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Social Psychology

The Association Between Smokers' Approach Bias and Heaviness of Use: A Focus on Light Smokers

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The relationship between heaviness of use and the approach bias (i.e., stronger approach than avoidance tendencies) toward tobacco remains ambiguous at both theoretical and empirical levels. Indeed, some models of addiction would formulate opposite predictions (i.e., positive vs. negative relationship) and, as it turns out, current evidence is mixed. In three studies, we investigated this relationship among smokers (relying on a continuous measure of heaviness) and compared approach/avoidance tendencies of light smokers and non-smokers (relying on group comparison). To measure approach/avoidance tendencies, we used the Visual Approach/Avoidance by the Self Task (VAAST) that visually simulates whole body movements. This task was used as irrelevant-feature version (i.e., instructions about another dimension). Heaviness of use was assessed continuously with daily cigarette use. Data were analyzed in two Integrative Data Analyses (IDAs; a kind of meta-analysis considering jointly the raw data of the three studies), thus taking into account both significant and non-significant effects (total N = 173). In our first integrative analysis (Studies 1-3), we observed an increase in the approach bias toward tobacco as a function of heaviness of use, as well as an avoidance bias among light smokers. In our second integrative analysis (Studies 2 and 3), we found that light smokers have a stronger avoidance bias than non-smokers. While the positive relationship between heaviness of use and approach tendencies toward tobacco is consistent with most addiction models, our finding on light smokers' avoidance bias stands in sharp contrast. These findings, however, can be incorporated into general motivational models or single-process propositional models that consider the role of goal-oriented or propositional processes, respectively.

Most people are aware of the negative health consequences of smoking, yet tobacco use remains "one of the biggest public health threats the world has ever faced" (World Health Organization, 2018). Some work emphasized the role of automatically activated psychological processes in maintaining this addictive behavior, such as an approach bias toward the addictive substance—faster reactions to approach than to avoid the substance (e.g., Bradley et al., 2004; Mogg et al., 2003; C. E. Wiers et al., 2013). However, results are mixed regarding whether light smokers have an approach bias toward tobacco (e.g., Larsen et al., 2014; Mogg et al., 2005; Thewissen et al., 2007) and, more generally, how approach/avoidance tendencies are associated with heaviness of use (Kakoschke et al., 2019). Addressing these questions is mostly important at the theoretical level. Indeed, some addiction models would make opposite predictions regarding the relation between the approach bias and heaviness of use (a positive correlation, cf. incentive sensitization theory, Robinson & Berridge, 1993, 2003; vs. a negative correlation, cf. incentive-habit model, Di Chiara, 2000). At the same time, these questions are also important at the practical level. Indeed, even a few cigarettes per day have an impact on health (Bjartveit & Tverdal, 2005) and light smoking is more difficult to maintain than light drinking or cannabis use, and more likely to progress to heavier use, over time (Epskamp et al., 2022). Therefore, the role of an approach bias for tobacco smoking may also have clinical implications. Hence, if better understood, approach/avoidance tendencies among light smokers could optimize intervention procedures.

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Approach Bias and Models of Addiction

Implicit or automatically activated cognitive processes (for reviews see Sheeran et al., 2016; Stacy & Wiers, 2010) help explaining the singularity of drug consumption: Pursuing drug use while knowing that this behavior is harmful for one's health. Drug consumption is associated with various biases, potentially implied in maintaining drug use, such as automatic drug-positive associations (e.g., De Houwer et al., 2006), but also attentional (e.g., Bradley et al., 2004) and approach biases toward drug (e.g., Mogg et al., 2003). To account for the approach bias, models of addiction rely on the general idea that individuals acquire automatically activated cognitive biases for cues referring to previous use experiences (e.g., Di Chiara, 2000; Robinson & Berridge, 1993, 2003; R. W. Wiers & Stacy, 2006; for a review see Watson et al., 2012).

According to the incentive sensitization theory (Robinson & Berridge, 1993, 2003), drug cues would acquire 'incentive salience' (i.e., more "wanting" without necessarily more "liking") among drug users, leading to increased drug attention and approach tendencies. Other approaches, as Tiffany's habit theory (Tiffany, 1990; Tiffany & Conklin, 2000), predict that over time and over drug intake, consumption becomes a habitual response, progressively replacing thoughtful and motivated behaviors. This shift from controlled to automatic responses is also in line with dual-process models of addiction (e.g., Everitt & Robbins, 2005; Stacy & Wiers, 2010; Strack & Deutsch, 2004; R. W. Wiers et al., 2007), suggesting that automatic/impulsive and controlled/deliberative processes compete with each other in drug consumption. Importantly, all these theoretical approaches predict that approach tendencies are associated with (accumulated) experience of use: The more individuals smoke, the stronger their approach bias toward tobacco cues.

Interestingly, the incentive-habit model (Di Chiara, 2000) would lead to the opposite prediction. This model proposes that the incentive value of drug cues is higher among light, less dependent, smokers—because of a stronger (initial) dopamine response to nicotine—and decreases as a function of heaviness of use. With experience, habitual responding toward drug cues would be more important in maintaining consumption but would not lead to a stronger approach bias (rather depending on the incentive value granted to the drug; e.g., Mogg et al., 2005).

Overall, all the theoretical accounts described so far—including the "incentive-habit" model—predict that, in comparison with non-smokers, light and heavy smokers should have an approach bias. However, the incentive-habit model and the other approaches predict opposite results concerning the correlation between heaviness of use and approach bias.

