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Relations Among Caffeine Consumption, Smoking, Smoking Urge, and Subjective Smoking Reinforcement in Daily Life

Hayley R. Treloar, MA,[1,*] Thomas M. Piasecki, PhD,[1] Danielle E. McCarthy, PhD,[2] and Timothy B. Baker, PhD[3]

Caffeine consumption and cigarette smoking tend to occur within the same individuals and at the same time. One potential explanation for this co-use is that caffeine consumption increases subjective smoking reinforcement. Electronic diaries were used to collect momentary reports of smoking, caffeine consumption, temptation/urge to smoke, and subjective smoking reinforcement in 74 prequit smokers. Momentary reports of caffeine consumption and smoking were associated, replicating previous findings. These results remained significant when contextual factors (time of day, weekday/weekend, presence of others, presence of others smoking, location, and past hour alcohol consumption) were covaried. Caffeine consumption was also associated with positive cigarette appraisals and reports of strong temptation/urge to smoke and urge reduction from the prior cigarette. Under the conditions of caffeine consumption versus at other times, smokers were significantly more likely to report their last cigarette as producing a rush/buzz, being pleasant, relaxing, and tasting good. The effects for temptation/urge to smoke and rush/buzz varied as a function of latency since smoking. Caffeine consumption increased reports of urge to smoke and rush/buzz only when smoking occurred more than 15 minutes prior to the diary entry. Findings suggest that caffeine consumption influences some aspects of smoking motivation or affects memorial processing of smoking reinforcement.

Introduction

Caffeine consumption is strongly associated with smoking in both epidemiological[1–4] and clinical populations.[5–7] More smokers than nonsmokers are coffee drinkers, with about 86% of smokers and 77.2% of nonsmokers reporting significant coffee consumption.[4] Not only do smokers tend to drink caffeine and caffeine drinkers tend to smoke, these behaviors often occur at the same time.[8–10] Shiffman *et al.* (2002) observed that the odds of smoking increased 55%, on average, during periods of caffeine consumption. One likely contributing factor is that smoking increases caffeine metabolism, thereby requiring smokers to consume more caffeine to achieve desired effects.[11,12] However, smokers also report that the palatability of cigarettes is enhanced by caffeine consumption, suggesting that some aspects of smoking motivation are influenced by caffeine consumption.[13]

Several behavioral and pharmacological mechanisms have been proposed to explain the association of caffeine consumption and smoking. One plausible explanation is that caffeine and tobacco may be used interchangeably, due to their similar stimulant effects. Albeit by different pathways, caffeine and nicotine both enhance dopaminergic activity,[14] and their popularity is due in part to their propensity to boost energy, concentration, alertness, and mood. Individuals who enjoy and seek these effects may use either substance for these outcomes. Double-blind experimental protocols in humans have also shown caffeine and nicotine to produce similar dose-dependent, positive, subjective drug effects when administered individually.[15,16] In addition, animal and human subjects trained to discriminate nicotine from placebo are more likely to identify a placebo as containing nicotine if it follows an acute administration of caffeine, which suggests that the interoceptive cues of nicotine and caffeine are similar.[17,18] With similar stimulant effects, it may not come as a surprise that caffeine and nicotine tend to be used by the same individuals. However, similar drug effects and shared risk factors are not adequate to explain the temporal co-occurrence of use.

One possible explanation for simultaneous use is that the reinforcing effects of both drugs are enhanced by co-use,

[1]Department of Psychological Sciences, University of Missouri, Columbia, Missouri.
[2]Department of Psychology, Rutgers, The State University of New Jersey, Piscataway, New Jersey.
[3]Center for Tobacco Research and Intervention, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin.
**Current affiliation:* Center for Alcohol and Addiction Studies, Alpert Medical School of Brown University, Providence, Rhode Island.

relative to use of either drug alone. Preclinical animal studies and experimental protocols in humans, however, have yielded inconsistent findings regarding such interactive effects. In animals, the effects of acute co-administration of caffeine and nicotine vary with previous nicotine exposure,[14] and chronic administration of caffeine does not affect nicotine discrimination.[17,19] In human studies, acute caffeine pretreatment does not increase smokers' ability to identify nicotine nasal spray as a stimulant or increase subjective reports of positive drug effects.[18,20] However, chronic caffeine consumption potentiated the positive, subjective effects of high doses of intravenously administered nicotine and reduced the subjective, negative effects of low doses in African American cocaine abusers.[16]

