Drug and Alcohol Dependence 101 (2009) 191–195

Contents lists available at ScienceDirect

Drug and Alcohol Dependence

journal homepage: www.elsevier.com/locate/drugalcdep

First cigarette on waking and time of day as predictors of puffing behaviour in UK adult smokers

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ARTICLE INFO

Article history:
Received 4 September 2008
Received in revised form 17 December 2008
Accepted 12 January 2009
Available online 4 March 2009

Keywords:
Puffing behaviour
Smoking deprivation
Diurnal effects

ABSTRACT

Background: There is known inter- and intra-individual variation in how cigarettes are smoked. The aim of this study was to explore the influence of diurnal factors, particularly the first cigarette of the day, on puffing behaviour in a sample of adult smokers.
Methods: We recruited 130 adults aged 18–60 years who were smoking one of seven cigarette brands popular in the UK. Puffing behaviour was measured using a portable smoking device (CReSSmicro) through which participants smoked their cigarettes over a 24 h study period. The primary outcome was total smoke volume per cigarette (obtained by summing the puff volumes for each cigarette). Secondary outcome measures were puffing frequency, average puff volume, average puff flow, average puff duration and inter-puff interval.
Results: Total smoke volume was found to be significantly associated with the time the cigarette was smoked ($P < 0.001$), with cigarettes smoked between 2 and 10 a.m. being smoked less intensively than other cigarettes. After adjusting for time of cigarette, the first cigarette on waking was smoked slightly less intensively than other cigarettes and significantly so if smoked within 5 min of waking ($P = 0.004$).
Conclusions: This study suggests that cigarettes smoked during the night and early morning, including the first cigarette of the day, are puffed less intensively. This is a potentially important finding that merits more research given the importance of the first cigarette of the day and diurnal smoking patterns for determining dependence, cessation and relapse.

1. Introduction

Considerable differences exist between individuals with respect to cigarette smoking behaviour (Benowitz, 2001; Hammond et al., 2005; US Department of Health and Human Services, 1996). Smokers differ in the type of cigarettes they smoke, how many they smoke and how they smoke them (measured by puffing behaviour, e.g. number of puffs, puff volume and puff duration), and these factors can be interrelated. For example, smokers tend to smoke brands that generate low nicotine emissions under machine testing more intensely than those with higher nicotine emissions in order to regulate their nicotine intake (Benowitz, 2001). Demographic factors can also account for some of the observed inter-individual differences in puffing and smoking behaviour (Eissenberg et al., 1999; Hammond et al., 2005; Melikian et al., 2007).

Less studied are diurnal changes in smoking patterns. Two recent studies have shown that circadian variations may exist both in terms of nicotine craving and use of cigarettes/nicotine gum, but neither study reported data on measures of puffing behaviour (Mooney et al., 2006; Teneggi et al., 2002). The first cigarette of the day has been useful for understanding smoking behaviour with latency to smoking after overnight abstinence being a robust predictor of nicotine dependence (Fagerstrom and Schneider, 1989; Heatherton et al., 1989), cessation (Baker et al., 2007; Kozlowski et al., 1994) and smoking relapse (Toll et al., 2007). Subjective effects of the first cigarette of the day have also been suggested as indicators of tolerance or nicotine sensitivity (Niaura et al., 2003; Pillitteri et al., 1997). So, clearly, the first cigarette smoked in the day is an important marker to study.

Technology now exists to measure puffing behaviour relatively easily and reliably using a portable hand-held device (Eissenberg et al., 1999; Lee et al., 2003; Shahab et al., 2008a). In this study we recruited smokers of seven popular cigarette brands in the

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doi:10.1016/j.drugalcdep.2009.01.013

UK and recorded their smoking behaviour over a period of 24 h using this device. The aim was to ascertain if puffing behaviour differs throughout the day, and in particular whether the first cigarette smoked on waking is smoked differently from subsequent cigarettes.

