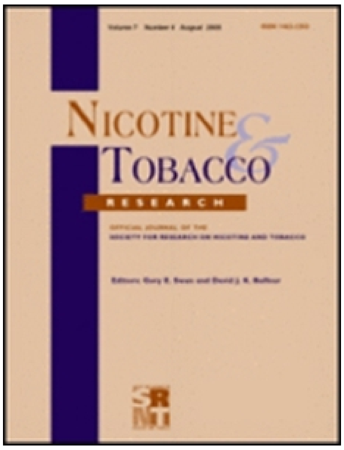

Nicotine & Tobacco Research
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713439766

The reliability and validity of self-reported puffing behavior: Evidence from a cross-national study

Lion Shahab [a]; David Hammond [b]; Richard J. O'Connor [c]; K. Michael Cummings [c]; Ron Borland [d]; Bill King [d]; Ann McNeill [e]
[a] Department of Epidemiology and Public Health, University College London, London, United Kingdom [b] Department of Health Studies and Gerontology, University of Waterloo, Waterloo, Canada [c] Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, NY [d] VicHealth Centre for Tobacco Control, The Cancer Council Victoria, Melbourne, Australia [e] Division of Epidemiology and Public Health, University of Nottingham, United Kingdom

Online Publication Date: 01 May 2008

To cite this Article Shahab, Lion, Hammond, David, O'Connor, Richard J., Michael Cummings, K., Borland, Ron, King, Bill and McNeill, Ann(2008)'The reliability and validity of self-reported puffing behavior: Evidence from a cross-national study',Nicotine & Tobacco Research,10:5,867 — 874

To link to this Article: DOI: 10.1080/14622200802027156

URL: http://dx.doi.org/10.1080/14622200802027156

Nicotine & Tobacco Research Volume 10, Number 5 (May 2008) 867–874

The reliability and validity of self-reported puffing behavior: Evidence from a cross-national study

Lion Shahab, David Hammond, Richard J. O'Connor, K. Michael Cummings, Ron Borland, Bill King, Ann McNeill

Received 23 March 2007; accepted 17 August 2007

Self-reported puffing behavior has considerable potential as an indicator of smoking intensity, particularly in survey research evaluating population-based changes in smoking patterns. However, little is known about the reliability and validity of self-reported puffing behavior. This study compared smokers' perceptions of their puffing behavior with measures of both machine-determined puffing behavior and nicotine uptake to assess the utility of self-report. We assessed self-reported puffing behavior as well as demographic and smoking characteristics of 118 smokers from Australia, Canada, the United Kingdom, and the United States. At two visits, participants were asked to provide a saliva sample and to smoke a cigarette through a portable smoking topography device, the CReSSmicro, to measure puffing behavior. Saliva samples were assayed for cotinine, a measure of nicotine uptake, to provide estimates of smoke exposure. Intraclass coefficients for all measures of self-reported general puffing behavior were above .6, indicating that self-reported measures had fair-to-good test–retest reliability. Self-report, in particular of interpuff interval and number of cigarette puffs, was correlated only moderately with machine-determined puffing measures ($.2<r<.4$), and no self-report measure related to smoke exposure as measured by cotinine. Self-reported measures of puffing behavior appear to be fairly reliable but are correlated only weakly with objective measures of smoking topography. Results suggest that smokers have a better perception of the time spent between puffs and of the number of puffs taken than of the intensity and depth of each puff or their actual smoke exposure.

Introduction

Self-reported smoking status is a relatively good indicator of biomarker-validated smoking status (Patrick et al., 1994), with some notable exceptions (West, Zatonski, Przewozniak, & Jarvis, 2007). Given that self-reported smoking status is a reliable proxy for biomarker-validated smoking status, smoking prevalence may be easily assessed in large nationally representative samples through standardized questionnaire items. However, smoking status and the number of cigarettes smoked per day are only crude indicators of tobacco consumption and intake. Puff topography studies show that significant variation exists among smokers in the way cigarettes are smoked (Hammond, Fong, Cummings, & Hyland, 2005). Some smokers inhale two to three times more smoke than others smoking the same number of cigarettes of the same brand by adjusting the number, size, and speed of their puffs to extract the desired amount of nicotine (Benowitz, 2001). As a result, smokers who switch to cigarettes with lower machine-measured tar and nicotine yields can compensate for lower nicotine delivery by smoking the cigarettes more intensively to maintain a relatively constant level of nicotine in their body (Benowitz, Jacob, Kozlowski, & Yu, 1986; Bridges et al., 1990; Djordjevic, Hoffmann, & Hoffmann, 1997).