Taken together, experimental findings do not identify a clear mechanism to explain the frequent co-occurrence of smoking and caffeine consumption. Although an effect of caffeine on smoking reinforcement has generally not been observed in controlled experimental studies of humans and animals, whether this lack of support is due to differences between the laboratory and real world is not known. For example, atypical routes of administration (e.g., intravenous,[15,16] nicotine nasal spray,[18,20] caffeine pill[21]) are often used to control the doses of caffeine and nicotine received by participants, resulting in conditions that are notably different from typical self-administration.

The current research used ecological momentary assessment methods (EMA)[22] to examine the relations among caffeine consumption, smoking behavior, craving to smoke, and self-reported cigarette effects in daily life. In a recent EMA study of prequit smokers, consumption of coffee/tea was not related to ratings of pleasantness or satisfaction from smoking[23] or to increased craving.[24]

An important initial question for the present research was whether a strong intertemporal association between caffeine consumption and smoking would be replicated in smokers' day-to-day environments. We also examined the influence of other contextual factors on cigarette smoking and caffeine use. Our primary goal was to examine whether cigarette smoking, as well as reports of urge to smoke and subjective reinforcement from cigarettes, were associated with momentary reports of *ad libitum* caffeine consumption. In a parallel set of analyses in the current sample,[25] time since the cigarette smoked moderated alcohol effects on cigarette effects, suggesting recall biases or other time-dependent effects are important for understanding the connection between appraisals of smoking effects and other drug use. Therefore, we tested whether caffeine effects were moderated by the latency since smoking in the current analyses.

Materials and Methods

Participants

Ninety adult smokers (cigarettes per day ≥ 15) were recruited through newspaper advertisements and waiting lists for a larger smoking cessation study.[26] Other data from these participants were used in prior publications.[25,26] Of the 90 eligible participants, 10 withdrew before providing baseline demographic information and other measures, and another four withdrew before receiving an electronic diary (ED). Two more withdrew before completing a 1-week ED training phase, resulting in a final sample of 74 smokers. Thirty-six (48.6%) were women, 67 (90.5%) were white, and the mean age of volunteers was 41.0 years ($SD = 12.30$ years). Participants reported smoking an average of 24.2 cigarettes per day ($SD = 9.93$) and had been smoking an average of 23.4 years ($SD = 11.91$ years).

Electronic diary and protocol

ED reports were collected with palmtop computers[27] with Pendragon Forms Software.[28] Audible prompts signaled participants to log a report four times per day. The first prompt was scheduled to sound at participants' self-indicated waking time. The second and third reports were randomly scheduled between waking and midday and between midday and bedtime. The final daily prompt was scheduled for participants' self-indicated, typical bedtime. The interviews were persistently available (i.e., they did not time out if not begun immediately after the alarm sounded).

Only prequit diary records were included in the current study analyses. Therefore, treatment procedures and postquit assessments are not described here, but are detailed by McCarthy *et al.*[26] The length of the prequit period was varied across participants. Therefore, following a training phase, some participants (55.4% of the analyzed sample) carried the ED for 6 weeks prior to the quit date while others made ED reports for 3 weeks prior to the quit date. The total number of prompts delivered by the ED during the prequit period was 9,660. Participants completed 7,940 diary entries in response to these prompts, representing a response rate of 82.2%. Diary entries completed within 30 minutes of a previous assessment were not analyzed (233 entries; 2.9%), resulting in a final set of 7,707 diary records used for analysis.

Measures

Caffeine consumption (past hour). The diary protocol stated, ''Check any of the following that you have consumed in the past hour.'' Participants were provided the following options: (a) coffee, (b) other caffeinated beverage, (c) decaf coffee, (d) other noncaffeine beverage, (e) alcohol, and (e) other intoxicating substance. Coffee and other caffeinated beverage options were collapsed into a dichotomous variable (1 = past-hour consumption endorsed, 0 = no consumption reported).

Recent smoking (past 15 minutes). In each diary entry, participants were asked, ''Have you smoked in the last 15 minutes?'' (1 = yes, 0 = no).

