Available online at www.sciencedirect.com
ScienceDirect
International Journal of Psychophysiology 62 (2006) 224–232
INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY
www.elsevier.com/locate/ijpsycho

Nicotine Stroop and addiction memory—an ERP study

Thorsten Fehr [a,b,*], Patrick Wiedenmann [a], Manfred Herrmann [a,c]

[a] Institute for Cognitive Neuroscience, Department of Neuropsychology/Behavioral Neurobiology, University of Bremen, Grazerstr. 6, 28359 Bremen, Germany
[b] Department of Neurologie II, Otto-von-Guericke-University Magdeburg, Germany
[c] Center for Advanced Imaging (CAI), University of Bremen, Germany

Received 2 June 2005; received in revised form 13 January 2006; accepted 15 January 2006
Available online 21 February 2006

Abstract

Drug-related cues have been shown to take effects on behavioral performance and physiological parameters such as event-related brain potentials (ERPs). In the present study we obtained EEG data during a modified Stroop task and during a color matching task using smoking related and neutral words (nicotine Stroop) in smokers and non-smoking controls. We assumed that in smokers smoking-related word meanings would interfere with color matching, and that this should be reflected in an ERP activation pattern comparable to that induced by the Stroop task. In smokers and non-smokers the classic Stroop-related interference effect of longer reaction times in the incongruent condition could be observed. This interference effect in both groups was related to a late posterio-central relative negativity and a right frontal relative positivity in the incongruent compared to the congruent condition. The behavioral data in the color matching task (nicotine Stroop) derived from both groups did not show a comparable interference effect related to the use of drug-related words. However, in smokers the smoking-related words elicited ERP activation patterns comparable to those evoked by the Stroop interference task. The ERP results are discussed as possibly reflecting a modulation of color processing of smoking-related words in smokers. The results imply an interference, but also attention enhancing, effect of smoking-related words in smokers, which maybe associated with addiction memory and enhanced sensitivity for drug-cues. Therefore, the addiction memory driven interference effect might be counteracted by performance enhancement induced by the same nicotine cues.

Keywords: Nicotine Stroop; Addiction memory; Interference; Cognitive control; ERP

1. Introduction

The development of addictive behavior in animals has been examined by a variety of studies (Wolffgramm, 1995; Wolffgramm and Heyne, 1995), and there is evidence for comparable mechanisms in humans (Böning, 1994, 2001). As one of the main components in the development of persistent addictive behavior a physiological formation of an addiction memory (AM) has been discussed. This concept found support by EEG (Warren and McDonough, 1999) and fMRI (Due et al., 2002) studies showing that drug-related cues induced specific brain activation patterns. Nevertheless, there is still a lack of knowledge to what extent drug-related cues have an influence on behavior in addicts. Sudden relapse scenarios after decades of abstinence might be explained by emotional factors (Grüsser et al., 2000), environmental background (Böning, 2001) and/or neuroadaptive (Koob and Le Moal, 1997; Koob et al. 1998; Nestler and Aghajanian, 1997, review) changes in addicts, developed during life periods of drug consumption.

To examine effects of AM on behavioral performance some studies (e.g. McCuskers and Gettings, 1997; Stetter et al., 1994; Lusher et al., 2004) demonstrated an interference effect of drug-related information on the reaction time in Stroop-like interference tasks. The classic color–word Stroop interference effect (Stroop, 1935) has been replicated in many studies. The basic principle of the Stroop paradigm is that the color of color words can be named faster and more accurate when the color and the meaning of the words are congruent. Incongruent color–word conditions (i.e. the word “green” printed in blue) result in more errors and longer reaction times (for review see MacLeod and MacDonald, 2000). Among other theories, this effect has been explained by differences in the relative strength of two competing neuronal pathways or networks (Cohen et al., 1990; MacLeod and MacDonald, 2000). If word meaning interferes color naming, other words, which are especially consolidated in

* Corresponding author. Tel.: +49 421 218 8254; fax: +49 421 218 4408.
E-mail address: fehr@uni-bremen.de (T. Fehr).

0167-8760/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2006.01.011

memory, might show a similar interference effect. Confirmatively, this assumption could be substantiated in spider phobics (Watts et al., 1986), social phobics (Mattia et al., 1993), pathological gamblers (McCuskers and Gettings, 1997) and alcoholics (Stetter et al., 1994; Lusher et al., 2004). Disease-related aspects were discussed as especially consolidated in memory because of the idiosyncratic relevance for the patients (Williams et al., 1996). Stetter et al. (1994) showed that alcoholics performed comparable to controls in the classic Stroop task, but behavioral performance was significantly affected by the color-naming of alcohol-related words. Consecutively, poorer performance in the alcohol Stroop condition could not be related to neuropsychological deficits in alcohol patients, but to the addiction-related content of the words. Furthermore, Lusher et al. (2004) showed poorer alcohol Stroop performance in alcohol patients regardless of demographic factors and mood states.

As could be shown in so-called "emotional Stroop tasks", individuals across different clinical populations were significantly slower in responding to stimuli idiosyncratic to their respective disease (Williams et al., 1996, review). Drug cues also have been shown to induce craving (Grüsser et al., 2000) and, therefore, these cues induce idiosyncratically emotional effects in drug users. Neuroimaging studies (for review see Wilson et al., 2004) reported drug-related cue-activation in cocaine, opiate, alcohol and cigarette addicts most commonly in the amygdala, the anterior cingulate cortex, the orbitofrontal cortex and the dorsolateral prefrontal cortex in combination with the feelings of urge to consume the drug (craving). Bringing together the results of different studies drug-related cues might be processed in a complex semantic network covering the processing of emotional and cognitive aspects. A competition between emotional and cognitive information processing could explain the results of a drug-cue induced performance reduction reported by Lusher et al. (2004) and Williams et al. (1996). However, a relationship between physiological data, drug-cues and behavioral performance reduction has not been shown yet.

ERP measurements showed characteristic components associated with drug-related cues across different substances. Franken (2003) reported that cocaine as well as heroin addicts showed an augmented late slow positive wave and feelings of craving according to the presentation of substance-related pictures. Smokers showed a relative lower N268 and higher P412 amplitude being confronted with smoking-related pictures (Warren and McDonough, 1999).

