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Original Investigation

The Role of Attentional Networks in Smoking Behavior Among Young Adults: Specific Contribution of Executive Control

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Abstract

Introduction: The exploration of cognitive impairments associated with tobacco use disorder has expanded during the last decades, centrally showing working memory and executive deficits among smokers. Despite their critical role in everyday life and in the smoking cessation process, attentional abilities have seldom been explored. Previous studies yielded discordant results, and the involvement of attentional deficits in smoking habits remains unclear.

Aims and Methods: Capitalizing on the Attention Network Test, a theory-grounded task allowing the simultaneous but distinct evaluation of three attentional networks (alerting, orienting, executive control), we explored attentional abilities in three groups of 25 college students (nonsmokers, light smokers, heavy smokers), matched for demographic and psychopathological characteristics.

Results: While light smokers did not present any deficit compared with nonsmokers, heavy smokers showed a specific impairment of the executive control subcomponent of attention, contrasting with preserved alerting and orienting attentional abilities. The executive control deficit was not related to current craving or to smoking duration.

Conclusions: Beyond the already explored memory and executive deficits, tobacco use disorder is associated with attentional impairments, characterized by a reduced ability to focus attentional resources on pertinent stimuli and resist to distractors interference. Given the assumed role of attentional impairments in smoking, our findings suggest that a critical step in future translational iterations is to develop neuropsychological rehabilitation programs tapping into the executive network of attention among smokers.

Implications: This study clarifies the presence and extent of attentional impairments in tobacco use disorder. We measured three attention networks (alerting, orienting, executive control) in light smokers, heavy smokers and matched healthy controls through a theory-grounded task (Attention Network Test). Heavy smokers (but not light ones) present a specific deficit for the executive control of attention. This deficit, uncorrelated with psychopathological comorbidities or current craving, appears directly related to smoking. Given the currently scattered literature on this topic, attentional processes deserve a thorough audit in tobacco use disorder, notably to develop specific neurocognitive rehabilitation.

Introduction

Tobacco use disorder remains a key public health issue, constituting the main cause of preventable death in Western countries.[1] Beyond the physical consequences associated with smoking habits,[2] their psychological correlates are also established, including disinhibition,[3] extraversion,[4] and low self-control.[5] More recent studies exploring the neuropsychological factors related to tobacco use,[6] documented impaired working memory,[7] increased impulsivity,[8] and reduced inhibition[9] in smokers. While acute nicotine consumption might enhance cognition,[10] its chronic intake thus has a long-term negative impact on high-level cognitive functions.[11]

Conversely, lower-level cognitive processes, and particular attention, have seldom been investigated. A recent meta-analysis[6] showed that only 11 studies assessed attention among smokers. This meta-analysis reported a significant but weak reduction of attentional abilities in smokers, with a wide heterogeneity across studies: Some showed slightly reduced performance in visual,[8] selective,[12] or sustained[13] attention. Others identified such deficits in specific groups (eg, only among non-educated smokers).[14] Finally, most studies did not identify any attentional deficit.[15–17] Such discrepancies are related to three shortcomings. First, studies were not anchored in sound attention models articulating subcomponents in a theory-grounded investigation. Without such conceptual framework, each previous work focused on isolated attentional subcomponents (eg, vigilance, sustained attention, divided attention), thwarting any coherent view of the impaired and preserved subcomponents' pattern. Second, previous studies did not distinguish participants according

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to smoking heaviness, hampering to determine the variation of attentional deficits with tobacco use severity. Third, most studies did not control for participants' socioeconomic status or other psychopathological (eg, depression, anxiety) and substance-related (eg, alcohol or cannabis consumption) disorders, frequently associated with smoking and impacting attentional abilities. These limitations prevent identifying the specific attentional subcomponents impaired in tobacco use disorder, and hence the development of neuropsychological rehabilitation programs.