2. Methods

2.1. Participants

We recruited adult smokers aged 18–60 years as part of a study focussing on smokers of manufactured and roll-your-own tobacco brands. Advertisements were placed in the local press and potential participants were also targeted via flyers, posters and bulletin boards situated in close proximity to University College London (UCL). Eligible participants had to be smoking a minimum of five cigarettes a day and be smoking a single brand for at least 3 months. Eligible cigarette brands were selected to include the most popular brands currently being smoked in the UK (Silk Cut Silver, Silk Cut Purple, Marlboro Gold, Richmond Super Kings, Benson & Hedges Gold, Mayfair King Size and Lambert & Butler Silver), this was based on UK sales data obtained from the International Tobacco Control Four Country Survey (Thompson et al., 2006). We aimed to recruit 20 smokers of each brand. Exclusion criteria were a self-reported history of lung and heart disease and pregnancy. Although recruited as part of the total study sample, smokers of roll-your-own cigarettes were not included in the present analysis.

2.2. Procedures

All participants completed a 5-min telephone survey which described the study and assessed eligibility. Those who expressed an interest were invited to visit the test centre on two separate occasions, 24 h apart. At the first visit, written consent was obtained and a brief survey on smoking attitudes and behaviours was administered. Participants were given full instruction on how to use the CReSSmicro device (Plowshare Technologies Inc., Baltimore, MD), and asked to smoke one of their own cigarettes through the device. They were then requested to smoke all their cigarettes over the next 24 h through this machine and place spent butts in tins which were provided and to note the date and time of the cigarette on the tin. The CReSS machine and cigarette butts were collected by the study team at the second visit when the same procedure as in the first visit was followed. All participants were offered a £50 incentive to take part in the trial which was awarded on completion of the two visits. The study was approved by the UCL Research Ethics Committee for non-National Health Service Human Research.

2.3. Analysis of puffing behaviour using the CReSSmicro device

The CReSSmicro device is a hand held battery-operated portable device which measures puffing behaviour variables including puff number, puff volume, puff duration, average puff flow, inter-puff interval, time and date. The device uses an orifice flow meter that produces a pressure drop related to the flow rate of smoke through the mouthpiece. Data were collected by asking the participant to insert a cigarette in the device and smoke the cigarette as normal. Once finished, the cigarette butt is withdrawn from the device and extinguished as usual before being placed in the butt tins provided. Cigarette butts with times were collected even if the cigarette was not smoked through the CReSS device. Data for each cigarette smoked remain on the device until downloaded for analysis and checked for consistency. Cigarettes with implausible values were excluded either because results indicated a faulty measurement (puff duration < 100 ms; inter-puff interval < 100 ms or puff volume < 10 ml) or highly unlikely results (more than one in four puffs per cigarettes with puff volume 10–25 ml; puff duration 100–700 ms or inter-puff interval 100–300 ms).

2.4. Measurements

At baseline, age, gender and body mass index (kg/m^2) were recorded for each participant. Smoking-related variables we considered included usual daily cigarette consumption and the number of cigarettes smoked through the CReSS machine during the 24 h study period ('CReSS cigarette consumption'). Self-reported time of first cigarette on waking and usual daily cigarette consumption were combined to calculate the heaviness of smoking index (HSI) (Heatherton et al., 1989), a short version of the Fagerström Test for Nicotine Dependence (FTND) (Heatherton et al., 1991) recorded on a scale from 0 to 6, with higher scores indicating greater nicotine dependence.

Two measures that were derived at the cigarette level were 'Time of cigarette' and 'First cigarette on waking'. Time of cigarette was coded as a six-level category for purposes of analysis; 6–10 a.m., 10 a.m.–2 p.m., 2–6 p.m., 6–10 p.m., 10 p.m.–2 a.m., 2–6 a.m. The first cigarette of the day upon waking was operationalised as the first cigarette smoked after 5 a.m. providing the time from the previous cigarette was 4 h or more. This time was chosen because visual inspection of the data showed that for all participants who smoked cigarettes between 3 and 5 a.m. the last cigarette in this interval was smoked within 4 h of the previous cigarette (i.e. they smoked throughout the night). This analysis was subsequently stratified by time to the first cigarette upon waking using a modified version of the FTND item 1 categories; ≤5, 6–30, 31–60 and >60 min.