Derived from the different stated approaches in the literature, in the present study we used a nicotine Stroop task that combines cognitive performance (color matching) with processing of neutral and drug-related words with high addiction memory load. We hypothesized that smokers in comparison to non-smokers would show an interference effect due to drug-related word meaning. As a physiological substrate of this interference effect, we expected smokers to show event-related activation patterns in the nicotine Stroop task comparable to those elicited by a classic Stroop task. Liotti et al. (1999) showed a prolonged late (500–800 ms) frontal positivity and an earlier (300–500 ms) medial–dorsal negativity during the incongruent Stroop condition in healthy participants. In addition to condition-related modulations of the ERPs we also took possible general differences between smokers and controls, such as a reduced visual P300 in smokers (Anokhin et al., 2000; Ilan and Polich, 1999), into account.

2. Methods and materials

2.1. Participants

Thirty-four healthy participants met the inclusion criteria of the study (no previous mental illness, no psychotropic medication, right handedness) and gave informed and written consent to participate in an approximately 3 h experimental session. The study sample consisted of 15 smokers (7 male, 26.7±3.9 years, 8 female, 28.0±4.3 years) and 19 non-smoking control subjects (8 male, 25.0±2.3 years, 11 female, 24.2±2.0 years). Smokers were screened for smoking history (cigarettes per day, mean 16.0±7.6 pcs., and duration of smoking career, mean 10.9±4.2 years). Severity of smoking dependency was assessed by the Fagerstroem test (Fagerstroem and Schneider, 1989; FTND mean 3.0±2.77). Handedness was assessed by a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1971).

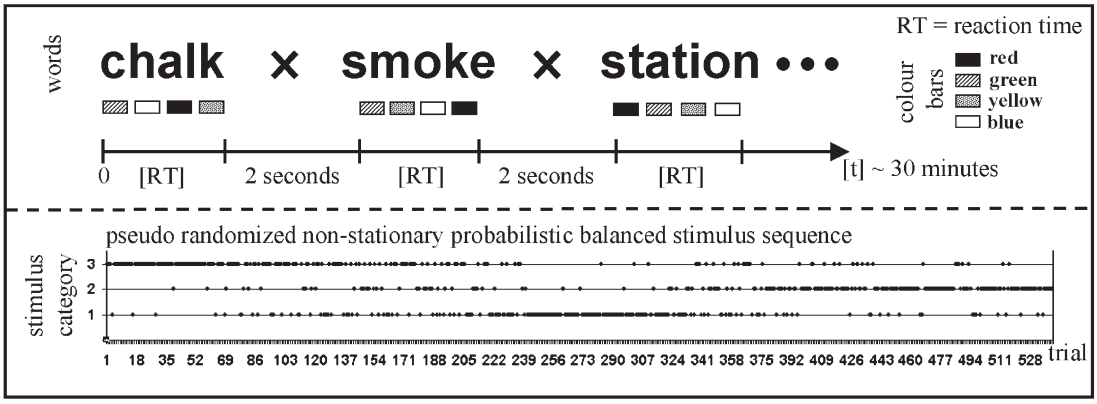
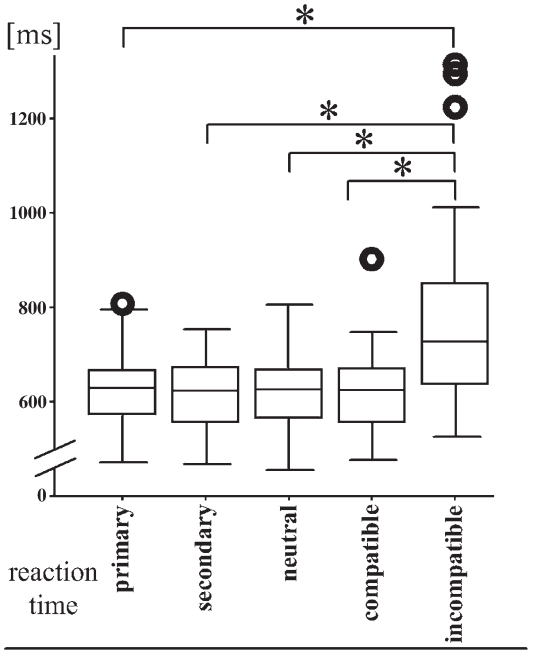


Fig. 1. Upper part: study design and task modalities (participants had to press a button according to the color bar representing the color of the stimulus); lower part: sequence of stimulus presentation.



	errors/all	error rate (%)
primary	4.9(± 4.6)/208	2.2(± 2.3)
scondary	2.9(± 4.2)/208	1.4(± 2.0)
neutral	3.8(± 4.8)/260	1.5(± 1.9)
compatible	0.1(± 0.4)/20	0.7(± 2.2)
incompatible	0.8(± 0.9)/20	4.1(± 4.7)

Fig. 2. Behavioral data: reaction times (upper part; boxplots: median, box enclosing second and third quartiles, maximum and minimum values, and outliers (more than 1.5 box lengths distance to box border) indicated by circles) and error rates (lower part). Significant differences (post hoc tests; $p<.05$) were indicated by asterisks.

2.2. Task and procedure

Nicotine consumption related colored words were used in a color matching task (nicotine Stroop task). The words used involved *primary target words* (*PW*, 52; e.g. cigarette, tobacco, ashtray, etc.), *secondary target words* (*SW*, 52; e.g. party, bus stop, restroom, etc.) and *neutral words* (*NW*, 65; e.g. database, grid, quail, etc.). Each word was presented four times in four different colors (red, green, yellow and blue for each word to avoid confounding COLOR × WORD effects). The words were matched for syllable length and approximately balanced for word frequency based on searching results using the German pages of the internet portal "Google".

Additionally, a modified version of the classic Stroop task (Stroop, 1935) was randomly integrated across the whole trial sequence. Color words like "green" were presented in green (*congruent condition*) or blue (*incongruent condition*) color. To validate the smoking related valence of the stimuli, primary and secondary smoking-related words were obtained by in-depth interviewing 20 heavy smokers and controls who were not participating in the study.

Participants were asked to ignore the meaning of the words and only press one of four buttons corresponding to the color of the word presented. Four colored rectangles, placed below the word, indicated the position of the button representing the target color (see Fig. 1). The position of the colored rectangles changed every trial to ensure that the subjects actively selected a color and not only performed color–motor responses. After response, a fixation cross appeared for 2 s prior the next trial.

