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The Importance of Filter Collection for Accurate Measurement of Cigarette Smoking

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Abstract

Objectives—We examined the impact of cigarette filter collection on reports of cigarettes per day (CPD) versus self-reported CPD and to assess the utility of a pre-intervention baseline period in smoking studies.

Methods—Using baseline data from 522 non-treatment seeking smokers, we assessed differences in self-reported CPD via phone screen (CPD PS) and during baseline (CPD BL). We analyzed self-reported cigarette measures to predict carbon monoxide (CO), a measure of smoke exposure.

Results—On average, CPD PS was 2.8 CPD more than CPD BL, and reporting multiples of 10 were more often found in CPD PS compared with CPD BL (54.7% vs 17.2%, respectively). CPD BL was more strongly associated with CO than self-report CPD. Number of cigarettes smoked today, time since last cigarette, and nicotine dependence were significantly associated with CO.

Conclusions—CPD BL using filter collection is a more accurate measure of cigarette consumption than self-report, which may have implications for assessment of nicotine dependence. When feasible, studies should include a pre-intervention baseline period for comparison data with study outcomes. In addition to CPD BL, studies should assess time since last cigarette and the number of cigarettes smoked today when using CO as a biological measure of smoke exposure.

Keywords

measuring cigarettes per day; nicotine dependence; methodology in smoking studies

Self-reported cigarettes smoked per day (CPD) is often used as a measure of cigarette consumption and to represent smoking intensity.^{1–4} CPD is used in epidemiological studies estimating smoking prevalence, as a measure of efficacy in intervention studies, and by researchers linking cigarette consumption with various smoking-related diseases.^{2,5} Despite the common use of self-report measures, bias may arise in using these measures. Digit bias

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Conflicts of Interest Statement

The authors have no competing interests to report.

or, heaping, which is a clustering of reported estimates around rounded values^{6–8} is common and has been well documented in the literature.^{1,9–15}

When studying smokers and their behaviors, global self-reports (eg, asking participants how much they smoke, on average) often serve as a primary assessment of how much a person smokes.^{2,16–18} Although self-reports of CPD are most appropriate for large-scale survey research, it is important to consider the potential for bias from these reports in smoking studies. In both clinical trials and observational studies, the use of other data collection methods when assessing daily cigarette intake could help reduce digit bias. Timeline follow-back (TLFB) methods originated in alcohol research¹⁹ and are considered a reliable and valid method of assessment of daily cigarette use.^{20,21} Among smokers, TLFB methods have shown test-retest reliability with a daily smoking diary²¹ and studies have demonstrated reliability in TLFB when assessing adolescent smoking, which is often more variable compared with adult smoking.²²

In studying smoking behavior in clinical trials, there is a need to capture a true representation of cigarette consumption, independent of study conditions, which can then serve as a comparison measure for end-of-study outcomes. In a study by Shiffman,² global reports (eg, asking participants how much they smoke, on average) were major sources of digit bias (6 times the amount expected), compared with measuring cigarette consumption through the use of ecological momentary assessment (EMA) (EMA fit the expected random distribution), although this position has been challenged. Shiffman² found that EMA in addition to TLFB was an improvement over global reports of CPD in terms of digit bias, as well as CPD validated by biochemical measures of smoking. This suggests that self-monitoring smoking behavior may result in more accurate reports of CPD by smokers.

For more precise measures of smoke exposure, biomarkers can be measured (cotinine, nicotine levels, and expired breath carbon monoxide [CO]);^{1,23,24} although desirable sources, they can be invasive and expensive to include in research. Etter and Perneger²⁵ investigated several methods to collect self-reported data measuring smoke exposure, including CPD, spent cigarette filters (on one study day), smoking behavior ratings, and saliva cotinine.²⁵ The best predictor of saliva cotinine was a model inclusive of CPD, smoking intensity (0–100 scale), a measure of smoking when ill, and type of cigarettes smoked.²⁵