The technology used to measure such puffing behavior has improved with the advent of portable,

Lion Shahab, M.Sc., Department of Epidemiology and Public Health, University College London, London, United Kingdom; David Hammond, Ph.D., Department of Health Studies and Gerontology, University of Waterloo, Waterloo, Canada; Richard J. O'Connor, Ph.D., K. Michael Cummings, Ph.D., Department of Health Behavior, Roswell Park Cancer Institute, Buffalo, NY; Ron Borland, Ph.D., Bill King, M.Sc., VicHealth Centre for Tobacco Control, The Cancer Council Victoria, Melbourne, Australia; Ann McNeill, Ph.D., Division of Epidemiology and Public Health, University of Nottingham, United Kingdom.

Correspondence: Lion Shahab, Cancer Research UK Health Behaviour Unit, Department of Epidemiology and Public Health, University College London, 2-16 Torrington Place, London WC1E 6BT, UK. Tel: +1 44 207679 6495; Fax: +1 44 207813 2848; E-mail: lion.shahab@ucl.ac.uk

ISSN 1462-2203 print/ISSN 1469-994X online © 2008 Society for Research on Nicotine and Tobacco
DOI: 10.1080/14622200802027156

hand-held devices (Henningfield, Yingling, Griffiths, & Pickens, 1980). However, measuring puffing topography remains a relatively costly, involved procedure that may not be feasible for large population-based studies. If this information could be collected with sufficient accuracy via self-report, it would be much easier to study puffing behavior in population samples. Yet, few studies have examined the extent to which smokers can provide accurate self-reports of their puffing behavior. Existing research provides conflicting findings. For example, self-reported inhalation was found to be significantly associated with biological markers of smoke intake in some studies (Burling, Lovett, Richter, & Frederiksen, 1983; Hofer, Nil, Wyss, & Battig, 1992; Nakayama et al., 1999) but not in other studies (Etter & Perneger, 2001; Frederiksen, Martin, & Webster, 1979; Hill, Haley, & Wynder, 1983).

Validated measures of self-reported puffing behavior would be particularly valuable for assessing individual variation in nicotine dependence, which could be useful in treatment planning, as well as for measuring compensatory shifts in response to tobacco control policies, such as increases in cigarette prices or taxation. For example, although tax or price increases have been demonstrated to reduce the number of cigarettes smoked (Jamrozik, 2004), it is not known whether smokers compensate by smoking each cigarette more intensely. However, there is good reason to believe that this is the case (e.g., Adda & Cornaglia, 2006; Ahijevych, Weed, & Clarke, 2004). If each cigarette is smoked "harder" then overall exposure may decrease little, if at all, resulting in a smaller than expected impact of taxation on health differentials. In addition, differences in puffing behavior in terms of demographic or smoking characteristics may provide valuable insights into sociodemographic determinants of risk exposure, smoking reduction, and cessation as implied by recent studies reporting sex differences in machine-assessed puffing behavior (Eissenberg, Adams, Riggins, & Likness, 1999; Hammond et al., 2005; Wood, Wewers, Groner, & Ahijevych, 2004).

As part of an international study assessing smokers' exposure to smoke carcinogens, we sought to assess the value of self-reported puffing behavior as a tool to estimate smoke intake. Self-reported puffing was compared with machine-determined smoking topography and a measure of nicotine uptake to examine its reliability and validity.

Method

Participants

Study subjects included 118 adult daily smokers recruited in four countries: Australia, Canada, the United Kingdom, and the United States. Participants were recruited through advertisements in local newspapers, flyers, E-mails, or posters on public bulletin boards at five different sites: Waterloo, in Canada; Melbourne, in Australia; London, in the United Kingdom; and Buffalo and Minneapolis, in the United States. Smokers who responded to the advertisements were screened for eligibility by means of a telephone interview. Participants were included if they were aged 18–50 years, had smoked at least 10 cigarettes daily for the past year, and had been a regular smoker of one particular cigarette brand for more than 3 months. A total of 17 eligible cigarette brands—three to five brands from each country—were selected on the basis of national sales and nicotine yield. At least one of the most popular 'light and regular' cigarette brands in each country were included. Smokers were ineligible if they had a history of lung or heart disease, or if they were pregnant. Participant characteristics are provided in Table 1. Ethical approval was sought and granted by local ethics committees at participating study sites.

Procedure

Participants visited the laboratory on two occasions, 24 hr apart, and were instructed to abstain from smoking at least half an hour before each visit in order to standardize conditions. At the first visit, participants were told the purpose of the study and their written consent was obtained. At both visits, participants were asked to provide information about their smoking behavior before saliva and urine samples were collected. Participants were asked to continue smoking as usual between visits, and at the end of each session, participants smoked a cigarette through the CReSSmicro machine (Plowshare Technologies, Baltimore, Maryland) to determine smoking topography. Participants were reimbursed the equivalent of US$50 for their time.