Stimuli were presented in a pseudo-randomized non-stationary probabilistic sequence (Friston, 2000). Emotional stimuli have been shown to take effect on subjects over half a minute and more (Garrett and Maddock, 2001) and, therefore, a probabilistic

Table 1
ERP statistics: time window [ms]; factors (AP = anterior–posterior and LAT = left- to right-sided electrode positions, CONDITION, and GROUP); degrees of freedom [*df*]; *F*-value; significance level [*p*]; Greenhouse-Geisser corrected *p*-value; upper part (A) for word and lower part (B) for Stroop task

(A) WORDS

[ms]	Factors	*df*	*F*	p	GG
Regional GROUP × CONDITION					
90–110	AP × LAT × CONDITION × GROUP	16, 312	2.7	<.01	<.01
200–250	LAT × CONDITION × GROUP	8, 256	2.5	<.05	<.05
400–500	AP × CONDITION × GROUP	4, 128	2.7	<.05	<.06
Regional GROUP					
90–110	AP × LAT × GROUP	8, 256	3.1	<.01	<.05
Regional CONDITION					
400–500	AP × LAT × CONDITION	4, 128	4.3	<.05	<.05
Regional					
90–110	AP	2, 64	6.6	<.01	<.05
90–110	LAT	4, 128	32.4	<.01	<.01
90–110	AP × LAT	8, 256	13.8	<.01	<.01
200–250	AP	2, 64	20.3	<.01	<.01
200–250	LAT	4, 128	8.2	<.01	<.01
200–250	AP × LAT	8, 256	17.9	<.01	<.01
400–500	AP	2, 64	18.1	<.01	<.01
400–500	LAT	4, 128	4.5	<.01	<.05
400–500	AP × LAT	8, 256	4.0	<.01	<.01

(B) STROOP

[ms]	Factors	*df*	*F*	p	GG
Regional GROUP					
90–110	AP × LAT × GROUP	8, 184	2.5	<.05	<.05
90–110	LAT × GROUP	4, 92	3.1	<.05	<.06
400–500	AP × GROUP	2, 46	6.4	<.01	<.05
400–500	LAT × GROUP	4, 92	3.6	<.01	<.05
Regional CONDITION					
400–500	AP × CONDITION	2, 46	10.1	<.01	<.01
Regional					
90–110	AP	2, 46	18.6	<.01	<.01
90–110	LAT	4, 92	11.8	<.01	<.01
90–110	AP × LAT	8, 184	9.3	<.01	<.01
200–250	AP	2, 46	13.8	<.01	<.01
200–250	LAT	4, 92	15.7	<.01	<.05
200–250	AP × LAT	8, 184	14.5	<.01	<.05
400–500	AP	2, 46	5.4	<.05	<.05
400–500	LAT	4, 92	4.9	<.01	<.01
400–500	AP × LAT	8, 184	2.6	<.01	<.01

weighted distribution of the different stimulus categories was chosen (see Fig. 1, lower part). The pseudo-randomized non-stationary probabilistic sequencing of different tasks provides a good compromise between a blocked and an event-related design. Additionally, Stroop-trials (20 congruent and incongruent each) were randomly inserted over the whole sequence of all trials. Subjects were seated in a dark room facing a monitor placed at 75 cm distance from their eyes. The stimuli were presented using the software "Presentation®" (Neurobehavioral Systems, Inc., Albany, USA) with a visual angle below 3.8° vertical and horizontal.

2.3. EEG recordings and statistical analyses

EEG data were recorded from 19 scalp electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, O2 placed according to the international 10–20 system; 200 Hz sampling rate; band-pass filter 0.1–70 Hz; average referenced; impedances below 50 kOhm; Nihon Kohden Systems, Neurofax, EEG 9110). Data was processed with the BESA® (MEGIS Software, Munich Germany) software for ERP averaging and Matlab® Tools (MathWorks Inc.; Aachen, Germany) to calculate the mean amplitudes for selected time windows. Only sweeps low on artifacts (extracted by visual inspection) were used for averaging. During the first run of the session subjects were asked to systematically move their eyes (20 blinks and 20 eye movements left, right, up and down each). Eye movements were averaged separately for blinks and each movement direction and the resulting topographies were used as prototypic templates for a spatio-temporal correlation with the EEG data. These correlations served as EOG for visual data inspection before task-related sweeps were accepted for averaging. For stimulus-locked analyses data were averaged 500 ms pre to 1200 ms post stimulus onset.

After averaging, evoked potentials were visually inspected, and time windows (subdivisions of the ERPs) were selected for further analyses. Mean amplitudes of the selected time windows were calculated. General linear models repeated measures ANOVAs were performed on behavioral data (reaction times, between subject factor GROUP, within subject factor CONDITION) and mean amplitude values (between subject factor GROUP, within subject factors CONDITION and CHANNELS; topographical analyses see below) using SPSS® (SPSS, Inc., Chicago, USA) and Statistica® (StatSoft, Inc., Tulsa, USA). CONDITION and CHANNEL variables were treated as repeated measurement factors and the GROUP variable as independent factor. Post hoc analyses (Fisher's LSD, least significant difference tests) were calculated according to the main ERP effects. Scalp distribution analyses were performed on mean amplitudes of different time windows including the electrode positions F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, Pz, P4 and P8. Latter electrode positions are distributed approximately equidistant and, therefore, appropriate for topographical analyses. From the outset Fp1 and Fp2 were excluded from all analyses because of their particular sensitivity to eye movements. General linear models including the factors GROUP, CONDITION, AP (anterior–posterior: frontal, central and posterior channels) and LAT (laterality: five levels from right to left electrode sites) were