In the present study, we evaluated data from a 5-day baseline period that was identical across 5 separate studies at the same research center, during which participants were asked to smoke their own brand of cigarettes that they provided for themselves. There were 2 primary aims of this study. The first aim was to examine the impact of filter collection, a method of self-monitoring, on reports of CPD. In addition, we sought to determine whether multiple CPD reports, verified by filter collection, collected during a 5-day baseline period differed from self-reported CPD during a phone screen assessment. The second aim of this study was to examine how measures of CPD were associated with CO. CO is often used as a biochemical measure of smoke exposure for observational and product switching studies.^{26,27} Therefore, identifying an optimal assessment of CO using an accurate measure of CPD is critical. We also examined whether heaping occurs in self-reported CPD measured at a

phone screen and/or during CPD reports during a baseline period, as heaping can bias self-reports of CPD. Heaping in self-reports often occurs in multiples of 5 or 10 and is not cigarette specific.^{14,15,28–30} For cigarette smokers, heaping at 10 or 20 (half-pack or full-pack of cigarettes) may impact the assessment of nicotine dependence, specifically with the Fagerström Test for Nicotine Dependence (FTND) because cut-points of this measure occur in counts of 10 (FTND categories: 10 or less, 11–20, 21–30, 31+). Heaping in self-reports, that differs from actual consumption, even by a few cigarettes, can lead to incorrect FTND classification. Furthermore, an observational baseline period in which smokers self-monitor cigarette consumption through filter collection and report CPD using TLFB methods, may not only help correct bias in CPD, but also provide more accurate comparison measures for study outcomes.

METHODS

Research Study Procedures

Participants were 522 unique smokers enrolled separately in 5 non-quit, smoking research studies (Clinical trial numbers: NCT01202942, NCT01898507, NCT01898559, NCT01329263, NCT02301351). Participants initially completed a telephone screening to determine eligibility; the phone screen included self-report of daily cigarette consumption. All participant sessions were conducted in a laboratory room within a nicotine addiction research clinic at a university medical school center. Recruitment for one study occurred from 2007–2013, a second from 2010–2011, and 3 of the 5 studies are currently active. All studies included an identical 5-day baseline period in which individuals smoked their own brand of cigarettes, as desired, prior to being randomized to the study conditions. Participants were not aware of their randomization condition until the conclusion of day 5. This 5-day baseline period allowed for the testing of reliability of patterns of daily smoking behaviors, allowed participants to become accustomed to study procedures (eg, use of a smoking topography device, completion of other smoking measures), and it served as a control period.

Procedures during the baseline period of all 5 studies were identical.^{26,31} Participants visited the lab on days 1 and 5, for a 2-hour session each day. On their first baseline visit (day 0), study procedures were explained and participants provided informed signed consent, a breath CO sample, and were given instructions explaining how to collect and store used cigarette filters in the date-stamped re-sealable bags provided. Participants also were provided with date-stamped, re-sealable bags and instructed on collecting their used cigarette filters, which they were required to collect each day and return the filters at their next study visit. These filter collection procedures have been used and described in previous research.^{26,31–33} During this visit, participants completed demographic assessments, smoking history, and smoked 2 of their own-brand cigarettes using the smoking topography device (breath CO samples taken before and after smoking own cigarettes). Nicotine dependence was assessed using the FTND.³⁴ On all days of the baseline period, participants smoked their own cigarettes, collected all spent cigarette filters; at the first and last baseline visit, participants reported CPD in a TLFB calendar, noting any filters that were mistakenly discarded.

Measures

Demographic measures—Age, sex, race, ethnicity and income were assessed at Day 0.

Cigarettes smoked per day (CPD)—Two measures of CPD were assessed: (1) CPD at initial phone-screen (CPD PS); CPD PS was self-reported over the phone prior to study enrollment; and (2) baseline CPD (CPD BL); CPD BL was collected using timeline-follow-back methods for 5 study days during the baseline period.¹⁹ The collection of spent cigarette filters served as a self-monitoring technique during the baseline period to verify CPD BL for each study day;^{26,31} filters for each baseline day were returned in separate date and time stamped re-sealable bags on the fifth, and final, baseline day.