2.5. Statistical analysis

Six outcome measures were used in our analysis. The primary outcome was a derived measure of total smoke volume per cigarette. This was obtained by summing the puff volumes for each cigarette. Five measures obtained directly from the CReSS-micro data were considered as secondary outcomes; (1) number of puffs, (2) average puff volume (ml), (3) average puff flow (velocity in ml/s), (4) average puff duration (ms), and (5) inter-puff interval (s). As each participant smoked multiple cigarettes over the study period, the generalised estimating equations (GEE) approach with an exchangeable correlation structure was used to allow for correlated outcome measurements within each individual (Liang and Zeger, 1986). Empirical standard errors were used to accompany GEE estimates in all cases. Our exposure variables of interest were (i) 'Time of cigarette' and (ii) 'First cigarette on waking'. The latter was defined as an indicator variable where smoke volume and the secondary outcomes for the first cigarette were compared with all other cigarettes the individual smoked over the 24 h study period. For each outcome measure separately, we constructed a multivariable regression model containing age (years), gender, BMI (kg/m^2), 'CReSS cigarette consumption', and cigarette brand in addition to the 'Time of cigarette' and 'First cigarette on waking' variables previously described. 'CReSS cigarette consumption' was used in our analysis because of the cigarette consumption related measures we considered, this was found to correlate most strongly with the puffing behaviour outcomes. All analyses were carried out using SAS v. 9.1.

3. Results

3.1. Description of sample

A total of 130 participants who smoked one of seven manufactured cigarette brands were included in the present analysis. Overall, the mean age of participants was 31.4 years (S.D. 10.5 years), 67 (51.5%) were male, the mean usual number of cigarettes smoked per day was 13.6 (S.D. 6.1) and the median time to first cigarette was 30 min (inter-quartile range 15–45 min).

A total of 1605 cigarette butts were collected by the 130 participants over the 24 h study period. Of these 1310 (81.6%) were smoked through the CReSSmicro device and provided valid data, 220 (13.7%) were not smoked through the device and 75 (4.7%) were excluded because of implausible data. The number of cigarettes smoked through the machine per participant ranged from 2 to 31 (median = 9). There was a moderate correlation between the number of cigarettes smoked through the CReSS machine and self-reported usual daily cigarette consumption ($R_{Spearman} = 0.52$). Averaged over all cigarettes, participants took an average of 13.2 (S.D. 4.1) puffs of volume 56.2 (S.D. 13.8) ml, with an average puff duration of 1.58 (S.D. 0.46) s and a mean inter-puff interval of 26.6 (S.D. 10.5) s. The mean total smoke volume was 711.7 ml (S.D. 208.3) per cigarette.

3.2. Time of day and first cigarette on waking

We observed important differences with respect to time of day (Table 1 and Fig. 1). Cigarettes smoked between the hours of 2 and 10 a.m. were smoked less intensively than those smoked at other times, characterised by a lower number of puffs per cigarette, lower average puff volume, lower average puff flow and a longer interval between puffs (Table 1). As a consequence, the total volume of smoke inhaled was less for cigarettes smoked throughout the night and early morning (estimated mean smoke volume 720.9 ml for cigarettes smoked from 6 to 10 p.m. vs. 657.2 ml for those smoked between 6 and 10 a.m.; Fig. 1). When time was considered as a category in the multivariable models, the differences in these outcomes between time periods were significant in all cases ($P < 0.05$). In a subsequent analysis, restricted to participants who smoked at least one cigarette between 10 p.m. and 10 a.m. the magnitude of the differences in puffing behaviour between the six time groups remained similar for all outcomes (data not shown).

Table 1
Puffing behaviour by time of cigarette[a].