Measures

Self-reported puffing behavior. Four different self-report measures of smoking behavior were assessed in a self-administered questionnaire: (1) interpuff interval, assessed by asking smokers how long on average they let the cigarette burn between puffs; (2) number of puffs per cigarette, determined by asking smokers if they (a) take a few puffs on each cigarette, (b) take more than a few puffs but not as many as they could, or (c) take as many puffs as they can on each cigarette; (3) depth of inhalation, determined by a single multiple-choice item in which smokers were asked if they (a) don't inhale into the chest at all, (b) inhale only a little into the chest, (c) inhale deeply into the chest, or (d) inhale into the chest as deeply as

Table 1. Demographic and smoking characteristics.

	Australia (n=20)	Canada (n=18)	United Kingdom (n=26)	United States (n=54)	All sites (N=118)
Demographic characteristics					
Mean age (*SD*), years	33.6 (7.0)	29.0 (9.4)	31.0 (7.2)	31.3 (10.0)	31.2 (8.9)
Percent male (*n*)	55.0 (11)	77.8 (14)	53.8 (14)	50.0 (27)	55.9 (66)
Smoking characteristics					
Mean cigarettes per day (*SD*)	18.6 (6.7)	15.1 (4.6)	15.9 (5.9)	17.5 (4.9)	17.0 (5.5)
Percent smokers of brands <1 mg nicotine (*n*)	55.0 (11)	11.1 (2)	100.0 (26)	37.0 (20)	50.0 (59)
Mean (*SD*) Heaviness of Smoking Index	3.1 (1.2)	2.5 (1.4)	2.5 (1.1)	3.2 (1.1)	2.9 (1.2)
Mean years of smoking (*SD*)	17.0 (8.2)	12.7 (9.1)	13.6 (7.4)	14.3 (10.1)	14.3 (9.1)
Percent quit attempt in past 5 years (*n*)	40.0 (8)	50.0 (9)	50.0 (13)	33.3 (18)	40.7 (48)
Median length of quit attempt (range), days	31.5 (0–356)	60.0 (3–510)	60.0 (1–420)	60.0 (2–270)	60.0 (0–510)
Percent quit plans (*n*)					
Next month	15.0 (3)	16.7 (3)	15.4 (4)	18.5 (10)	16.9 (20)
Next 6 months	25.0 (5)	22.2 (4)	34.6 (9)	22.2 (12)	25.4 (30)
Beyond 6 months	35.0 (7)	27.8 (5)	38.5 (10)	51.9 (28)	42.4 (50)
No quit plan	25.0 (5)	33.3 (6)	11.5 (3)	7.4 (4)	15.3 (18)

possible; and (4) smoking intensity, assessed by asking smokers to indicate on a scale from 1 (not at all hard) to 10 (as hard as possible) how "hard" they smoked cigarettes on average.

Machine-determined puffing behavior. The CReSS-micro machine is a battery-operated, hand-held portable device that measures a full complement of smoking topography variables including puff volume, puff count, puff duration, peak flow, interpuff interval, time, and date. The device uses an orifice flow meter mouthpiece that produces a pressure drop related to the flow rate of smoke through the mouthpiece. Data are collected by having the participant insert a cigarette in the device and smoke the cigarette as normal. Once the participant is finished, the cigarette butt is withdrawn from the device and extinguished, as usual. Data are stored on the device until downloaded for analysis.

Marker of smoke exposure. Saliva samples were collected using a dental roll, which participants were asked to keep in the mouth until saturated. Samples were assayed for cotinine, a major metabolite of nicotine that provides a very sensitive and specific quantitative measurement of tobacco intake using a tandem mass spectrometric method (Bernert, McGuffey, Morrison, & Pirkle, 2000).

Demographic, smoking, and cigarette characteristics

At the first visit, smokers were asked about their smoking history, quit attempts, future quit plans, as well as general demographic information. Questionnaire items were used to calculate the Heaviness of Smoking Index (HSI; Heatherton, Kozlowski, Frecker, Rickert, & Robinson, 1989), a short version of the Fagerström Test for Nicotine Dependence. The HSI is derived from the time to the first cigarette (≤5 min=3 points; 6–30 min=2 points; 31–60 min=1 point; >60 min=0 points) and number of cigarettes smoked per day (1–10=0 points; 11–20=1 point; 21–30=2 points; >30=3 points), producing a scale ranging from 0 to 6 with higher scores indicating greater dependence on nicotine.