Empirical Data on the Relation Between Heaviness of Use and Approach Bias

First, the literature is consensual about the fact that heavy smokers have a larger approach bias toward tobacco than non-smokers (Bradley et al., 2004, 2008; Machulska et al., 2015; Mogg et al., 2003; C. E. Wiers et al., 2013). However, results regarding light smokers are mixed: One study found that they have an approach bias toward tobacco (Thewissen et al., 2007), but another did not (Woud et al., 2016). Moreover, two studies found that light smokers have a larger approach bias than non-smokers (Bradley et al., 2008; Mogg et al., 2005), while two did not find any significant difference (Larsen et al., 2014; Machulska et al., 2015).

Second, results are also mixed on the correlation between heaviness of use and the approach bias. Some studies did not find any significant relationship between heaviness of use (e.g., number of cigarettes per day, pack per year, FTND score) and the approach bias (Larsen et al., 2014; C. E. Wiers et al., 2013), some studies found that lower levels of nicotine dependence were associated with a greater approach bias (Mogg et al., 2005; Watson et al., 2013) while other studies found opposite results (Detandt et al., 2017). Interestingly, this inconsistency can also be found for other automatic biases, as the attentional bias toward tobacco (e.g., Bradley et al., 2004; Mogg & Bradley, 2002).

Although it seems clearly established that heavy smokers have approach tendencies toward tobacco, results are mixed about whether light smokers also have an approach bias. More generally, it is still not established how approach/avoidance tendencies are linked to heaviness of use (Kakoschke et al., 2019).

The Current Research

This work aimed at 1) testing whether light smokers have an approach bias and 2) investigating the link between heaviness of use (from light smokers to heavy smokers) and approach/avoidance tendencies. We improved the conditions of investigation generally implemented in the literature regarding both the methodology and the reliability of empirical data.

A first methodological improvement was to use the VAAST (Rougier et al., 2018), a task simulating the visual aspects associated with a forward/backward movement of the whole self in a virtual environment[1]. This task is highly efficient in capturing approach/avoidance tendencies, compared to other existing tasks (e.g., Stimulus-Response Compatibility task; De Houwer et al., 2001; Approach/Avoidance Task; Rinck & Becker, 2007) that sometimes lack replicability (e.g., Krieglmeyer et al., 2010; Rotteveel et al., 2015; Rougier et al., 2018). The VAAST has been used to measure approach/avoidance tendencies toward a large variety of stimuli, such as positive/negative words and images (e.g., Aubé et al., 2019; Degner et al., 2021; Juneau et al.,

1 The VAAST is freely accessible for both demo and online/lab testing (https://www.psytoolkit.org/experiment-library/vaast_images.html).

2021; Rougier et al., 2018), positive/negative odors (Cereghetti et al., 2021), social media logo/control stimuli (Wadsley & Ihssen, 2022), faces wearing (or not) a medical mask (Ingram et al., 2021), autistic/non autistic children (Aubé et al., 2021), and ingroup/outgroup first names (Aubé et al., 2019; Rougier et al., 2020). Importantly, the VAAST effects seem to have meaningful predictive value: For instance, approach/avoidance tendencies toward in- and outgroup members predicted self-reported prejudice and trustworthiness ratings of out-group individuals (i.e., Rougier et al., 2020). Finally, the VAAST can be easily implemented as an irrelevant feature task (hereafter called the "IF-VAAST").

A second methodological improvement concerns the assessment of heaviness of use. First, we recruited participants having levels of consumption as variable as possible (considering our prescreening) and we treated this variable as a continuous measure (rather than subgroups, e.g., low vs. high tobacco dependency; Detandt et al., 2017) to maximize our chances to find a correlation between heaviness of use and approach/avoidance tendencies (McClelland, 2000). Second, we assessed heaviness of use with the self-reported average number of cigarettes per day. This measure is easy-to-report, and, because it is associated with observable behaviors, it should be less biased than some other measures of tobacco dependency (as the Fagerstrom Test for Nicotine Dependence [FTND]; e.g., Detandt et al., 2017; Larsen et al., 2014; Watson et al., 2013) that may require more introspection (Rehm et al., 2013). To remove potential confounds with heaviness of use we also measured other smoking characteristics (motivation to quit smoking, years of smoking, latency since the last cigarette, and FTND scores). Indeed, we know from previous literature that these smoking characteristics are sometimes related to variation in approach/avoidance bias (Detandt et al., 2017; Larsen et al., 2014; Watson et al., 2013). For instance, approach tendencies toward tobacco increase as the latency since the last cigarette increases (e.g., Watson et al., 2013). Our goal was therefore to control for the effect of these variables in the event that they had an extreme influence on the observed approach/avoidance tendencies (i.e., to the point of hiding the effect of heaviness of use).

A final improvement concerns the reliability/robustness of the data. We conducted multiple replications of our main effects, we analyzed our results with mixed-model analyses (i.e., using both participants and stimuli as random factors, Judd et al., 2012; Westfall et al., 2014), and we performed two Integrative Data Analyses (IDA; Curran & Hussong, 2009). Importantly, mixed-model analyses maximize the robustness and the generalizability of the findings compared to traditional analyses of variance (Judd et al., 2012; Westfall et al., 2014). Moreover, IDA[2] consist in analyzing data by considering jointly all the datasets of all three studies (of course using all the data at hand). One important difference compared to regular meta-analyses is that IDA are to be used when raw data are available, while regular meta-analyses are performed on summary statistics (e.g., effect sizes). This analysis thus provides a broader and more accurate picture of results. Results related to each study are not presented in the main document but can be found in the Supplementary Material section. Of note, we decided to conduct IDA analyses after analyzing all three studies and to reach clearer conclusions.