Cigarette time	Mean (S.E.)						*P*-Value
	6–10 a.m.	10 a.m.–2 p.m.	2–6 p.m.	6–10 p.m.	10 p.m.–2 a.m.	2–6 a.m.	
Total smoke volume (ml)	657.2 (24.3)	726.9 (20.9)	751.4 (18.0)	720.9 (19.8)	663.6 (18.8)	624.6 (36.6)	<0.001
Number of puffs	12.42 (0.41)	13.45 (0.36)	13.53 (0.34)	13.35 (0.33)	12.84 (0.39)	12.49 (0.63)	0.014
Average puff volume (ml)	55.8 (1.4)	56.6 (1.2)	58.2 (1.2)	55.9 (1.2)	54.3 (1.3)	51.9 (1.6)	<0.001
Average puff flow (ml/s)	36.6 (0.8)	38.0 (0.7)	39.4 (0.6)	38.4 (0.7)	35.3 (0.7)	35.5 (1.1)	<0.001
Average puff duration (s)	1.61 (0.04)	1.59 (0.04)	1.58 (0.04)	1.54 (0.04)	1.64 (0.05)	1.57 (0.06)	0.02
Inter-puff interval (s)	31.2 (2.0)	25.9 (1.3)	23.0 (1.2)	25.6 (1.2)	30.4 (1.6)	33.1 (3.3)	<0.001

The *P*-value was obtained by fitting time of cigarette as a 6 level within participant category in the generalised estimating equations model. S.E., standard error.
[a] Adjusted for age, sex, body mass index, CReSS cigarette consumption, cigarette brand and first cigarette on waking.

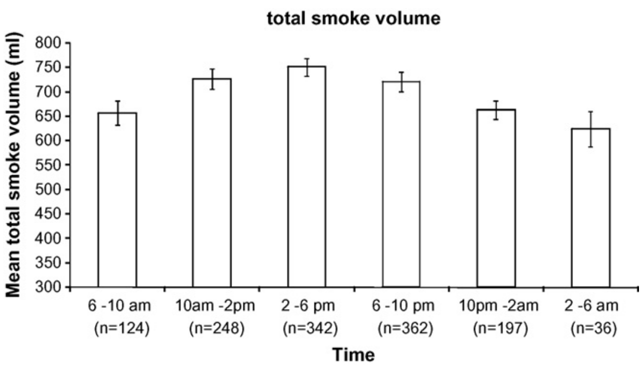

Fig. 1. Mean total smoke volume according to time of cigarette (±standard error). Mean values are adjusted for age, sex, body mass index, CReSS cigarette consumption, cigarette brand and first cigarette on waking (yes vs. no). *n* refers to the total number of cigarettes smoked in each time period.

In order to ascertain whether the effect of time of day was due solely to an effect of nicotine deprivation on puffing outcomes, the first cigarette smoked on waking was identified for each participant. A total of 121 cigarettes were identified using our definition of the first cigarette on waking, on eight occasions the first cigarette was smoked within 4 h of the preceding cigarette and on one occasion no cigarettes were smoked on the day of the second visit. However, puffing behaviour data were missing for 20 participants (16.5% of participants for whom a first cigarette was identified) as their first cigarette was not smoked through the CReSS machine. When time of cigarette was adjusted for in the multivariable analysis, the first cigarette was found to have significantly lower values than subsequent cigarettes for average puff volume and average puff flow with a borderline association ($P = 0.11$) for total smoke volume (Table 2). In a further analysis, participants were stratified according to how long this first cigarette was smoked after waking on the day of the second visit (Table 2). Among smokers who smoked their first cigarette within 5 min of waking ($n = 12$) the difference in total smoke volume between the first and other cigarettes was particularly pronounced ($\beta = -172.3$, $P = 0.004$), whilst this difference was also significant among those who smoked this cigarette between 31 and 60 min after waking ($n = 28$, $\beta = -55.4$, $P = 0.05$). For the secondary outcomes, average puff volume and average puff flow, the differences between first and other cigarettes were significant for all three categories where the time to first cigarette after waking was less than 1 h (Table 2). Differences in puffing behaviour between the first and subsequent cigarettes were small among smokers ($n = 20$) for whom the first cigarette of the day was smoked after 1 h and on no occasion were significant.