Cigarette brands were characterized by standard ISO/FTC nicotine yields rather than brand name (e.g., light, mild, regular) because of country differences in terminology used. Percent filter ventilation, an indicator of the degree of air dilution in cigarette smoke produced by the ventilation holes in cigarette filters, was measured with a KC-3 digital apparatus (Borgwaldt-KC, Richmond, Virginia) following an established protocol (Kozlowski et al., 1998).

Data analyses

Statistical analysis was carried out using SPSS version 14.0. Test–retest reliability was evaluated by computing intraclass correlation coefficients (ICCs) using a two-way mixed model. Pearson product moment correlation coefficients or Spearman's rho coefficients (if the measures were nonparametric) were used to assess the degree of association between the various self-report measures and machine-determined measures of puffing behavior. To assess whether the results remained consistent across various subgroups, stratified analyses were performed controlling for demographic and smoking history variables. Group differences were assessed by means of chi-square or Mann–Whitney U tests for dichotomous and ordinal data, and by t tests or analysis of variance (ANOVA) for continuous variables. In addition, within-subject changes across visits were determined with paired t tests, and stepwise linear regression was conducted for multivariate analysis.

Results

Participant and country characteristics

A total of 157 smokers from four countries participated in this study. Of these, 17 were excluded because they violated the study protocol (participants failed to return for the follow-up appointment, had smoked different cigarettes, or had shared their CReSS machine with others), and 22 were excluded because some or all of their data were lost or missing because of machine failure. We found no significant differences between excluded and included participants in any of the demographic or smoking characteristics except for quit attempts. Excluded participants were more likely to have attempted to quit smoking in the last 5 years than those included in the analysis (Fisher's exact test, p=.02).

The 118 participants for whom we have complete data reported smoking a variety of eligible brands. The most popular brands in each country were Marlboro Gold (61.5%, United Kingdom), Newport (38.9%, United States), Players Light (61.6%, Canada), and Peter Jackson Super Mild (40.0%, Australia). Across sites, half of participants smoked cigarettes with machine-based nicotine yields of 1 mg or above, whereas the other half smoked cigarettes with machine-based nicotine yields below 1 mg, as determined by standard ISO/FTC testing protocols; however, this characteristic differed by country; $\chi^2(3)=40.7$, $p<.001$. In Canada significantly fewer participants smoked lower nicotine yield cigarettes than in any other country, whereas in the United Kingdom all participants smoked lower nicotine yield cigarettes, given regulatory limits in the European Union. ANOVA indicated a small difference between countries in the heaviness of smoking among participants; $F(3, 113)=3.3$, $p=.024$. Yet Tukey post-hoc analysis did not reveal significant disparities between specific countries and we found no other significant country-level differences for demographic or any additional smoking characteristics. As shown in Table 1, the average participant had been smoking for more than 14 years and currently smoked approximately 17 cigarettes/day. Just under half of participants had attempted to stop smoking in the past 5 years; however, the majority of participants had no plans to quit in the next 6 months.

Reliability assessment

Test–retest reliability over a 24-hr interval for both self-report and puff topography measures are shown in Table 2. ICCs for all measures of self-reported puffing behavior and for four of the six machine-determined measures of puff topography were above .6, indicating fair-to-good reliability. Thus self-reported puffing behavior—notwithstanding natural variability in smoking topography—showed similar stability over time to machine-determined puffing behavior in this sample. Since test–retest reliability was established and paired t tests revealed no significant differences between visits on any self-report or CReSSmicro measure, further analyses were carried out using mean values across visits.

Table 2. Intraclass coefficients (ICCs) of puffing behavior measures (N=118).

	ICC (95% *CI*)
Self-report	
Puffs per cigarette	0.628 (0.505–0.726)
Interpuff Interval	0.760 (0.672–0.827)
Inhalation depth	0.773 (0.689–0.837)
Smoking intensity	0.774 (0.689–0.837)
CReSSmicro device	
Puffs per cigarette	0.466 (0.314–0.596)
Interpuff Interval	0.498 (0.350–0.622)
Puff volume	0.701 (0.597–0.783)
Peak puff flow	0.819 (0.749–0.870)
Average puff flow	0.810 (0.738–0.864)
Puff duration	0.649 (0.532–0.743)

Validity assessment

Table 3 shows the correlations among the four self-reported measures of cigarette puffing behaviors as well as among the six machine-determined measures of smoking topography. These correlations tended to be in the anticipated direction, underscoring their reliability. Among self-reported measures, greater smoking intensity was associated with a larger number of cigarette puffs and a greater inhalation depth; the latter two measures were also positively correlated. Self-reported interpuff interval was negatively correlated with the number of cigarette puffs, though this correlation was not significant. In contrast, number of machine-determined puffs per cigarette was negatively correlated with machined-determined interpuff interval as well as with all other CReSSmicro parameters. Moreover, puff volume—being a function of peak and average puff flow as well as puff duration—was positively correlated with these measures and a greater average puff flow was associated with a greater peak puff flow but with a shorter puff duration by offsetting the need to puff for longer.

