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Smoking addiction: the shift from head to hands: Approach bias towards smoking-related cues in low-dependent versus dependent smokers

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Abstract

The dual process theory is central to several models of addiction, implying both an increase of stimulus salience and deficits in inhibitory control. Our major aim is to provide behavioral evidence for an approach bias tendency in smokers and more specifically during smoking cue exposure. The second aim is to examine whether this bias differs in low-dependent versus dependent smokers.

Thirty-two smokers (17 low dependent and 15 dependent; cut-off FTND of 4) and 28 non-smokers performed a modified Go/NoGo task using tobacco-related words and neutral words as stimuli.

Smokers generally made more mistakes and tended to be faster for smoking-related cues specifically. Low dependents acknowledged more their dependency in declarative questionnaires while making more errors and being slower specifically on smoking cues; dependent smokers were less prone to indicate their addiction, but were faster and accurate when it came to picking the smoking cues.

These results suggest that a shift has operated from a mental preoccupation with smoking in the low-dependent group, to smoking as a motor habit in our dependent group. This finding invites experts to rethink smoking addiction in the light of this crucial moment, namely, the shift "from head to hands".

Keywords

Approach bias, attention, Go/NoGo task, incentive salience, smoking addiction

Introduction

Tobacco smoking is one of the most common health-impairing behaviors, which seems to persist, despite the awareness of its negative consequences on health and intensive prevention and treatment efforts (Le Faou and Scemama, 2005). Indeed, tobacco seems to be the most addictive substance among addictive drugs (32% of users become dependent; Inserm, 2015) and a smoker dies, on average, 15 years earlier than a non-smoker (US Department of Health and Human Services, 2010).

On a cognitive level, addiction is generally considered as an imbalance between two systems, which are both (indirectly) mediated by dopaminergic systems and smoking addiction does not break the rule (Bassareo and Di Chiara, 1999; Pontieri et al., 1995; Stacy and Wiers, 2010; Tanda et al., 1997). Several models refer to this dual-process theory as a global explanation for addiction including its development, maintenance, and relapse (Goldstein and Volkow, 2002; Kornreich, et al., 2012; Kreusch et al., 2013; Noël et al., 2010; Robinson and Berridge, 1993; Wiers et al., 2007). Indeed, among the strongest clinical evidence for addiction is both the reactivity towards addiction-related stimuli at the one hand, and the inability to refrain from their approach at the other.

This perspective thus conceives addiction as mainly dependent on this double process, implying automatic bottom-up activities characterized (a) by an increase of the stimulus salience which is going "to grasp" the attention in an involuntary way (once this system is sensitized, it leads to repeated behaviors towards the object of consumption) and (b) by a lack of resources for the executive inhibition of a dominant drug behavioral response.

In the present study, we will focus on the first process (the bottom-up activities) which can be associated to the concept of "wanting" or to the incentive salience theory (IST) proposed by Robinson and Berridge (2003; Nestor et al., 2011). Nevertheless, it has to be noted that, whereas those two systems are (partially) structurally and functionally distinct (Wiers et al., 2007), on a behavioral level, they are hard to disentangle: disinhibition

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towards salient cues can either be due to inhibition impairment or to an approach bias related to the concept of "wanting". "Wanting" is defined as the amount of energy an organism is ready to invest in order to obtain a reward and reflects the activation degree of the dopaminergic systems mediating the addictive behavior. Unfortunately, this definition is well operationalized in animal models, but is more difficult to directly translate in human beings. Even if the concept includes an individual's need to use drugs as well as instrumental drug-seeking and -taking behaviors, to the best of our knowledge, Robinson and Berridge never exactly indicated which type of behavioral effect defines "wanting" in humans.

Tibboel et al. (2015; Robinson and Berridge, 2000) consider "wanting" as a *preconscious* process which, by definition, cannot be recorded with an explicit measure. Therefore, measures of automatic attitudes, which are supposed to capture "wanting" as automatic processes, are most often used to that purpose (Tibboel et al., 2015; Wiers et al., 2002). The most commonly used paradigms are the Implicit Association Test (IAT) and the Approach Avoidance Tasks (AAT). In the IAT, the strength of associations between concepts and evaluations (or attributes) are measured. The main idea is that making a response is easier when closely related items share the same response key. The reactions times (RTs) and number of errors for word categories which are congruent versus incongruent with implicit reaction tendencies are indicative of these tendencies (Tibboel et al., 2015). Taken together, the results with the IAT support the theory that cigarette-related cues are processed in a relatively automatic way (Mogg et al., 2003; Tibboel et al., 2011; Wiers et al., 2013), as is the case for other substances (e.g. alcohol; Field et al., 2009). However, these authors also report results, which are in apparent contradiction with IST (Tibboel et al., 2015; Watson et al., 2013; Wiers et al., 2013; for details, see Discussion). Also, it remains unclear to which extent these tasks really tag automatic processes as they do imply minimal cognitive control (Mogg et al., 2005). Therefore, in the present study, we propose to shift the paradigm to direct measures of motor mobilization linked to the addictive cue, which are probably closer to the original significance of the "wanting" concept. Indeed, given that smoking is a highly rewarding motor skill and smokers show activation in action-related brain areas while watching smoking cues (Wagner et al., 2011), it is surprising that only a few studies have been conducted on automatic action tendencies for smoking cues in cigarette smokers (Fleming and Bartholow, 2014). Targeting the *oculomotor* mobilization (as in visual probe tasks) might also put the focus on attentional processes (Mogg et al., 2003). This might be more proximal to evaluative mental events than to the motor event directly involved in obtaining the incentive, as is the locomotor activity of the rats (Robinson et al., 2005). For example, a visual probe task measuring early attentional shifts at the gaze level also delivers inconsistent results. Some studies suggest that the attentional bias is larger in more frequent, heavy smokers (e.g. Mogg and Bradley, 2002; Zack et al., 2001), whereas in others that was either not the case (e.g. Munafo et al., 2003; Waters and Feyerabend, 2000; Waters et al., 2003a) or the reverse was true, and a larger attentional bias has been found in lighter smokers (Bradley et al., 2004, Experiment 1; Waters et al., 2003b). Therefore, we decided to focus on *hand* motor mobilization, which on one hand is closer to the locomotor activity measured in mice in the Berridgean paradigm, and on the other is less linked to cognitive deliberation, and therefore more prone to automatization. For all these reasons, in the present study, we used a modified Go/NoGo task in which smoking cues were used as target Go and NoGo cues. Such a task has already shown promising results with other addictions (e.g. alcohol, Kreusch et al., 2013), but was never applied, to our knowledge, to a smoker population.