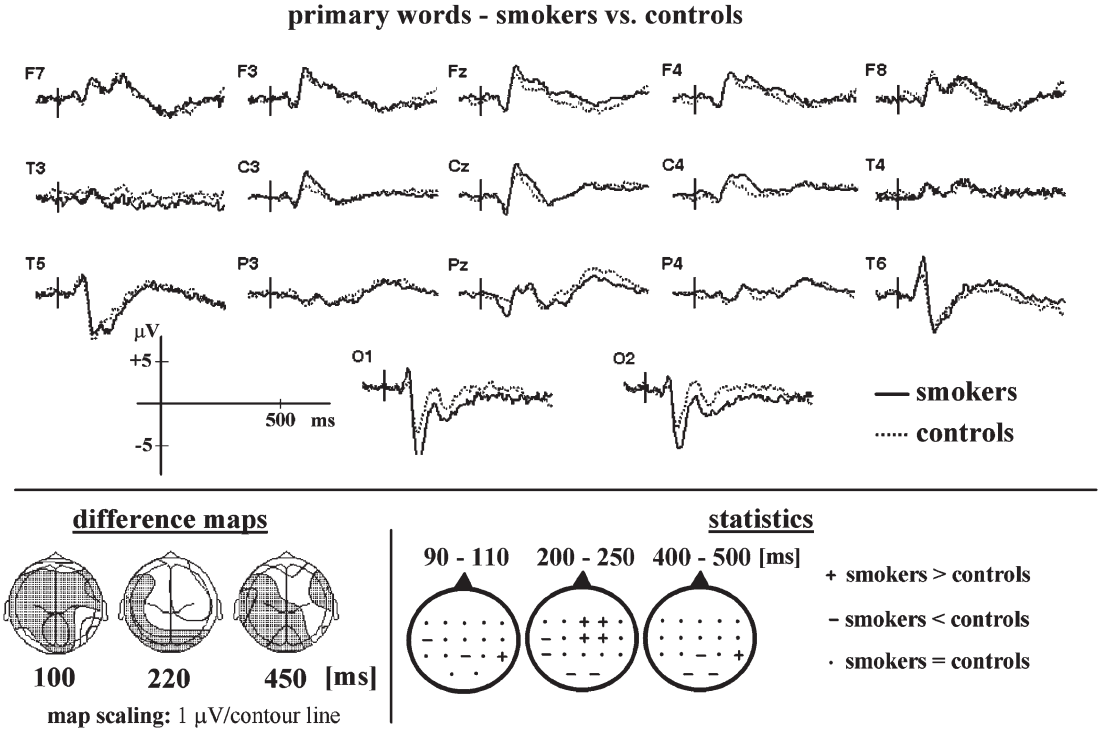


Fig. 3. Upper part: ERPs for smokers and controls (primary words); lower left part: corresponding potential maps: top view (100, 220 and 450 ms post stimulus); back of the head is below; white areas represent positive and shaded areas negative polarity (average referenced); map scaling: 1 µV/contour line. Difference map = smokers − controls; lower right part: significant condition differences (post hoc tests for 17 channel positions and three time windows (mean amplitudes); $p < .05$).

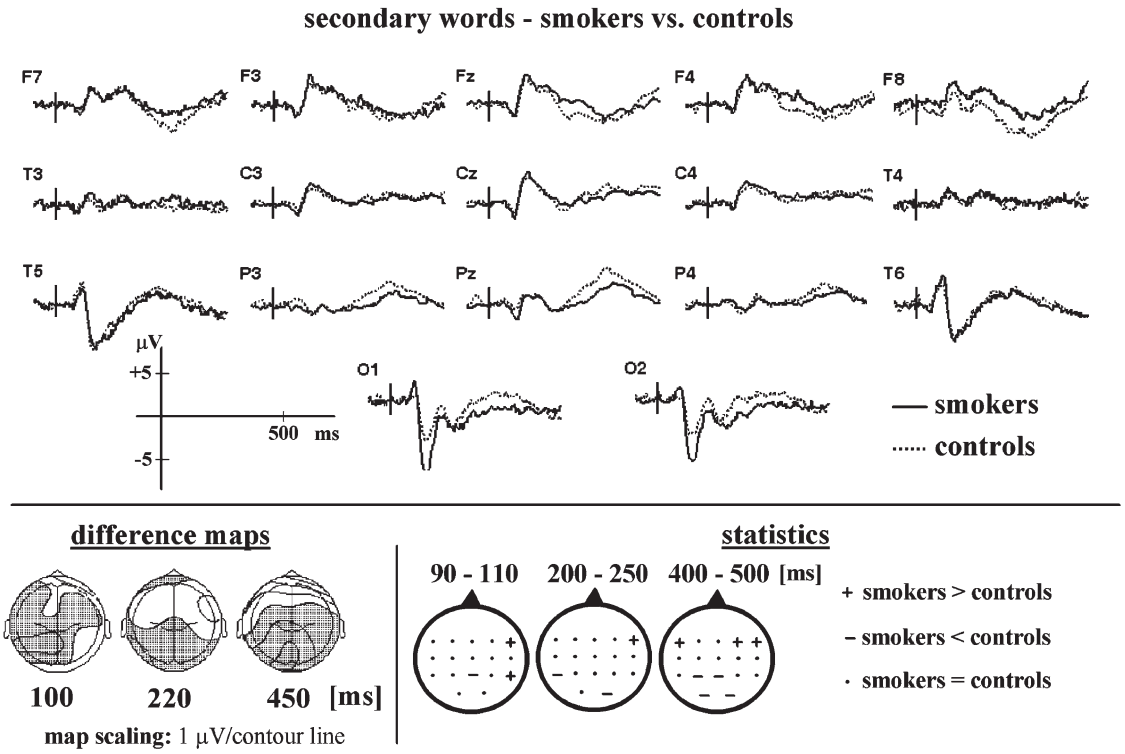


Fig. 4. Upper part: ERPs for smokers and controls (secondary words); lower left part: corresponding potential maps: top view (100, 220 and 450 ms post stimulus); back of the head is below; white areas represent positive and shaded areas negative polarity (average referenced); map scaling: 1 µV/contour line. Difference map = smokers − controls; lower right part: significant condition differences (post hoc tests for 17 channel positions and three time windows (mean amplitudes); $p < .05$).