Self-reported measures of puffing behavior were compared with machine-determined smoking topography to evaluate the content validity of self-report. Table 4 shows the association between self-report and machine measures, indicating significant but weak correlations between some of these measures. This table includes two additional variables, which are composites of machine-determined puffing variables: total smoke volume (puff volume × puff number) and total puffing duration (puff duration ×

Table 3. Correlations within self-reported and within machine-determined measures of puffing behavior.

Self-report	Puffs per cigarette[a]	Interpuff interval	Inhalation depth[a]
Interpuff interval	−.063		
Inhalation depth[§]	.185*	−.048	
Smoking intensity	.375**	−.035	.625**

CReSSmicro device	Puffs per cigarette	Interpuff interval	Puff volume	Peak puff flow	Average puff flow
Interpuff interval	−.555**				
Puff volume	−.416**	−.142			
Peak puff flow	−.181*	−.066	.567**		
Average puff flow	−.905**	−.057	.399**	.905**	
Puff duration	−.327**	−.124	.654**	−.105	−.305**

Note. [a]Spearman's rho (elsewhere Pearson's *r*). *$p<.05$; **$p<.01$ level.

puff number). These variables were calculated to provide a measure of smoking behavior at the cigarette level as opposed to the puff level. Similarly, a compound measure of the self-report variables was computed by adding average self-reported puffs per cigarette, self-reported inhalation depth, and the categorized and reverse-coded self-reported interpuff interval (six categories; lower interval limits in seconds: 0, 5, 10, 15, 20, 30) to obtain an equivalent overall measure of self-report with greater values indicating harder smoking of cigarettes. This measure was reliable (Cronbach's $\alpha=.88$).

As might be expected, the two measures of the number of puffs per cigarette were positively correlated. In a comparison of categorical responses, smokers who reported taking more puffs per cigarette took a greater number of puffs as measured by the CReSSmicro device, compared with people who reported taking fewer puffs; however, this difference reached only near significance, $F(2, 115)=2.8$, $p=.065$. The same applied to the total puffing duration per cigarette: Smokers who reported taking more puffs per cigarette had a tendency to spend a longer time inhaling per cigarette, $F(2, 115)=2.5$ $p=.084$.

Although we found a significant correlation between the self-reported and machine-determined interpuff interval, smokers on average underestimated the time they spent between taking cigarette puffs in absolute terms by about 5.2 s. Although roughly one-third overestimated and two-thirds underestimated the interpuff interval, only 12 participants correctly reported, to within 2 s, the time they spent between taking puffs. This difference between actual and perceived interpuff interval was significant, $t(117)=4.4$, $p<.001$. In addition, self-reporting a longer interpuff interval was associated with a smaller total inhalation volume and a shorter inhalation duration per cigarette as recorded by the smoking topography device.

As can be seen in Table 4, the relationship between the measures of interpuff interval and puffs per cigarette was asymmetric. Whereas the self-reported interpuff interval was negatively correlated with the machine-determined puffs per cigarette, the machine-determined interpuff interval was not significantly correlated with the self-reported puffs per cigarette. Moreover, smokers' self-reported depth of inhalation was not significantly correlated with puff volume, inhalation volume per cigarette, or any other CReSSmicro measure. Although self-reported smoking intensity also was not correlated with any machine measures, including average and peak puff flow, it was significantly related to the total time that people spent with a cigarette (i.e., sum of the puffing time and the interpuff interval; $r=.24$, $p=.009$, not shown). The compound self-report measure was significantly correlated with both the individual

Table 4. Correlations between self-reported and machine-determined puffing behavior measures.

	Self-report measures				
CReSSmicro measures	Puffs per cigarette[a]	Interpuff interval[b]	Inhalation depth[a]	Smoking intensity[b]	Self-report compound[b]
Puffs per cigarette	.240**	−.325**	.118	.032	.397**
Interpuff interval	.015	.395**	.037	.145	−.370**
Puff volume	−.072	−.029	−.022	−.008	−.070
Peak puff flow	−.077	.013	.007	.001	−.079
Average puff flow	−.069	.008	.043	.063	−.060
Puff duration	.010	−.050	−.006	.064	.299**
Total puffing duration (per cigarette)	.201*	−.283**	.043	.109	−.021
Total smoke volume (per cigarette)	.170	−.290**	.065	.043	.282**

Note. [a]Spearman's rho. [b]Pearson's *r*. *$p<.05$; **$p<.01$ level.