In our three studies, we systematically assessed approach/avoidance tendencies among light smokers (represented by an approach/avoidance compatibility effect) and, more broadly, the association between heaviness of use and approach/avoidance tendencies toward tobacco. In Studies 2 and 3 our samples also included non-smokers, allowing us to compare the approach/avoidance pattern of results of light smokers with the one of non-smokers. Now we present the general method used in Studies 1-3[3,4].

Method

Participants and Design

To estimate our sample size, we relied on the numbers often used to compare the approach bias of smokers and non-smokers (i.e., around N = 20 per condition; e.g., Bradley et al., 2004; Mogg et al., 2003; C. E. Wiers et al., 2013). In Study 1, we estimated that we needed at least 30 participants but excluded one non-smoker participant recruited by mistake (M_{age} = 23.11, SD_{age} = 5.15, 16 females; M = 7.81 cigarettes/day, SD = 4.52). In the following studies we increased our sample size to increase statistical power. In Study 2, we recruited 80 participants but removed 3 participants because of programming errors and one ex-smoker recruited by mistake, leaving us with 76 participants (M_{age} = 20.11, SD_{age} = 2.97, 55 females; with 53 smokers, M = 6.33 cigarettes/day, SD = 3.84). In Study 3, we recruited 86 participants. Due to technical programming issues, we removed 14 participants, as well as the data of 3 ex-smokers recruited by mistake and 3 other participants having more than 50% of error in the IF-VAAST leaving us with a sample of 68 participants (M_{age} = 20.71, SD_{age} = 2.53, 40 females; with 55 smokers, M = 6.34 cigarettes/day, SD =

2 IDA are also known as "Individual Patient Data meta-analysis" (e.g., Riper et al, 2018), or "mega-analysis" (e.g., Liu et al., 2019).

3 Originally, Study 1 also aimed to test the effect of an avoidance training of tobacco-related stimuli (vs. control condition without training) on subsequent tobacco consumption. For many possible reasons—not elaborated upon here—this training manipulation had no effect on tobacco consumption. Nevertheless, we were able to investigate the link between approach/avoidance tendencies and heaviness of use. We only included participants from the control condition, that is, participants who were presented tobacco-related and control stimuli for both approach and avoidance actions.

4 In Study 3, we additionally used the Approach/Avoidance Task (AAT, Rinck & Becker, 2007) in its irrelevant version (hereafter "IF-AAT"). Given that this task was used in only one of our studies, the procedure and results relating to this task are not described in the main document but can be found in the Supplementary Material section.

4.98). All participants took part in the study in exchange for 10 euros.

The design was always a 2 (compatibility: compatible vs. incompatible) x continuous (heaviness of use: number of cigarettes/day) x 2 (instruction: approach tilted right vs. approach tilted left) with heaviness of use and instruction variables being between-participants[5]. Half of the participants were instructed to approach images tilted to the left and to avoid images tilted to the right; the other half received the opposite instruction (counterbalanced). Depending on image content (tobacco-related vs. neutral) and required action (approach vs. avoidance), each trial could thus either result as compatible (i.e., approaching tobacco and avoiding control) or incompatible (i.e., approaching control and avoiding tobacco). Being faster for compatible (incompatible) compared to incompatible (compatible) trials would reflect an approach (avoidance) bias toward tobacco. Stimuli were those used by Mogg et al. (2003; see also Bradley et al., 2004; Watson et al., 2013), consisting in 40 color photographs representing tobacco-related scenes or objects (e.g., a woman holding a cigarette to her mouth) paired with 40 color photographs depicting control scenes or objects (e.g., a woman applying lipstick). Control images were similar regarding shapes and orientations, and matched as closely as possible for content except for the smoking related cues.

The IF-VAAST was divided into two identical blocks (160 trials each in Studies 1 and 2 and 80 each in Study 3). Each stimulus was presented 4 times in total in Studies 1 and 2 and 2 times in Study 3. Half of the trials was compatible and the other half incompatible. Before the first block, participants performed a training phase of 20 trials. In Studies 1 and 2 training stimuli were 20 images (10 tobacco-related and 10 control) randomly selected from the whole pool of stimuli and in Study 3 the images were grey squares tilted to the left vs. right (e.g., Cousijn et al., 2011).

Procedure and Measures

A few weeks before each study, university students received an online pre-screening questionnaire aimed at recruiting variable samples of daily smokers (Studies 1-3) and non-smokers (Studies 2 and 3). Selected participants then had the opportunity to take part in the laboratory study where they performed the IF-VAAST. Finally, participants answered additional questions (e.g., years of smoking) either in the pre-screening questionnaire or at the end of the study.

Pre-screening questionnaire. In addition to filler questions (relating to cognitive abilities and addictions), smokers indicated the number of smoked cigarettes per day (we selected only participants smoking more than one cigarette per day) and non-smokers indicated whether they were ex-smokers (we discarded ex-smokers given that abstinent individuals seem to display a different bias than non-smokers; Rinck et al., 2018).

IF-VAAST. After giving their written consent, participants sat in front of the screen (23-inch, 60Hz) with a chin rest (screen distance 75cm). Stimuli were displayed on a background giving an impression of depth. The back of the head of a character, representing the participant, was also displayed [6] in the environment (see Figure 1). Stimuli were tilted by 3 angular degrees to the left or right and participants responded with a button box: The middle button was used to start, the one on the top to approach, and the one below to avoid.