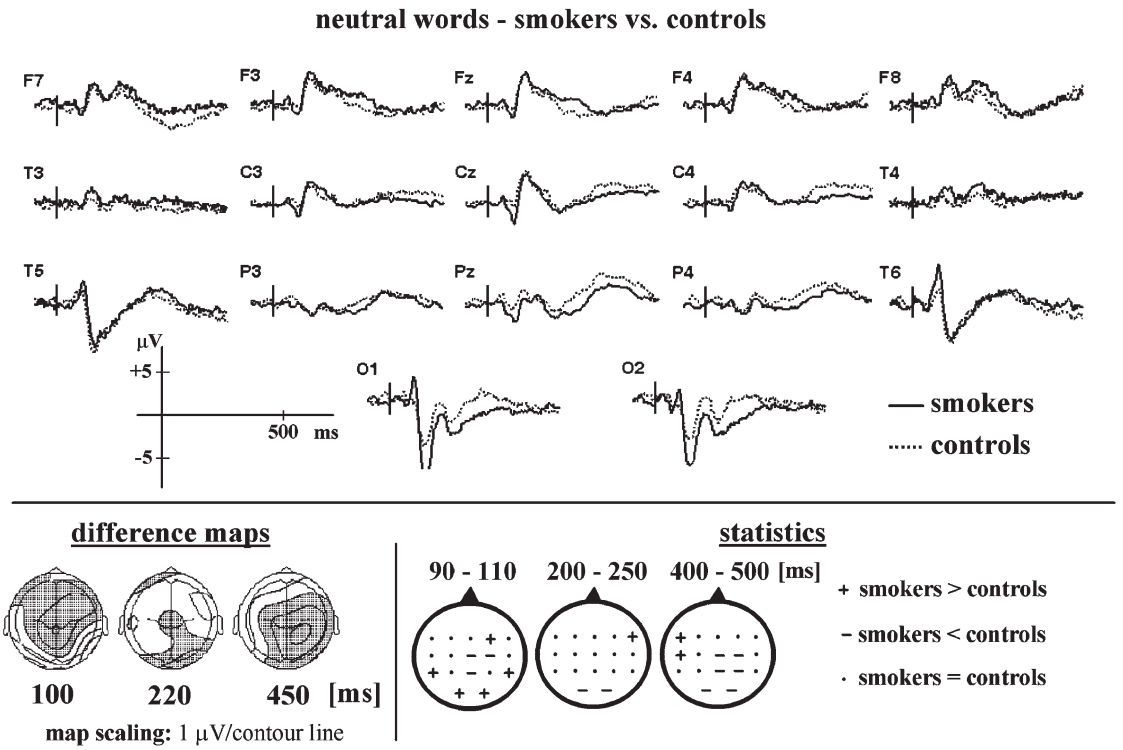


Fig. 5. Upper part: ERPs for smokers and controls (neutral words); lower left part: corresponding potential maps: top view (100, 220 and 450 ms post stimulus); back of the head is below; white areas represent positive and shaded areas negative polarity (average referenced); map scaling: 1 µV/contour line. Difference map = smokers − controls; lower right part: significant condition differences (post hoc tests for 17 channel positions and three time windows (mean amplitudes); $p < .05$).

performed using Greenhouse-Geisser adjustments. According to Urbach and Kutas (2002) and Haig et al. (1997) no normalization of EEG signals was performed in the present study because normalization procedures have been shown to unnecessarily distort the signals and even eliminate real differences.

3. Results

3.1. Behavioral data

Smokers and non-smokers showed no reaction time differences. The nicotine Stroop task showed no condition effects on performance (primary and secondary drug-related vs. neutral words). In the classic Stroop task incongruent color–words compared to congruent words resulted in significantly longer reaction times ($F(4,128)=29.2$, $p<.001$ (Greenhouse-Geisser (GG): $p<.001$); post hoc test: incongruent (772±200 ms)> congruent (624±84 ms), $p<.001$ (Fig. 2). Error rates were not further analyzed, because means were below 5% for all conditions.

3.2. ERP data

3.2.1. Color-matching task with smoking-related words (nicotine Stroop)

Main ERP effects were analyzed for 15 channels, three conditions (with uncorrected, and Greenhouse-Geisser (GG) adjusted p-values) and two groups (as independent factor) for mean amplitudes of three time windows (Table 1A). Several effects reached significance ($p<.05$, Table 1A). Post hoc test results were only considered when significant at a 5% level (Figs. 3, 4 and 5 lower right panel).

Topographical analyses (including the repeated measurements factors "anterior–posterior electrode positions (AP)", "left to right side electrode positions (LAT)"s, CONDITION, and GROUP as independent factor) confirmed regional task-related and/or group-specific differences for the time windows 90–110 ms, 200–250 ms and 400–500 ms (summarized in Table 1).

Apart from general differences, smokers compared to controls exhibited different specific condition-related ERP waveforms.