Accordingly, the first aim of the present study is to clarify whether "wanting" operates in the same way in smokers as it does in other addictions by using a paradigm specifically focusing on approach bias. Indeed, although the classic Go/NoGo task measures response inhibition, recent research has proposed a modified Go/NoGo task as a measure of the approach bias (Kreusch et al., 2013). In this modified Go/NoGo task, non-problem versus problem drinkers had to press a button on a target presentation when the target-word was alcohol-related in the experimental condition and upon neutral words in the control condition. For smoking addiction, we propose to measure the approach bias for pressing the button upon a cigarette-related word as compared to a control word. This could be a better measure of "wanting" (Robinson and Berridge, 1993) or incentive salience (see Kreusch et al., 2013) as the smoking-related words are incentive stimuli. According to Berridge (2001), they are "motivational magnets" by their virtue of eliciting approach actions and consummatory behaviors. Thus, we expect a stronger approach bias specifically for smoking cues in smokers, as evidenced either by shorter reaction times for cigarette Go-stimuli and/or by a higher percentage of commission errors (False Alarms errors: FA) for cigarette NoGo-stimuli.

The second aim will be to investigate whether the dependence status of the smokers influences this approach bias or "wanting". Indeed, even if nicotine has a massive impact on neuronal receptors (Henningfield et al., 2009), to explain and predict societally important outcomes, such as an inability to quit smoking, heavy use, and other problems due to smoking or tobacco use it may be that dependence is a better predictor than simple measures of number of cigarettes smoked or blood levels of nicotine (IARC, 2008; Piper et al., 2006; US Department of Health and Human Services, 2014). Dependence, in this approach, is a *psychological* construct, which is only partially based on physiological indications (e.g. number of cigarettes smoked a day) and also weighs heavily upon behaviors, judgments and decisions of the smoker (e.g. if one decides to continue smoking when ill; Fagerström and Schneider, 1989). This type of psychological distinction is not obvious since literature tends to consider smokers as dependent according to the law of all or nothing (if one smokes, he is an addict). Alternatively, the discriminative criteria between low and high dependency are not sensitive enough and light smokers rarely reach the criteria for dependency, as the quantity of cigarettes consumed are considered as simply too low (e.g. Mueller et al., 2012; Piper et al., 2006). In other words, there has rarely been a differentiation within the smokers group on the basis of their level of psychological dependence – even if authors typically concluded by advising to do so in further research (Machulska et al., 2015; Thewissen et al., 2007).

Furthermore, growing evidence shows that acute consumption of a drug reinforces not only the strong motivational properties of an addiction-related cue (incentive salience) and the diminution of inhibition abilities, but also that the level of practice leads to a certain degree of automaticity (Field et al., 2009; Noël et al.,

Table 1. Group characteristics (means ± SD) and behavioral data.

	Non-smokers	Smokers		
	n = 28	Total group	Low dependent	Dependent
		n = 32	*n* = 17	*n* = 15
Age (years)	30.2 ± 9.7	31.3 ± 9.9	28.8 ± 7.3	34.1 ± 11.8
Gender (% female)	86	47[a]	47[b,c]	93
MCSD	9.6 ± 2.4	9.4 ± 2.5	9.1 ± 2.2	9.8 ± 3
Minutes without smoking	/	294.1 ± 278.9	220 ± 190[b]	385 ± 145
#cigarettes/day	/	11.5 ± 5.8	12.0 ± 4.0	10.8 ± 7.2
FTND	/	4.3 ± 1.9	2.8 ± 0.8[b]	6.0 ± 1.1
TQSU	/	59.5 ± 20.2	65.6 ± 16.7[b]	52.5 ± 22.0
UPPS	78.6 ± 12.1	92.8 ± 12.3[a]	98.1 ± 9,5[b,c]	87.7 ± 13.6[c]
r(MCSD)	n.s.	n.s.	0.56 ($p < 0.05$)	n.s.
Precraving	/	41.9 (29.9)	54 ± 16[b]	28 ± 31
r(MCSD)	/	n.s.	n.s.	n.s.
Postcraving	/	59 (27)	74 ± 18[b]	42 ± 26
r(MCSD)	/	n.s.	0.55 ($p < 0.05$)	n.s.
Mean of RT Go Smoke (ms)	438 ± 27	413 ± 82	430 ± 25[b]	395 ± 116[b]
r(FA Go Smoke)	n.s.	n.s.	−0.68 ($p < 0.05$)	n.s.
%False Alarm Go Smoke	15 ± 17	23 ± 21	26 ± 25	20 ± 18
Mean of RT Go Neutral (ms)	433 ± 24	421 ± 42	414 ± 40[b,c]	429 ± 26
r(FA Go Neutral)	−0.39 ($p < 0.05$)	n.s.	−0.69 ($p < 0.05$)	n.s.
%False Alarm Go Neutral	20 ± 15	29[b] ± 18	33 ± 18[c]	26 ± 19

[a]Significantly different from non-smokers at $p < 0.05$.
[b,c]Significantly different from dependent smokers, resp. non-smokers at $p < 0.05$.
n.s. non-significant.