Urge to smoke and cigarette effects. In each diary assessment, participants were asked, ''Have you had a strong temptation/urge to smoke in the last 15 minutes?'' (1 = yes, 0 = no). In addition, each diary interview asked, ''What was your most recent cigarette like? (check all that apply).'' Checklist items used in the present analyses were: (a) rush/buzz, (b) good taste, (c) pleasant, (d) relaxing, (e) reduced urge. These items were recoded into separate dichotomous variables (1 = endorsed, 0 = not endorsed). Administration of the cigarette effects item was contingent on the participant reporting having smoked one or more cigarettes since the last diary report in response to an earlier item in the diary assessment. As a result, ratings of cigarettes were missing for 307 diary records (4%) for which this criterion was not met.

Contextual variables. Several contextual predictors/covariates of urge and cigarette effects were examined. Diary time stamps recorded the time and date of each entry. We recoded these time stamps to create a set of dummy codes indicating *time of day*: 4am–12pm (reference category), 12pm–4pm, 4pm–8pm, 8pm–12am, and 12am–4am. Additionally, we coded whether each record was made on a *weekend* (defined as falling between 6pm Friday and 6pm Sunday) or a weekday. Two diary items assessed whether smoking occurred in the presence of others, and if so, whether these other individuals were smoking. One item asked, ''In the last 15 minutes, have you been with: (check all that apply)'' and was followed by these checklist options: (a) no one, (b) spouse/partner, (c) other family member, (d) other person you know, (e) stranger. These responses were collapsed to create a *presence of others* variable (0 = no one, 1 = any other response). A second item asked, ''In the last 15 minutes, have you seen any of these people smoke? (check all that apply)'' followed by the same checklist options. These responses were recoded to create a *presence of others smoking* variable (0 = no one, 1 = any other response). A final item assessed the current location of the participant when the alarm sounded. Response options for the *location* variable were: (a) primary residence (''home''), (b) work or school, (c) bar/restaurant, (d) other public place, (e) vehicle, and (g) other location. Each response option was coded as a dichotomous variable and all locations were entered as a set in the present analyses, with ''home'' as the reference category.

Analytic strategy

To account for the clustering of observations within participants, a Generalized Estimating Equations (GEE) approach[29,30] was implemented with STATA/SE v9.0.[31] Each dependent variable was coded as a dichotomous variable (e.g., recent smoking or not, urge endorsed or not). We specified a binomial family and logit link function to obtain the log odds of smoking in response to a particular predictor variable (i.e., contextual variables, presence or absence of caffeine consumption). An AR(1) autoregressive within-cluster correlation structure was specified.

First, in separate models, we examined whether caffeine consumption and smoking were predicted by contextual variables: time of day, weekend, presence of others, presence of others smoking, location, and past hour alcohol consumption. Next, we tested whether caffeine consumption and recent smoking were associated with smoking urge and subjective appraisals of reinforcement from the last cigarette. We anticipated that cigarette appraisals may be influenced by how recently the last cigarette was smoked (e.g., drug effects change with time, recent cigarette effects may be more available in memory, ratings of distant cigarettes may be influenced by expectancies). Therefore, we also included recent smoking as a potential moderator of caffeine effects in multivariate analyses. All contextual factors were included as covariates with caffeine consumption, recent smoking, and an interaction term to test whether recent smoking moderated the effects of caffeine consumption on smoking urge and reinforcement.

Results

Momentary reports of caffeine consumption and smoking

Caffeine consumption. In 3,027 diary entries (39.3%), caffeine consumption was reported to have occurred within the past hour. Consumption of coffee as opposed to other forms of caffeine was indicated in approximately half of these entries (56.0%). On average, participants reported caffeine use in 40.91 diary records ($SD = 31.3$).