When participants pressed the start button, the white circle displayed in the center of the screen was replaced by a fixation cross (for a random duration of 800-2000 ms), which was followed by the stimulus. According to the participants' action, the whole visual environment (i.e., the background image and the target image) was zoomed in (i.e., approach) or zoomed out (i.e., avoidance) by 10% for each button press (i.e., 0.13 angular degrees), giving the visual impression of walking forward or backward. Participants had to press the approach or avoidance key four times for a complete movement. They were instructed to respond as quickly and accurately as possible and we recorded response times from the onset of the target image to the first key press to approach/avoid.

Additional measures. As a function of the study, we measured years of smoking (Study 1: M = 71.34 months, SD = 43.94; Study 2: M = 54.46 months, SD = 24.24; Study 3: M = 54.85 months, SD = 32.33), the motivation to quit smoking (i.e., Questionnaire de Motivation à l'Arrêt du Tabac, score from 0 to 20, Aubin et al., 2004; Study 1: M = 3.93, SD = 3.19), nicotine dependence with the Fagerstrom Test for Nicotine Dependence (FTND, e.g., Detandt et al., 2017; Larsen et al., 2014; Watson et al., 2013; Study 2: M = 1.14, SD = 1.20; Study 3: M = 2.39, SD = 2.13), and the latency since the last cigarette (Study 2: M = 4.70 hours, SD = 11.10; Study 3: M = 19.31 hours, SD = 72.01). Finally, we asked participants about their age and sex.

Integrative Analyses

An IDA (Curran & Hussong, 2009) is close to a meta-analysis, except that it allows the use of raw data (rather than the summary statistics, e.g., effect sizes), but requires the use of identical measures within all studies. Given that our data fulfilled these requirements and that the IDA has advantages compared to the classic meta-analysis (greater power and reliability; Liu et al., 2019), we carried out an IDA by aggregating the data of our three studies. This also

5 Study 3 also included the IF-AAT. All participants went through both tasks and the task order was counterbalanced. Instructions remained the same between the IF-VAAST and the IF-AAT for a given participant (i.e., approach right- vs. left-tilted images). See the Supplementary Material section for more information.

6 Similar effect size for approach/avoidance effects can be found in the VAAST without this character (Rougier et al., 2018).

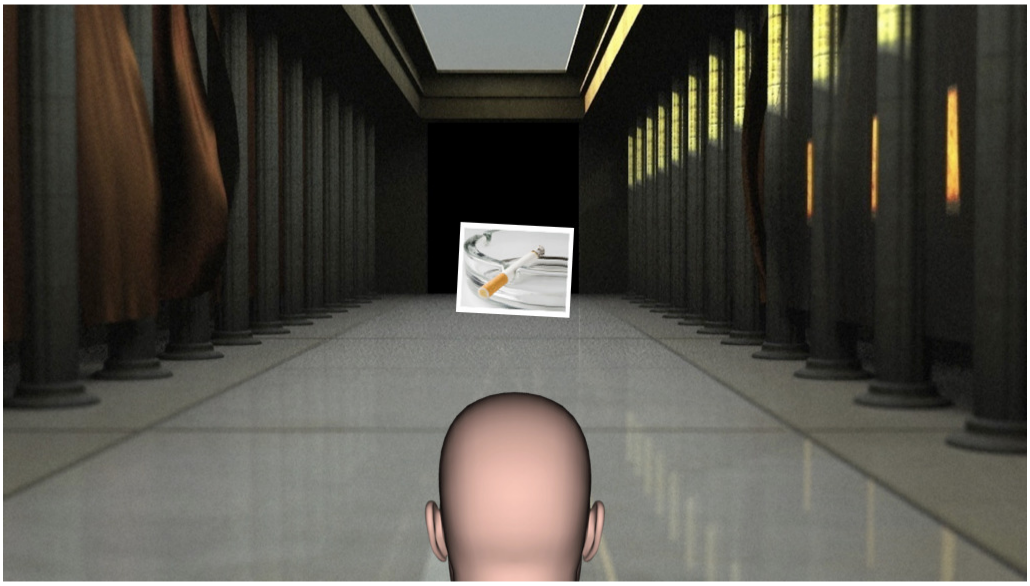

Figure 1. Visual background of the IF-VAAST

Note. In this example, the stimulus is tobacco-related and tilted to the right.

allowed us to use mixed model analyses in testing our effects (there are, to our knowledge, no standards for meta-analyses in mixed models). Mixed-models controlled for potential differences between studies (i.e., models included a variable coding for the type of study), that is, the observed effects were those *above and beyond* potential differences between studies (e.g., whether studies produced significant vs. non-significant effects). Finally, by combining our datasets, we were also able to test the average split-half reliability of the IF-VAAST.