2007). Recent neurophysiological research has even shown that the striatum, known to be of crucial interest regarding addiction, is much more complex than previously thought. The ventral striatum would generate new behaviors learning and consequence-oriented behavior, whereas the dorsal striatum would be responsible for the development of habits (recent data even show that the density of neurons in this region would be correlated to motor stereotypy; Canales and Graybiel, 2000) and a temporal switch can be seen in individuals who consume a drug to individuals who abuse of the drug (Everitt and Robbins, 2005; Yin and Knowlton, 2007). This switch transition from habit learning to automatic associations will be investigated in our two smoker groups: we hypothesize that the dependent smokers group will manifest more automatic behavior towards smoking-related cues than the low-dependent group.

To summarize, the aim of the present study is two-fold: first, to test the prediction that smokers will generally show an approach tendency toward smoking-related cues (measured by both shorter reaction times on Go-Smoke stimuli and by more commission errors on NoGo-Smoke stimuli) and, second, to explore potential differences in the processing of smoking-related cues between low-dependent and dependent smokers.

Method

Participants

Sixty participants (mean age = 30.8 ± 9.7 see Table 1 for demographic data) were recruited via the hospital where the experiment was located (CHU Brugmann), by way of email, through personal contacts and by announcements on social networks. Through a brief phone screening, major medical problems, as well as past or current drug consumption (other than moderate alcohol and cigarette) were excluded. Smokers were urged to an abstinence of 2 h prior to the experiment to avoid floor or ceiling effects of the urge to smoke during the task (Thewissen et al., 2007). Non-smokers never smoked in the past (10 cigarettes in the whole life was the maximum allowed). Both groups are similar concerning their age and level of education, but there are significantly less women in the smokers group. The local ethics committee of the Brugmann Hospital approved the study.

Measures

Personality and behavioral questionnaires

Fagerström Test for Nicotine Dependence (FTND) and Tiffany Questionnaire for Smoking Urges (TQSU). The FTND is a six-item questionnaire (with different response types, most of them either binary or four-way), which is a widely used, reliable, and valid (Etter, 2005; Etter and Perneger, 1999; IARC, 2008; Kozlowski et al., 1994; Piper et al., 2006) self-report measure aimed to capture the degree of nicotine dependence. Nevertheless, when focusing on each item of the questionnaire, five of them are behavioral measures (e.g. how long do you wait for your first cigarettes, would you smoke when ill, in places where it is prohibited etc.). Fagerström (Heatherton et al., 1991: 1120)

himself considers the "time to the first cigarette"-item also as a predictor of biochemical measures, and thus, depending on the weight accorded to this question as a physiological versus a behavioral parameter, one might say that at least half of the weight of a result on an FTND questionnaire is given by psychological rather than by direct physiological parameters. Accordingly, in the present research, we have divided our smoker population in two groups of respectively *low-dependent* (score from 1 to 4) and *dependent* smokers (scores of 5 or more) on the basis of their results on the FTND and the standardized nomenclature (Heatherton et al., 1991; Pomerleau et al., 1989). The TQSU is a 12-item questionnaire (with responses on a 7-point Likert scale) as a classic self-report measure of craving (e.g. "I have a desire for a cigarette right now"; "Smoking would make me less depressed").

The Urgency Premeditation Perseverance and Sensation seeking impulsive behavior scale (UPPS). The UPPS (Whiteside and Lynam, 2003) is a well-validated and frequently used self-report questionnaire, composed of 45 items (with responses on a 7-point Likert scale), which describes the difficulty to restrain general behavioral reactions in situations that elicit strong emotion (*Urgency*), the difficulty to anticipate expected situations (lack of *Premeditation*), the difficulty to sustain prolonged activity (lack of *Perseverance*), and the tendency to search for new emotionally arousing situations (*Sensation seeking*; Cirilli et al., 2011). If both the FTND and the TQSU are quick assessments with acceptable psychometric properties of smoking behavior, the UPPS is an elaborate measure of general impulsivity, which thoroughly investigates its different facets and might therefore be more sensitive to how people represent themselves. Links between tobacco dependency and UPPS have been consistently demonstrated (Mitchell, 1999, 2004; Reynolds et al., 2007).

The Marlowe-Crowne Social Desirability scale (MCSD). As we wished to give specific importance to the measurement of psychological parameters, we have also included the MCSD (Crowne and Marlowe, 1960). It is a 33-question scale (with dichotomic responses), which was largely validated (Evans, 1982; Johnson et al., 2012; Sârbescu et al., 2012). A high score corresponds to a tendency to conform in a socially desirable way, i.e. to show a behavior, which is thought to conform more to the social expectations, or the expectations of the situation (e.g. "I never hesitate to go out of my way to help someone in trouble"). As the social context of the present research is an explicit invitation based upon the smoking behavior, the wish to be "socially desirable", then, would imply a readiness to speak about, as well as to acknowledge, the proper smoking behavior and dependency as well as the symptoms linked to it.

Go/NoGo modified for smoking. Approach bias toward cigarette cues was recorded through a modified version of the classical Go/NoGo task. The modification involved the use of cigarette-related and neutral words to specifically test approach tendencies and inhibition capacities toward cigarette-related cues. In this task, four blocks, each including 20 words (15 Go-words, 5 NoGo-words), were presented in a counterbalanced order successively to the participants.

The words were selected through an unpublished pilot study. Twenty-five people (age: 37; SD: ±13.78) were asked to report all the words related to tobacco in an online survey (Limesurvey). In total, 478 words were proposed and, after weighing the redundancies, 134 were left. From these, 40 were selected with the following criteria: (a) words were one or two syllables long, (b) they had a high frequency of occurrence, (c) ambiguous words were eliminated. This selection was then proposed to 50 new participants (age: 32.28; SD: 11.29) who had to rate the words both on their tobacco-relatedness and on their emotional level (with the pleasantness and arousal scales of the Self-Assessment Manikin, SAM; Bradley and Lang, 1994). This led to the final selection of 20 words, which were both highly related to cigarettes and least emotional. Neutral stimuli were matched for length and familiarity. The words were presented in the center of the screen during 500 milliseconds (ms) with an inter-stimulus interval of 1000 ms.

