiety and impaired emotion regulation, i.e. emotional inhibitory control, in real life social contexts. Emotional inhibitory control is defined as the ability to control ones impulses, emotions and thoughts [20] and can be assessed by means of Affective Go/No-Go (AGN; e.g. [21,22]) as well as Emotional Stroop Tasks (EST; [23]).

The AGN task assesses participants' emotional response inhibition ability by measuring the amount of response errors in terms of commission errors (defined as button presses to No-Go stimuli and therefore mirroring failed inhibition [22]). The EST investigates interference (i.e. the ability to suppress irrelevant emotional information during cognitive performance) by measuring the Reaction Time (RT) for the color naming of differently valenced words (among other parameters; [24]).

Neurobiological studies suggest a complex network of brain regions including the prefrontal cortex (PFC), amygdala, hippocampus, insular cortex, ventral striatum and other interconnected regions to be involved in emotional inhibitory control [25,26]. In particular, the role of the PFC in this domain has been reinforced by research in the recent years [27]. The dorsolateral prefrontal cortex (DLPFC) is suggested to be involved in the cognitive selection of sensory information [26] and the orbitofrontal cortex is related to reward anticipation as well as decision making under ambiguity [28,29]. The Anterior Cingulate Cortex (ACC) is functionally involved in conflict monitoring and in inhibition processes, regardless of stimulus type [4,30]. Structurally, several recent studies suggest reduced gray matter volume in the ACC of internet and internet gaming addicts relative to healthy controls [31–33]. Moreover, Wang et al. (2015) observed an association between reduced gray matter volume of the ACC and impaired cognitive inhibitory control processing in internet gaming addicts during the performance of a classical color-word Stroop task [32]. There are no comparable studies for emotional inhibitory control processing related to positive, negative or anxious affects in internet addicts, although increased social and general anxiety have been associated with internet gaming and social network addiction [8,9,12–14]. Thus, the psychological and neural basis of emotional inhibitory control in relation to social and general anxiety remains to be explored and compared between healthy controls and specific internet addicts (using internet games or social networks). Specifically the dorsal ACC (dACC) has been functionally associated with both negative affect (such as social exclusion, pain or anxiety) and cognitive control [26,34–36]. By conducting a 'coordinate-based' meta-analysis of 939 studies in order to assess common or different activation clusters in the ACC during negative affect, pain and cognitive control, Shackman et al. [36] observed that all these three domains activate a common region within the dACC [36].

Based on the theoretical model of Brand et al. [4] and empirical findings suggesting increased social and general anxiety, emotion regulation deficits and impaired inhibitory control in internet addiction of specific applications linked to social communication, the present study aims to assess neuropsychological and neurobiological differences in emotional inhibitory control processing related to socially and generally anxious stimuli between specific internet addicts (i.e. internet gaming and social network addicts) and healthy controls.

While we neuropsychologically assessed social and general anxiety-related emotional inhibitory control by means of the AGN (response inhibition) and EST (interference), interference in relation to socially anxious stimuli was additionally assessed by functional Magnetic Resonance Imaging (fMRI).

Firstly, we hypothesized specific internet addicts to show impaired emotional inhibitory control, especially related to anxious stimuli, as reflected in worse emotional response inhibition (i.e. more commission errors; [22,37]) during anxiety-related blocks of the AGN and a stronger interference (i.e. longer RTs; [24]) to socially anxious words relative to healthy controls in the EST. Furthermore, on the background of the dACC's role in anxiety-related affect (e.g.

social exclusion) and cognitive control as well as increased social anxiety in specific internet addiction, we secondly hypothesized specific internet addicts to have stronger inhibitory demands than controls in response to social anxiety-related stimuli (relative to positive, negative and neutral words), reflected in altered dACC activation during EST performance.

We further exploratively assessed whether these measures differ between addicted internet gamers and social network users and whether they are related to the severity of addiction as well as to anxiety and social anxiety-related measures.

2. Methods

2.1. Participants

The study was approved by the local ethics committee (application number 2013-528N-MA). Participants were recruited at the local day clinic of the Department of Addictive Behaviour and Addiction Medicine at the Central Institute of Mental Health in Mannheim, as well as by means of advertisements on the web pages of the Central Institute of Mental Health and Mannheim University. All participants were informed about the study procedures and gave written informed consent according to the Declaration of Helsinki prior to study participation. For this study, we included n = 44 healthy controls and n = 51 specific internet addicts (comprising n = 30 internet gaming and n = 21 social network addicts). Due to fMRI incapability (e.g. left handedness, metal parts in the body), the AGN sample was decimated to an EST subsample of n = 23 healthy controls and n = 25 specific internet addicts (subdivided into n = 13 internet gaming and n = 12 social network addicts). Decisive for group assignment was a clinical interview with an experienced psychologist and the obtained scores on the subscale of the checklist for the Assessment of Internet and Computer game Addiction within the previous 30 days (AICA_30, see “Psychometric instruments”; [38]).

As an additional measure for addiction severity, we applied the scale for online addictive behavior in adults as a self-report questionnaire (OSVe-S; German designation: Skala zum Onlinesuchtverhalten bei Erwachsenen; [39]; see below). Participants did not have any further axis-I psychiatric disorders or substance use disorders (except nicotine dependence), were not treated with any psychotropic medication and had normal or corrected-to-normal vision. Potential psychiatric comorbidities were assessed on the basis of the Structured Clinical Interview for DSM-IV (SCID I and II; [40]). There was no significant difference between the groups regarding age or gender (although there were slightly more males in the addicted group than in the control group). Specific internet addicts of the EST subsample were less educated than healthy controls (see Table 1). Regarding the three subgroups of internet gaming and social network addicts as well as healthy controls, the corrected Bonferroni post-hoc tests revealed no significance between the groups (Tables 2 and 3).

The hours of computer and internet use per day as well as the addiction severity (AICA_30, AICA_lifetime and OSVe-S) were significantly different between specific internet addicts and controls (see Table 1).

2.2. Psychometric instruments

Participants were screened for existence and degree of computer and internet addiction by means of an interview based on the AICA [38]. The latter is an established diagnostic clinical interview assessing the severity of participants’ computer and/or internet addiction during the previous 30 days (AICA_30) as well as over the lifetime (AICA_lifetime) by recording participant’s computer or internet use (e.g. “Is there any impairment in the personal area of life due to the usage of computer games/internet offers?”). Besides, it was made use of the OSVe-S [39], as it additionally enables the differentiation between abusive (cut-off <13.5 and >7) and normal internet use (cut-off <7); e.g. “How strong are you occupied with thoughts about online offers/activities per day?”). Participants scoring ≥13 on the AICA_30 or ≥13.5 on the OSVe-S were assigned to the addicted group. Participants scoring <7 on the OSVe-S were assigned to the control group [38]. The Barratt Impulsiveness Scale (BIS-11; [41]) was used to record impulsivity and feelings of stress were assessed by means of the Perceived Stress Scale (PSS, [42]). The neuroticism scale of the NEO-FFI served as an indicator for unpleasant emotions such as anxiety [43]. Participant’s degree of social anxiety was explored by means of the questionnaire for Social Anxiety and Social Competence deficits (SASKO; [44]). The latter investigates the anxiety of speaking in front of others or being in the focus of social attention (subscale ‘speaking’), of being socially rejected (‘rejection’), of interacting socially (‘interaction’), deficits in social perception (‘information’) as well as feelings of loneliness (‘loneliness’). The emotional competence questionnaire (EKF; German designation: Emotionale-Kompetenz-Fragebogen) was applied for the assessment of the self-rated emotional competence [45]. The instrument comprises 62 items, which are divided into four subscales measuring the constructs of a) recognizing and understanding one’s own emotions (EKF-EE), b) recognizing and understanding others’ emotions (EKF-EA), c) the ability to regulate and control one’s own emotions (EKF-RE) and d) emotional expressiveness (EKF-EX).

2.3. Affective Go/No-Go task (AGN)

The AGN task was applied in a validated German version [46] as part of the Cambridge Neuropsychological Test Automated Battery (CANTAB) to assess participant’s emotional response inhibition. The AGN comprised 13 blocks of either 18 positive and neutral, negative and neutral, or anxious and neutral words, as already given in the German version. The valenced words (i.e. positive, negative and anxious) were target stimuli, while the neutral words represented distractor stimuli. The recognition of target stimuli was to be acknowledged by means of a button press as fast as possible, while the reaction to neutral stimuli was to be inhibited. The order of the block’s valence (i.e. positive, negative or anxious blocks) was constant across participants, while the presentation of valenced vs. neutral words within each block was randomized. Single words appeared on the testing screen after intervals of 900 ms and were presented for 300 ms. The commission errors in the respective blocks of anxious valence (i.e. amount of button presses to distractor stimuli, here: neutral words) served as test outcome. A lower number of commission errors reflects the ability to inhibit unwanted behavior in an emotional context (i.e. valenced words) and therefore serves as an indicator for an individuals’ ability of emotional response inhibition.