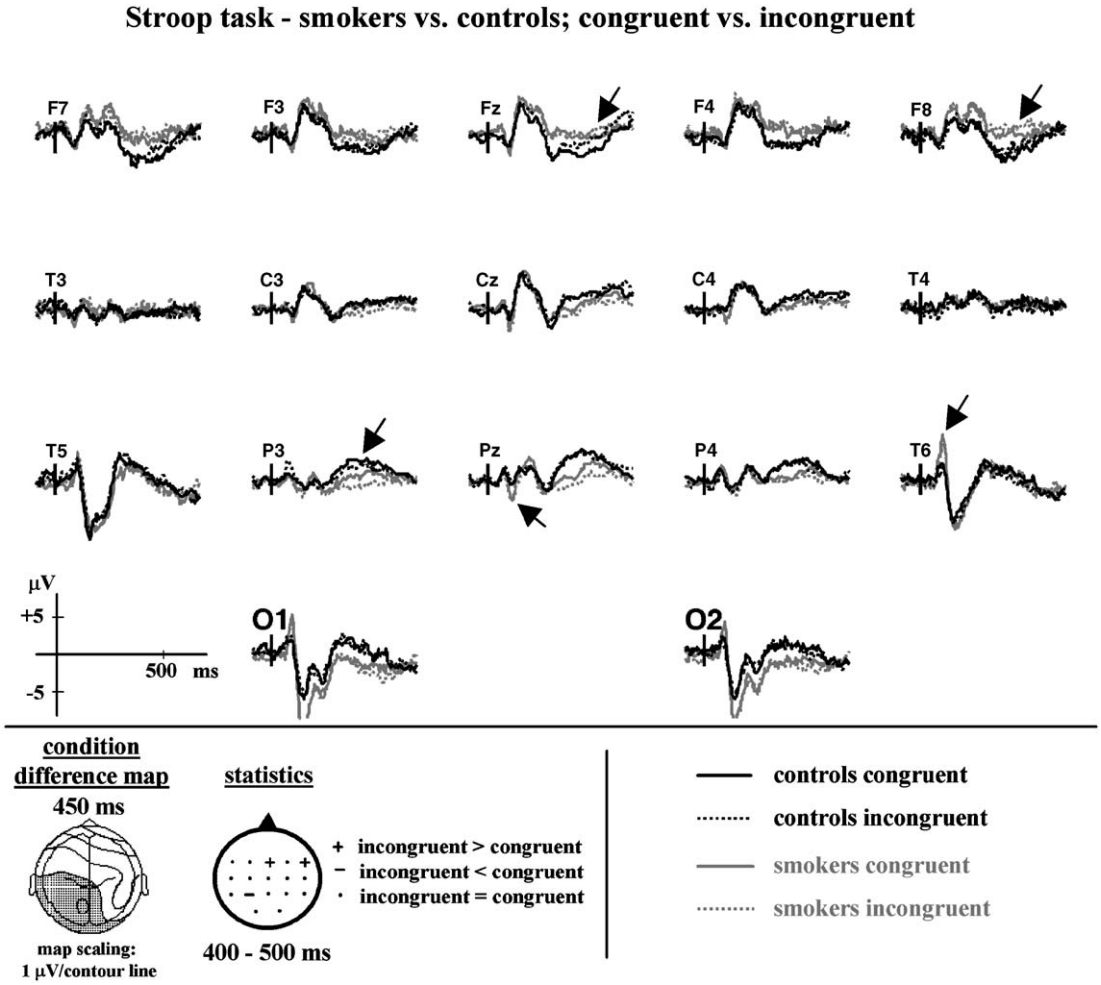


Fig. 6. Upper part: ERPs for all subjects (congruent and incongruent Stroop condition); lower left part: corresponding potential map: top view (450 ms post stimulus); back of the head is below; white areas represent positive and shaded areas negative polarity (average referenced); map scaling: 1 µV/contour line. Difference map=incongruent−congruent condition; lower right part: significant condition differences (post hoc tests for 17 channel positions and one time window (mean amplitude); $p<.05$).

3.2.2. Early ERP differences

Smokers showed a posterior (O1, O2), a posterio-temporal (T5, T6), and a right frontal (F4) relative positivity and a posterio-central (Pz, Cz, C4) negativity elicited by NW between 90 and 110 ms (Fig. 5). Additionally, smokers showed a relative positivity at F8 only for SW, and at T6 for both SW (Fig. 4) and PW (Fig. 3). Furthermore, a relative negativity could be observed at Pz for SW (Fig. 4) and PW, and at T3 for PW only (Fig. 3).

3.2.3. Late ERP differences

Irrespective of the condition, smokers in contrast to controls showed a posterior (O1, O2 and/or Pz) relative negativity and a left frontal (F7) relative positivity between 400 and 500 ms (Figs. 3–5 and Table 1A).

Late ERP condition influences were mainly characterized by a relative negativity over posterior regions and a relative frontal and/or fronto-temporal positivity (left hemispheric for NW and more pronounced at right-hemispheric sites for SW and PW) for smokers compared to controls (see Figs. 3, 4 and 5 for illustration of the statistical details, ERPs and potential maps).

3.2.4. Stroop-task

The Stroop data analyses were based on the EEG data of 25 participants (11 smokers and 14 controls) because too little sweeps were left for averaging in nine subjects. Main ERP effects were tested for 15 channels and three conditions (with uncorrected and Greenhouse-Geisser adjusted p values) and two groups (as independent factor) for mean amplitudes of three time windows (summarized in Table 1B). In contrast to the nicotine Stroop, smokers compared to controls exhibited no different GROUP × CONDITION-related ERP wave forms, but only general GROUP *or* CONDITION differences during the time windows 90–110, 200–250 and 400–500 ms post-stimulus (for details, see Table 1). Post hoc tests were only considered when significant at a 5% level (Fig. 6, lower panel). Between 400 and 500 ms all subjects showed a relative negativity over left posterio-central regions, and a predominantly right frontal relative positivity for the incongruent compared to the congruent condition (see Fig. 6 for details).

Smokers and non-smokers showed significant differences at several channel positions. Around 100 ms after stimulus onset, smokers showed a right posterio-temporal relative positivity and/or a relative negativity at Pz (see Fig. 6). During 400 and 500 ms, smokers showed a broad posterior relative negativity and/or a frontal relative positivity.

4. Discussion

Based on the theoretical framework described in the Introduction, we assumed that nicotine-related words would reduce the performance of color matching in smokers. This hypothesis was not supported by the analysis of the behavioral data. Furthermore, we suggested that in smokers smoking-related word meanings would interfere with color matching, and that this should be reflected in an ERP activation pattern comparable to that induced by the classic Stroop. Indeed, early and late ERP topographies showed condition specific differences between tasks and groups. This implies that in smokers smoking-related words modulate simple color matching processing.

4.1. Early ERP differences in nicotine Stroop and classic Stroop

Around 100 ms post-stimulus (P/N100), smokers showed condition-related topographical differences in contrast to controls. During the neutral words condition, smokers in contrast to controls showed a larger posterio-central negativity (N1) and a posterior, posterio-temporal and right frontal positivity (P1). During the secondary words and the primary words condition these differences were restricted to parietal and right temporal sites. Additionally, smokers showed a relative negativity at left temporal sites for primary words and a relative positivity at right frontal sites for secondary words. Early ERP components have been shown to be generally enhanced in smokers (Crawford et al., 2002). This enhancement has been discussed as a general increased arousal level. In the present study, however, the P/N100 group differences were additionally modulated by word contents. Furthermore, the word contents were idiosyncratically relevant for the smokers. Smoking related words seem to automatically affect early ERP components usually discussed as representing primary information processing. Interestingly, during the classic Stroop task smokers in comparison to controls showed no condition-related group differences, but only a general relative negativity at parietal and a relative positivity at occipital and right temporal electrode sites around 100 ms. This supports the suggestion that group-related P/N100 differences in the nicotine Stroop task might be induced by the content of the presented words. Indeed, one must consider that the Stroop task used in this study is a modified version of the original Stroop task. Furthermore, the trial sequence might have influences on the results and limits the comparability between the different tasks. Words were presented in a non-stationary pseudo-blocked way, whereas Stroop trials were stationary probabilistic, pseudo-randomized distributed over the whole experiment. Additionally, Stroop trials were rarely presented. Rare presentation of stimuli can modulate ERP-effects. As a consequence, the different form of Stroop task presentation must be considered when comparing the different tasks.