Participants had to respond when a Go stimulus was presented (Go trial) and to refrain from responding when a NoGo stimulus was presented (NoGo trial). A Go trial could either be composed of (a) 15 neutral words and five smoking-related words (Go Neutral) or (b) 15 smoking-related words and five neutral words (Go Smoke). Before the start of each block, an instruction indicated which type of stimulus was the Go stimulus. When a Go stimulus was presented, participants had to press the space bar of a keyboard as fast and accurately as possible. The pictures were presented in the center of the screen during 500 ms, with an inter-stimulus interval of 1000 ms and the image disappeared either after 500 ms or after the subject response. Participants first completed one trial block, which was similar to the test blocks (20 trials). The whole task took approximately 8 min and was performed with E-Prime software (Psychology software tools, Inc.).

Design and procedure

Participants were tested one by one in a quiet room from the Brugmann Hospital. They signed a consent form and completed a pretest subjective craving (only smokers): participants self-reported their craving of a cigarette by answering in % to the question "how much do you want to have a cigarette right now?". This was followed by the modified Go/NoGo task, the rest of the questionnaires implying an identical posttest craving, FTND, TQSU (only smokers) as well as UPPS and MCSD (all participants) and a debriefing.

Data analysis

Task performance was analyzed twice (depending of the fact we were investigating the differences between (a) no smokers and smokers or (b) no smokers, low-dependent smokers, and dependent smokers) following the same analytical structure depending on the group and type of stimulus. Dependent variables of the study were the mean reaction times (RTs) on Go trials and the percentages of FA, defined as a response on a NoGo trial, on which the participant was instructed to refrain from responding. Participant reaction times on Go trials and percentages of FA were analyzed with 2 (word type) × 2/3 (group) mixed analyses of variance (ANOVA). These ANOVAs used group as between-subject variable and word stimulus as within-subject variables. A multiple linear regression was finally conducted in order to examine the contribution of the main dependent variables in the definition of the groups. All the statistical analyses were performed using the software package SPSS 23 (IBM, Microsoft).

Results

Table 1 summarizes the demographic and behavioral differences between the smokers, non-smokers, and the subgroups of smokers: low and dependent smokers (see also further, Figures 1-4).

Smokers versus non-smokers

Concerning the reaction times on Go trials, there was no group effect (smokers vs non-smokers) on mean RTs for Go trials nor was there an interaction effect between groups and context (Go Smoke or Go Neutral). Nevertheless, the inter-subject effects revealed a marginal significance depending on the group ($F(1, 58) = 3.5$; $p = 0.07$) with smokers tending to be faster than the control group independently of context (see also Figure 1). Concerning the FA errors on the NoGo trials, the ANOVA on the percentage FA revealed a significant main effect of the stimulus ($F(1, 58) = 7$; $p < 0.05$), both groups making more errors in the NoGo Smoke (this is the Go Neutral) context. In addition, a significant main effect for the group was found ($F(1, 58) = 4.7$ $p < 0.05$) with smokers making more errors whatever the condition. The interaction between group and condition was not statistically significant (see also Figure 3). A mean comparison between groups also revealed a significant difference for the FA in the Go Neutral (NoGo Smoke) with smokers making more errors when they have to refrain themselves from pressing while seeing cigarettes-related words.

In addition, there is a significant difference for the UPPS $t(58) = -4.48$ $p < 0.001$) with the non-smokers scoring at 78.6 ± 12.1, whereas smokers score at 92.8 ± 12.3.

Non-smokers, low-dependent and dependent smokers

Group demographic characteristics. Our smokers group was divided into two groups (based on the FTND cut-off <4: low dependency; 4 or more: dependency), with no difference regarding the quantity of cigarettes smoked per day. Interestingly, when we focus on the FTND items, we note that only three questions significantly differ between the two groups, namely: "Do you find it difficult to refrain from smoking in forbidden places?" ($t(30) = -2.7$; $p < 0.05$); "Do you smoke even if you are sick in bed?" ($t(30) = -2.74$; $p < 0.05$); "Do you smoke more frequently in the morning?" ($t(30) = -4.68$; $p < 0.05$). It is interesting to note that the items are not physiological measures. There are significantly less women in the low-dependent group than in the dependent or in the non-smokers group.

Personality and declarative behavior characteristics. Counterintuitively, UPPS scores in both dependent smokers and non-smokers are significantly lower than in low-dependent smokers [$t(30) = 2.31$; $p < 0.05$; $t(41) = -2.26$; $p < 0.05$] (see Table 1). Likewise, low-dependent smokers reported substantially less time without smoking before the experiment ($p < 0.05$) and had higher TQSU-scores ($t(30) = 1.9$; $p < 0.05$). In line with this, they reported higher craving prior to the experiment (precraving: $t(30) = 2.79$; $p < 0.001$) as well as after the task (postcraving: $t(30) = 4.14$; $p < 0.001$) compared to dependent smokers. Finally, only in low dependents had the craving scores increased between pre- and post-experiment measures ($t(16) = -3.32$; $p < 0.05$). Pearson

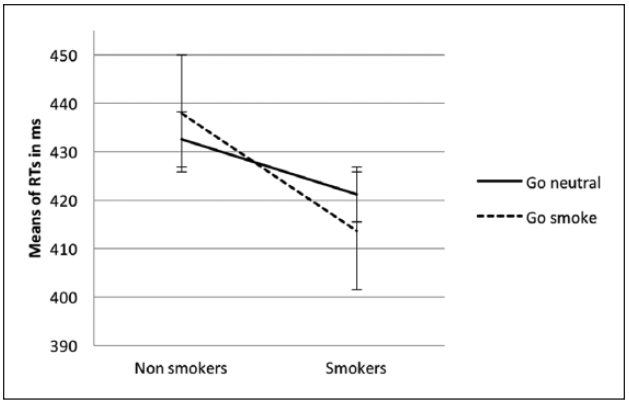

Figure 1. Reaction times means as a function of the group. Comparison of smokers with non-smokers in both the Go Neutral and Go Smoke conditions.