2.4. Emotional Stroop Task (EST)

The EST was carried out during fMRI. The task was adapted from Witthöft et al. [24] to include the four categories of positive, negative, neutral as well as socially anxious words ([24]; see Table 4). Throughout the paradigm, each category was presented four times, resulting in a total of 16 blocks. Each of the word stimuli was presented once in one of the colors red, green, blue and yellow, distributed across the blocks. Participants were asked to indicate the color of each presented word as fast as possible by pressing one of the four buttons corresponding to the four colors (index finger = red, middle finger = green, ring finger = blue, little finger = yellow). Words were presented one after another in the

Table 1
Sample description for healthy controls and specific internet addicts. The study was performed with a large (AGN) sample as well as with a subsample (EST) for fMRI explorations.

	AGN sample					EST sample				
	Overall sample (N = 95)	Healthy controls (n = 44)	Specific internet addicts (n = 51)	Test-statistic	p-value	Overall sample (N = 48)	Healthy controls (n = 23)	Specific internet addicts (n = 25)	Test-statistic	p-value
Gender (n = male)	52 (54.74%)	20 (45.45%)	32 (62.75%)	$2.850^{\chi2(CT)}$	0.091	27 (56.25%)	10 (43.48%)	17 (68.00%)	$2.927^{\chi2(CT)}$	0.087
Age (SD)	27.15 (8.21)	28.59 (9.80)	25.90 (6.39)	-1.198^{z}	0.231	25.85 (5.67)	26.13 (5.49)	25.60 (5.93)	-0.591^{z}	0.554
Years of education (SD)	14.86 (2.39)	15.30 (2.30)	14.49 (2.42)	-1.626^{z}	0.104	15.06 (2.43)	15.87 (2.26)	14.32 (2.38)	-2.216^{z}	0.027*
Computer-/internet-use (Ø, h/day; SD)	2.73 (1.36)	1.89 (.90)	3.45 (1.27)	-5.576^{z}	<0.001**	2.63 (1.36)	1.91 (.90)	3.28 (1.40)	-3.348^{z}	0.001**
AICA_30 (SD)	9.07 (7.90)	2.25 (1.95)	14.96 (6.13)	-7.818^{z}	<0.001**	8.38 (7.53)	2.35 (1.87)	13.92 (6.41)	-5.455^{z}	<0.001**
AICA_lifetime (SD)	14.75 (10.67)	4.16 (2.60)	23.88 (4.96)	-8.386^{z}	<0.001**	14.46 (10.08)	4.87 (2.58)	23.28 (4.86)	-5.945^{z}	<0.001**
OSVe-S (SD)	8.25 (5.83)	2.93 (1.55)	12.84 (3.92)	-8.386^{z}	<0.001**	7.64 (5.39)	3.09 (1.57)	11.82 (4.06)	-5.892^{z}	<0.001**

SD = Standard Deviation, AICA_30 = Assessment of Internet and Computer game Addiction of the previous 30 days, AICA_lifetime = Lifetime maximum of Internet and Computer game Addiction, OSVe-S = Self-report questionnaire for internet addiction-related behavior (Skala zum Onlinesuchtverhalten bei Erwachsenen), z = Mann-Whitney *U* test statistic, χ^2 (CT) = Chi^2 Crosstab test statistic; *$p \leq 0.05$, **$p \leq 0.01$.

Table 2
Sample description for the subgroups.

	AGN sample					EST sample				
	Healthy controls (n = 44)	Internet gaming addicts (n = 30)	Social network addicts (n = 21)	Test-statistic	p-value	Healthy controls (n = 23)	Internet gaming addicts (n = 13)	Social network addicts (n = 12)	Test-statistic	p-value
Gender (n = male)	20 (45.45%)	22 (73.33%)	10 (47.62%)	$6.147^{\chi2(CT)}$	0.046*	10 (43.48%)	11 (84.62%)	6 (50.00%)	$5.965^{\chi2(CT)}$	0.051
Age (SD)	28.59 (9.80)	27.07 (7.73)	24.24 (3.24)	$2.387^{\chi2(KW)}$	0.303	26.13 (5.49)	27.15 (7.39)	23.92 (3.34)	$1.938^{\chi2(KW)}$	0.380
Years of education (SD)	15.30 (2.30)	14.30 (2.38)	14.76 (2.51)	$3.139^{\chi2(KW)}$	0.208	15.87 (2.26)	14.69 (2.36)	13.92 (2.43)	$5.420^{\chi2(KW)}$	0.067
Computer-/internet use (Ø, h/day; SD)	1.89 (.90)	3.67 (1.12)	3.14 (1.42)	$32.975^{\chi2(KW)}$	<0.001**	1.91 (.90)	3.69 (1.32)	2.83 (1.40)	$13.434^{\chi2(KW)}$	0.001**
AICA_30 (SD)	2.25 (1.95)	15.33 (6.60)	14.43 (5.51)	$61.346^{\chi2(KW)}$	<0.001**	2.35 (1.87)	14.69 (7.49)	13.08 (5.20)	$30.024^{\chi2(KW)}$	<0.001**
AICA_lifetime (SD)	4.16 (2.60)	25.77 (3.58)	21.19 (5.47)	$73.254^{\chi2(KW)}$	<0.001**	4.87 (2.58)	25.85 (3.56)	20.50 (4.64)	$37.075^{\chi2(KW)}$	<0.001**
OSVe-S (SD)	2.93 (1.55)	13.28 (3.93)	12.21 (3.92)	$70.230^{\chi2(KW)}$	<0.001**	3.09 (1.57)	12.54 (4.40)	11.04 (3.68)	$34.899^{\chi2(KW)}$	<0.001**

SD = Standard Deviation, AICA_30 = Assessment of Internet and Computer game Addiction of the previous 30 days, AICA_lifetime = Lifetime maximum of Internet and Computer game Addiction, OSVe-S = Self-report questionnaire for internet addiction-related behavior (Skala zum Onlinesuchtverhalten bei Erwachsenen), χ^2 (CT) = Chi^2 Crosstab test statistic, χ^2 (KW) = Chi^2 Kruskal-Wallis test statistic; *$p \leq 0.05$, **$p \leq 0.01$.

middle of the screen, while the assignment of the four buttons to the respective color was displayed throughout the task at the bottom of the screen in smaller writing. These four color words were written in the respective color. For the behavioral analyses, RT differences of correct responses for socially anxious, positive and negative relative to neutral stimuli were used as the main behavioral outcome measure for emotional interference.

The word and color order within each block was randomized and the blocks of the different categories were presented in the order of a Latin square. The 10 words per category were matched category-wise for word length, frequency, valence and arousal in written German language. They were presented for 1.5 s, followed by a fixation cross as inter-stimulus interval with a mean duration of 0.3 s [24]. Between the blocks, a fixation cross and the information that a next block will follow were presented for 9 s and 1 s, respectively. The duration of each block amounted to 18 s and the complete paradigm took about 7 min. Prior to the actual task performance, participants completed a short training session in the scanner, but without scanning. The training paradigm involved arrays of letters instead of real words in order to get used to the response buttons. The experiment was implemented with the program Presentation Version 16.3 (Neurobehavioral Systems, Albany, Calif., USA) and task presentation in the scanner was mediated by digital goggles (Resonance Technology, Inc., Los Angeles, California). After the scanning, all words presented as stimuli in the EST were rated via paper-pencil by each participant regarding each word's valence (i.e. emotional resonance) and arousal on a 9-point scale with the help of the Self-Assessment Manikin (SAM) affective rating system [47].

Specific internet addicts did not show significant differences in arousal and valence compared to healthy controls [Mann-Whitney U (MWU) tests]. Within-group analyses (Friedman tests) comparing the valence and arousal between the four categories revealed significant differences in all comparisons. Only the valence between

Table 3
Post-hoc tests for the subgroups. P-values Bonferroni corrected.