A classical task allowing the integrated and controlled evaluation of attentional subcomponents is the Attention Network Test (ANT),[18] simultaneously measuring the three attentional networks identified in the Posner's dominant model of attention:[19] (1) *alerting*, the ability to reach and maintain a high level of sensitivity towards environmental stimuli, and of readiness to react to them; (2) *orienting*, the ability to select pertinent information in the environment by engaging, disengaging, and shifting attentional resources from one stimulus to another; (3) *executive control*, the ability to solve conflicts between relevant and irrelevant stimuli through top-down attentional control, thus prioritizing the stimuli pertinent to the ongoing task. The dissociation between attentional networks proposed by the ANT is supported by neuroimaging data that identified distinct cerebral circuits related to each network: Alerting is related to superior temporal and thalamic activations, orienting relies on superior parietal lobule, prefrontal cortex, and fusiform gyrus activations; and executive control is mostly associated with precuneus, thalamic, cingulate, and superior as well as inferior frontal gyri activations.[20–22]

The ANT has been widely used to identify attentional deficits in psychiatric disorders.[23] Specific impairments in attentional networks have also been identified in substance use disorders, including reduced orienting abilities among people presenting cannabis dependence[24] or impaired executive control among cocaine consumers,[25] cannabis users,[26] and in severe alcohol use disorder.[27] Conversely, the ANT has only been used in tobacco research to explore the acute effects of nicotine, through studies administrating nicotine to smokers or nonsmokers. While earlier studies, using less controlled attentional tasks, had suggested that nicotine increased attentional abilities, particularly among nonsmokers,[28] studies using the ANT showed that increased nicotine levels generated shorter reaction times (RT) during cognitive tasks[29] but did not specifically improve the efficiency of attentional networks[29,30] and might even reduce orienting abilities.[31] The long-term links between tobacco use disorder and attentional abilities have thus not been explored with the ANT in a well-controlled group of smokers.

Our main objective was to explore such a link and to tackle the issues related to earlier studies by measuring, through the ANT, attentional abilities in smoking college students. We focused on this population because (1) most previous studies using the ANT to explore the acute effects of nicotine[29,31] or the attentional impact of tobacco use disorder[12,16] have included young adults. Selecting a similar sample here allowed an easier comparison with these studies; (2) long-term tobacco use disorder in older adults is associated with high rates of psychopathological comorbidities, as well as with large lifetime variations in smoking habits. Focusing on a younger population with limited psychopathological disorder and linear tobacco use disorder allowed a higher control of comorbidities and smoking history; (3) we wanted to explore the link between smoking and attention at the early stages of tobacco use disorder, to exclude any influence of later lifetime events on attentional abilities. Our aim was also to determine whether attentional abilities are modulated by heaviness of smoking habits, by comparing healthy controls, light smokers, and heavy smokers. Given previous results[6] showing that tobacco use disorder is associated with impaired attention (particularly for rejecting irrelevant information) and with executive control deficits, we hypothesized that smokers, and particularly heavy smokers, would mostly exhibit reduced abilities in the executive control of attention compared with healthy controls.

Methods

Participants

We first conducted a screening phase by sending an e-mail to all the students of the University (UCLouvain, Belgium, approximately 28 000 individuals), proposing them to fill in an online questionnaire on Qualtrics software. This self-reported questionnaire assessed sociodemographic characteristics (age, gender, education level, mother tongue), psychological and physiological variables (present neurological or psychopathological disorder, visual abilities, medication), and tobacco as well as alcohol use (frequency and intensity of consumption). We obtained 4520 complete answers, and we then selected 1710 students fulfilling the following inclusion criteria: native French speaker, 18–25 years old, no past or present psychological, or psychiatric disorder, no past or present drug consumption (except alcohol and tobacco), absence of alcohol use disorder [measured by the Alcohol Use Disorders Identification Test (AUDIT)],[32] no current use of other tobacco-related products than cigarettes (eg, e-cigarettes, oral tobacco), no current psychotropic medication, no major neurological problem, normal or corrected-to-normal vision. We then selected three groups presenting the targeted smoking profiles: nonsmoking healthy controls (HC, who had not smoked during the last year and had never been regular smokers), light smokers (LS, who smoked between two and eight cigarettes per day), and heavy smokers (HS, who smoked between 10 and 25 cigarettes per day). All individuals who agreed to participate in the experiment (ie, who gave their e-mail addresses during the screening phase) and corresponded to one of the three targeted profiles (178 students) were contacted to participate in the experimental phase. We recruited all available participants until our sample size (25 participants) was obtained for each group. Seventy-five college students [65.3% women; mean age: 21.80 years old (SD = 2.02)] thus performed the experiment. A power computation (performed in G*Power v3.1.9.7) indicated that a total sample size of 69 was required to detect a Group × Attentional network (three groups, three measurements) interaction in a repeated-measures ANOVA, assuming a medium ($f = 0.20$) effect size with 0.90 power, and $\alpha = .05$, thus suggesting that our study was sufficiently powered. All participants provided their written informed consent and this study's protocol was approved by the local ethics committee (Psychological Science Research Institute, UCLouvain) and complied with the Helsinki Declaration of 1975, as revised in 2008.