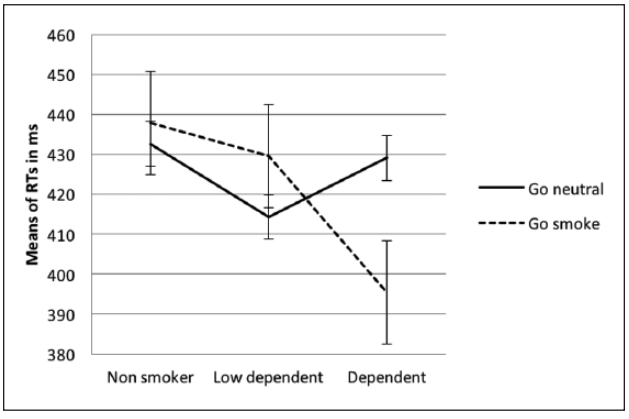

Figure 2. Reaction times means as a function of the group. Comparison of the three groups (0 = control; 1 = low-dependent smokers; 2 = dependent smokers) in both the Go Neutral and Go Smoke conditions.

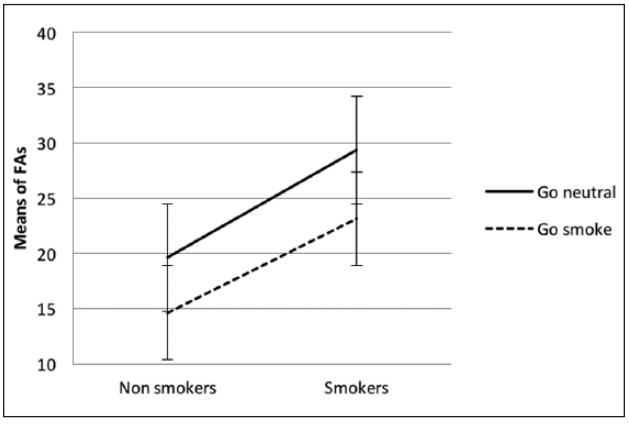

Figure 3. False alarms means as a function of the group. Comparison of smokers with non-smokers.

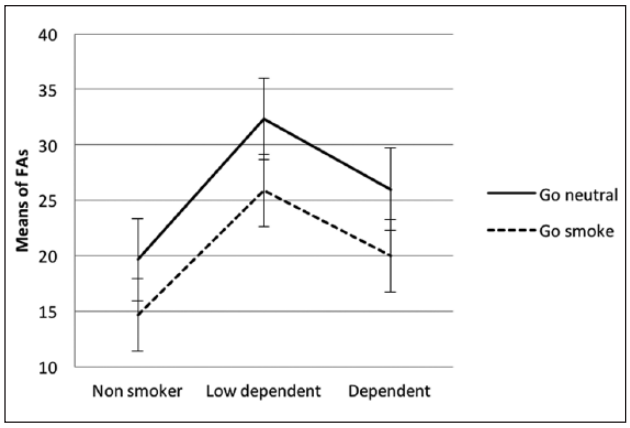

Figure 4. False alarms means as a function of the group. Comparison of the three groups (0 = control; 1 = low-dependent smokers; 2 = dependent smokers) in both the Go Neutral and Go Smoke conditions.

correlations were used to test correlations between MCSD and TQSU, UPPS and craving scores. Interestingly, MCSD correlated positively both with post-craving ($r = 0.55$; $p < 0.05$) and UPPS ($r = 0.56$; $p < 0.05$) in low-dependent smokers, whereas no correlation was found in dependent smokers. Note that correlations between MCSD and TQSU were not significant (nor between MCSD and FTND).

Hand motor behavior characteristics. Concerning the Go reaction times, the main effect of the group on mean RTs was not statistically significant. However, the interaction between group and condition was marginally significant ($F(2, 57) = 2.77$; $p = 0.07$). Dependent smokers were the fastest in the Go smoke (i.e. in the NoGo Neutral) trials, whereas low-dependent smokers and control participants behaved similarly (see Table 1 and Figure 2).

Concerning the FA errors on the NoGo trials, the ANOVA on percentage commission errors (or FA) revealed a marginally significant main group effect ($F(2, 57) = 2.92$; $p = 0.06$): low-dependent smokers made most FA and control participants least, independent of condition. In addition, a significant main effect for the word type was found ($F(1, 57) = 6.9$; $p = 0.01$) with the three groups making more commission errors for smoke cues in the Go Neutral (i.e. NoGo Smoke) condition. The interaction between group and condition was not statistically significant.

Interestingly, RTs and FA for smoke cues in the Go Neutral (i.e. NoGo Smoke) condition were correlated (the faster they were, the more errors they made) both in non-smokers ($r = -0.39$; $p < 0.05$) and in low-dependent smokers ($r = -0.69$; $p < 0.05$) but not in dependent smokers (see Table 1 and Figure 4). Low-dependent smokers also had their RT and FA scores negatively correlated in the Go Smoke (NoGo Neutral) condition. Note that we have also checked the correlations of these (hand) motor results with the MCSD, but no correlations were found.

Predictability of the motor hand behavior characteristics for the dependency group. In order to examine the contribution of the difference between FA and RT rates in the definition of our three groups (non-smokers, low-dependent smokers and dependent smokers), which were originally based on the FTND cut-off, we conducted multiple linear regression analysis with the age, the FAs for Go Smoke and Go Neutral and RTs for Go Smoke and Go Neutral as predictors. Interestingly, only the Go Smoke RT was marginally significant ($\beta = -0.24$; $t(8) = -1.81$, $p = 0.07$), which means that RT for the Go Smoke condition tend to predict the belonging group (non-smokers, low-dependent smokers or dependent smokers).