	AGN sample						EST sample					
	Healthy controls-internet gaming addicts		Healthy controls-social network addicts		Internet gaming addicts- social network addicts		Healthy controls-internet gaming addicts		Healthy controls-social network addicts		Internet gaming addicts- social network addicts	
Gender (n = male)	5.649$^{\chi2(CT)}$	0.017	0.027$^{\chi2(CT)}$	0.870	3.494$^{\chi2(CT)}$	0.062						
Age (SD)												
Years of education (SD)												
Computer-/internet use (Ø, h/day; SD)	−5.601^{z}	<0.001**	−3.411^{z}	0.001**	−1.259	0.208	−3.551^{z}	<0.001**	−1.932^{z}	0.053	−1.592^{z}	0.111
AICA_30 (SD)	−6.756^{z}	<0.001**	−6.128^{z}	<0.001**	−0.969	0.333	−4.654^{z}	<0.001**	−4.304^{z}	<0.001**	−0.791^{z}	0.429
AICA_lifetime (SD)	−7.283^{z}	<0.001**	−6.498^{z}	<0.001**	−3.181^{z}	0.001**	−4.940^{z}	<0.001**	−4.810^{z}	<0.001**	−2.517^{z}	0.012*
OSVe-S (SD)	−7.278^{z}	<0.001**	−6.548^{z}	<0.001**	−0.872^{z}	0.383	−4.879^{z}	<0.001**	−4.816^{z}	<0.001**	−0.872^{z}	0.383

SD = Standard Deviation, AICA_30 = Assessment of Internet and Computer game Addiction of the previous 30 days, AICA_lifetime = Lifetime maximum of Internet and Computer game Addiction, OSVe-S = Self-report questionnaire for internet addiction-related behavior (Skala zum Onlinesuchtverhalten bei Erwachsenen), z = Mann-Whitney *U* test statistic, m = Mean difference in the Tukey HSD post-hoc test; *$p \leq 0.05$, **$p \leq 0.01$, χ^2 (CT) = Chi^2 Crosstab test statistic.

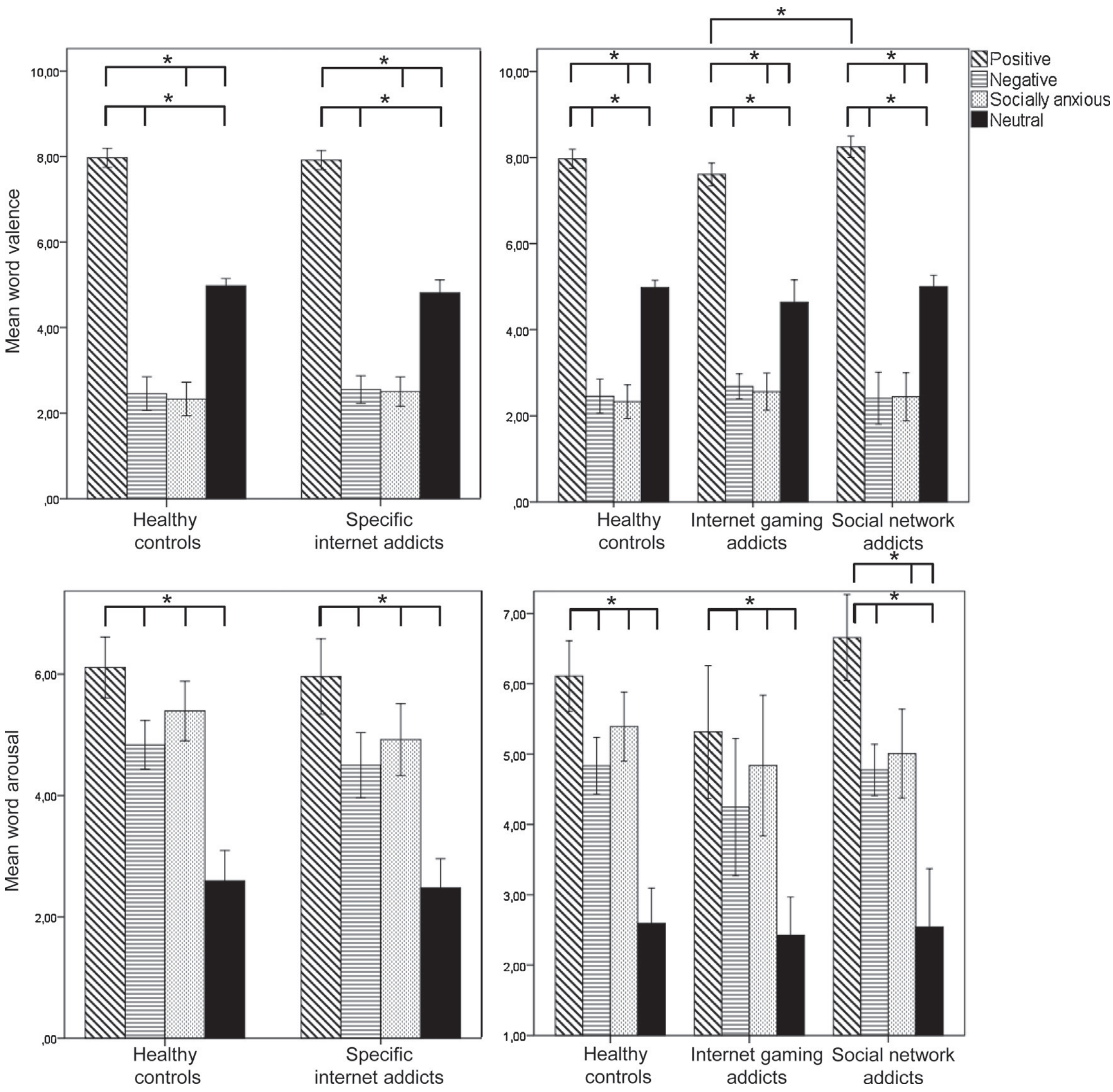

Fig. 1. Ratings for valence and arousal of EST words.

Table 4
Original and English EST stimuli words.

Social anxiety-related words	Positive words	Negative words	Neutral words
Original German words			
ängstlich	anziehend	verendet	förmlich
hilflos	super	habgierig	belanglos
einsam	lebenslustig	unangenehm	neutral
unterwürfig	euphorisch	zerfressen	zusammenhanglos
blamiert	großartig	böse	bürgerlich
sitzengelassen	interessant	verfault	solide
panisch	vergnügt	impotent	nichtssagend
gehemmt	glücklich	asozial	typisch
abstoßend	leidenschaftlich	herablassend	anatomisch
dämlich	witzig	verwahrlost	eckig
Translated words			
anxious	attractive	perished	formal
helpless	super	avaricious	insignificant
lonely	fun-loving	awkward	neutral
submissive	euphoric	eroded	incoherent
disgraced	great	bad	civil
abandoned	interesting	rotten	solid
panic-fueled	cheery	impotent	expressionless
inhibited	happy	antisocial	typical
repellent	passionate	dismissive	anatomical
dimwitted	funny	shabby	angled

socially anxious and negative words did not significantly differ in specific internet addicts as well as in healthy controls (see Fig. 1).

A Kruskal-Wallis test for the exploration of between-subgroup differences revealed that internet gaming addicts rated the valence of positive words significantly lower than social network addicts ($\chi^2 = 8.687$; $p = 0.013$; post-hoc $z_{positive} = -2.807$, $p = 0.005$). Within-group analyses (Friedman tests) showed significant differences in valence and arousal between each category, except between negative and socially anxious word blocks for valence (in every group) as well as between socially anxious and negative ones in the group of social network addicts for arousal (see Fig. 1).

2.5. *fMRI*

The scanning sessions were conducted at a 3T whole-body tomograph (Trio; Siemens, Erlangen, Germany). Functional whole-brain images were collected under the application of a T2*-weighted Echo-Planar Imaging (EPI) sequence [Repetition Time (TR) = 2000 ms, Echo Time (TE) = 30 ms, Flip Angle (FA) = 80°, Field of View (FOV) = 192 mm x 192 mm, matrix size 64 × 64, 32 slices, slice thickness = 3.00 mm, distance factor = 33 %, voxel size = 3 × 3 × 3 mm]. The number of acquired functional volumes amounted to 219. Structural images were acquired by means of a T1-weighted Magnetization Prepared Rapid Gradient Echo (MPRAGE) sequence (TR = 2300 ms, TE = 3.03 ms, FA = 9°, FOV = 256 mm × 256 mm, 192 slices, slice thickness = 1.00 mm, distance factor = 50 %, voxel size = 1 × 1 × 1 mm) in order to exclude participants exhibiting brain abnormalities (see [48]). The correction of magnetic field inhomogeneity was mediated by the automated Siemens multi-angle projection (MAP)-Shim. The registration of scanner triggers as well as the recording of behavioral responses was accomplished by the Presentation® software (Version 16.3, Neurobehavioral Systems, Inc., Albany, CA, USA).

3. Statistical analyses

The statistical analyses were conducted for the comparison between healthy controls and specific internet addicts. The comparisons between healthy controls and addicts of gaming as well as social networks were conducted exploratively. We also included years of education as a covariate in our analyses.