Measures and Analyses

Psychopathological and Tobacco-Related Measures

We measured psychopathological variables before starting the experiment: (a) depressive symptoms, using the Beck

Depression Inventory (BDI-II),[33,34] a 21-item questionnaire, each leading to a 0–3 score (total score range: 0–63); (b) anxiety, using the State-Trait Anxiety Inventory (STAI),[35,36] proposing 20 items related to state anxiety (STAI A) and 20 items related to trait anxiety (STAI B), each leading to a 1–4 score (total score range: 20–80); (c) impulsivity, using the UPPS-P Impulsive Behavior Scale,[37,38] a 20-item questionnaire, each related to an impulsivity facet (positive urgency, negative urgency, lack of premeditation, lack of perseverance, sensation seeking; score range for each item: 1–4; score range for each facet: 4–16).

In both smoking groups, we also measured: (a) the duration of smoking habits, the number of cigarettes per day, and the number of pack-years (ie, the packs of cigarettes smoked per day by the participant, multiplied by the length of consumption in years); (b) the heaviness of physical addiction to nicotine, using the Fagerström test,[39,40] a 6-item questionnaire (score range: 0–10); (c) current smoking craving, using the short version of the Questionnaire on Smoking Urges (QSU),[41,42] a 12-item, each related to a craving facet [Facet 1 (7 items): relief of negative affect, Facet 2 (5 items): intention and desire to smoke; score range for each item: 1–7]. We calculated a mean score for each facet and for the total score (range: 1–7).

Stimuli and Task Description

The ANT evaluated the efficiency of three attentional networks: alerting, orienting, and executive control.[18] Participants had to determine as quickly and accurately as possible the direction (left or right) of a central arrow (the target) located in the middle of a horizontal line presented either at the top or bottom of the screen (Figure 1). They responded by pressing the corresponding button (left or right) on the keyboard. Each target was preceded by either no cue, a central cue (an asterisk replacing the fixation cross), a double cue (two asterisks, one appearing above and one below the fixation cross), or a spatial cue (an asterisk appearing above or below the fixation cross, indicating the location of the upcoming target) (Figure 1; upper part). Three possible flankers also appeared horizontally on each side of the target: arrows (two on each side of the target) pointing in the same direction as the target (congruent condition), arrows pointing in the opposite direction than the target (incongruent condition), or