Discussion

The first aim of this study was to test the hypothesis that smokers would show an approach tendency towards smoking-related cues in a modified Go-NoGo task. As expected, the smokers generally make more mistakes, whatever the condition (neutral words as cues or smoking-related words as cues) and, specifically, tend to be faster for smoking-related cues. However, contrary to our expectations, there were no differences between groups concerning the FA errors rate in the NoGo Smoke (i.e. the Go Neutral) context. The present results show a significant approach tendency in the treatment of cigarettes cues relative to control stimuli in all participants, including non-smokers. This cognitive bias may be interpreted as an approach tendency due to the fact that smoking-related cues are more easily recognized as they constitute our daily environment, whether one smokes or not, and as the cues belonged to only one semantic category contrary to the neutral cues. Nevertheless, two results are as expected: (a) simple comparisons revealed a significant difference for the FA in the Go Neutral (NoGo Smoke) with smokers making more errors when they have to refrain themselves from pressing upon seeing cigarette-related words and (b) the UPPS scores were significantly different between groups with smokers declaring themselves more impulsive than the control group. In other words, the Kreusch et al. (2013) paradigm, verified with alcohol-dependent individuals, gives results in the expected direction transposed to a nicotine-dependent population, although, disappointingly, results generally remain marginally significant.

The second aim was to explore differences between low- and high-dependent smokers, in order to develop higher sensitivity and accuracy when describing the wide and heterogeneous group of smokers.

Our results show that low-dependent smokers have higher scores for all declarative questionnaires by which they have to position themselves in reference to their addiction: indeed, surprisingly, they consistently declare higher (pre- and post-) craving and they have higher UPSS and higher TQSU scores than dependent smokers. At face value, these elements would be more indicative of high dependency; however, their motor scores betray that this is not the case. Interestingly, their MCSD scores correlate positively with their post-craving as well as with their UPPS scores and this was *not* the case for the dependent smokers. As indicated, the MCSD measures social desirability, which can be defined as the need to obtain approval by answering in a socially appropriate and accepted way (Crowne and Marlowe, 1960). The logic behind the development of its items was based on the assumption that a person cannot always behave in a socially desirable manner. The items thus assess daily personal or interpersonal behaviors that are either desirable but not frequent (e.g. "I never hesitate to go out of my way to help someone in trouble"), or conversely, socially disapproved but likely (e.g.: "It is sometimes hard for me to go on with my work if I am not encouraged"). Thus, the more the participant acknowledges

respectively denies these behaviors, the more he is thought to act in a socially desired way. As a reminder, there is no difference between the two smoker groups regarding their absolute MCSD scores as such, which means that the correlations we find are not due to a group effect: low-dependent smokers are not more inclined towards socially desirable behavior *in general* than dependent smokers. But, when it comes to what they say about their smoking behavior specifically, the correlational results show that the low-dependent declarations are sensitive to a concern with social desirability, whereas there is no social desirability sensitivity whatsoever in the declarations of the dependent smokers concerning their smoking behavior. Therefore, one way to interpret these two series of findings together is that, possibly, these low-dependent smokers manage their impression on their smoking behavior by behaving as they think we expect them to do. They volunteered to participate to this research on the basis of an ad which was entitled 'Addiction and Language' and the information on the experiment clearly declared that "the focus of the study addresses the nicotine dependency symptoms and the way one speaks about it". Accordingly, the MCSD-correlation betrays that our low-dependent smokers group readily self-report to be significantly addicted as the experimental set-up expects.

In contrast, so-called dependent smokers, have lower (pre- and post-) craving scores, lower TQSU and UPPS scores than low-dependent smokers, they indicate that they could abstain smoking for a longer time before the experiment and, even if the difference was not significant, also reported lower absolute numbers of cigarettes smoked a day. Why, then, do we persist in thinking that, in accord with the results on the FTND, the first group is the "low dependent" and the second the (really) "dependent" group? Would all results not find an expected interpretation by merely switching around the labels – and to heck with the FTND…? As said, another group of results, however, confirm the FTND-distinctions, namely those concerning the hand motor approach behavior. Indeed, they show that the dependent smokers make less FA than low-dependent smokers in the Go Neutral condition and are the quickest in the Go Smoke condition. Also, there is no correlation whatsoever between their RTs and FAs: going quicker does not make their hands less sure. The low-dependent participants, on the contrary, make more FAs generally and even more commission errors with NoGo Smoke (Go Neutral) stimuli. Also, they are slower than the dependent group when they have to press the keyboard upon seeing tobacco-related stimuli (Go Smoke condition). Finally, their RTs and FAs score correlate negatively. In other words, the faster they are, the more mistakes they make: this is a logical bias linked to the fact that people tend to make more mistakes when they want to be fast, when prompted to do so. Unlike their declarative results, which show their eagerness to indicate their smoking behavior, the hand motor approach behavior of the low-dependent smokers is substantially slower and more error prone as compared to dependent smokers. In summary, our dependent group has fast hands and sure moves in picking their objects of dependence, whereas the low-dependent participants were slower and clumsier. Taking all this together, we are inclined to conclude that in the low-dependent group the addiction is still very much in the mind and that, when evolving from a recreational to a dependent use of cigarettes, the addiction shifts from mind to hands.