Table 1. Adjusted Odds Ratios and Associated Confidence Intervals for Multivariate Models Predicting Past-Hour Caffeine Consumption and Recent Smoking From Contextual Variables

	Caffeine consumption		*Recent smoking*	
Predictor	*OR*	*95% CI*	*OR*	*95% CI*
Time of day				
12pm–4pm	0.76***	0.66–0.86	0.96	0.84–1.10
4pm–8pm	0.62***	0.55–0.71	1.06	0.92–1.21
8pm–12am	0.48***	0.42–0.54	1.20**	1.06–1.36
12am–4am	0.36***	0.20–0.63	0.79	0.47–1.33
4am–12pm (reference)	*1.00*	—	*1.00*	—
Weekend	1.05	0.93–1.18	0.97	0.87–1.08
Presence of others	0.91	0.82–1.01	0.81***	0.73–0.90
Presence of smoking	1.47***	1.27–1.69	3.60***	3.12–4.14
Location				
Work/school	2.40***	2.12–2.73	0.51***	0.45–0.59
Vehicle	1.40***	1.17–1.66	2.06***	1.71–2.47
Other public place	1.09	0.85–1.39	0.86	0.67–1.11
Other location	1.05	0.85–1.29	0.87	0.71–1.07
Bar/restaurant	1.44*	1.00–2.06	1.29	0.90–1.84
Home (reference)	*1.00*	—	*1.00*	—
Alcohol consumption	0.34***	0.27–0.44	1.33**	1.10–1.61
Caffeine consumption	—	—	1.61***	1.46–1.79
Recent smoking	1.60***	1.45–1.77	—	—

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
OR, odds ratio; CI, confidence interval.

Recent smoking and urge. Smoking in the past 15 minutes was reported in 3,345 diary entries (43.4%). A strong urge to smoke was indicated in 3,503 diary records (45.5%).

Contextual predictors of caffeine consumption and smoking

Table 1 presents the adjusted odds ratios for multivariate models predicting caffeine consumption and recent smoking from contextual covariates (including alcohol consumption and smoking or caffeine, respectively). Caffeine consumption was significantly associated with increased odds of cigarette smoking (OR = 1.61, $p < 0.001$, [95% CI 1.46, 1.79]), even after accounting for the influence of alcohol consumption and other contextual factors.

Smoking urge and subjective cigarette effects

Table 2 summarizes the results of models predicting urge to smoke and subjective cigarette effects from caffeine consumption, recent smoking, and their interaction. Caffeine consumption and recent smoking were significantly associated with increased odds of reporting temptation/urge to smoke, all positive cigarette appraisals, and urge reduction. Temptation/urge to smoke and rush/buzz main effects were qualified by an interaction between caffeine use and smoking. Stratified analyses (Table 2) indicated that, when smoking was recent (past 15 minutes), caffeine use was unrelated to temptation/urge to smoke. However, when smoking was nonrecent (>15 minutes prior), caffeine consumption was significantly associated with temptation/urge to smoke (OR = 1.23, $p = 0.004$, [95% CI 1.07, 1.42]). Similarly, caffeine consumption was unrelated to rush/buzz reports when smoking was recent, but was significantly associated with increased likelihood of rush/buzz endorsement when smoking was nonrecent (OR = 1.58, $p < 0.001$, [95% CI 1.23, 2.03]). Caffeine consumption was associated with increased endorsement of good taste regardless of the delay since the last cigarette (recent smoking: OR = 1.31, $p < 0.001$, [95% CI 1.16–1.48]; nonrecent smoking: OR = 1.37, $p < 0.001$, [95% CI 1.24, 1.53]). Counts of records endorsing smoking urge and positive, subjective effects of cigarettes stratified by recent smoking and caffeine consumption are displayed in Table 3.

Discussion

It is widely acknowledged that caffeine consumption is associated with cigarette smoking,[3,4] and moreover, that smoking frequently occurs in the context of caffeine consumption.[9,10] Clinically, it is important to consider whether caffeine consumption encourages smoking or makes it more difficult to quit.[21] Although the high rates of co-use of caffeine and tobacco suggest that these agents complement each other, few studies have examined the effect of caffeine on smoking reinforcement in daily life. Using real-time records of smokers' daily experiences, we found that the odds of smoking increased with caffeine consumption, even when correlated contextual predictors of caffeine consumption and smoking, were statistically controlled. In addition, caffeine consumption predicted increased reports of urge to smoke and subjective reinforcement from cigarettes.