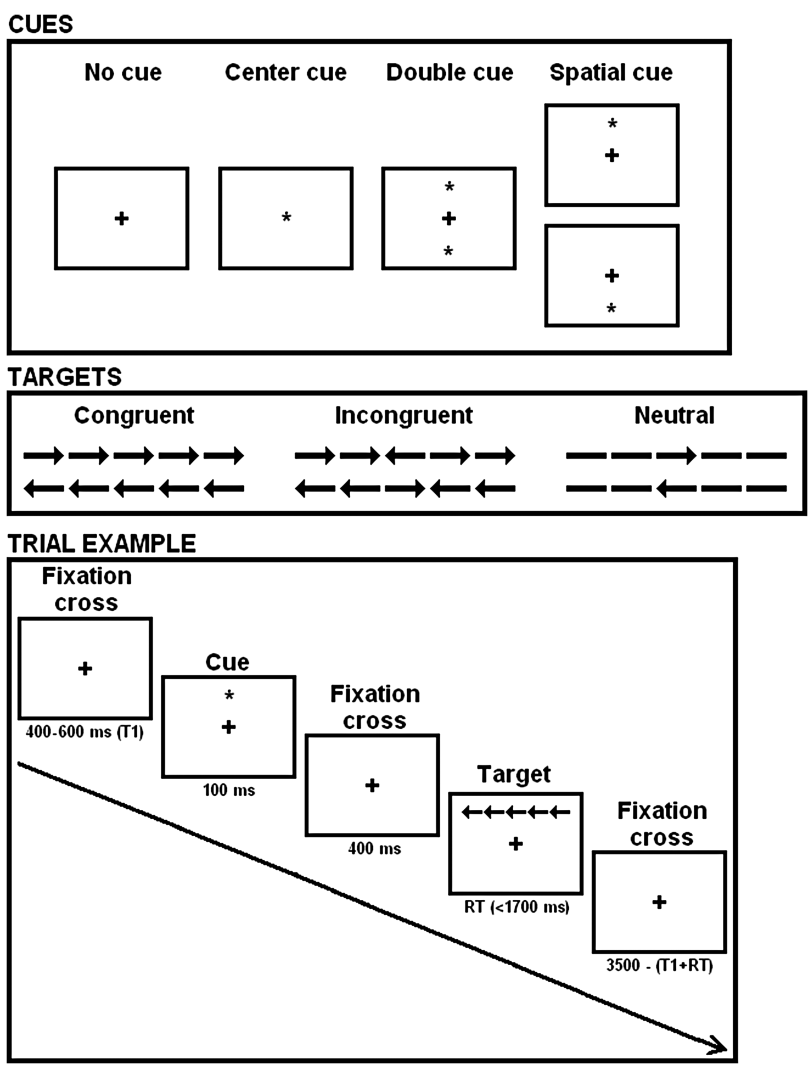

Figure 1. Description of the Attention Network Test, presenting the four possible cues (upper part), the six possible targets (middle part), and a trial example (lower part, ie, congruent trial preceded by a spatial cue, the correct response being "left"). Adapted from Fan et al.[18]

dashes (neutral condition) (Figure 1; middle part). Each trial comprised: (1) a central fixation cross (random duration between 400 and 1600 ms); (2) a cue (100 ms); (3) a central fixation cross (400 ms); (4) a target and its flankers, appearing above or below the fixation cross, and remaining on the screen until the participant answered or for 1700 ms if no response occurred; and (5) a central fixation cross (lasting for 3500 ms minus the sum of the first fixation period's duration and the RT) (Figure 1; lower part). We recorded RT (in ms) and accuracy score (correct or wrong answer) for each trial.

The ANT comprised 288 trials (three blocks of 96 trials, with a short break between blocks). The combination of four cues (no cue, center cue, double cue, spatial cue), three flankers (congruent, incongruent, neutral), two directions of the target (left, right), and two localizations (upper or lower part of the screen) generated 48 possible trials. We randomized trials presentation, each trial appearing twice per block. The task was programmed and administered via E-Prime 2 Professional (Psychology Software Tools, Pittsburgh, PA, USA).

Procedure

This study comprised three steps. First, participants were provided with full details on the aims and procedure and filled in the questionnaires. During this step, we also checked that participants had not smoked during the last three hours, as requested during the recruitment. This is because nicotine has a short-term impact on cognition, notably reducing RT[29] and potentially increasing global attentional abilities.[28] Recent smoking could thus have increased attentional abilities in smokers, biasing our results. Second, participants performed the ANT after completing a preliminary practice session (24 randomly selected trials). The distance between the participant's eyes and the screen was 50 cm, and the target stimuli subtended a visual angle of 4° in the horizontal field. Finally, participants were debriefed and received compensation (10€). Each session was administrated individually in a dimly lit and quiet room.

Preparation of the Data

In line with earlier ANT studies,[18,27] we excluded data from trials with incorrect answers (3.32% of trials), RT lower than 200 ms or greater than 3000 ms (0.12%), and RT exceeding 2 SD below or above each participant's mean for each experimental condition (2.8%). A preliminary analysis showed no difference in RT or accuracy according to the direction and localization of the arrow. We thus merged these trials, leading to 24 trials for each of the 12 experimental conditions (four cues by three flankers). We computed indices (ie, difference scores between two experimental conditions presenting the same working memory and motor planning requirements but differing regarding the attentional resources involved) for the three attentional networks, both for RT and accuracy and for each participant individually.[18] This approach yielded three indices: (1) *alerting*, by subtracting the mean score for the double cue trials from the mean score for the no cue trials (ie, No cue—Double cue); (2) *orienting*, by subtracting the mean score for the spatial cue trials from the mean score for the central cue trials (ie, Central cue—Spatial cue); (3) *executive control*, by subtracting the mean score for congruent flanker trials from the mean score for incongruent flanker trials (ie, Incongruent flanker—Congruent flanker). For both alerting and orienting indices, greater subtraction scores for RT (and lower for accuracy) indicated greater efficiency. Conversely, greater subtraction scores for RT (and lower for accuracy) on executive control indicated increased difficulty.[20]