3.1. *Psychometry and neuropsychology*

Psychometric data analyses were accomplished by means of SPSS Statistics 20 (Statistical Package for the Social Sciences, SPSS Inc., Chicago, IL; Release 20.0.0). After having checked the variables for normality, within and between-group differences in the psychometric as well as in the behavioral outcome measures of the EST and the AGN were assessed with parametric paired and unpaired *t*-tests (normally distributed variables) or via nonparametric Wilcoxon's signed rank and MWU tests (non-normally distributed variables), respectively. For the explorative three-group comparisons, Analyses of Variance (ANOVA) and Kruskal-Wallis tests as well as Friedman tests for the comparison across categories were applied. For post-hoc tests, a Bonferroni α-correction was done.

Furthermore, Spearman's rho correlations were applied in order to explore associations between addiction severity and the outcome measures for emotional response inhibition (commission errors in the AGN task) and interference (RT of the correct responses in the EST task).

The differences in RT of the EST between emotional and neutral words (i.e. positive-neutral, negative-neutral, socially anxious-neutral), between socially anxious vs. positive and negative words as well as between socially anxious vs. positive, negative and neutral words were used for statistical within and between-group analyses. As described by Witthöft et al. [24], extreme RTs of <300 ms and >1000 ms were removed from the data [24].

3.2. *Neurobiology*

For neurobiological evaluations, Statistical Parametric Mapping (SPM, version SPM 8, Wellcome Trust Centre for Neuroimaging, University College London, London, UK) was utilized at the basis of Matlab R2012b (The MathWorks, Inc., Natick, MA, USA). The data preprocessing comprised motion correction, realignment, spatial normalization to the Montreal Neurological Institute (MNI) template with a new voxel size of 3 × 3 × 3 mm and smoothing with an 8 mm full width at half maximum kernel.

First-level analyses included the evaluation of effect estimations for the four categories (i.e. positive, negative, neutral and socially anxious) by applying the general linear model with regressors for the onsets and duration of every condition as well as the six movement parameters obtained from the realignment preprocessing step on a voxel-by-voxel basis. In a succeeding step, individual contrast images of condition-specific mean brain activation for our contrast of interest, i.e. *social anxiety vs. positive + negative + neutral (rest)*, were calculated. By means of second-level analyses, the individual contrast images were then compared for differences in Blood Oxygenation Level Dependent (BOLD) responses within and between the groups for our contrast of interest based on one and two-sample *t*-tests as well as full factorial ANOVAs. A threshold of $p < 0.001$ as well as an extent threshold of 10 voxels were applied and results were reported at a cluster threshold of $p_{FWE} \leq 0.05$. The Automatic Anatomical Labeling (AAL)-toolbox of SPM was used for the assignment of significantly activated clusters to their respective brain regions. The detection of Brodmann Areas (BAs) was conducted via the xjview-toolbox (xjView Toolbox for SPM; http://www.alivelearn.net/xjview8/) run under Matlab. Activation maps were displayed by means of Chris Rorden's MRIcro brain image viewer in neurological convention (i.e. left = left, right = right) on the ch2bet-template (Chris Rorden, 1999–2005, version 1.40 build 1).

Table 5
Psychometric measures of the AGN and EST sample. Given are the means with standard deviations in brackets.

	AGN sample				EST sample			
	Healthy controls (n = 44)	Specific internet addicts (n = 51)	Test-statistic	p-value	Healthy controls (n = 23)	Specific internet addicts (n = 25)	Test-Statistic	p-value
Social anxiety (sum SASKO)	21.95 (13.53)	49.94 (24.01)	-5.816^z	<0.001**	22.96 (13.98)	46.52 (24.33)	-3.768^z	<0.001**
SASKO: Speaking	6.41 (4.27)	14.00 (7.92)	-4.905^z	<0.001**	7.09 (3.85)	13.40 (7.65)	-3.066^z	0.002**
SASKO: Rejection	5.68 (3.67)	12.73 (6.95)	-5.223^z	<0.001**	6.00 (3.90)	11.44 (6.39)	-3.197^z	0.001**
SASKO: Interaction	3.86 (3.49)	9.76 (5.34)	-5.616^z	<0.001**	4.26 (3.73)	8.84 (5.59)	-3.175^z	0.001**
SASKO: Information	4.70 (3.07)	8.90 (4.76)	-4.281^z	<0.001**	4.65 (2.96)	8.72 (5.23)	-2.773^z	0.006**
SASKO: Loneliness	1.30 (1.79)	4.55 (3.72)	-4.525^z	<0.001**	0.96 (1.46)	4.12 (3.41)	-3.721^z	<0.001**
Emotional competence (mean EKF)	60.59 (6.37)	52.19 (7.62)	5.773^t	<0.001**	60.90 (5.38)	51.21 (7.99)	4.885^t	<0.001**
EKF-EE	60.80 (8.15)	51.20 (10.52)	4.911^t	<0.001**	61.43 (7.27)	51.16 (10.31)	3.959^t	<0.001**
EKF-EA	68.36 (9.19)	63.27 (12.07)	2.283^t	0.025*	68.83 (8.24)	60.68 (12.57)	2.630^t	0.012*
EKF-RE	51.89 (6.49)	44.55 (9.47)	4.332^t	<0.001**	52.35 (6.45)	45.92 (8.42)	2.950^t	0.005**
EKF-EX	61.30 (11.69)	49.75 (14.09)	4.306^t	<0.001**	61.00 (11.26)	47.08 (15.13)	3.590^t	0.001**
Neuroticism (NEO-FFI)	1.25 (0.67)	2.01 (0.79)	-4.434^z	<0.001**	1.20 (.68)	1.87 (.71)	-3.067^z	0.002**
Perceived stress (PSS)	12.98 (5.80)	19.96 (7.09)	-5.199^t	<0.001**	13.43 (6.13)	19.16 (7.51)	-2.879^t	0.006**
Impulsivity (sum BIS-11)	56.09 (8.76)	63.57 (10.99)	-3.399^z	0.001**	54.65 (9.05)	65.20 (11.66)	-3.348^z	0.001**

SASKO = Social Anxiety and Social Competence deficits-scale, EKF = Emotional competence questionnaire, EKF-EE = Recognizing and understanding the own emotions, EKF-EA = Recognizing and understanding others' emotions, EKF-RE = Regulation and control of the own emotions, EKF-EX = Emotional expressiveness, NEO-FFI = NEO Five Factor Inventory, PSS = Perceived Stress Scale, BIS–11 = Barratt Impulsiveness Scale, z = Mann-Whitney *U* test statistic, t = t statistic, $^*p \leq 0.05$, $^{**}p \leq 0.01$.

4. Results

Psychometrically, we observed significant deficits in impulsivity and perceived stress as well as on all scales of social anxiety and emotional competence in specific internet addicts compared to healthy controls (Table 5).

Explorative analyses in the subgroups showed that between healthy controls and internet gaming addicts most of the psychometric variables differed significantly (see Tables 6 and 7). Healthy controls and social network addicts showed a heterogeneous pattern of significant results across the variables. However, regarding the results in the AGN and EST samples, social network addicts showed significantly higher scores in the overall social anxiety score (sum SASKO) as well as in the SASKO subscales of 'speaking' and 'rejection'. Furthermore, the general emotional competencies were significantly lower in this group. Between both addicted groups (internet gaming and social network addicts), only the interaction anxiety (AGN sample) and feelings of loneliness (AGN and EST sample) were significantly different.

In all psychometric analyses, including the years of education as a covariate did not change the results.

4.1. AGN

Regarding the main outcome measure of emotional response inhibition, specific internet addicts and healthy controls showed significantly more commission errors at positive words than at negative or anxious ones (Friedman: $\chi^2_{\text{healthy controls}} = 32.224$, $p < 0.001$; post-hoc $z_{\text{positive-negative}} = -4.118$, $p < 0.001$; $z_{\text{positive-anxiety}} = -4.432$, $p < 0.001$; $\chi^2_{\text{specific internet addicts}} = 40.923$, $p < 0.001$, post-hoc $z_{\text{positive-negative}} = -4.525$, $p = < 0.001$; $z_{\text{positive-anxiety}} = -4.931$, $p = < 0.001$). The same holds for the subgroups of specific internet addicts ($\chi^2_{\text{internet gaming addicts}} = 18.893$, $p < 0.001$; post-hoc $z_{\text{positive-negative}} = -3.052$, $p = 0.002$; $z_{\text{positive-anxiety}} = -3.172$, $p = 0.002$; $\chi^2_{\text{social network addicts}} = 23.570$, $p < 0.001$; post-hoc $z_{\text{positive-negative}} = -3.494$, $p < 0.001$; $z_{\text{positive-anxiety}} = -3.839$, $p < 0.001$; see Fig. 2).

In contrast to our first hypothesis, we did not find any significant differences in commission errors on anxious stimuli between specific internet addicts and healthy controls ($z_{\text{specific internet addicts vs. healthy controls;anxious stimuli}} = -0.494$, $p = 0.621$). We also did not find any between-group differences in other word categories. Spearman correlations between addiction severity and AGN anxiety-related commission errors in the overall sample revealed that the emotional response inhibition ability in anxiety-blocks decreased (i.e. more commission errors) with increasing addiction severity (i.e. higher OSVe-S scores; Spearman's rho correlation coefficient $r_{\text{commissions anxiety-OSVe-S}} = 0.220$, $p = 0.032$).