(though not the total) puff duration and the total smoke volume per cigarette, suggesting some correspondence between overall machine-determined puffing behavior and self-report.

Although the magnitude of some of the correlations between self-reported and machine-assessed puffing behaviors was reduced to nonsignificance when we looked only at female smokers, low-tar as compared with high-tar cigarette smokers, and smokers with a low as opposed to a high HSI score, none of these group differences in correlation coefficients were statistically significant. This finding was confirmed by further analysis. To systematically evaluate the possible influence of demographic or smoking characteristics, we calculated difference scores by subtracting self-report data from machine puffing data, either directly as for the interpuff interval or using a z score transformation to account for incompatibility in measurement scales. Stepwise multiple regression analysis predicting absolute values of these difference scores (i.e., the precision of smokers' estimates as compared with machine estimates) did not reveal any significant predictors.

To assess the construct validity of self-report and thus its utility, self-reported puffing behavior was related to cotinine, a biomarker of nicotine uptake and smoke exposure. Valid cotinine results were obtained from 110 participants and average levels were comparable to population studies ($M=292$ ng/ml; range=55–622). None of the self-report measures was significantly associated with average cotinine levels in bivariate analysis, and stepwise linear regression was conducted to estimate independent effects of self-report on cotinine. Controlling for age, sex, HSI, filter ventilation, as well as body mass index (to adjust for differences in metabolism), the results confirmed bivariate analysis: Only greater heaviness of smoking ($\beta=.43$, $t=5.3$, $p<.001$) and age ($\beta=.39$, $t=4.8$, $p<.001$), but not self-reported puffing, predicted cotinine levels. These results were not significantly changed when we included ISO nicotine yield in the prediction model, nor when we looked at cotinine levels from visits 1 and 2 separately.

Discussion

This is the first multicountry study to investigate the reliability and validity of self-reported puffing behavior. In agreement with previous research, machine-determined smoking topography indicated that smokers' puffing behavior was relatively consistent for at least short periods (Hammond et al., 2005; Lee, Malson, Waters, Moolchan, & Pickworth, 2003). The present study was able to show that self-reports of general puffing behavior were equally stable, confirming results from an earlier study (Etter & Perneger, 2001).

Self-reported measures of puffing behavior were by and large weakly correlated with machine-determined measures in the expected direction: A longer reported interpuff interval was related to a longer machine-measured interpuff interval, although we found a difference in absolute terms. Similarly, a greater number of self-reported puffs per cigarette was associated with a greater number of machine-measured cigarette puffs, whereas a greater self-reported smoking intensity was related only to a longer smoking duration and not to a greater average or peak puff flow, indicating that smokers' interpretation of intensity may be linked more strongly to temporal than physical factors such as speed of inhalation. Consistent with previous research (Adams, Lee, Rawbone, & Guz, 1983; Tobin, Jenouri, & Sackner, 1982), we found that self-reported depth of inhalation was not correlated with either cotinine or machine-determined inhalation at the mouth level. However, a composite of the self-report measures was significantly associated with the total puffing volume, indicating that smokers had some general understanding of their overall smoking topography. This relationship between the machine and self-reported measures was not significantly influenced by any of the assessed demographic variables or smoking characteristics.

Self-reported puffing behavior also was validated against a biomarker of nicotine intake to estimate the relationship between self-report and actual smoke exposure. The analysis of self-reported puffing behavior and cotinine levels showed that the measures used in the present study bore little, if any, relation to smoke intake. This finding differs from that reported in Etter and Perneger (2001), which found self-reported smoking intensity to be a good predictor of cotinine. This discrepancy has a number of possible explanations. One possibility is that the Etter and Perneger measure of smoking intensity ("Indicate, on a scale from 0–100, the intensity of your smoking") may have been better at capturing puffing behavior than our measure. Alternatively, the discrepancy may be related to differences in the samples. In the present study, participants were recruited at five sites in four countries, thus including smokers of a much broader and varied range of cigarettes. Finally, differences in the methodology may have contributed to contradictory findings. In contrast to the previous study, in which one saliva sample was collected by mail, in the present investigation saliva samples were obtained in person on two occasions.

The weak association of self-report with machine-determined puffing behavior, but not with salivary cotinine, a measure of smoke intake, will be the result of a number of intervening factors. The bodily uptake of smoke constituents depends not only on inhalation behavior but also on smoke parameters such as mean particle size and on smoker parameters such as lung morphology, vital capacity, rate of breathing, and clearance of the lung (e.g. Darby, McNamee, & van Rossum, 1984). In addition, individual variability exists in the extent to which smokers metabolize nicotine, which may depend in part on genetic polymorphisms of the CYP2A6 gene (e.g., Malaiyandi, Sellers, & Tyndale, 2005; Nakajima, Kuroiwa, & Yokoi, 2002). The variability in cotinine values caused by these factors may explain why self-reported puffing behavior was not related to cotinine, although smokers can report with some validity their puffing behavior.