Statistical Analyses

We performed statistical analyses using SPSS 25.0 (IBM, Inc.) and set the significance level at an alpha of .05 (bilateral). First, we performed descriptive statistics and one-way analyses of variance (ANOVAs) or independent samples *t*-tests to explore group differences. Second, we performed two types of ANOVAs, separately for accuracy and RT: (1) 3 × 4 × 3 ANOVAs with Group (HC, LS, HS) as between-subjects factor and Cue (no cue, central cue, double cue, spatial cue) as well as Flanker (congruent, incongruent, neutral) as within-subjects factors; (2) 3 × 3 ANOVAs with Group (HC, LS, HS) as between-subjects factor and Attentional Network (alerting, orienting, executive control) as within-subjects factor. Significant main effects and interactions were followed by post-hoc Bonferroni-corrected independent samples *t*-tests. As we focused on potential deficits among smokers, the results section will present group comparisons, and the overall effects (ie, significant results not related to group differences) are reported in Supplementary Material. Pearson's correlations (performed in an exploratory way and thus uncorrected) measured the relationships between attentional performance, demographic factors, psychopathological symptoms, and tobacco-related variables in the whole sample and in each group.

Results

Demographic, Psychopathological, and Alcohol-Related Measures

As detailed in Table 1, groups did not significantly differ for age, gender, depression, anxiety, and alcohol consumption. We found no group difference for lack of perseverance and sensation seeking, but smoking groups scored higher than HC for negative urgency, positive urgency, and lack of premeditation. Smoking groups differed regarding the number of cigarettes smoked per day, pack-years, and the Fagerström test, but not on the duration of smoking habits or tobacco craving.

Outcome Measures

General Analysis

We performed a 3 (groups) × 4 (cues) × 3 (flankers) ANOVA separately for RT and accuracy (Table S1 presents the full results):

- Accuracy: We found no main Group effect [$F(2,72) = 1.97$, $p = .15$, $\eta^2_p = .05$], nor interactions with Cue [$F(6,216) = 1.07$, $p = .38$, $\eta^2_p = .03$], Flanker [$F(4,144) = 2.39$, $p = .05$, $\eta^2_p = .06$] or triple interaction [$F(12,432) = 0.91$, $p = .54$, $\eta^2_p = .02$].
- RT: We found no main Group effect [$F(2,72) = 1.58$, $p = .21$, $\eta^2_p = .04$] nor interaction with Cue [$F(6,216) = 1.41$, $p = .21$, $\eta^2_p = .04$] or triple interaction [$F(12,432) = 1.38$, $p = .17$, $\eta^2_p = .04$], but a Group × Flanker interaction was found [$F(4,144) = 4.56$, $p = .002$, $\eta^2_p = .11$]: Groups did not differ for congruent [HC-LS: $t(48) = 0.94$, $p = .88$, Cohen's $d = 0.27$; HC-HS: $t(48) = 1.67$, $p = .77$, $d = 0.48$; LS-HS: $t(48) = 0.07$, $p = 1$, $d = 0.02$] and neutral [HC-LS: $t(48) = 1.09$, $p = .66$, $d = 0.31$; HC-HS: $t(48) = 1.47$, $p = 1$, $d = 0.42$; LS-HS: $t(48) = 0.26$, $p =$

Table 1. Sociodemographic, Psychopathological and Tobacco-Related Measures Among Non-smoking Healthy Controls (HC), Light Smokers (LS), and Heavy Smokers (HS): Mean (SD)

