

## **Consumption and Foraging Behaviors for Common Stimulants (Nicotine, Caffeine)**

James G. Phillips, Jonathan Currie, and Rowan P. Ogeil

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## Consumption and Foraging Behaviors for Common Stimulants (Nicotine, Caffeine)

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**Q3**

5 Models are needed to understand the emerging capability to track consumers' movements. Therefore, we examined the use of legal and readily available stimulants that vary in their addictive potential (nicotine, caffeine). One hundred sixty-six participants answered the Kessler Psychological Distress Scale (K10), the Severity of Dependence Scale for nicotine and caffeine, and reported the number of times and locations stimulants were purchased and used. On average, nicotine dependent individuals made their purchases from 2 locations, while caffeine dependent individuals consumed caffeine at 2 locations, but some people exhibited a greater range and intensity of use. Stimulant foraging behavior could be described by power laws, and is exacerbated by dependency. The finding has implications for attempts to control substance use.

### KEYWORDS

Nicotine; caffeine; dependence; foraging; location aware; mobile phone

**Q4**

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**Q5**

### Highlights

- 15
- Stimulant foraging can be explained by power laws, and is greater in dependent users.
  - Nicotine dependent individuals purchase nicotine from an average of two locations.
  - Caffeine dependent individuals consume caffeine at an average of two locations.
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**Q6**

### Introduction

The use of psychoactive substances can lead to increased involvement, preoccupation with the substance, and dependence.<sup>1</sup> Attempts to control the availability of psychoactive substances may be challenged by the increased appetitive behaviors of heavier users.<sup>2</sup> The tracking of patterns of substance use was only possible under specific circumstances, for example when documented by overdose.<sup>3</sup> However, this may change as emerging technologies (e.g., Google's "Your Timeline") have the potential to track and record people's purchases,<sup>4,5</sup> or their locations.<sup>6,7</sup> Hence, the present article sought methods of understanding the behavior of substance users, by considering the purchase and consumption of two legally available stimulants (nicotine and caffeine).

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Nicotine is a widely used stimulant.<sup>8</sup> Regular smoking is associated with dependence and long-term health problems,<sup>9</sup> and restrictions are placed on nicotine use by specific groups (e.g., minors). In contrast, few formal constraints are placed upon the use of caffeine. Caffeine is also used as a cognitive enhancer, but it has less addictive potential.<sup>10,11</sup> Moderate consumption of caffeine is not associated with long-term adverse health effects.<sup>12</sup> However, dosages and patterns of caffeine use have changed over the last 15–20 years,<sup>13</sup> and a dependence syndrome has been documented.<sup>14</sup> DSM5 indicates that caffeine warrants further study.<sup>15</sup>

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### Simple central place foraging

Studies of animal foraging behavior may offer convenient models to assist in the understanding of the ways in which substances might be acquired by users.<sup>16</sup> The simplest (Central Place) model of foraging would propose that substance users commence their search for resources from a home base or some other familiar place.<sup>16</sup> For example, there are relationships between the density of outlets licenced to sell alcohol, and engagement in risky patterns of alcohol consumption (e.g., "bingeing"),<sup>17</sup> dependence,<sup>18</sup> and increased levels of crime.<sup>19</sup> If the locations where

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**Q7**

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substances are available are fixed and known, then a substance user can systematically check them until the desired substance is obtained. In this case, the number of times a substance is purchased would be directly linearly proportional to the number of locations at which a user purchases substances.

### Random brownian motion

However, recent research has suggested that relationships between spatial density of substance providers and harm are not linear in nature. These relationships depend on a variety of factors, such as individual drinking patterns and preferences, and social and structural characteristics such as access to transport.<sup>20</sup> Where conditions are more uncertain, researchers have applied alternative models of foraging behavior.<sup>21,22</sup> If resources are randomly available and access is influenced by a multiplicity of factors, foraging would likely involve a more random search pattern. Random motions that have a *probabilistic element* are called Brownian motions. A search with a probabilistic element would fit the number of purchases and locations onto exponential functions that are linear on single log plots.<sup>21,23</sup>

However, there are other factors, such as dependence, that may also influence appetitive behaviors.<sup>1</sup> Phillips and Ogeil<sup>24</sup> asked people the numbers of times and places at which they consumed alcohol and gambled. People were asked about visits to a specific venue, and visits to other venues. Problem gamblers or problem drinkers were found to visit a specific venue more often,<sup>24</sup> but problem drinkers and problem gamblers had an extended range, as they also reported that they visited other venues more often.<sup>24</sup>