4.2. Late ERP differences in nicotine Stroop

Smokers in contrast to controls showed a frontal relative positivity during time windows between 200 and 500 ms (Figs. 3–5). This relative positivity was more prominent at right locations during the color matching of secondary words and more left hemispheric during the neutral word condition (between 400 and 500 ms). SECONDARY WORDs mainly described situations in which a person generally has to act in a goal directed way (e.g. *Kiosk* means to buy something or *station* means to wait for a train and enter it). Thus, the frontal positivity might reflect a preparation process (the task relevant color

matching) and/or a disturbance (addiction memory related action modulation) of goal directed behavior demanded by the task. This interpretation is supported by a study of Markela-Lerenc et al. (2004) who located two active sources, one attributed to the left inferior prefrontal and the other to the right anterior cingulate cortex, explaining a late frontal ERP positivity during the Stroop task. Furthermore, it is consensus that prefrontal regions and the anterior cingulate cortex are involved in goal directed behavior and executive processing (Goldman-Rakic, 1998).

Similar to the ERPs of the SECONDARY WORDs, but during an earlier time window, smokers compared to controls showed an early right frontal positivity between 200 and 250 ms during the primary smoking-related word condition. This may indicate that smokers and non-smoking controls automatically process the stimuli in a different way. Smokers may allocate more attentional resources to the stimuli. Additionally, smokers showed a sustained posterior relative negativity between 100 and 500 ms in comparison to control subjects. Confirmatively, a generally reduced P300 for smokers was reported by Anokhin et al. (2000), and by Ilan and Polich (1999). This relative negativity might reflect an invariable aspect of smoker's physiology associated with information processing, whereas the frontal positivity, which was modulated by the stimuli, might be related to interference resolution processes, induced by words associated with addiction memory (AM) contents.

4.3. Behavioral results versus ERP results

The behavioral data showed no significant differences between smokers and non-smoking controls. This result can be explained by several aspects. First, the basic color-matching task might be too simple in order to induce enough interference resolution demands in smokers. A second explanation might be derived from the hypothesis that smoking enhances or normalizes cognitive performance in smokers (Kumari et al., 2003; Lawrence et al., 2002; Pritchard et al., 1995; and others). Therefore, behavioral differences in the processing of PRIMARY WORDs and SECONDARY WORDs between smokers and controls may be reduced. It has been shown that smoking-related cues activate similar brain regions as during nicotine consumption (Stein et al., 1998). As a consequence, the assumed influence on task performance might be counteracted to some extent by a stimulating effect of the smoking-related word meanings. Additionally, smokers were not deprived and, therefore, disturbing effects of craving should not influence cognitive performance (Newhouse et al., 2004). A third explanation could be derived from the sample characteristics. The smokers in our study were moderate smokers as indicated by the Fagerstroem test (Fagerstroem and Schneider, 1989). Indeed, a smoking history of 11 years and a mean age of 27 years indicates that at least several smokers in our study started smoking in late adolescents or early adulthood. The age of onset with smoking is inversely related to the persistence of smoking behavior as reported by Kandel (2002). Furthermore, Jamner et al. (2003) described the adolescence as a period of novelty seeking and risk taking, impulsivity, enhanced social orientation, and heightened emotionality (see also Spear, 2000) in combination with functional and morphological brain maturation processes. This provides the basis for life long behavioral consequences. Smoking behavior, positive socio-emotional contexts, and reinforcement by the substance itself would provide an effective scenario for the establishment of an addiction memory circuit during early life periods. In consequence, young smokers might show neurophysiological activity patterns modulated by smoking-related stimuli, but only low evidence for substance abuse measured by Fagerstroem-scores.

According to our hypothesis, smokers and controls did not differ in performance during the classic Stroop task, and both groups showed the well established Stroop-effect. Consistent with the EEG literature (Liotti et al., 1999), the ERP topographies of the incongruent condition showed a relative negativity at left centro-posterior electrodes, and a right frontal relative positivity when compared to the congruent condition. In the present study, we argued that in smokers smoking-related word meanings would interfere with color matching, which should be reflected in an ERP activation pattern comparable to that induced by the classic Stroop. For smokers, our data showed a late relative positivity tending towards right frontal regions when word meanings were attributed to smoking-related issues. This data can be interpreted as reflecting a modulation of brain activity in smokers due to smoking-related word contents.

Although some results of this heuristic EEG approach to the neuronal basis of addiction memory in smokers could not be discussed in detail, the central finding of group-related differences demonstrated further evidences for the concept of an addiction memory. This argument is corroborated by ERP topographies, which indicate that nicotine-related word meaning was processed in a similar way as interference resolution processing during the classic Stroop-task. Indeed, spatio-temporal brain dynamics, underlying such complex processes, have further to be investigated in detail by advanced methods as by combined biosignal analysis and imaging studies.

References

Anokhin, A.P., Vedeniapin, A.B., Sirevaag, E.J., Bauer, L.O., O'Connor, S.J., Kuperman, S., Porjesz, B., Reich, T., Begleiter, H., Polich, J., Rohrbaugh, J.W., 2000. The P300 brain potential is reduced in smokers. Psychopharmacology 149, 409–413.

Böning, J., 1994. Warum muβ es ein Suchtgedächtnis geben? Klinische Empirie und neurobiologische Argumente. Sucht 40, 244–252.

Böning, J.A.L., 2001. Neurobiology of an addiction memory. J. Neural Transm. 108, 755–765.

Crawford, H.J., McClain-Furmanski, D., Castagnoli, N.Jr., Castagnoli, K., 2002. Enhancement of auditory sensory gating and stimulus-bound gamma band (40 Hz. oscillations in heavy tobacco smokers. Neurosci. Lett. 317, 151–155.

Cohen, J.D., Dunbar, K., McClelland, J.L., 1990. On the control of automatic processes a parallel distributed processing account for the Stroop effect. Psychol. Rev. 97, 332–361.

Due, D.L., Huettel, S.A., Hall, W.G., Rubin, D.C., 2002. Activation in mesolimbic and visuospatial neural circuits elicited by smoking cues evidence from functional magnetic resonance imaging. Am. J. Psychiatry 159, 954–960.

Fagerstroem, K.O., Schneider, N.G., 1989. Measuring nicotine dependence: a review of the Fagerstroem Tolerance Questionnaire. J. Behav. Med. 12, 159–181.

Franken, I.H., 2003. Drug craving and addiction integrating psychological and neuropsychopharmacological approaches. Prog. Neuro-psychopharmacol Biol. Psychiatry 27, 563–579.