	HC (n = 25)	LS (n = 25)	HS (n = 25)	F(2,72) Value (p-value)	T(48) Value (p-value) HC-LS	T(48) Value (p-value) HC-HS	T(48) Value (p-value) LS-HS
Sociodemographic measures							
Age	21.44 (2.31)	21.72 (1.99)	22.44 (2.27)	1.00 (0.37)	/	/	/
Gender ratio (female/male)	15/10	17/8	17/8	0.47 (χ2) (0.79)	/	/	/
Psychopathological measures							
Depressive symptoms (BDI-II)	6.96 (4.52)	9.96 (4.62)	9.48 (5.52)	2.69 (0.07)	/	/	/
State-anxiety (STAI-A)	35.60 (10.10)	34.36 (7.62)	36.40 (8.42)	0.34 (0.71)	/	/	/
Trait-anxiety (STAI-B)	42.56 (9.08)	44.00 (8.69)	43.60 (9.89)	0.16 (0.85)	/	/	/
Alcohol consumption (AUDIT)	7.80 (4.39)	10.16 (4.47)	9.72 (4.83)	1.89 (0.16)	/	/	/
Impulsivity (UPPS-P)							
Negative urgency	8.68 (3.12)	10.92 (3.55)	10.56 (3.04)	3.44 (0.04)	2.37 (0.02)	2.16 (0.04)	0.39 (0.70)
Positive urgency	10.48 (2.58)	11.64 (3.04)	12.72 (2.01)	4.72 (0.01)	1.45 (0.15)	3.42 (0.01)	1.48 (0.15)
Lack of premeditation	6.76 (2.22)	8.64 (2.50)	9.24 (2.98)	6.27 (0.03)	2.81 (0.07)	3.34 (0.02)	0.77 (0.44)
Lack of perseverance	7.04 (2.61)	7.84 (1.97)	6.84 (2.46)	1.26 (0.29)	/	/	/
Sensation seeking	10.52 (2.54)	11.12 (2.40)	11.36 (3.46)	0.58 (0.56)	/	/	/
Tobacco-related measures							
Number of cigarettes per day	/	5.28 (1.81)	13.08 (4.42)	/	/	/	8.17 (<0.001)
Duration of smoking habits (in years)	/	4.17 (2.40)	6.00 (3.49)	/	/	/	1.99 (0.05)
Pack years	/	1.08 (0.80)	4.17 (4.34)	/	/	/	3.21 (0.003)
Fagerström test score	/	1.68 (1.18)	3.24 (2.03)	/	/	/	3.32 (0.002)
Craving (QSU): total score	/	3.98 (0.32)	3.95 (0.37)	/	/	/	0.28 (0.78)
Craving (QSU): relief of negative affect	/	2.86 (0.57)	2.91 (0.73)	/	/	/	0.31 (0.75)
Craving (QSU): intention and desire to smoke	/	5.55 (0.73)	5.41 (0.66)	/	/	/	0.73 (0.47)

1, d = 0.07] trials, but HC presented shorter RT for incongruent trials than HS [t(48) = 3.07, p = .047, d = 0.89], other group comparisons being non-significant [HC-LS: t(48) = 1.77, p = .21, d = 0.51; LS-HS: t(48) = 0.57, p = 1, d = 0.16].

Attentional Networks Analysis

We performed a 3 (groups) × 3 (attentional networks) ANOVA separately for RT and accuracy (Figure 2):

- Accuracy: We found no main Group effect [F(2,72) = 1.53, p = .22, η^2_p = .04] nor interaction [F(4,144) = 3.05, p = .05, η^2_p = .08].
- RT: We found a main Group effect [F(1,72) = 5.15, p = .008, η^2_p = .13], qualified by an interaction [F(4,144) = 3.05, p = .02, η^2_p = .08]: We found no group differences for alerting [F(2,74) = 0.01, p = .99 η^2_p = .01] and orienting [F(2,74) = 2.94, p = .06, η^2_p = .07] but groups differed on executive control [F(2,74) = 4.87, p = .01, η^2_p = .12], as HC presented better executive control (i.e. reduced index for this network) than HS [t(48) = 3.52, p = .008, d = 1.02], the other comparisons being non-significant [HC-LS: t(48) = 1.99, p = .18, d = 0.57; LS-HS: t(48) = 1.04, p = .71, d = 0.30].

Correlational Analyses

In the whole sample, we found significant positive correlations between (a) executive control index for accuracy and sensation seeking (r = 0.254, p = .028) as well as BDI (r = 0.232, p = .046); and (b) executive control index for RT and the duration of smoking habits (r = 0.303, p = .048). We also found significant correlations (a) in HC, between executive control index for RT and STAI A (r = 0.449, p = .024) as well as STAI B (r = 0.436, p = .029); (b)