### Lévy Walk

Simulations and studies of animal foraging behavior suggest that random Brownian motion may suffice when resources are plentiful, but that other forms of search may become necessary if resources are scarce.<sup>23,25</sup> Where resources are scarce, a form of foraging called a Lévy walk may be more efficient. During a Lévy walk foragers typically search within an area, but their movements are super-diffusive as they occasionally perform larger movements to extend their range so that they no longer cover the same ground.<sup>26</sup> In humans this has been likened to the decision as to whether to exploit “here” or explore “there.”<sup>27</sup>

However, these behaviors may not actually arise from conscious consideration as similar search patterns also occur in lower organisms.<sup>28</sup> Simulations suggest that Lévy walk foraging tends to reduce periods of famine.<sup>29</sup> As both resource availability and trip length have probabilistic elements, Lévy walk foraging would fit the numbers of purchases and locations onto power laws that are linear on double log plots.<sup>16,21,23</sup>

The foraging of substance users is relevant to: (1) governments and legislators who may wish to restrict access to a substance,<sup>30</sup> and (2) the development of reminder technologies<sup>31–33</sup> to provide outpatient support for people seeking to reduce the amounts that they drink or gamble.<sup>34</sup> While previous studies have estimated visits to relatively *fixed sites* of consumption,<sup>24</sup> it is also important to determine patterns of purchase and consumption occurring for *more readily accessible* products, such as nicotine and caffeine, that are associated with substance dependency.

To obtain an estimate of frequency of foraging, the present article uses the self-reported number of times and locations per day that consumption occurred, and examined the numbers of times and locations per week that purchases were made. Although these are not the raw frequencies of trips used by other researchers,<sup>23</sup> the temporal contiguity of events can be used as an estimator of event frequency.<sup>35</sup> Therefore, the consideration of times/locations per day/week would be homologous when converted into probability density functions.<sup>35</sup> A comparison of two stimulants with varying addictive potential, and different constraints upon access will then provide insights into patterns of use and appropriate models explaining stimulant foraging (Simple Central Place, Random Brownian Motion, or Lévy Walks).

## Methods

### Participants

There were 166 participants (74 males, 92 females) with a mean age of 28.43 years (standard deviation 9.99 years). The majority of the sample (69.9%) had some form of employment, and 51.2% reported undertaking some form of study. Most participants had some level of post-secondary school education, with 14.5% having a trade or apprenticeship, and 57% having an undergraduate or postgraduate university qualification. After reading an explanatory statement, participants completed an online survey approved by

155 institutional ethics committees. The survey was avail-  
 160 able for 3 months. It was hosted on SurveyMonkey  
 and posted on Australian (My Monash; Whirlpool  
 Forum) and international (Reddit) online bulletin  
 boards.

## 160 **Materials**

Participants were asked the typical number of times  
 and places each: (1) day they used nicotine and caf-  
 feine; and (2) week they purchased nicotine and caf-  
 feine. Guidelines as to caffeine content were provided  
 165 to assist participants in estimating their daily dose of  
 caffeine in milligrams. As the number of instruments  
 devoted to caffeine is limited, the Severity of Depen-  
 dence Scale (SDS)<sup>36</sup> was adapted for use with caffeine  
 (obtained Cronbach's alpha = .83). For comparison  
 170 purposes the same scale was used for nicotine  
 (obtained Cronbach's alpha = .94). A cutoff of "4" on  
 this scale is commonly used to separate "non-depen-  
 dent" from "dependent" substance users.<sup>37,38</sup> Only 12  
 175 respondents were dependent upon both caffeine and  
 nicotine. As an index of psychological distress, partici-  
 pants were also asked to complete the K10.<sup>39</sup>

## Results

Participants that reported dependence upon nicotine  
 (SDS = 7.08, SE = .38) smoked significantly more  
 180 times a day ( $t(164) = 11.574, p < .001, \eta^2 = .45$ ) than  
 participants that were not dependent upon nicotine  
 (SDS = .21, SE = .06). Nicotine dependent individuals  
 also smoked in significantly more places ( $t(164) =$   
 13.502,  $p < .001, \eta^2 = .53$ ) and *purchased* nicotine in  
 185 significantly more places ( $t(164) = 10.607, p < .001,$   
 $\eta^2 = .41$ ) at more times ( $t(164) = 12.995, \eta^2 = .51$ ;  
 see Table 1). Nicotine dependence as measured by the  
 SDS was associated with higher levels of psychological

**Table 1.** Mean number of times and places per day that a stimu-  
 lant is used and the number of locations and times that a stimu-  
 lant is purchased per week (standard errors in brackets).