The present study has a number of limitations. The restricted relationship between the more objective measures and the self-report measures could reflect the inherent difficulty of the self-report task: Smokers may have limited awareness of their discrete smoking behaviors, or the questions we asked to determine puffing behavior, or the combination of these questions, may have been suboptimal. Self-reported puffing was assessed with fairly crude questions that reflected general or typical puffing behavior, whereas machine-determined puffing related to two particular cigarettes. However, the limited association between self-report and machine measures also may be related to problems with the latter measure. If the cigarettes were smoked in an atypical way with the device, this would reduce the utility of the machine measures as a gold standard for intake. Although a previous study using this device concluded that it provides a reliable and valid index of conventional smoking (Lee et al., 2003), some degree of reactivity cannot be excluded especially since participants only used the device for a total of two cigarettes. Given that smoking behavior is known to be variable, this "snapshot" measurement of smoking topography may limit the conclusions that can be drawn based on machine measures alone.

The study also has a number of strengths. It was able to replicate findings across several countries in a controlled setting using comparable procedures. Not only does this lend a degree of generalizability to our results that could not be obtained from a single country study, but it also confirms the viability of this approach. Indeed, cross-national studies will arguably become ever more important for tobacco control as tobacco companies pursue increasingly globalized strategies and policies.

Overall, the modest concordance between self-reported and machine-determined smoking topography but not with cotinine suggests that smokers have only limited self-awareness of their puffing behavior and nicotine intake and that more research is needed to see if questions with better sensitivity can be developed. In general, the results imply that smokers have a greater understanding of the number of puffs and the time spent between puffs than they do of the depth, strength, or intensity of each puff. It is not clear whether smokers' self-perceptions of smoking topography are sensitive to changes in smoking behavior over time—an area that requires further investigation. Given these restrictions, our findings suggest that self-reported puffing, as assessed in the present study, has only limited utility for the evaluation of smoking topography and smoke exposure in international questionnaire studies (or surveys) of smoking behavior.

Acknowledgments

This write-up of this work was supported in part by the Roswell Park Trans-disciplinary Tobacco Use Research Center, funded by National Cancer Institute grant CA111236. The analytical measurements were carried out and funded by the U.S. Centers for Disease Control and Prevention. The authors thank David Ashley, Tom Bernert, Cliff Watson, and Robert West for their help. The authors of this manuscript have no conflicts of interest to declare.

References

Adams, L., Lee, C., Rawbone, R., & Guz, A. (1983). Patterns of smoking: Measurement and variability in asymptomatic smokers. *Clinical Science*, *65*, 383–392.

Adda, J., & Cornaglia, F. (2006). Taxes, cigarette consumption, and smoking intensity. *American Economic Review*, *96*, 1013–1028.

Ahijevych, K., Weed, H., & Clarke, J. (2004). Levels of cigarette availability and exposure in Black and White women and efficient smokers. *Pharmacology, Biochemistry, and Behavior*, *77*, 685–693.

Benowitz, N. L. (2001). Compensatory smoking of low-yield cigarettes. In: National Cancer Institute (Ed.), *Risks associated with smoking cigarettes with low machine-measured yields of tar and nicotine* (pp. 39–64). Bethesda, MD: U.S. Department of Health and Human Services, National Institutes of Health, National Cancer Institute.

Benowitz, N. L., Jacob, P., III, Kozlowski, L. T., & Yu, L. (1986). Influence of smoking fewer cigarettes on exposure to tar, nicotine, and carbon monoxide. *The New England Journal of Medicine*, *315*, 1310–1313.

Bernert, J. T., Jr., McGuffey, J. E., Morrison, M. A., & Pirkle, J. L. (2000). Comparison of serum and salivary cotinine measurements by a sensitive high-performance liquid chromatography-tandem mass spectrometry method as an indicator of exposure to tobacco smoke among smokers and nonsmokers. *Journal of Analytical Toxicology*, *24*, 333–339.

Bridges, R. B., Combs, J. G., Humble, J. W., Turbek, J. A., Rehm, S. R., & Haley, N. J. (1990). Puffing topography as a determinant of smoke exposure. *Pharmacology, Biochemistry, and Behavior*, *37*, 29–39.

Burling, T. A., Lovett, S. B., Richter, W. T., & Frederiksen, L. W. (1983). Alveolar carbon monoxide: The relative contributions of daily cigarette rate, cigarette brand, and smoking topography. *Addictive Behaviors*, *8*, 23–26.