Friston, K.J., 2000. Experimental Design and Statistical Issues. In: Mazziotta, J.C., Toga, A.W. (Eds.), Brain Mapping the Disorders. Academic Press, San Diego, CA, pp. 33–58.

Garrett, A.S., Maddock, R.J., 2001. Time course of the subjective emotional response to aversive pictures relevance to fMRI studies. Psychiatry Res. 108, 39–48.

Goldman-Rakic, P.S., 1998. The prefrontal landscape Implications of functional architecture for understanding human mentation and the central executive. In: Roberts, A.C., Robbins, T.W. (Eds.), The Prefrontal Cortex Executive and Cognitive Functions. New York Oxford Univ. Press, pp. 87–102.

Grüsser, S.M., Heinz, A., Flor, H., 2000. Standardized stimuli to assess drug craving and drug memory in addicts. J. Neural Transm. 107, 715–720.

Haig, A.R., Gordon, E., Hook, S., 1997. To scale or not to scale McCarthy and Wood revisited. Electroencephalogr. Clin. Neurophysiol. 103, 323–325.

Ilan, A.B., Polich, J., 1999. P300 and response time from a manual Stroop task. Clin. Neurophysiol. 110, 367–373.

Jamner, L.D., Whalen, C.K., Loughlin, S.E., Mermelstein, R., Audrain-McGovern, J., Krishnan-Sarin, S., Worden, J.K., Leslie, F.M., 2003. Tobacco use across the formative years a road map to developmental vulnerabilities. Nicotine Tob. Res. 5 (Suppl. 1), 71–87.

Kandel, D.B., 2002. The natural history of smoking and nicotine dependence. Transactions 2002 of The Royal Society of Canada SEVENTH SERIES, vol. II.

Koob, G.F., Le Moal, M., 1997. Drug abuse Hedonic homeostatic dysregulation. Science 278, 52–58.

Koob, G.F., Sanna, P.P., Bloom, F.E., 1998. Neuroscience of addiction. Neuron 21, 467–476.

Kumari, V., Gray, J.A., Fytche, D.H., Mitterschiffthaler, M.T., Das, M., Zachariah, E., Vythelingum, G.N., Williams, S.C., Simmons, A., Sharma, T., 2003. Cognitive effects of nicotine in humans an fMRI study. NeuroImage 19, 1002–1013.

Lawrence, N.S., Ross, T.J., Stein, E.A., 2002. Cognitive mechanisms of nicotine on visual attention. Neuron 36, 539–548.

Liotti, M., Woldorff, M.G., Perez III, R., Mayberg, H.S., 1999. An ERP study of the temporal course of the Stroop color–word interference effect. Neuropsychologia 38, 700–711.

Lusher, J., Chandler, C., Ball, D., 2004. Alcohol dependence and the alcohol Stroop paradigm evidence and issues. Drug Alcohol Depend. 75, 225–231.

McCuskers, C.G., Gettings, B., 1997. Automaticity of cognitive biases in addictive behaviours further evidence with gamblers. Br. J. Clin. Psychol. 36, 543–554.

MacLeod, C.M., MacDonald, P.A., 2000. Interdimensional interference in the Stroop effect: uncovering the cognitive and neural anatomy of attention. Trends Cogn. Sci. 4, 383–391.

Markela-Lerenc, J., Ille, N., Kaiser, S., Fiedler, P., Mundt, C., Weisbrod, M., 2004. Prefrontal–cingulate activation during executive control: which comes first? Cogn. Brain Res. 18, 278–287.

Mattia, J.I., Heimberg, R.G., Hope, D.A., 1993. The revised Stroop colour-naming task in social phobics. Behav. Res. Ther. 31, 305–313.

Nestler, E.J., Aghajanian, G.K., 1997. Molecular and cellular basis of addiction. Science 278, 58–63.

Newhouse, P.A., Potter, A., Singh, A., 2004. Effects of nicotinic stimulation on cognitive performance. Curr. Opin. Pharmacol. 4, 36–46.

Oldfield, R., 1971. The assessment and analysis of handedness. The Edinburgh Inventory. Neuropsychologia 9, 97–113.

Pritchard, W.S., Robinson, J.H., deBethizy, J.D., Davis, R.A., Stiles, M.F., 1995. Caffeine and smoking subjective, performance, and psychophysiological effects. Psychophysiology 32, 19–27.

Spear, L.P., 2000. The adolescent brain and age-related behavioral manifestations. Neurosci. Biobehav. Rev. 24, 417–463.

Stein, E.A., Pankiewicz, J., Harsch, H.H., Cho, J.K., Fuller, S.A., Hoffmann, R. G., Hawkins, M., Rao, S.M., Bandettini, P.A., Bloom, A.S., 1998. Nicotine-induced limbic cortical activation in the human brain: a functional MRI study. Am. J. Psychiatry 155, 1009–1015.

Stetter, F., Ackermann, K., Chaluppa, C., Straube, E.R., Mann, K., 1994. Experimentelle Hinweise auf ein alkoholbezogenes semantisches Netzwerk. -Eine kontrollierte Verlaufsuntersuchung mit dem Stroop-und Alkohol-Stroop-Test bei Alkoholpatienten. Sucht 40, 171–185.

Stroop, J.R., 1935. Studies of interference in serial verbal reactions. J. Exp. Psychol. 18, 643–662.

Urbach, T.P., Kutas, M., 2002. The intractability of scaling scalp distributions to infer neuroelectric sources. Psychophysiology 39, 791–808.

Warren, C.A., McDonough, B.E., 1999. Event-related brain potentials as indicators of smoking cue-reactivity. Clin. Neurophysiol. 110, 1570–1584.

Watts, F.N., Trezise, L., Sharrock, R., 1986. Colour naming of phobia-related words. Br. J. Psychol. 77, 97–108.

Williams, J.M.G., Mathews, A., MacLeod, C., 1996. The emotional Stroop task and psychopathology. Psychol. Bull. 120, 3–24.

Wilson, S.J., Sayette, M.A., Fiez, J.A., 2004. Prefrontal responses to drug cues a neurocognitive analysis. Nat. Neurosci. 7, 211–214.

Wolffgramm, J., 1995. Abhängigkeitsentwicklung im Tiermodell. Zeitschr. Klin. Psychol. 24, 107–117.

Wolffgramm, J., Heyne, A., 1995. From controlled drug intake to loss of control irreversible development of drug addiction in the rat. Behav. Brain Res. 70, 77–94.