	Nicotine		Caffeine	
Non-dept	Times used	Places used	Times used	Places used
	.70 (.27)	.23 (.07)	2.41 (.21)	1.64 (.09)
Dependent	Times bought	Places bought	Times bought	Places bought
	11.87 (1.35) <sup>aa</sup>	3.00 (.28) <sup>aa</sup>	1.66 (.12)	3.43 (.32)
	Times used	Places used	Times used	Places used
	1.46 (.12) <sup>aa</sup>	2.34 (.30) <sup>aa</sup>	3.68 (.28) <sup>aa</sup>	2.21 (.12) <sup>aa</sup>
	Times bought	Places bought	Times bought	Places bought
			2.43 (.31) <sup>aa</sup>	5.78 (.90) <sup>aa</sup>

<sup>a</sup>Significantly different from non-dependent.

distress as measured by the K10 ( $r(164) = .248, p <$   
 .001). 190

Participants that reported a dependence upon caf-  
 feine (SDS = 6.24, SE = 0.32) had a significantly ( $t$   
 (164) = 3.201,  $p < .01, \eta^2 = .06$ ) higher estimated  
 dose of caffeine (405 mg SE = 32) than the estimated  
 dose (283 mg SE = 21) of those that were not depen- 195  
 dent upon caffeine (SDS = 0.98, SE = 0.09). Caffeine  
 dependent individuals reported *consuming* caffeine at  
 significantly more times ( $t(164) = 2.805, p < .05, \eta^2$   
 = .07) and places ( $t(164) = 3.673, p < .001, \eta^2 = .08$ )  
 than those that were not caffeine dependent (see 200  
 Table 1). Caffeine dependent individuals *purchased*  
 caffeine in significantly more places ( $t(164) = 3.096,$   
 $p < .01, \eta^2 = .06$ ) and more times ( $t(164) = 2,805, p$   
 $< .01, \eta^2 = .05$ ). Caffeine dependence was associated  
 with higher levels of psychological distress ( $r(164) =$  205  
 .307,  $p < .001$ ).

Simple, Brownian, and Lévy Walk models of forag-  
 ing behavior were then applied to the patterns of for-  
 aging behavior, by testing whether the overall data  
 were best fit by a linear, exponential function or power 210  
 law. Whereas a simple linear model could explain  
 between 12.6 and 73.5% of the variance, and an expo-  
 nential model explained between 13.4 and 73.6% of  
 the variance, a power law explained between 31.9 and  
 88.9% of the variance. Power laws always provided the 215  
 best fit to spatio-temporal patterns of stimulant pur-  
 chase and use.

Lines of best fit for power laws describing the times  
 that stimulants were used (per day) or purchased (per  
 week) may be see in Table 2. Although good fits were 220  
 obtained for nicotine data, the better fit was obtained  
 for daily use. Fits were not as good for the caffeine  
 data, with the better fit occurring for caffeine weekly  
 purchases.

To visualize foraging behavior Figure 1 presents scatter  
 plots and lines of best fit for daily smoking and  
 weekly caffeine purchases. Although the overall sample  
 used nicotine on average about four times a day in  
 around one location, some individuals demonstrated a  
 greater range and intensity of use. The use of caffeine 230  
 seemed somewhat more uniform. Again the overall sam-  
 ple exhibited somewhat restricted caffeine purchasing  
 behavior (about two times per week from around four  
 places) but there were still some individuals that demon-  
 strated a greater range and intensity of purchasing. 235

To understand the foraging patterns of stimulant  
 users, a power law was then fitted separately to

**Table 2.** Lines of best fit for power laws describing use and purchase of stimulants (times and places are natural log transformed +1), for complete sample, dependent, and non-dependent stimulant users (Adjusted  $r^2$  in brackets).