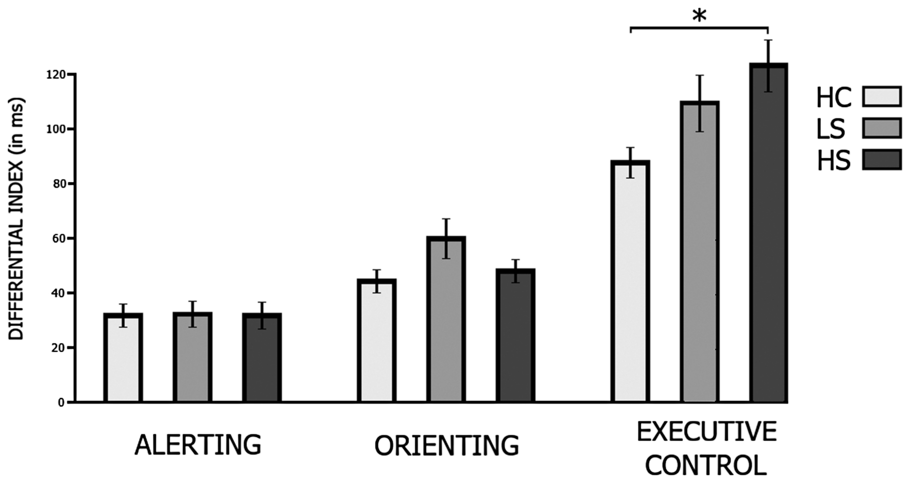

Figure 2. Differential indices (in ms) for the three attentional networks (ie, alerting, orienting, and executive control) among healthy controls (HC), light smokers (LS), and heavy smokers (HS). Columns represent the mean value for each index in each group. Error bars represent the standard errors of the mean. *$p < .01$

in LS, between executive control index for accuracy and sensation seeking ($r = 0.487$, $p = .014$); (c) in HS, between executive control index for accuracy and the Fagerström test score ($r = 0.464$, $p = .02$). We found no other significant correlation between attentional performance and demographic, psychopathological or tobacco-related characteristics, neither in the whole sample nor within each group (all $r < .0.22$, $p > .05$).

Discussion

We examined attentional abilities among smokers through the ANT, offering an integrated exploration of the three attentional networks related to Posner's model:[19] alerting, orienting, and executive control. HS presented a deficit for the executive control network of attention, compared with matched HC (together with preserved alerting and orienting abilities), while LS presented a preserved performance for all attentional networks. Groups did not differ in accuracy, as expected since the ANT is classically related to a ceiling effect in performance,[27] replicated here (mean performance: 96.68%). HS were, however, impaired in attentional control, as demonstrated by two differences with HC regarding RT: first, the general analysis showed that HS were specifically slower for incongruent stimuli: the presence of non-relevant flankers negatively impacted their processing of the target. Second, the attentional networks analysis confirmed this result by identifying a specific deficit for the attentional control network in HS. This coherent pattern indexes executive control deficit, and specifically a difficulty to resist to distractors interference: HS have difficulties to inhibit confusing and irrelevant stimuli (ie, incongruent flankers) to focus their attention on significant ones (ie, the central target). In other words, HS present a reduced ability to solve the conflict between task-relevant and task-irrelevant information. This is in line with earlier results showing impaired executive performance in smokers,[9] particularly regarding the ability to inhibit the processing of irrelevant stimuli.[43] The LS-HS comparison also showed that this deficit appears only among people presenting heavy smoking habits (ie, between 10 and 25 cigarettes per day).

Conversely, no group differences were observed for alerting and orienting, suggesting no beneficial or negative effect of smoking on the ability to (1) globally mobilize attentional resources to increase phasic alertness and vigilance before the arrival of a target, and (2) change the focus of these attentional abilities according to task requirements to orient one's attention towards an upcoming pertinent target. This result suggests a dissociation between the short-term effects of nicotine, (ie, increased low-level attentional abilities, particularly alerting),[28] and its long-term effects (ie, no impact on alerting and orienting). Preserved alerting and orienting abilities also show the absence of a global attentional deficit in HS (eg, related to reduced cognitive abilities or motivation) and thus the specificity of the executive control deficits reported. The strength of our results is further supported by the fact that attentional networks indices are based on difference scores between two experimental conditions (ie, differential index), thus excluding the possibility that group differences are due to a global slowing down in HS. Finally, results are not the consequence of a higher difficulty of the executive control subtask, as earlier studies among populations with substance abuse showed different impairment patterns (eg, orienting deficit in cannabis users).[24]