4. Discussion

In a study comprising 130 UK cigarette smokers, we observed important diurnal patterns whereby cigarettes smoked throughout the night and early morning were smoked with less intensity than those smoked at other times of the day. If smoked within 1 h of waking, we also found that the first cigarette of the day was smoked less intensively even after accounting for the time of day effect. There is currently a dearth of studies examining diurnal patterns in puffing behaviour so the present study has highlighted important findings which need further exploration.

Our findings concerning diurnal patterns were somewhat unexpected given the importance of time to first cigarette in measuring dependence and the assumption that people might smoke the first cigarette of the day more intensely to compensate for overnight abstinence. Our data suggest that smoke intake per cigarette rises during the day, peaking around mid-afternoon before decreasing again. This is concordant with a recent study which showed that whilst refraining from smoking over 72-h, levels of self-reported craving increased throughout the day after a low level in the morning (Teneggi et al., 2002). Furthermore, an older study with a fixed schedule of smoking cigarettes every 30 min found a similar circadian pattern in blood nicotine concentrations (Benowitz et al., 1982). Our findings differ from the few studies that have examined diurnal puffing patterns. A small study which measured puffing behaviour outcomes reported no diurnal effects (Morgan et al., 1985), whilst another reported no difference in smoking outcomes when specifically comparing the first and second cigarettes smoked following overnight abstinence (Kolonen et al., 1992).

In our study the first cigarette on waking had a significant effect on smoking behaviour after adjusting for time of cigarette for two outcomes measures (average puff volume and average puff flow) with a borderline association for the primary outcome (total smoke volume). This effect was particularly noticeable among participants whose first cigarette was smoked within 5 min of waking. It is possible that tolerance to nicotine is reduced in the morning due to overnight abstinence, resulting in a lower intensity of smoking to reduce unpleasant side-effects and to offset a relatively greater sensory reinforcement from the first cigarette of the day compared with cigarettes smoked during the rest of the day. There is at present a lack of consensus over the extent to which either smoking deprivation or craving scores influence smoking or puffing behaviour (Houtsmuller and Stitzer, 1999; Zacny and Stitzer, 1985) and these issues require further exploration in relation to our findings.

Methodological issues must also be taken into consideration when interpreting our findings concerning diurnal effects on puffing behaviour. The percentage of cigarettes with missing CReSS data was slightly higher for cigarettes smoked throughout the night (28% between 2 and 6 a.m.) compared with those consumed during the day (17.3% between 10 a.m. and 10 p.m.). This would only introduce bias into our results if cigarettes not smoked through the CReSS device were smoked less intensively on average than other cigarettes. Cigarettes excluded due to faulty measurements only accounted for a small percentage of those with missing data so it is unlikely that these exclusions would have contributed in any way to lower values of puffing intensity for night time cigarettes.

Table 2
Puffing behaviour for the first cigarette of the day compared with other cigarettes[a]: overall and stratification of participants by time to 1st cigarette.

	All participants (n = 101)				Stratification of participants by time to first cigarette							
					1st cigarette ≤5 min (n = 12)		1st cigarette 6–30 min (n = 41)		1st cigarette 31–60 min (n = 28)		1st cigarette >60 min (n = 20)	
	Mean (S.E.) (1st cigarette)	Mean (S.E.) (other cigarettes)	β (S.E.)	P	β (S.E.)	P	β (S.E.)	P	β (S.E.)	P	β (S.E.)	P
Total smoke volume (ml)	678.0 (26.4)	715.6 (16.3)	−37.56 (23.2)	0.11	−172.3 (60.5)	0.004	−26.18 (33.03)	0.43	−55.40 (28.17)	0.05	31.68 (49.25)	0.52
Number of puffs	13.16 (0.45)	13.23 (0.30)	−0.08 (0.36)	0.84	−1.73 (0.74)	0.02	−0.04 (0.54)	0.93	0.12 (0.40)	0.77	0.54 (0.86)	0.53
Average puff volume (ml)	53.2 (1.4)	56.5 (1.1)	−3.37 (1.01)	<0.001	−8.19 (3.34)	0.01	−3.12 (1.46)	0.03	−4.59 (1.41)	0.001	0.03 (1.03)	0.98
Average puff flow (ml/s)	36.2 (0.8)	38.0 (0.6)	−1.81 (0.58)	0.002	−3.16 (1.42)	0.03	−2.28 (0.78)	0.004	−2.36 (0.92)	0.01	0.32 (1.03)	0.75
Average puff duration (s)[b]	1.57 (0.05)	1.58 (0.04)	−13.1 (35.2)	0.71	−73.7 (79.0)	0.35	8.2 (47.9)	0.86	−16.4 (60.4)	0.79	−16.1 (41.9)	0.70
Inter-puff interval (s)	26.1 (1.9)	26.5 (1.3)	−0.32 (1.61)	0.85	4.79 (3.40)	0.16	−0.96 (2.38)	0.69	0.90 (2.52)	0.72	−3.38 (2.10)	0.11