	Complete Sample	Non-Dependent	Dependent
Nicotine (daily use)	$Y = 1.673X + .026$ ( $R^2 = .89$ )	$Y = 1.593X - .003$ ( $R^2 = .90$ )	$Y = 1.195X + .739$ ( $R^2 = .40$ )
Nicotine (weekly purchases)	$Y = .712X + .051$ ( $R^2 = .86$ )	$Y = .882X + .015$ ( $R^2 = .87$ )	$Y = .457X + .369$ ( $R^2 = .59$ )
Caffeine (daily use)	$Y = .350X + .184$ ( $R^2 = .32$ )	$Y = .339X + .169$ ( $R^2 = .32$ )	$Y = .185X + .428$ ( $R^2 = .06$ )
Caffeine (weekly purchases)	$Y = .505X + .275$ ( $R^2 = .66$ )	$Y = .505X + .258$ ( $R^2 = .64$ )	$Y = .485X + .344$ ( $R^2 = .65$ )

consumption patterns of the nicotine dependent and caffeine dependent individuals (see Table 2). For each group significant fits were obtained. The greater intercept for dependent stimulant users indicate a greater base rate of substance use. The shallower slopes for dependent stimulant users indicate that substance use and purchase are occurring over a greater range of locations.

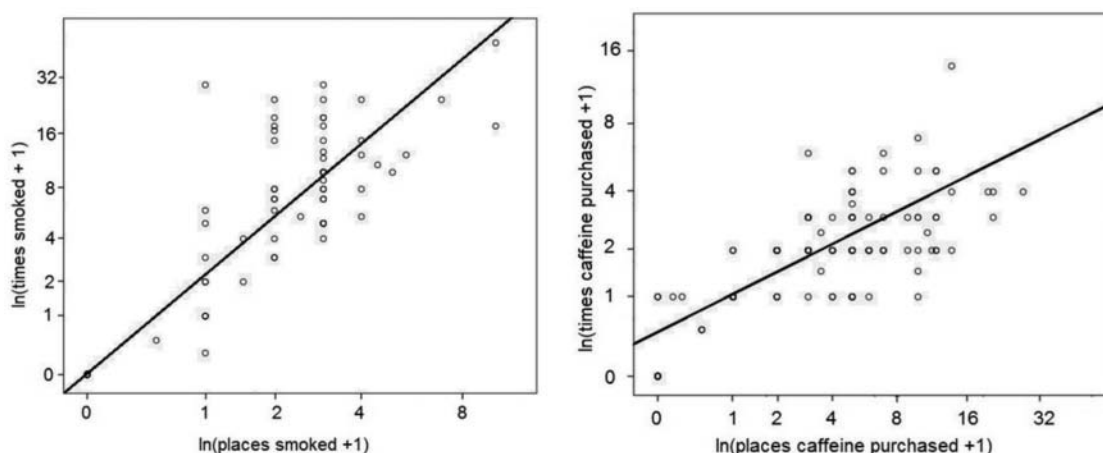
## Discussion

The present study examined common stimulants, and applied models of foraging behavior to their patterns of use. As frequency of consumption (or purchasing) increased, the range of locations where stimulants were consumed (or purchased) increased, but the best fit to these relationships was not linear. A power law best describes the foraging behavior of common stimulant users. For most individuals, stimulant use and purchase is limited to a couple of locations, but some individuals make appreciably greater access to stimulants over a wider number of locations. Such relationships are seemingly stronger for the stimulant with the greater addictive potential (nicotine). In addition, dependent users of stimulants appear to engage in

greater consumption over a larger range of locations. However, even dependent users of legally available stimulants seem to *purchase* these stimulants on average at a relatively limited number of times (i.e., nicotine) or *consume* them at a limited number of locations (i.e., caffeine).

As a power law provides the better fit to data, this implies that Lévy Walks might better explain stimulant foraging behavior than Simple Central Place or Random Brownian motion. Even though much stimulant use might be close to a habitual location, some users demonstrate a greater range. The tendency to travel further, and/or access from more sources has implications for governments or legislators attempting to restrict access,<sup>40–42</sup> as even one site providing substances to minors can increase purchasability and access in a neighbourhood.<sup>30</sup> Not only are dependent substances users likely to pay more,<sup>2</sup> the present data suggest that they probably access more locations as well,<sup>24</sup> and this poses potential problems for attempts to restrict access.