The first IDA tested 1) the crucial interaction between compatibility and heaviness of use as well as 2) the approach/avoidance bias among light smokers. As this analysis focused on smokers, non-smokers were excluded. The second IDA investigated whether light smokers have approach/avoidance tendencies that differ from those of non-smokers. Thus, in this analysis, we included non-smokers and light smokers only (i.e., we removed participants identified as heavy smokers). For the two IDA, we removed incorrect trials (Study 1: 1.28% of the trials, Study 2: 2.70%, Study 3: 2.45%), as well as response times (RTs) faster than 350 ms and exceeding 1600 ms (Study 1: 2.42% of the trials, Study 2: 2.29%, Study 3: 2.37%) and to normalize their distribution, we transformed RTs using an inverse function (Ratcliff, 1993)[7]. Note that the distribution of heaviness of use was somewhat skewed with more light smokers (than heavy smokers). Skewed distributions of independent variables, however, do not require to be transformed (Irwin & McClelland, 2003). None of our control variables (instructions, years of smoking, motivation to quit, nicotine dependence, and latency since the last cigarette) influenced our main results in each study taken separately (all *ps* < .34, see the Supplementary Material for further detail). Moreover, control variables that were common between the three studies (instructions, years of smoking) did not moderate our main results in the two IDA. We thus removed them from subsequent analyses.

Split-Half Reliability of the IF-VAAST

Because the IF-VAAST was used in the tobacco domain for the first time, we tested its reliability regarding the compatibility effect. We obtained the split-half reliability by computing two separate compatibility scores for the first and the second half of the trials (e.g., Field et al., 2011) and we took into account all the participants (smokers and non-smokers) of the three studies. Results showed a relatively small and non-significant correlation, $r = .13$, 95% CI [-.02; .27], $p = .09$.

Integrative Analysis 1: Interaction Between Compatibility and Heaviness of Use

We pooled data from Studies 1-3 into one dataset (N = 141, M_{age} = 20.81, SD_{age} = 3.62, 92 females; M = 6.73 cigarettes/day, SD = 4.45). We excluded non-smokers and we kept variables related to the interaction between compatibility and heaviness of use. The mixed model analysis relied on a 2 (compatibility: compatible vs. incompatible) x continuous (heaviness of use: number of cigarettes/day) x 3 (study: Study 1 vs. Study 2 vs. Study 3) design with all variables except compatibility being between participants.

7 We selected filters and transformations (out of several options, e.g., Rougier et al., 2018) that resulted in the most normal RTs distribution.

Compatibility was contrast coded (compatible coded -0.5 and incompatible coded +0.5), heaviness of use was used in its mean deviated form. The study variable was coded with two orthogonal contrast codes: C1 opposing Study 1 to Study 3 (with Study 1 coded -1, Study 2 coded 0 and Study 3 coded +1) and C2 opposing Study 1 and Study 3 against Study 2 (with Study 1 coded -1, Study 2 coded +2 and Study 3 coded -1). We crossed all these variables as fixed effects and we estimated intercepts and random slopes of compatibility for participants, stimuli, and their interaction[8]. We computed effect sizes (partial η^2) for the mixed-model analyses by relying on the "*t* back" method, that is, by relying on the *F*-value and degrees of freedom estimated for the corresponding test (see Correll et al., 2022)[9]. We did so for all mixed-model analyses reported in this article.

For an average level of heaviness of use, participants were significantly faster for incompatible trials (M = 716 ms, SE = 9 ms) than for compatible trials (M = 718 ms, SE = 9 ms), b = 8.03x10^{-6}, F(1, 127.10) = 3.99, p = .048, η^2 = .03. The compatibility by heaviness of use interaction was significant, b = -2.90x10^{-6}, F(1, 116.70) = 10.45, p = .002, η^2 = .08, indicating that the difference between compatible and incompatible trials (approach bias) increased as a function of the increase in heaviness of use (see Figure 2) [10]. Individuals high on heaviness of use (+1SD) were descriptively, but not significantly, faster for compatible trials than for incompatible ones, b = -4.49x10^{-6}, F(1, 128.50) = 0.70, p = .41, η^2 = .005. Conversely, individuals low on heaviness of use (-1SD), that is light smokers, were significantly faster for incompatible trials than for compatible ones, b = 2.06x10^{-5}, F(1, 116.70) = 12.66, p < .001, η^2 = .10, thus showing an avoidance bias.

Integrative Analysis 2: Compatibility Effect Among Light vs. Non-Smokers

We used raw data from Studies 2 and 3—Study 1 only had smokers and thus was not crossed with the group condition (non-smokers vs. light smokers). In this analysis, light smokers were considered as a group (instead of participants at -1SD of heaviness of use, as in IDA 1) and included participants below the group median of 5.86 cigarettes/day. We pooled data into one dataset (N = 94, M_{age} = 20.53, SD_{age} = 2.15, 66 females; M = 3.38 cigarettes/day for smokers, SD = 1.87) and only kept variables relating to the interaction between compatibility and the group of participants (i.e., non-smokers vs. light smokers). We used a mixed model analysis relying on a 2 (compatibility: compatible vs. incompatible) x 2 (group: non-smokers vs. light smokers) x 2 (study: Study 2 vs. Study 3) design with all variables except compatibility being between participants. We crossed all variables as fixed effects and we estimated intercepts and random slopes of compatibility for participants, stimuli, and their interaction. We contrast coded compatibility (compatible coded -0.5 and incompatible coded +0.5), group (non-smokers coded -0.5 and light smokers coded +0.5), and study (Study 2 coded -0.5 and Study 3 coded +0.5) variables.

On average, response time for compatible trials (M = 720 ms, SE = 12 ms) and incompatible trials (M = 717 ms, SE = 11 ms) did not significantly differ, b = -1.57x10^{-6}, F(1, 6107.00) = 0.09, p = .76, η^2 < .001. More important, the interaction between compatibility and group of participants (i.e., non-smokers vs. light smokers) was significant, b = 2.16x10^{-5}, F(1, 7459.00) = 4.42, p = .036, η^2 < .001, indicating that the difference between compatible and incompatible trials (i.e., approach bias) differed between non-smokers and light smokers (see Figure 3)[11]. Non-smokers were descriptively, but not significantly, faster for compatible trials than for incompatible ones (approach bias), b = -1.24x10^{-5}, F(1, 7543.00) = 2.13, p = .14, η^2 < .001. Conversely, light smokers were descriptively, but not significantly, faster for incompatible trials than for compatible ones (avoidance bias), b = 9.22x10^{-6}, F(1, 6090.00) = 2.51, p = .11, η^2 < .001.