Regarding differences in commission errors for each category between the subgroups (internet gaming addicts, social network addicts and controls), explorative Kruskal Wallis tests revealed no significant results. Including years of education as a covariate in all neuropsychological analyses did not change the findings.

4.2. EST

4.2.1. Behavior

Our data revealed 97.85 % correct responses in the overall sample.

Table 6
Psychometric measures of the AGN and EST sample. Given are the means with standard deviations in brackets.

	AGN sample					EST sample				
	Healthy controls (n = 44)	Internet gaming addicts (n = 30)	Social network addicts (n = 21)	Test-statistic	p-value	Healthy controls (n = 23)	Internet gaming addicts (n = 13)	Social network addicts (n = 12)	Test-statistic	p-value
Social anxiety (sum SASKO)	21.95 (13.53)	55.10 (24.03)	42.57 (22.52)	36.027$^{\chi2(KW)}$	<0.001**	22.96 (13.98)	48.92 (27.03)	43.92 (21.91)	14.240$^{\chi2(KW)}$	0.001**
SASKO: Speaking	6.41 (4.27)	14.27 (8.08)	13.62 (7.88)	24.095$^{\chi2(KW)}$	<0.001**	7.09 (3.85)	12.23 (8.11)	14.67 (7.27)	10.556$^{\chi2(KW)}$	0.005**
SASKO: Rejection	5.68 (3.67)	13.67 (7.17)	11.38 (6.56)	28.227$^{\chi2(KW)}$	<0.001**	6.00 (3.90)	11.46 (6.42)	11.42 (6.64)	10.223$^{\chi2(KW)}$	0.006**
SASKO: Interaction	3.86 (3.49)	11.33 (5.35)	7.52 (4.57)	35.406$^{\chi2(KW)}$	<0.001**	4.26 (3.73)	10.23 (6.21)	7.33 (4.62)	10.874$^{\chi2(KW)}$	0.004**
SASKO: Information	4.70 (3.07)	9.80 (5.02)	7.62 (4.13)	20.069$^{\chi2(KW)}$	<0.001**	4.65 (2.96)	9.15 (6.16)	8.25 (4.22)	7.700$^{\chi2(KW)}$	0.021*
SASKO: Loneliness	1.30 (1.79)	6.03 (3.54)	2.43 (2.91)	31.425$^{\chi2(KW)}$	<0.001**	0.96 (1.46)	5.85 (3.44)	2.25 (2.26)	19.128$^{\chi2(KW)}$	<0.001**
Emotional competence (mean EKF)	60.59 (6.37)	50.58 (7.79)	54.50 (6.90)	19.157^{F}	<0.001**	60.90 (5.38)	48.94 (8.55)	53.67 (6.85)	14.014^{F}	<0.001**
EKF-EE	60.80 (8.15)	49.67 (11.45)	53.38 (8.84)	13.130^{F}	<0.001**	61.43 (7.27)	48.31 (11.70)	54.25 (7.90)	9.572^{F}	<0.001**
EKF-EA	68.36 (9.19)	61.60 (13.15)	65.67 (10.15)	3.506^{F}	0.034*	68.83 (8.24)	58.00 (13.02)	63.58 (11.91)	4.374^{F}	0.018*
EKF-RE	51.89 (6.49)	43.30 (10.24)	46.33 (8.16)	10.299^{F}	<0.001**	52.35 (6.45)	45.46 (7.40)	46.42 (9.72)	4.314^{F}	0.019*
EKF-EX	61.30 (11.69)	47.73 (14.18)	52.62 (13.78)	10.222^{F}	<0.001**	61.00 (11.26)	44.00 (17.27)	50.42 (12.29)	7.227^{F}	0.002**
Neuroticism (NEO-FFI)	1.25 (0.67)	2.07 (0.78)	1.93 (0.83)	19.868$^{\chi2(KW)}$	<0.001**	1.20 (0.68)	1.92 (0.68)	1.81 (0.78)	9.610$^{\chi2(KW)}$	0.008**
Perceived stress (PSS)	12.98 (5.80)	20.50 (7.57)	19.19 (6.45)	13.691^{F}	<0.001**	13.43 (6.13)	20.00 (7.44)	18.25 (7.81)	4.289^{F}	0.020*
Impulsivity (sum BIS-11)	56.09 (8.76)	64.03 (12.19)	62.90 (9.25)	11.553$^{\chi2(KW)}$	0.003**	54.65 (9.05)	68.23 (11.72)	61.92 (11.15)	13.362$^{\chi2(KW)}$	0.001**

SASKO = Social Anxiety and Social Competence deficits-scale, EKF = Emotional competence questionnaire, EKF-EE = Recognizing and understanding the own emotions, EKF-EA = Recognizing and understanding others' emotions, EKF-RE = Regulation and control of the own emotions, EKF-EX = Emotional expressiveness, NEO-FFI = NEO Five Factor Inventory, PSS = Perceived Stress Scale, BIS–11 = Barratt Impulsiveness Scale, χ^2 (KW) = Chi^2 Kruskal-Wallis test statistic, F = ANOVA test statistic, *$p \leq 0.05$, **$p \leq 0.01$.

Table 7
Post-hoc tests for the subgroups. P-values Bonferroni corrected.

	AGN sample						EST sample					
	Healthy controls-internet gaming addicts		Healthy controls-social network addicts		Internet gaming addicts- social network addicts		Healthy controls-internet gaming addicts		Healthy controls-social network addicts		Internet gaming addicts- social network addicts	
Social anxiety (sum SASKO)	−5.545^{z}	<0.001**	−3.867^{z}	<0.001**	−1.886^{z}	0.059	−3.015^{z}	0.003**	−3.165^{z}	0.002**	−0.572^{z}	0.567
SASKO: Speaking	−4.271^{z}	<0.001**	−3.787^{z}	<0.001**	−0.316^{z}	0.752	−1.838^{z}	0.066	−3.234^{z}	0.001**	−0.873^{z}	0.382
SASKO: Rejection	−4.918^{z}	<0.001**	−3.559^{z}	<0.001**	−1.141^{z}	0.254	−2.515^{z}	0.012*	−2.736^{z}	0.006*	−0.136^{z}	0.892
SASKO: Interaction	−5.538^{z}	<0.001**	−3.508^{z}	<0.001**	−2.488^{z}	0.013*	−3.027^{z}	0.002**	−2.155^{z}	0.031	−1.042^{z}	0.297
SASKO: Information	−4.311^{z}	<0.001**	−2.558^{z}	0.011*	−1.412^{z}	0.158	−2.274^{z}	0.023	−2.272^{z}	0.023	−0.247^{z}	0.805
SASKO: Loneliness	−5.424^{z}	<0.001**	−1.638^{z}	0.101	−3.489^{z}	<0.001**	−4.181^{z}	<0.001**	−1.967^{z}	0.049	−2.576^{z}	0.010*
Emotional competence (mean EKF)	10.010^{m}	<0.001**	6.085^{m}	0.004*	−3.925^{m}	0.122	11.960^{m}	<0.001**	7.236^{m}	0.011*	−4.724^{m}	0.196
EKF-EE	11.129^{m}	<0.001**	7.415^{m}	0.011*	−3.714^{m}	0.355	13.127^{m}	<0.001**	7.185^{m}	0.067	−5.942^{m}	0.222
EKF-EA	6.764^{m}	0.026	2.697 ^{m}	0.615	−4.067 ^{m}	0.385	10.826^{m}	0.014*	5.243^{m}	0.358	−5.583^{m}	0.396
EKF-RE	8.586 ^{m}	<0.001**	5.553 ^{m}	0.033	−3.033 ^{m}	0.399	6.886^{m}	0.033	5.931^{m}	0.084	−0.955^{m}	0.947
EKF-EX	13.562 ^{m}	<0.001**	8.676 ^{m}	0.036	−4.886 ^{m}	0.386	17.000^{m}	0.002**	10.583^{m}	0.078	−6.417^{m}	0.459
Neuroticism (NEO-FFI)	−4.133^{z}	<0.001**	−3.069^{z}	0.002**	−0.355^{z}	0.723	−2.802^{z}	0.005*	−2.210^{z}	0.027	−0.436^{z}	0.663
Perceived stress (PSS)	−7.523 ^{m}	<0.001**	−6.213 ^{m}	0.002**	1.310 ^{m}	0.762	−6.565^{m}	0.024	−4.815^{m}	0.136	1.750^{m}	0.804
Impulsivity (sum BIS-11)	−2.772^{z}	0.006*	−2.858^{z}	0.004*	−0.230^{z}	0.818	−3.447^{z}	0.001**	−2.001^{z}	0.045	−1.688^{z}	0.091

SASKO = Social Anxiety and Social Competence deficits-scale, EKF = Emotional competence questionnaire, EKF-EE = Recognizing and understanding the own emotions, EKF-EA = Recognizing and understanding others' emotions, EKF-RE = Regulation and control of the own emotions, EKF-EX = Emotional expressiveness, NEO-FFI = NEO Five Factor Inventory, PSS = Perceived Stress Scale, BIS–11 = Barratt Impulsiveness Scale, z = Mann-Whitney *U* test statistic, m = Mean difference in the Tukey HSD post-hoc test, *$p \leq 0.05$, **$p \leq 0.01$.