Maybe then, dependency is not so much a matter of numbers of cigarettes smoked a day, but may denote a shift from a 'central preoccupation' (including declarative and attentional processes) to 'peripheric automatization'. Likewise, Di Chiara (2000) proposes that nicotine dependence shifts from an incentive learning process in the early stages to an automatic and habituated treatment of the cues. This implies therefore that smoking cues are either evaluated as motivational, salient, and positive for the first stage or treated automatically in later stages. We might add, in view of the present results, that these "early[1]" stages involve an evaluative process implying a subjective judgment, whereas a short-cut of this subjective implication may be supposed in the 'automatic and habituated' behavior. Most interestingly, the shift is not simply from declarative behavior to motor behavior as oculomotor results, for example, seem closer to the declarative phenomena (and moreover, "declaration", strictly spoken, is also a motor behavior). For example, Mogg et al. (2005) compared low-nicotine-dependent smokers (Fagerström scores <3) to moderate to high-nicotine-dependent smokers (Fagerström scores >3) in a visual probe task and found that smokers with low levels of dependence have an enhanced attentional bias for smoking-related cues, as reflected by their longer duration of gaze on such cues. Therefore, it is probably more accurate to describe the shift as a shift from central, cognitive, evaluative processes to peripheric grasping behavior immediately proximal to the target. However, while our results seem to follow the automaticity hypothesis (Yin and Knowlton, 2007), we would like to stress that they show that dependent smokers are not only faster to grasp smoking-related cues – which would be easily understood as an enhanced automaticity towards these cues – but, remarkably, they also perform better when they have to refrain themselves from pressing in the NoGo. Therefore, we are inclined to think that the results cannot solely be understood through a learning-habits theory of motor stereotypy. Clinically, this might be of crucial interest as it is reflected in what can be seen in addiction (whatever the substance). Indeed, addiction does not simply lead to a passive state of deficiency characterized by a globally hypofunctional inhibitory system or by an overwhelming irrational wanting; paradoxically, consumption might also give advantages and lead individuals to become more effective in certain abilities.

Otherwise, the present results show how subjective reports can be influenced by concerns with social desirability, and thereby in apparent contradiction with the motor behavioral results. We propose that the hand motor mobilization proximal to the cigarette stimuli is more closely related to Robinson and Berridge's "wanting" than are the cognitive or declarative questionnaire responses and even more closely related than the oculomotor mobilization as in the visual probe task. The hand motor mobilization in smokers, then, is proposed to be the most comparable to the locomotor mobilization in mice, taken as measure for "wanting" in the Robinson and Berridge-research but also used as a measure for incentive sensitization by others (e.g. Mead and Stephens, 1998). Indeed, and importantly, "wanting" is supposed to include pre- or unconscious processes (Tibboel et al., 2015). Robinson and Berridge (2000: S105; see also Berridge, 1996, 1999) explicitly point out: " the incentive–sensitization theory holds that drugs can activate positive core processes of motivation *in the absence of conscious awareness*, so that positive effects may not be indicated on any scale of subjective affective intensity. Indeed, the neural system responsible for incentive salience attribution can sometimes produce *'wanting' in the absence*

of conscious awareness of 'wanting' itself" (our italics). Di Chiara (2000) reports that in a blind self-administration of placebo versus nicotine, smokers administrate themselves more nicotine without reporting any change in the subjective measures of craving or satisfaction. In that perspective, we propose that what fundamentally distinguishes the so-called "low dependent" and the "dependent" smokers might be that only in the dependent smokers there is "wanting" in the absence of conscious awareness of/preoccupation with "wanting". In dependency, a shift has operated from a mental preoccupation with smoking, which might still be sensitive to social desirability concerns (i.e. sensitive to others in general), to smoking as a non-negotiable – we might say "intimate" – hand motor habit. Interestingly, though not completely analogous to the present results, Ferguson et al., (2016: 233) found that the smoking behavior of daily smokers was under considerable stimulus control – such as refraining from smoking when prohibited – but this control was *weaker* at higher smoking rates. In the proposed approach this, then, would indicate that the smoking habit at lower smoking rates is still negotiable in relation to others. In line with the present research they add: *"*The fact that daily smoking appears to be influenced also by stimulus control would appear at odds with purely pharmacological models in as much as they demonstrate that such models have trouble explaining the range of smoking behaviors observed.*"* and cite Shiffman and colleagues (2015) who had already proposed that smoking patterns can be better explained by a model of smoking that also allows for stimulus control to influence smoking.

This approach thereby sheds new light to the earlier reported and seemingly contradictory results. As predicted by IST, several studies show that addicts will approach their addiction-related stimuli faster than controls and independently of the valence they attribute to them (De Houwer et al., 2006; Wiers et al., 2002). However, testing smokers in conditions of smoking deprivation did not affect the "wanting" scores on the IAT, whereas, according to the IST, the level of satiation should modify the "wanting" (if the subject is satiated he will experiment less "wanting") (Tibboel et al., 2011). In the AAT (Mogg et al., 2003) participants approach or avoid stimuli on the basis of the stimulus dimension that is being assessed (e.g., approach biases for picture depicting either a cigarette or a neutral stimulus). With this test, it has been shown that, as expected, smokers were faster to move a manikin toward cues linked to cigarettes compared to neutral cues and that they maintained their gaze longer on smoking-related pictures (Bradley et al., 2004; Mogg et al., 2003). Also, AAT scores were correlated with craving when smokers were deprived; however, even if smoking thereupon led to reduced explicit craving it also led to an *increase* in approach scores (Watson et al., 2013), which is opposite to IST predictions. To clarify these seemingly incoherent results, we propose, in line with reasoning indicated higher, that incentive salience has to be understood as a motor investment in the 'Berridgean' sense; that is, as a motor trace which, once engraved, operates independently of mental preoccupation and autonomously continues to push forward to grasp for its object. When we propose that it does so with a level of autonomy, we specifically imply that it does so even if that object, which was one day adequate in giving satisfaction (or even "liking"), is no longer doing so, and that a major part of the relief tied to the addictive behavior is now the relief of merely discharging the automatically invested preparation of the addictive behavior (see also Bazan and Detandt, 2013). In fact, consciously, or we might say rationally, people can report that they crave less for cigarettes after consuming them but on a motor level, reality is different confirming the neurobiological findings which show that "wanting" is located in a system (the NAS-DA) which can work independently of the homeostatic or hedonic processing (Berridge, 1996; Berridge and Robinson, 1998).