β represents the difference between the adjusted mean values when comparing the 1st cigarette of the day with subsequent cigarettes, S.E., standard error. The above analysis comprised participants for whom the first cigarette of the day contained valid puffing behaviour data (n = 101).

[a] Adjusted for age, sex, body mass index, CReSS cigarette consumption, cigarette brand and time of day.

[b] For average puff duration β coefficients (and S.E.s) were multiplied by 1000.

There may also be an issue of confounding if night time smokers had noticeably different characteristics to those who did not smoke cigarettes at other times. The generalised estimating equations approach does not remove between participant confounding but we did find a similar effect when restricting our analysis to participants who smoked at least one cigarette throughout the night time. Workplace environmental restrictions are liable to have accounted for our findings at least in part (Chandra et al., 2007; Chapman et al., 1997). It may be that if cigarettes during the daytime are only consumed during restricted break periods at work, these may be smoked more intensively to compensate for reduced availability. We are unaware of any equivalent research which has examined characteristics of night time smokers. Future research in this area could help us understand possible reasons as to why cigarettes may be smoked less intensively during this period.

Our sample is likely to be fairly representative of adult smokers in the UK with respect to the level of cigarette consumption as we did not set out to include only heavy smokers (the cut-off for inclusion was 5 cigarettes per day and the usual average daily cigarette consumption was 13.6), or attempt to target smokers on the basis of their intention to quit in the foreseeable future. Therefore our findings may be more easily extrapolated to all UK smokers rather than more heavily addicted smokers who would be more representative of those attending smoking cessation programmes. As recruitment took place in close proximity to a University our sample is unlikely to be representative with respect to age, with younger smokers over-represented among our sample (mean age of participants = 31.4 years). One limitation of our analysis is that puffing behaviour measures only give an indication of mouth-level exposure rather than providing biochemical verification of smoke inhalation. However, our primary outcome measure, total smoke volume, has been shown to correlate well with biochemically assessed human smoke exposure in a number of studies (Bridges et al., 1990; Burling et al., 1985; Hammond et al., 2005; Shahab et al., 2008b; Zacny et al., 1987).

In conclusion, cigarette time was a predictor of smoke inhalation as estimated by total smoke volume, with some evidence that the first cigarette may be smoked less intensively even after accounting for time of day. Diurnal effects on puffing behaviour have received only modest attention in the literature and represent an important area for further research, particularly in the light of findings suggesting a link between diurnal smoking patterns and risk of relapse after quitting (Mooney et al., 2006).

Role of funding source

This study was funded by the UK Department of Health (DoH). The DoH had no further role in the study design; in the collection, analysis and interpretation of data; in the writing of the report or in the decision to submit the paper for publication.

Contributors

MJG undertook the statistical analysis and wrote the first draft of the manuscript. LS contributed to the design of the study and helped carry out the research. DH and RJC both contributed to the design of the study. AM contributed to the design of the study and supervised the research. All authors commented on the statistical analysis and contributed to and approved the final manuscript.

Conflict of interest

LS has received an honorarium for a talk and travel expenses from a pharmaceutical company making smoking cessation products.

Acknowledgements

We thank Erdem Pulcu for his help in carrying out the research and Robert West for his support in setting up the study at University College London.

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