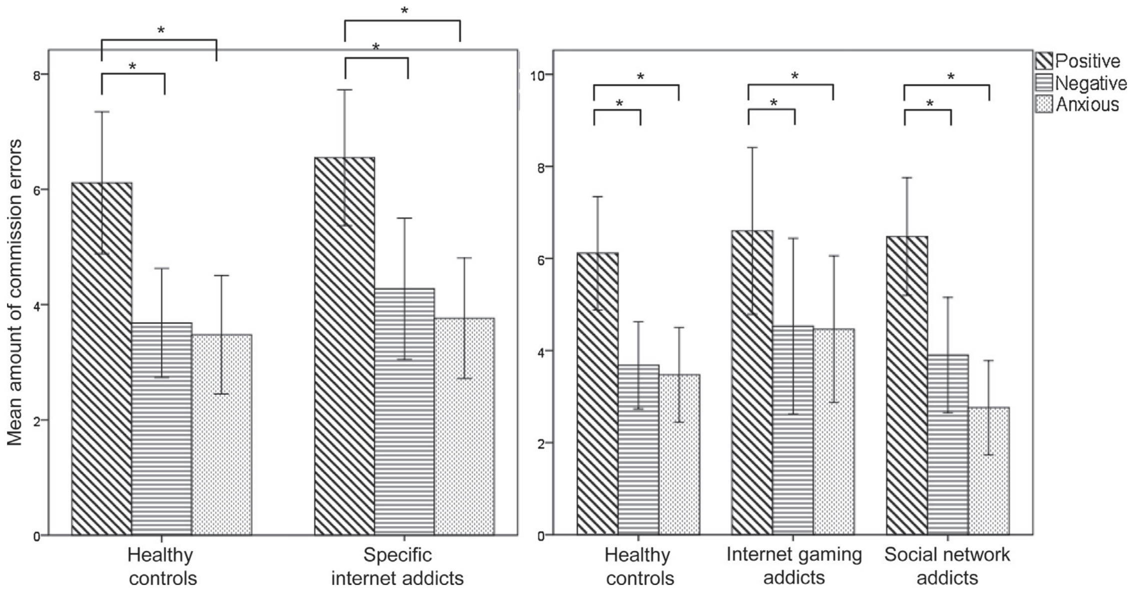

Fig. 2. Number of commission errors.

Contrary to our first hypothesis that specific internet addicts show longer RT on socially anxious words compared to healthy controls, we did not find significant between-group differences ($z_{\text{specific internet addicts vs. healthy controls;social anxiety-neutral}} = -0.712$, $p = 0.476$; $z_{\text{specific internet addicts vs. healthy controls;(socially anxious-neutral)-mean(positive-neutral,negative-neutral)}} = -0.795$, $p = 0.427$). Furthermore, there also were no between-group differences in other emotional categories (i.e. positive-neutral, negative-neutral).

However, Friedman tests for within-group comparison between the four categories revealed significantly longer RTs to socially anxious compared to positive and negative words as well as in relation to all other categories in specific internet addicts [$\chi^2 = 15.960$, $p = 0.001$; Wilcoxon signed rank post-hoc test: $z_{\text{socially anxious-neutral} > \text{positive-neutral}} = -2.731$, $p = 0.006$; $z_{\text{(socially anxious-neutral)minus(mean((positive-neutral)+(negative-neutral)))} > \text{positive-neutral}} = -2.704$, $p = 0.007$; $z_{\text{socially anxious-neutral} > \text{negative-neutral}} = -2.677$, $p=0.007$; $z_{\text{(socially anxious-neutral)minus mean((positive-neutral)+(negative-neutral))} > \text{negative-neutral}} = -3.162$, $p = 0.002$].

Exploratively, Kruskal-Wallis tests for subgroup comparisons (internet gaming and social network addicts as well as healthy controls) did not indicate any significant group differences in RTs for each contrast. Within-group comparisons (Friedman tests) showed significantly longer RTs to socially anxious compared to positive and negative words as well as in relation to all other categories in internet gaming addicts [$\chi^2 = 8.723$, $p = 0.033$; $z_{\text{socially anxious-neutral} > \text{positive-neutral}} = -2.132$, $p = 0.033$; $z_{\text{(socially anxious-neutral)minus mean((positive-neutral)+(negative-neutral))} > \text{positive-neutral}} = -2.411$, $p=0.016$; $z_{\text{socially anxious-neutral} > \text{negative-neutral}} = -2.341$, $p = 0.019$; $z_{\text{(socially anxious-neutral)minus mean((positive-neutral)+(negative-neutral))} > \text{negative-neutral}} = -2.760$, $p = 0.006$; see also Fig. 3]).

Including years of education as a covariate in the analyses did not change the findings.

4.2.2. Neurobiology

4.2.2.1. Overall sample. In the overall EST sample, the left DLPFC, superior frontal gyrus, superior temporal gyrus as well as the inferior parietal lobe (IPL) were significantly higher activated during positive relative to neutral word blocks (see Fig. 4 and Table 8).

The analyses for other contrasts (*negative vs. neutral, socially anxious vs. neutral* and *socially anxious vs. rest*) revealed no significant differences.

4.2.2.2. Within-group comparisons. In contrast to our second hypothesis that specific internet addicts show altered dACC activation in socially anxious word blocks (*socially anxious vs. rest*) during the EST, within-group differences revealed no significant results.

Explorative analyses for other contrasts (*socially anxious vs. neutral, positive vs. neutral, negative vs. neutral*) revealed no significant differences within controls and specific internet addicts.

The further explorative subgroup analyses revealed clusters of significant hypoactivations in the left middle and superior temporal gyrus of internet gaming addicts ($n = 13$) for our contrast of interest (i.e. *social anxiety > rest*; BA 21, 22, 48, cluster size = 75, MNI = −45 −19 −2, $t_{max} = 5.44$, $p_{cluster} = 0.014$; see Fig. 5). After including years of education as a covariate, the result failed slightly the level of significance (i.e. *social anxiety > rest*; cluster size = 53, MNI = −45 −19 −2, $t_{max} = 5.22$, $p_{cluster} = 0.051$).

Within the group of social network addicts, no significant brain activations in the contrast of interest (i.e. *social anxiety > rest* and rest > *social anxiety*) were observed. Apart from cerebellum and fusiform gyrus activation in social network addicts on neutral compared to negative words (BA 18, cluster size = 111, MNI = −9 −85 −11, $t_{max} = 5.49$, $p_{cluster} = 0.002$), the other assessed contrasts revealed no significant within-subgroup differences.

4.2.2.3. Between-group comparisons. Opposed to our second hypothesis, significant alterations in brain activation were not observed between specific internet addicts and controls on socially anxious words in the dACC.

However, explorative analyses revealed internet gaming addicts to exhibit significantly lower brain activation in a cluster within the left middle and superior temporal gyrus during socially anxious words (vs. all other word categories) relative to social network addicts in the corresponding post-hoc comparison (see Fig. 6 and Table 9).

Further between-group analyses (controls vs. specific internet addicts, controls vs. internet gaming addicts, controls vs. social network addicts and internet gaming vs. social network addicts) regarding all other contrasts (*socially anxious vs. neutral, positive vs. neutral, negative vs. neutral*) showed no significance.

After including years of education as a covariate, the result failed slightly the level of significance (i.e. *social anxiety > rest*; BA 21, 48; cluster size = 101, MNI = −45 −25 −2, $t_{max} = 4.39$, $p_{cluster}=0.055$).