General Discussion

Little is known about the association between heaviness of use and approach/avoidance tendencies and more specifically about light smokers. In the first integrative analysis (Studies 1-3), an interaction showed that stronger heaviness of use was significantly associated with larger approach tendencies toward tobacco and a simple effect showed that light smokers had an avoidance bias. In the second integrative analysis (Studies 2 & 3), we found that light smokers had a different approach/avoidance tendency than non-smokers with descriptively an avoidance bias for the former and an approach bias for the latter, even though these simple effects were not significant. Overall, the association between approach/avoidance tendencies toward to-

8 Results related to random effects are available as Supplementary Material.

9 It should be noted that effect sizes computed in mixed-model analyses are typically smaller than effect sizes computed in more traditional analysis of variance (i.e., "by-participant" analyses; e.g., Judd et al., 2012, 2017). This is the case because mixed-model analyses consider multiple random factors (e.g., participants and stimuli), therefore additional sources of variation. It follows that readers used to interpreting effect sizes for by-participant analyses should refrain from interpreting our effect sizes in light of those values, or directly compare effect sizes from these fundamentally different types of analyses.

10 Overall, the interaction did not significantly vary as a function of the study (omnibus test: χ^2 = 10.79, p = .095). According to our first contrast code C1, this interaction effect did not significantly differ between the two, b = 9.59x10^{-7}, F(1, 131.70) = 0.70, p = .41, η^2 = .005. However, according to the contrast code C2, this interaction was significantly larger in these two studies as compared to Study 2, b = 1.55x10^{-6}, F(1, 101.80) = 6.53, p = .01, η^2 = .06. For more information on each study and on how they differ, please refer to Supplementary Material.

11 This interaction effect did not significantly differ between Study 2 and Study 3, b = 3.72x10^{-5}, F(1, 7459.00) = 3.28, p = .07, η^2 < .001.

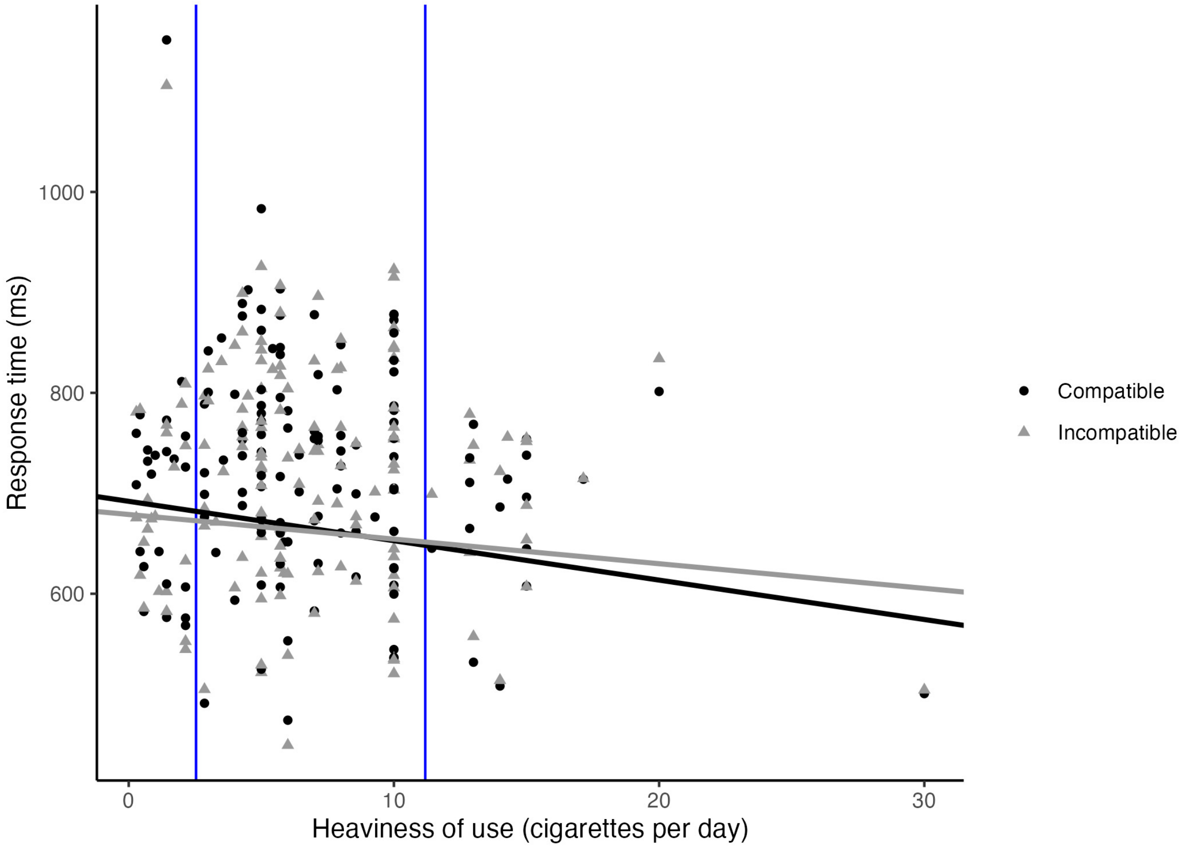

Figure 2. Response time (ms) as a function of trial (compatible vs. incompatible) and heaviness of use (number of cigarettes per day) in the Integrative Data Analysis 1 (Studies 1-3)

Note. Each dot represents a participant's score for the compatible (circle) and incompatible (triangle) condition. Vertical bars (originally colored in blue) indicate the values of -1SD (light smokers) and +1SD (heavy smokers). The slopes were derived from the parameters of the mixed effects model with transformed response time (with an inverse function) that were then untransformed for the sake of readability.

bacco and heaviness of use seems more complex than expected.