Given that we found temporal contiguity between caffeine consumption and smoking, it is not surprising that they

TABLE 2. ODDS RATIOS AND ASSOCIATED CONFIDENCE INTERVALS FOR MULTIVARIATE INTERACTIVE MODELS PREDICTING URGE TO SMOKE AND CIGARETTE EFFECTS

	Multivariate, interactive models						*Stratified analyses*			
	Caffeine		*Smoking*		*Caffeine × smoking*		*Caffeine use with recent smoking*		*Caffeine use without recent smoking*	
Dependent measure	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Urge	1.27***	1.11–1.46	6.65***	5.85–7.56	0.78*	0.65–0.95	0.92	0.79–1.07	1.23**	1.07–1.42
Rush/buzz	1.44**	1.15–1.81	2.06***	1.68–2.52	0.67**	0.50–0.90	0.86	0.70–1.06	1.58***	1.23–2.03
Good taste	1.34***	1.22–1.47	1.23***	1.13–1.34	1.01	0.89–1.15	1.31***	1.16–1.48	1.37***	1.24–1.53
Pleasant	1.30***	1.15–1.46	1.39***	1.25–1.55	0.87	0.74–1.02	1.07	0.93–1.23	1.32***	1.16–1.51
Relaxing	1.19**	1.06–1.35	1.43***	1.28–1.60	1.00	0.85–1.18	1.16*	1.02–1.33	1.18*	1.03–1.34
Reduced urge	1.14**	1.04–1.26	1.27***	1.16–1.39	0.93	0.82–1.07	1.05	0.93–1.18	1.24***	1.11–1.38

All contextual variables listed in Table 1 were included as covariates in these models. The pattern of significance did not change when univariate models were considered without covariates.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3. Endorsement of Urge and Positive Cigarette Appraisals Within Recent and Nonrecent Smoking and Caffeine Records

	Nonrecent smoking				*Recent smoking*			
	Nonrecent caffeine (n = *2,808*)		*Recent caffeine* (n = *1,554*)		*Nonrecent caffeine* (n = *1,872*)		*Recent caffeine* (n = *1,473*)	
	n	%	n	%	n	%	n	%
Urge	704	25.1	460	29.6	1,344	71.8	995	67.5
Rush/buzz	162	5.8	120	7.7	224	12.0	171	11.6
Good taste	696	24.8	515	33.1	530	28.3	545	37.0
Pleasant	638	22.7	433	27.9	603	32.2	467	31.7
Relaxing	876	31.2	553	35.6	773	41.3	703	47.7
Reduced urge	1,428	50.9	882	56.8	1,132	60.5	889	60.4

shared some of the same contextual predictors. We observed that being in the presence of other smokers was associated with a modest increase in the odds of caffeine consumption (47%) and associated with a 260% increase in the odds recent smoking, even when controlling for several other correlated contextual variables. In contrast, merely being in the presence *of others per se* (regardless of their smoking status) was associated with *decreased* odds of recent smoking and not significantly associated with caffeine use. Taken together, these findings suggest that the social facilitation of smoking is fueled by the camaraderie or stimulus properties of mutual smoking behavior, rather than simply being in a social setting. The findings could also reflect prohibitions on smoking in workplaces or other locations; these constraints (rather than a search for social contact *per se*) may lead smokers to cluster in designated smoking-permitted areas. The sensory cues of others' smoking or sharing a ''smoke break'' may prompt consumption of both caffeinated beverages and cigarette smoking. A more complete look at this association would include assessment of the presence of others consuming caffeine.

There were several methodological differences between our study and a previous ecological study examining the effect of coffee/tea on reports of cigarette craving[24] and smoking satisfaction.[23] First, the definition of caffeinated beverages in the current study included coffee as well as any other type of caffeinated beverage, rather than coffee/tea consumption in particular. Next, the temporal resolution of assessment of caffeine consumption and smoking differed across research protocols. In prior work, participants self-initiated ED records prior to smoking each cigarette.[23,24] Our study protocol involved participants responding to four prompts across the study day, thereby permitting analysis of cigarettes smoked within two temporal windows prior to ratings: viz. within the last 15 minutes or before. Last, we had participants choose from a list of possible effects of smoking rather than using multipoint ratings.

Latency since smoking moderated the effect of caffeine consumption in models predicting urge to smoke and rush/buzz. When the last cigarette was smoked recently, caffeine consumption was not related to reports of urge to smoke or rush/buzz. Thus, these findings agree with previous ecological research that focused on craving and smoking satisfaction ratings made shortly after smoking and failed to find any caffeine effects.[23,24] However, similar to previous findings for alcohol consumption and smoking reinforcement,[25] when cigarette reports were delayed, caffeine consumption was associated with increased reports of urge to smoke and rush/buzz. Notably, even where significant interactions were not observed, when smoking was *not* recent, positive cigarette appraisals were significantly more likely with caffeine consumption than without. This effect was generally not observed when smoking was recent.