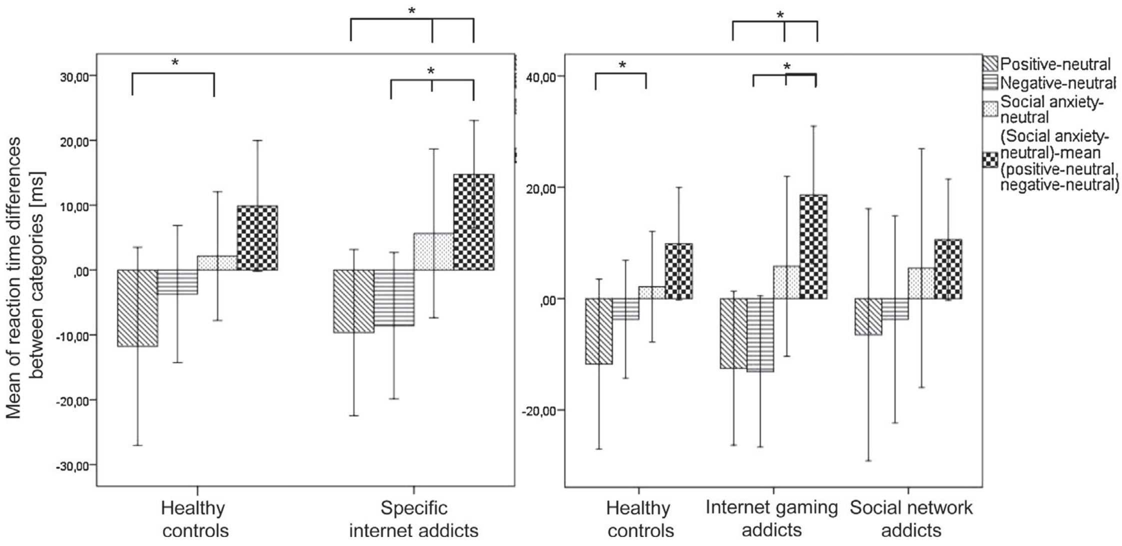

Fig. 3. Within-group differences in the mean RT differences.

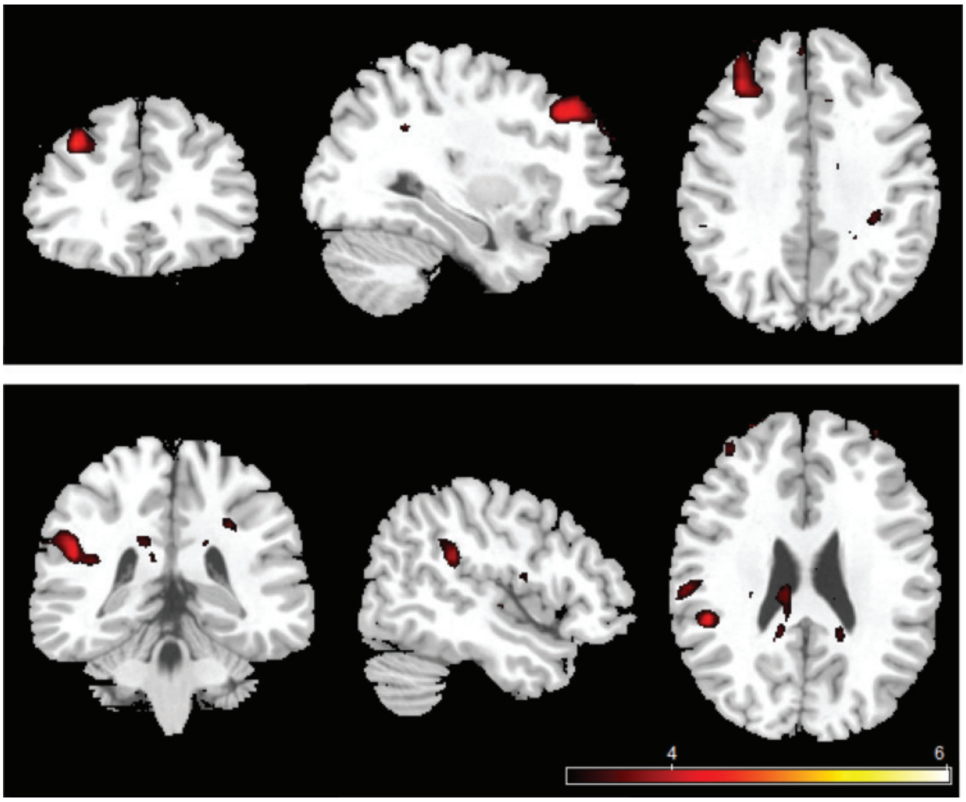

Fig. 4. One-sample *t*-test for the overall EST sample showing significantly higher brain activation in the left DLPFC and superior frontal gyrus (peak voxel MNI −33 32 37; BA 8/9; upper image), the left superior temporal gyrus and the left IPL (peak voxel MNI −48 −37 25; BA 13; lower image) during positive relative to neutral word blocks. Brain-extracted chi-square template in MNI space with SPM contrast image-overlay: $p_{uncorr} < 0.001$, T = 3.27, #voxel ≥ 10.

The significant finding was also observed without the neutral condition in the applied contrast (i.e. *social anxiety > positive + negative*; result not shown) and after including years of education as a covariate (i.e. *social anxiety > positive + negative*; cluster size = 90, MNI = −45 −22 −2, $t_{max} = 4.40$, $p_{cluster}$=0.050).

5. Discussion

Given the association of specific internet addiction with social anxiety, emotional competence deficits as well as impaired inhibitory control processing and the dACC's role in cognitive control over negative and anxious emotions, the presented study aimed to assess anxiety-related emotional inhibitory control processing and its relation to the dACC in specific internet addicts (internet gaming and social network addicts).

In line with previous studies [9,11,49], our psychometric results revealed specific internet addicts to show higher social anxiety, emotional competence deficits, impulsivity and perceived stress. These factors often lead to social isolation, distrust and a perceived lack of social support and are assumed to have a high impact on

Table 8
One-sample *t*-test for the overall EST sample for the contrast *positive > neutral*.

H	Lobe	BA	Brain region	Cluster size	MNI coordinates			t_{max}	$p_{cluster}$
					x	y	z		
Positive > neutral									
L	Temporal	–	Supramarginal gyrus, superior temporal gyrus, rolandic operculum, insula	81	−48	−40	22	4.03	0.047
L	Frontal	8/9	DLPFC and superior frontal gyrus	164	−33	32	37	4.57	0.002
Neutral > positive									
–									

H = Hemisphere, L = Left, R = Right, BA = Brodmann Area, MNI = Montreal Neurological Institute, $p_{cluster}$ = FWE-corrected p-values reported on cluster level ($p_{FWE} < 0.05$).

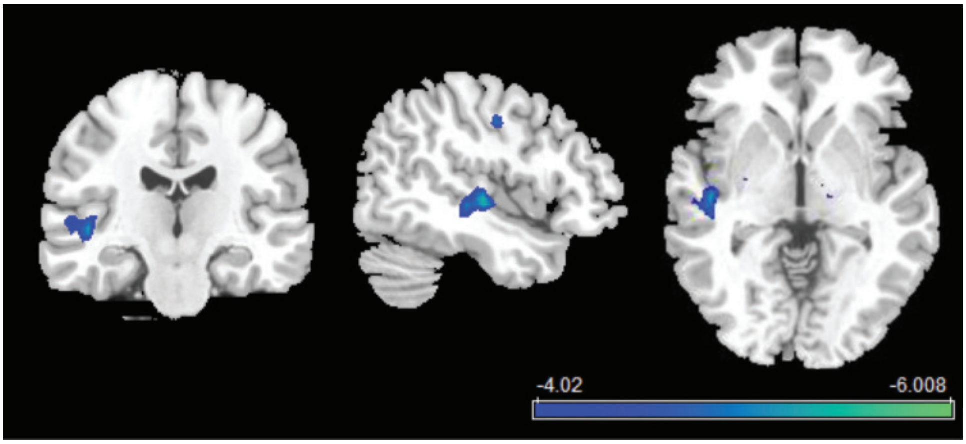

Fig. 5. Within-group brain hypoactivation in the left middle and superior temporal gyrus of internet gaming addicts for the contrast *social anxiety > rest* in the (peak voxel MNI 47 19 2). Brain-extracted chi-square template in MNI space with SPM contrast image-overlay: $p_{uncorr} < 0.001$, T = 3.93, #voxel ≥ 10.