Contribution to Models of Addiction

As outlined in the Introduction section, contemporary models of addiction—except the incentive-habits model (Di Chiara, 2000; Mogg et al., 2005)—rely on the general idea that the more people smoke, the greater their approach tendencies. This idea fits well with our results. Conversely, our results are less consistent with the idea that the incentive value granted to tobacco, and therefore the approach bias, is larger at early stages of nicotine dependence (Mogg et al., 2005). A surprising result for both accounts, however, is that light smokers have larger avoidance tendencies than non-smokers. Indeed, if the very (even minimal) experience of smoking develops approach tendencies toward tobacco, how is it possible to account for avoidance tendencies among light smokers?

One possibility is to turn to dual-process models of addiction (e.g., Stacy & Wiers, 2010; Strack & Deutsch, 2004). According to these models, drug consumption is the result of an imbalance between impulsive and deliberative processes (R. W. Wiers & Stacy, 2006). As a function of the increase in substance use, the impulsive system would predominate, giving less room for the influence of deliberative processes. Importantly, however, the impulsive and deliberative systems can interact with each other so that motivational processes can moderate approach tendencies (Deutsch & Strack, 2006; R. W. Wiers et al., 2016; R. W. Wiers & Stacy, 2006). In line with motivated behaviors and self-regulation processes (e.g., Köpetz et al., 2013; Stroebe et al., 2008), one can speculate that light smokers invest to a greater extent the goal of controlling smoking behaviors to maintain a low level of consumption (for a similar reasoning with alcohol see Spruyt et al., 2013; Townshend & Duka, 2007), ultimately resulting in stronger avoidance tendencies.

An alternative reasoning—but yielding to consistent predictions—can also be considered with the single-process propositional model (De Houwer, 2009, 2014; Van Dessel et al., 2019). According to De Houwer (2014), the endorsement and then the activation of—sometimes opposite—propositions (e.g., "I like tobacco", "I should avoid tobacco") could drive approach/avoidance tendencies toward the product. Thus, it would not be the deliberative system influencing the impulsive system but rather automatically activated propositions (e.g., "I should avoid tobacco") present among light smokers influencing approach/avoidance tendencies. Accordingly, given that light smokers should possess more propositions related to tobacco-avoidance than non-smok-

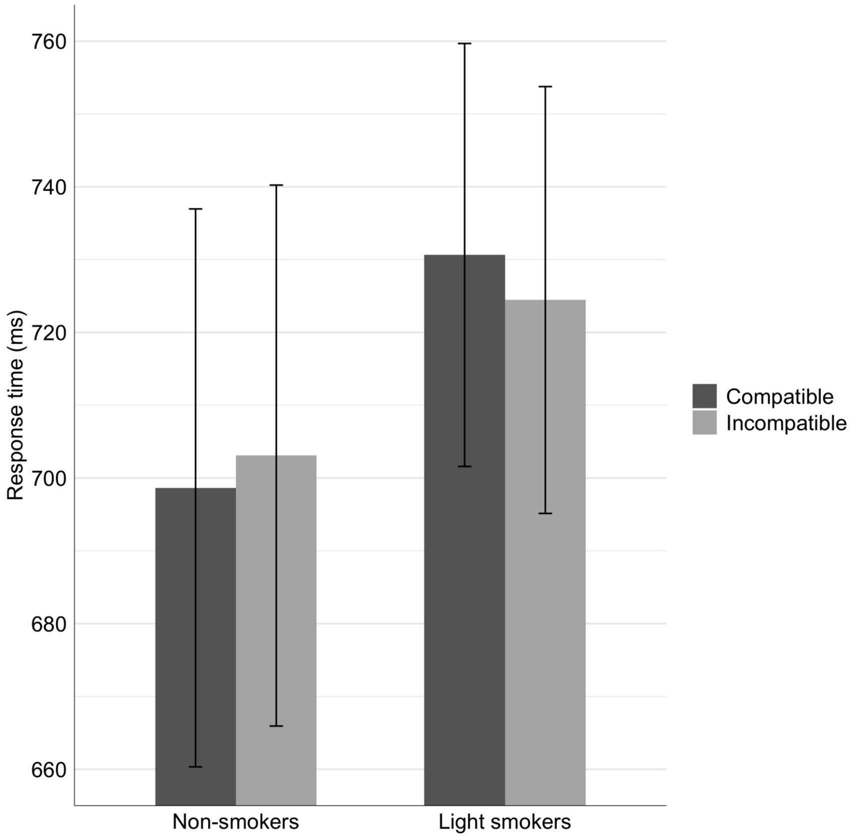

Figure 3. Response time (ms) as a function of trial (compatible vs. incompatible) and the group (non-smokers vs. light smokers) in the Integrative Data Analysis 2 (Studies 2 and 3)

Note. Error bars represent the 95% confidence intervals. For the sake of readability, untransformed response time are represented in the figure (instead of response time transformed with an inverse function).

ers, they would display more avoidance tendencies. To disentangle these explanations, future work could test whether avoidance bias of light smokers depends on the availability of cognitive resources (more than non-smokers or heavy smokers, e.g., Sharbanee et al., 2013; following a motivated behavior account) and/or if this group has a larger activation of the proposition "I should avoid tobacco" (e.g., De Houwer et al., 2015; following the single-process propositional account).