As distinguishing dependent from recreational drug use may be a surprisingly difficult task, we propose that the approach bias task might also be a valuable tool in helping to make these distinctions. Indeed, our exploratory linear regression analysis shows that RTs on Go Smoke approach bias task tend to predict the FTND group belonging. Thereby, this measure has been able to make a diagnostic difference between people who seem to be, at the same time, more conscious of their dependence and more disrupted by smoking-related cues and those who treat them more automatically and have less shared preoccupation with their dependence. Inversely, our results also show that the FTND, which does not merely distinguish smoker categories on the basis of the number of cigarettes smoked per day, is able to predict the motor profile towards the addictive stimuli of both groups. This predictive ability of the FTND is all the more interesting, as it has been criticized as a tool to assess tobacco dependence (Etter, 2005; Etter and Perneger, 1999). What differentiates the FTND from other questionnaires is that it also includes indications of precisely the automaticity and urge to smoke, such as the difficulty to refrain from smoking in forbidden places and the fact of smoking when ill – and in fact it is precisely those two items that are significantly different between our low-dependent and our dependent group. In other words, the FTND scores correlate with the motor parameters, while other current means for identifying substance abuse, whenever they are too direct and/or too cognitive (e.g. our craving scores as well as the TQSU which very much has the same principle as the craving VAS) prove to be inadequate or confusing (see also, Smith and Ersche, 2014).

Limits

First, participants' emotional ratings (both valence and arousal) of the cues have not been assessed in this study, although these data would have been of interest. Indeed, they might have complemented the interpretations regarding the group differences (both for the RT's and errors) as interference from the emotional valence of the cues cannot be excluded. For example, if smokers are less accurate with the neutral cues, it might also be because they allocate less attention to neutral cues. A way to disentangle this issue could be to include an additional stimulus category in the paradigm (see e.g. Noël et al., 2007). Second, owing to practical issues, the gender ratio has not been respected and a next study should control whether this variable modifies the tendencies or not. However, one interesting element on a possible bias induced by the gender imbalance in our low-dependent versus dependent population, is that women have generally been shown to be more inclined to socially adapt their behavior to what they suppose is wished for socially than men (Eagly and Wood, 1991; Félonneau and Becker, 2008). However, as our low-dependent population is both the group with the most men and the group who are most inclined to behave in a more socially desirable way when it comes to reporting their smoking behavior, the gender

imbalance, if anything, is expected to have handicapped rather than biased the outcome; i.e. with more women in the low-dependent group, logically, we would have expected stronger results in the same direction. Hence, we think the differences between the low-dependent population and the dependent population are genuine.

Conclusion and perspectives

In conclusion, the approach bias paradigm for tobacco addiction, though giving results in the expected direction, remained disappointingly inconclusive and non-significant. However, when distinguishing in our smoker population a low dependent from a dependent group on the basis of the FTND, we were able to show two types of results: it seems low-dependent participants show a mental preoccupation concerning their smoking behavior, are able and willing to 'negotiate' their smoking behavior in function of others and of the social environment and likewise their motor behavior in grasping for a cigarette (stimulus) shows hesitation; the dependent participants, however, seem to be quite unpreoccupied by their smoking behavior as well as unconcerned by social prerogatives, while in parallel their motor cigarette grasping is fast and sure.

From these observations different conclusions were drawn. First, the psychological concept of dependency is more suitable to predict the motor smoking habit than the sheer number of cigarettes. Moreover, to our knowledge, no research previously formulated the possibility of a paradox between an automatized motor processing proximal to the stimulus and a metacognitive preoccupation with the dependence (as the behavioral and the MCSD results have allowed us to uncover). This is of crucial interest in addiction in which this paradox is at the very center of the pathology: indeed, it is the mechanism by which a behavior can be maintained without acknowledging it consciously – or even, while claiming one wants to stop. Second, the hand motor mobilization (measured by the approach bias task) is proposed as a parallel of the locomotor activation in the "Robinson and Berridge-mice", i.e. as a measure of "wanting" or of incentive salience. The approach bias paradigm might also be a good complement for clinical use. Third, our research confirms the idea of the independence of the trace as a "peripheric" automatic process from subjective evaluative "central" operations, possibly paralleling the disconnect between "wanting", the amount of motor mobilization which an organism is ready to invest in order to obtain a reward, and "liking" (Berridge, 1996) or pleasure (Bazan and Detandt, 2013) which might also imply evaluative affective, and therefore conscious, effects.

Finally, our results suggest that there may be an underlying heightened vulnerability to drug dependence in certain individuals which might take place right into their hand motor mobilization; the addictive abilities of the stimuli not residing solely in the addictive properties of the drug itself nor in the sole evaluative or cognitive processing. It would therefore be interesting to perform these tests in longitudinal studies in order to predict which group might stop more easily. Logically, we expect that the low-dependent group would be prompter to quit and more affected by talking therapy as their addiction is still negotiable. Another possibility would be to perform drug challenge tests, which are frequently used to identify dispositional or acquired differences in neurotransmitter responses (Netter et al., 2002), to compare our two smokers groups. This test might be of particular relevance if it can be shown that there are differences in dopamine levels even if the quantity of cigarettes consumed is not different.

In our opinion, this study has contributed to a complementary way of understanding addiction, mainly regarding its behavioral effects. We propose this might be an opportunity to invite experts to rethink smoking habits in the light of this crucial moment, possibly deciding dependency, namely, the shift "from head to hands".

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Contributors

Sandrine Detandt designed the study, wrote the protocol, conducted literature research, statistical analysis, and wrote the manuscript. Ariane Bazan supervised the study (from the design to the protocol) and co-wrote the manuscript. Etienne Quertemont and Paul Verbanck contributed to and have approved the final manuscript.

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Note

1. It is worth noting that the stages are readily assumed "early", whereas the implicit fact that they would necessarily evolve into dependence, or stronger dependence, has not been studied in the cited research, including the present one. While for dependent smokers, an earlier 'low-dependent' stage may be logically supposed, it is not here proven that an earlier stage generally speaking does lead to dependency.

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