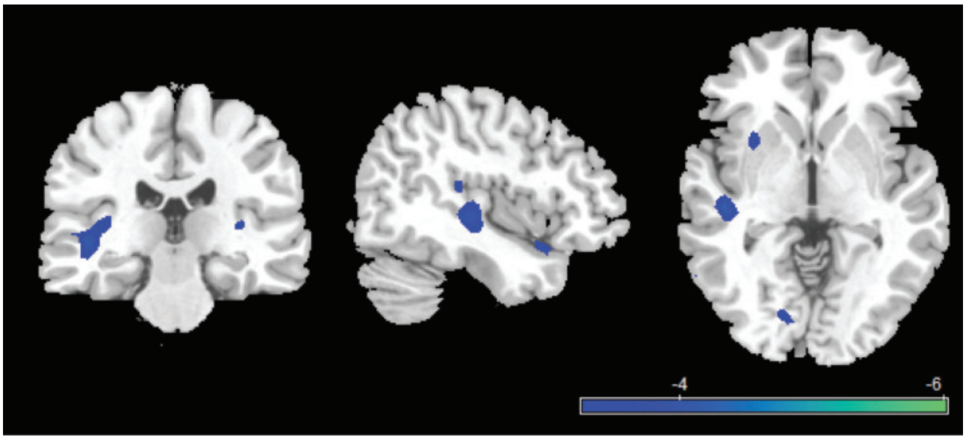

Fig. 6. Full factorial ANOVA and post-hoc tests for the contrast *social anxiety > rest* showing decreased brain activation in internet gaming addicts relative to social network addicts in the left middle and superior temporal gyrus (peak voxel MNI −45 −25 −2, cluster size = 101, $t_{max} = 4.39$, $p_{cluster} = 0.036$). Brain-extracted chi-square template in MNI space with SPM contrast image-overlay: $p_{uncorr} < 0.001$, T = 3.93, #voxel ≥ 10.

Table 9
Exploratory between-group comparison involving controls, internet gaming as well as social network addicts for the contrast *social anxiety > rest*.

H	Lobe	BA	Brain region	Cluster size	MNI coordinates			t_{max}	$p_{cluster}$
					x	y	z		
Social network addicts > internet gaming addicts									
L	Temporal	21, 48	Middle/superior temporal	101	−45	−25	−2	4.39	0.036
Internet gaming addicts > social network addicts									
–									

H = Hemisphere, L = Left, R = Right, BA = Brodmann Area, MNI = Montreal Neurological Institute, $p_{cluster}$ = FWE-corrected p-values reported on cluster level ($p_{FWE} < 0.05$).

the risk for an addicted use of specific internet applications [4]. Additionally, in concordance with Lemmens et al. [50], reporting higher loneliness in pathological online gamers, our explorative subgroup analyses revealed significantly higher ratings of loneliness in internet gaming addicts relative to healthy controls and social network addicts. This possibly indicates a higher tendency for social withdrawal, which has already been described for internet gaming addicts [51].

Regarding our assessment of emotional inhibitory control, we assumed stronger interference (i.e. longer RTs in the EST) on socially anxious words and impaired response inhibition (i.e. more commission errors in the AGN) on anxious stimuli in specific internet addicts compared to healthy controls. In contrast to this hypothesis, we did not find significant group differences in RT (EST) and commission errors (AGN). Also the explorative subgroup analyses did not reveal any significant between-group differences in these behavioral measures. Correspondingly, studies investigating the cognitive domain of inhibitory control in internet addicts, did not find significant differences to healthy controls, neither during Go/No-Go tasks nor during Stroop task performance [52,53]. It is suggested that despite the observed differences in valence and arousal between stimuli-categories (see Fig. 1), the tasks might not have been sensitive enough to detect group differences in behavioral measures.

However, in the overall sample we found an association between reduced emotional response inhibition ability (i.e. more commission errors) to anxious stimuli in the AGN and addiction severity. Potentially, this association might suggest that significant between-group differences are also diminished by underlying gradual alterations in anxiety-related response inhibition during the transition from non-problematic to addictive specific internet use [54].

Additionally, in the subgroup analyses, we detected significantly longer RTs in the EST for socially anxious words compared to the other categories within the group of internet gaming addicts, which was not observed in social network addicts or healthy controls. This result might give a hint that social anxiety-related interference especially plays a role in IGA.

Neurobiological analyses of the EST in the overall sample showed increased activations in the left DLPFC, the superior frontal gyrus, the superior temporal gyrus as well as the IPL during positive relative to neutral word blocks. In previous studies, the DLPFC was found to be mainly associated with cognitive inhibitory control processing [55,56], in particular with the cognitive selection of relevant sensory information.

Due to the generally higher salience of positive stimuli, it might be possible that participants are more distracted during the color naming of positive words and therefore they might have to counteract stronger against this disruption. The other contrasts did not reveal any within-group differences in the overall sample. However, considering our psychometric results of significant differences in arousal and valence between the EST word-categories (positive > neutral > negative and socially anxious words), we anticipate that the EST paradigm works sufficiently for the exploration of neurobiological correlates of emotional inhibitory control processing.

Due to previous findings of increased social anxiety in specific internet addicts, we hypothesized altered dACC activation in specific internet addicts relative to healthy controls during emotional interference by socially anxious words in the EST. However, we did not find any within and between-group differences in dACC activation on socially anxious stimuli compared to the other conditions. Instead of altered dACC activation, the explorative analyses revealed significant hypoactivations in the left middle and superior temporal gyrus of internet gaming addicts, which also consisted relative to social network addicts for our contrast of interest (i.e. *socially anxious > positive + negative + neutral* EST word blocks). These brain regions play a major role in the storage and retrieval of semantic, i.e. lexical knowledge [57–61]. Furthermore, in particular the left middle temporal gyrus has been associated with the successful retrieval of words or expressions during communication. Jeong et al. [60] reported increased activation in the left middle and superior temporal gyrus during social interaction as well as a positive correlation between activation in the middle temporal gyrus during interaction in a second language and oral proficiency (i.e. how fluently appropriate words can be retrieved, sequences formulated or expressions formed in the communicative context; [60]). Communication requires pre-established discourse conventions or dialog schemas that have been acquired through intensive experiences with social interaction [62,63]. Transferring these findings into our results of middle temporal gyrus hypoactivation during the interference of socially anxious stimuli in internet gaming addicts, we suggest that social words might be less retrievable than positive, negative or neutral words in the semantic storage of internet gaming addicts.

In addition, a previous study reported reduced superior temporal gyrus activation (among other regions) in social anxiety disorder patients relative to healthy controls during the cognitive emotional regulation (by actively thinking in a way that modifies negative emotions) when watching social threat stimuli (i.e. harsh facial expressions; [64]). Due to the association of IGA with social anxiety [9], our result of middle and superior temporal gyrus hypoactivation on social anxious stimuli in internet gaming addicts might give a first hint for a neurobiological correlate of reduced efficiency in the regulation of socially anxious emotions in real social contexts. Thus, internet gaming might depict a coping strategy for internet gaming addicts in order to avoid face-to-face social interactions [4,12,65–69].

These considerations might be in line with the I-PACE model of Brand et al. (2016; [4]), suggesting social distrust, loneliness and a lack of social support as main factors intensifying the use of internet applications related to communication features. Our results suggest that these deficits are even stronger in internet gaming compared to social network addicts. However, we did not detect neurobiological differences between internet gaming addicts and healthy controls. One reason might be the low sample sizes of the subgroups. Additionally, when including years of education as a covariate, the hypoactivation in the left middle and superior temporal gyrus in internet gaming addicts did slightly miss significance level. Therefore, these results should be handled with caution and be confirmed in further studies including higher sample sizes.

However, to the best of our knowledge, this is the first study investigating emotional inhibitory control processing in specific internet addiction.

In conclusion, our findings did not confirm our hypotheses of impaired emotional inhibitory control in the neuropsychological tasks (AGN and EST) and altered dACC activation upon socially anxious stimuli during EST performance in specific internet addicts (i.e. internet gaming and social network addicts).

We only detected in the explorative subgroup analyses significantly longer RTs in the EST for socially anxious words within the group of internet gaming addicts and decreased activations in the left middle and superior temporal gyrus during the interference of socially anxious words relative to positive, negative and neutral words within IGA as well as compared to social network addicts.

Given the function of the left middle temporal gyrus in the successful retrieval of words or expressions during communication, these findings suggest that in particular socially anxious words might be less retrievable in the semantic storage of internet gaming addicts and might indicate deficiencies in the handling of speech in social situations. As mentioned above, these findings have to be confirmed in further studies with larger sample sizes in order to assess the validity of the activated regions. But the results are a starting point and may suggest a stronger therapeutic focus on the training of communication skills, in particular in addicted internet gamers.

Compliance with ethical standards

All authors have no conflicts of interests to declare.

This study involved human participants, who gave written informed consent prior to study participation.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Contributions

Julia Dieter contributed to data collection, study management, data analyses and manuscript preparation. Sabine Hoffmann was involved in manuscript revision and psychometric data analyses. Daniela Mier provided the paradigm version and contributed to data analyses. Iris Reinhard verified statistical data analyses. Martin Beutel contributed to data collection and manuscript preparation. Sabine Vollstädt-Klein and Falk Kiefer were involved in the supervision of and assistance in the study and manuscript-related proceedings. Karl Mann supervised the manuscript preparation. Tagrid Leménager supervised the study and also supervised and contributed to data collection, data analyses as well as manuscript preparation. All authors approved of the manuscript's final version.

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