Our efficient group pairing on sociodemographic and psychopathological variables supports the proposal that group differences are indeed related to tobacco use disorder. Group differences were observed on some impulsivity facets, in line with previous results showing increased impulsivity in smokers.[44] However, impulsivity is not a major contributor of our results, as (1) we found no difference on impulsivity between the two groups of smokers, despite their different ANT patterns; (2) we observed no coherent pattern of correlations between impulsivity and experimental results. In the same vein, the influence of psychopathological variables on attention appears weak, which was expected as participants only exhibited sub-clinical levels of depression and anxiety. The correlations only indicated that depression and state or trait anxiety might be related to executive control indices for accuracy and RT, respectively. These correlational analyses should nevertheless be taken cautiously as they were performed on limited samples and were not adjusted for multiple comparisons.

The grouping criteria allowed a clear dissociation between the two groups of smokers regarding the number of cigarettes per day, pack years and the physical dependence (measured through the Fagerström test), but we found no differences for smoking habits duration or current craving. The differential results between LS and HS cannot be explained by a longer duration of smoking habits or by a more intense craving among HS at testing time. This matching on craving, and the total absence of correlations between craving and experimental results, are crucial as we explicitly requested participants to avoid smoking before testing, and as it had been suggested that craving could strongly contribute to attentional impairments among smokers.[45] This proposal is not supported by our data, showing that executive control in HS is impaired independently of current tobacco craving. This deficit also appears more related to the heaviness of current smoking habits than to their duration.

It should be acknowledged that our sample comprised young smokers with installed tobacco use disorder but quite limited duration of smoking habits (and hence relatively low pack years), low heaviness of physical nicotine addiction and low use of smoking as a coping strategy to face negative affect (ie, Facet 1 of the QSU). The observed deficit might thus be increased in young adults presenting heavier smoking habits or in older adults with longer-lasting tobacco use disorder, potentially through a higher impact on executive control abilities or impairment of the other networks. Moreover, we selected students without other substance use disorder to explore the specific links between smoking and attention, but substance use comorbidities are the rule rather than the exception in youth, particularly with alcohol and cannabis.[46] As these two substances impact attention, future studies should explore the cumulative effect of tobacco and other substance abuse on attentional abilities. Finally, the cross-sectional nature of our design precludes interpretations regarding the causal relationships between tobacco use and attentional deficits: smoking may directly generate attentional impairments via neurotoxic or vascular effects, but some cognitive impairments might also be present before the initiation of smoking and facilitate its emergence.[12]

Despite these limitations, our theory-grounded evaluation of attention clarifies the contradictory results reported earlier: when offering a distinct evaluation of the three attentional networks and controlling for biasing variables, the attentional deficit observed in tobacco use disorder is exclusively related to the executive control of attention. The various patterns of results observed earlier[6] might thus be explained by the fragmented evaluation of attentional subcomponents, using multi-determined tasks without strict control of biasing factors. The present results thus bear significant implications. At the theoretical level, they reinforce the experimental validity of the model underlying the ANT, by showing that the three networks are related to distinct and independent attentional processes. They also underline that the cognitive deficits in tobacco use disorder are not exclusively related to memory and executive functions, but also encompass attention. At the clinical level, they underline that cognitive deficits are a key feature of tobacco use disorder. Neuropsychological impairments can reduce quality of life and real-life performance, but also the ability to quit smoking.[47] Reducing attentional impairments in smokers could thus act as a therapeutic lever to facilitate smoking cessation. Neuropsychological rehabilitation programs focusing on each attentional network have been developed, and those focusing on the improvement of executive control[48] could be proposed to heavy smokers, together with recently developed rehabilitation programs using neuroscience-informed tools to reduce cognitive impairments in substance use disorders.[49,50]

In conclusion, this first exploration of attentional networks in tobacco use disorder using the ANT demonstrated the presence of a differential deficit between impaired executive control and preserved alerting and orienting networks in HS, participants with lighter smoking habits presenting no attentional impairment. This result constitutes an important clarification of the previously scattered literature on attentional abilities in tobacco use disorder, and paves the way for rehabilitation programs focusing on the impacted attentional subcomponents.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at https://academic.oup.com/ntr.

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Declaration of Interests

Alexandre Heeren receives honoraria for his editorial work from Elsevier. The other authors declare no conflict of interest.

Data Availability

The dataset (SPSS version) is freely available at: https://www.uclep.be/wp-content/uploads/ANT_Smokers.sav

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