In general, there was deterioration in appetitive ratings of cigarettes with distant versus proximal smoking. For instance, ''pleasant'' ratings were less common with nonrecent cigarettes, but recent use of caffeine mitigated this drop. A similar pattern was observed for ''reduced urge'' and ''rush/buzz.'' The cause of this effect is unknown. One possibility is that the reports from short smoking-report latencies are more accurate; that is, the 15-minute-plus delay biases or distorts memory of the actual effects of smoking, but caffeine reduces such memorial biasing. On the other hand, the results may elucidate a process in which the ongoing experience of drug effects changes with joint use. In general, as time since smoking increases, the appetitive effects of the cigarette generally decrease (see Table 3). It is possible that this occurs due to reduced dopaminergic tone or release, which, in turn, could be due to distributional tolerance to nicotine or nicotinic receptor desensitization.[32,33,a] However, caffeine could mitigate this effect because it also stimulates dopamine release via different mechanisms.[34] In other words, caffeine may maintain dopaminergic tone via nonnicotinic mechanisms. This account is similar to Sayette *et al.*'s suggestion that alcohol enhances ''savoring'' of smoking cues, separate from actual cigarette effects.[35] Likewise, mild tobacco deprivation may modulate the impact of dopaminergic agonists so that caffeine consumption becomes increasingly influential as interoceptive withdrawal signals increase, manifesting as increased impact of caffeine since time of last smoking.[33,36,37,38] Such effects might also

[a]This account suggests that mesolimbic dopamine activation would enhance hedonic ratings (e.g., rush/buzz) and urge level. The involvement of dopamine in drug urge or ''wanting'' is strongly established; there is less evidence that dopamine modulates hedonic experience. It may be that dopamine enhances reports of hedonic aspects of drug effects because dopamine enhances drug wanting (craving for drug) and many drug users are not skilled in distinguishing between drug liking and drug wanting (see Berridge[36] for a discussion of these issues).

spur smoking behavior. Of course, other accounts are possible (e.g., caffeinated beverages are conditioned stimuli for cigarettes and therefore elicit conditioned dopaminergic or other conditioned responses to the nicotine unconditioned stimulus). Future laboratory and ecological research is needed to probe more carefully whether the association of caffeine consumption and smoking is mediated by increased positive expectancies and urges. More generally, the finding that both alcohol and caffeine appear to modulate the motivational effects of tobacco in a time dependent manner should encourage further exploration of the temporal dynamics of smoking effects.

The present study has potential limitations. We could not resolve the order in which caffeine and cigarettes were used when both behaviors were indicated in the same diary report. Because the assessment window for caffeine use (past hour) was wider than for our recent smoking question (past 15 minutes), one would expect that caffeine use frequently preceded recent smoking episodes. However, in the event that a participant consumed caffeine after a cigarette, and both drugs were consumed within 15 minutes of the diary prompt, the participant should have answered both questions affirmatively. Future ecological research on caffeine and tobacco should employ refined assessments with better temporal resolution. Another limitation is that data on caffeine dose were not collected. Finally, while the term ''smoking reinforcement'' is used in this paper, we did not gather data on functional reinforcement *per se*, but rather examined reports of craving and the subjective effects of cigarette use.

Conclusions

Our findings that caffeine consumption was associated with temptation to smoke and rush/buzz, particularly for deprived smokers, and increased reports of taste satisfaction from cigarettes suggests that caffeine consumption influences processes that could contribute to initiation, continuation, and recovery from tobacco dependence. In the current sample, caffeine consumption was reported for more than half of all smoking records (56%). In addition, odds of smoking were increased by 61% during caffeine consumption intervals. Although the clinical importance of these findings cannot be conclusively ascertained, our data argue for continued investigation of the relation between caffeine consumption and smoking in real-world settings.

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Author Disclosure Statement

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Address correspondence to:
Hayley Treloar, MA
Center for Alcohol and Addiction Studies
Brown University
Box S121-5
Providence, RI 02912

E-mail: hayley_treloar@brown.edu