Limitations and Future Directions

Although this work constitutes an interesting theoretical contribution, our results should be considered with caution considering the fact that specific effects usually observed in the literature did not reach significance (e.g., approach bias for heavy smokers), some of the observed effects were close to the critical threshold (e.g., differences in approach/avoidance between light and non-smokers observed in IDA 2), and the split-half reliability in the VAAST was relatively low. Future endeavor should be dedicated to replicate the present findings (e.g., with a relevant feature version of the VAAST). Below we develop in more detail some of these limitations.

First, our sample of heavy smokers only descriptively displayed an approach bias on average, yet it seems well established that heavy smokers have an approach bias toward tobacco (Bradley et al., 2004, 2008; Machulska et al., 2015; Mogg et al., 2003; C. E. Wiers et al., 2013). In fact, our qualification of heavy smokers (i.e., around 11 cigarettes/day)—that was based on the distribution of our sample—relied on a somewhat lower level of tobacco consumption compared to the literature (i.e., 15 cigarettes/day in Bradley et al., 2008; Mogg et al., 2003; Watson et al., 2013; 23 cigarettes/day in C. E. Wiers et al., 2013). Accordingly, our results do not exclude an approach bias, but rather suggest that a stronger effect should be observed among heavier smokers.

Second, when it comes to moderate the approach bias with heaviness of use, variability in heaviness of use seems to be a crucial parameter. Indeed, when referring to the detailed results for each study, readers might notice that the compatibility by heaviness of use interaction (when considering only smokers) was significant in Studies 1 and 3, but not in Study 2 (see Supplementary Materials for more information; see also Footnote 10). As it turns out, the sample of smokers of Study 2 was descriptively less variable (SD = 3.84) than the sample of smokers of Studies 1 (SD = 4.32) and 3 (SD = 4.98). Because this could be an explanation for this discrepancy, future studies should take this factor into account to maximize chances of producing the expected interaction.

Third, although this work suggests that the IF-VAAST is a valuable option to relate approach/avoidance tendencies to real-life indicators (see also Rougier et al., 2020), the test-retest reliability of this task was rather low (on average r = .13). Considering that task reliability is much poorer when using a task irrelevant feature instructions (e.g., r = .04; Field et al., 2011; see also Kersbergen et al., 2015; R. W. Wiers et al., 2013), the obtained value is not surprising. Indeed, because participants are not asked to process the target feature of stimuli (here, neutral vs. tobacco-related), task irrelevant feature versions necessarily imply more noise (i.e., unexplained variability) in the data, ultimately leading to lower test-retest reliability scores. The task version (relevant vs. irrelevant feature) always comes with a tradeoff. Whereas the irrelevant feature version usually comes with poorer reliability than relevant ones, they also decrease voluntary control issues (e.g., Machulska et al., 2015; Watson et al., 2013; C. E. Wiers et al., 2013). In our case, we did not aim to use the task as an absolute index of approach/avoidance, but rather as a tool to demonstrate effects of empirical and theoretical importance (e.g., relationship between approach bias and tobacco consumption). We thus considered a task less prone to controllability to be more important than a task producing good reliability. As such, the IF-VAAST proved its value. Future work should test the reliability of the VAAST in relevant-feature paradigm to gauge whether it could also be used as a good absolute index of approach/avoidance biases.

Finally, this work focused on approach/avoidance tendencies, but the association between smoking characteristics and automatic biases toward tobacco should be further investigated on other related biases, such as the attentional bias. Indeed, research on this topic also reveals mixed results (Bradley et al., 2004; Mogg et al., 2005; Mogg & Bradley, 2002; Munafò et al., 2003; Waters, Shiffman, Bradley, et al., 2003; Waters, Shiffman, Sayette, et al., 2003; Waters & Feyerabend, 2000; Zack et al., 2001). Future work should systematically address this question as we did in the present contribution.

Conclusion

The relationship between smokers' approach/avoidance tendencies and heaviness of use in the literature is mixed and inconsistent. This work constitutes a unique contribution in systematically addressing the question of the existence and the direction of this association. Although a positive association between heaviness of use and approach tendencies is in line with current models of addiction, unexpected findings regarding the presence of an avoidance bias among light smokers also challenges these models. Accordingly, this work is a call for more theoretical and empirical research on light smokers.

Author's Note

This research was part of Marine Rougier's thesis under the supervision of Dominique Muller and Annique Smeding.

Contributions

Contributed to conception and design: MR, DM, AS, RWW, LN

Contributed to acquisition of data: MR, LN

Contributed to analysis and interpretation of data: MR, LN

Drafted and/or revised the article: MR, DM, AS, RWW, LN

Approved the submitted version for publication: MR, DM, AS, RWW, LN

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Competing Interests

None to declare.

Data Accessibility Statement

The data and the R scripts for all the reported studies can be found at: https://osf.io/fcp4h/?view_only=a47504c43f3544918c763e6d666adc80.

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