With increasing dependence upon a stimulant, the number of times or locations at which a stimulant is purchased or consumed increases, and similar patterns have been observed for alcohol.<sup>18</sup> This might

**Figure 1.** Scatter plots of best fitting power law for nicotine consumption per day, and best fitting power law for caffeine purchases per week.



arise from: tolerance, destructive foraging, scarcity, or stimulant use. With increasing *tolerance* there is a need to increase the size and frequency of dosage, and this might contribute to the number of sites where stimulants are purchased.<sup>43</sup> However, studies of foraging suggest that an organism might also increase its range because their behavior creates a scarcity of resources due to *destructive foraging*,<sup>26</sup> exhausting a site's resources or in other ways preventing subsequent use. Conceivably the problem behaviors exhibited by gamblers or drinkers increase the likelihood that they be temporarily barred from a specific venue, but this is less likely for smokers or consumers of caffeine. Possibly greater consumption could lead to *scarcity*. As dependent individuals consume more, they risk exhausting their supplies and are thus required to extend their range.<sup>22,44</sup> Extending search patterns has been suggested to reduce the likelihood of scarcity or famine,<sup>29</sup> but this seems unlikely for such readily available stimulants. Indeed it is also possible that the *use of stimulants* may actually encourage a range of foraging behaviors,<sup>44</sup> and there is experimental evidence to support such observations.<sup>43,45</sup>

### Implications

These power laws provide a method of quantifying a cohorts' foraging behaviors that is sensitive to dependency and addictive potential. The power laws of dependent users exhibited: (1) higher intercepts, indicating greater consumption; (2) shallower slopes, indicating that substance use occurs across a greater range of locations. Greater addictive potential seems to be associated with greater use per location. It is likely that dependent users of illegal stimulants would make a greater use of the more restricted number of sites where purchases are available. Hence, greater intercepts and steeper slopes would be expected to any power laws applied to the foraging of those dependent on illegal stimulants.

The present data are relevant to the development of technologies messaging clients and reminding them of their goal to reduce or abstain.<sup>33,34,46–48</sup> Such technologies enable therapists to provide out-patient support, allowing interventions to be delivered “on site” in “real time,”<sup>6,31,32</sup> with programs messaging addicted clients and reminding them as to their goal to reduce or abstain. The present data would be relevant to the

development of interventions that might be more spatially and temporally contingent upon risk.

The movements of smart phone users can be estimated from their mobile phone calls.<sup>49</sup> For each call, the closest mobile phone tower can be used as an indicator of the phone user's location, hence resolution is a function of tower density. From such data, González et al.<sup>49</sup> noted that humans have a predictable range, typically spending the majority of their time in two locations (e.g., home and work), with temporal periodicities corresponding to a 24-hour cycle.

The present consideration of readily available substances offers insights as to the practical limits that might be required for systems that seek to provide outpatient support for dependent substance users.<sup>31–33</sup> While there might be 306,695 tobacco outlets in the United States,<sup>50</sup> given people's movements are relatively predictable,<sup>51,52</sup> it could be feasible for apps to operate on the more limited number of venues and times that users and therapists can jointly nominate, and that might be more meaningfully associated with points of risk in their life space (e.g., Google's “Your Timeline”). Such subscription systems could message and interrupt users at times or locations when they indicate that they tend to be more vulnerable, and disrupt habitual behavior patterns. The greater range of locations frequented by dependent users would have implications for the upper limits required for such systems.

### Limitations

Although an online survey was employed, online surveys may actually canvas a wider section of the community.<sup>53</sup> Indeed, the methodology suggested is appropriate as it samples the population of technology users that would be likely to adopt such apps.<sup>54,55</sup> Most substance users possess mobile phones,<sup>56</sup> although there are indications that such populations may be concerned about their privacy.<sup>56,57</sup>

The present foraging data from stimulant users were consistent with power laws,<sup>58</sup> and the use of daily frequencies actually acknowledges the periodicity of foraging behaviors.<sup>59</sup> However, the use of daily frequencies may not be mathematically equivalent to outcomes obtained by raw frequency counts over an extended period,<sup>35</sup> hence the author's recommend further study using GPS and improved methods of collecting self-reported use.<sup>33,55,60</sup>

## Conclusion

380 Even though caffeine and nicotine are readily legally  
available, the foraging behavior of dependent users  
resembles that of organisms in circumstances of scar-  
city. Dependent stimulant users access stimulants  
more often and in more locations. Although the total  
385 number of outlets for stimulants is quite high, the  
number of places a dependent user of stimulants actu-  
ally frequents is potentially much less. However, some  
dependent users of stimulants appear to engage in a  
greater range and intensity of use than others, and  
390 this may have implications for regulation and  
management.

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**Q10**

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