Darby, T. D., McNamee, J. E., & van Rossum, J. M. (1984). Cigarette smoking pharmacokinetics and its relationship to smoking behaviour. *Clinical Pharmacokinetics*, *9*, 435–449.

Djordjevic, M. V., Hoffmann, D., & Hoffmann, I. (1997). Nicotine regulates smoking patterns. *Preventive Medicine*, *26*, 435–440.

Eissenberg, T., Adams, C., Riggins, E. C., III, & Likness, M. (1999). Smokers' sex and the effects of tobacco cigarettes: Subject-rated and physiological measures. *Nicotine & Tobacco Research*, *1*, 317–324.

Etter, J. F., & Perneger, T. V. (2001). Measurement of self reported active exposure to cigarette smoke. *Journal of Epidemiology and Community Health*, *55*, 674–680.

Frederiksen, L. W., Martin, J. E., & Webster, J. S. (1979). Assessment of smoking behavior. *Journal of Applied Behavior Analysis*, *12*, 653–664.

Hammond, D., Fong, G. T., Cummings, K. M., & Hyland, A. (2005). Smoking topography, brand switching, and nicotine delivery: Results from an in vivo study. *Cancer Epidemiology, Biomarkers & Prevention*, *14*, 1370–1375.

Heatherton, T. F., Kozlowski, L. T., Frecker, R. C., Rickert, W., & Robinson, J. (1989). Measuring the heaviness of smoking: Using self-reported time to the first cigarette of the day and number of cigarettes smoked per day. *British Journal of Addiction*, *84*, 791–799.

Henningfield, J. E., Yingling, J., Griffiths, R. R., & Pickens, R. (1980). An inexpensive portable device for measuring puffing behavior by cigarette smokers. *Pharmacology, Biochemistry, and Behavior*, *12*, 811–813.

Hill, P., Haley, N. J., & Wynder, E. L. (1983). Cigarette smoking: Carboxyhemoglobin, plasma nicotine, cotinine and thiocyanate vs self-reported smoking data and cardiovascular disease. *Journal of Chronic Diseases*, *36*, 439–449.

Hofer, I., Nil, R., Wyss, F., & Battig, K. (1992). The contributions of cigarette yield, consumption, inhalation and puffing behaviour to the prediction of smoke exposure. *The Clinical Investigator*, *70*, 343–351.

Jamrozik, K. (2004). Population strategies to prevent smoking. *British Medical Journal*, *328*, 759–762.

Kozlowski, L. T., Mehta, N. Y., Sweeney, C. T., Schwartz, S. S., Vogler, G. P., & Jarvis, M. J., et al. (1998). Filter ventilation and nicotine content of tobacco in cigarettes from Canada, the United Kingdom, and the United States. *Tobacco Control*, *7*, 369–375.

Lee, E. M., Malson, J. L., Waters, A. J., Moolchan, E. T., & Pickworth, W. B. (2003). Smoking topography: Reliability and validity in dependent smokers. *Nicotine & Tobacco Research*, *5*, 673–679.

Malaiyandi, V., Sellers, E. M., & Tyndale, R. F. (2005). Implications of CYP2A6 genetic variation for smoking behaviors and nicotine dependence. *Clinical Pharmacology and Therapeutics*, *77*, 145–158.

Nakajima, M., Kuroiwa, Y., & Yokoi, T. (2002). Interindividual differences in nicotine metabolism and genetic polymorphisms of human CYP2A6. *Drug Metabolism Reviews*, *34*, 865–877.

Nakayama, T., Yokoyama, T., Yoshiike, N., Ichimura, T., Yamamoto, A., & Tanaka, H. (1999). Behavioral factors predicting serum cotinine concentrations of male smokers in a Japanese community. *Journal of Epidemiology*, *9*, 143–145.

Patrick, D. L., Cheadle, A., Thompson, D. C., Diehr, P., Koepsell, T., & Kinne, S. (1994). The validity of self-reported smoking: A review and meta-analysis. *American Journal of Public Health*, *84*, 1086–1093.

Tobin, M. J., Jenouri, G., & Sackner, M. A. (1982). Subjective and objective measurement of cigarette smoke inhalation. *Chest*, *82*, 696–700.

West, R., Zatonski, W., Przewozniak, K., & Jarvis, M. J. (2007). Can we trust national smoking prevalence figures? Discrepancies between biochemically-assessed and self-reported smoking rates in three countries. *Cancer Epidemiology, Biomarkers, and Prevention*, *16*, 820–822.

Wood, T., Wewers, M. E., Groner, J., & Ahijevych, K. (2004). Smoke constituent exposure and smoking topography of adolescent daily cigarette smokers. *Nicotine & Tobacco Research*, *6*, 853–862.