Number of cigarettes smoked prior to study session—Participants were asked to report the number of cigarettes smoked on the study session day up until the beginning of the lab visit, this is reported on the day of session.

Time since last cigarette—Participants reported the duration since last cigarette smoked, reported on the day of session; recorded in number of hours (including fraction of hours, eg, 15 minutes = .25 hours).

Menthol status—Menthol status was recorded as a binary variable: menthol/non-menthol.

Exhaled carbon monoxide (CO)—CO is a biochemical indicator of smoke exposure, and was assessed using the Vitalograph Breath CO Analyzer (McNeil International, Lenexa, KS), measured in parts per million (ppm).^{27,35} The same type of CO monitor was used for all participants; devices were routinely calibrated following manufacturer guidelines.

Nicotine dependence—Dependence was assessed using the Fagerström Test for Nicotine Dependence.³⁴ The FTND is a 6-item self-report measure of nicotine dependence (range: 0 to 10) with satisfactory internal consistency.

Initial CO assessment—CO assessments were collected at the beginning of the first and last baseline visits, before any cigarettes had been smoked during the study session, serving as a proxy of usual CO level.^{27,35}

Analyses

Analyses were computed using Stata 14³⁶ for all full days that participants were smoking their own brand of cigarettes. Data from the first baseline visit were excluded when computing descriptive statistics because only partial data was available (participants collected filters through the end of the day after their first lab visit). We computed means, standard deviations and 95% confidence intervals for each of the 4 full baseline days for both CPD BL and returned cigarette filters. We computed identical statistics for CPD PS. Spearman's rank correlation coefficient was calculated. Cronbach's alpha tested the reliability of within-participant CPD BL. To determine whether digit bias occurred in CPD PS, and CPD BL, frequencies of multiples of 10 were examined.

Means and standard deviations were computed for initial CO on days 0 and 5, and a t-test was used to detect any significant differences between CO by day. To test whether CPD PS or CPD BL better explained initial CO, 2 mixed models regressions were analyzed. Two separate models were analyzed using initial CO from each of the 2 study days as the dependent variable ($N = 1043$), with each of the CPD variables separately as predictors, followed by *post hoc* likelihood calculations to estimate which model was a better fit. A final linear regression model using the better fit variable (CPD BL) was then analyzed to determine the predictive value of the following cigarette-related variables collected during study sessions, on initial CO: FTND score, time since last cigarette and number of cigarettes smoked prior to study session, in addition to CPD.

RESULTS

Participant Characteristics

A total of 526 participants completed the first baseline session. Four participants withdrew after completing the third baseline day. In total, 522 smokers completed all days of the baseline period. The mean age of the sample was 40.7 years. The sample was 67.9% male. Regarding race/ethnicity, 71.5% were white, 22.1% were African-American, and 7.4% were non-white or another race (Asian, more than one race, refused or did not report race). Finally, 66.7% of the sample had an annual income of \$35,000 or less.

Baseline Smoking Characteristics

The average age participants started smoking was 16.6 years, and 78.2% of the sample was non-menthol smokers. The average CPD reported during the phone screen was 19.0 ($SD = 6.25$). Figure 1 shows means and 95% CI's for CPD BL and filters collected for each baseline day. Means did not differ significantly between CPD BL and filters collected on any full days of participation.

The mean CPD BL over 4 days was 16.3 ($SD = 6.32$) and the mean number of filters collected was 15.4 ($SD = 6.37$), excluding the first and last baseline day for both measures (Figure 1.). Based on 95% confidence intervals, CPD PS (95% CI = 18.47–19.52) and average CPD BL (15.72 – 16.80) were significantly different. CPD BL and filters collected were highly correlated ($\rho = .90$, $p < .001$). The alpha coefficient for CPD BL was 0.93 ($p < .05$) across the 4 baseline days and 0.93 ($p < .05$) for filters collected. CPD BL and filters returned were similar; 43.4% of smokers' CPD was the same as the number of cigarettes filters returned during this time period. If CPD BL count differed from filter count, the difference was between one to 3 cigarettes. Among those reporting more CPD BL than filters collected, 79.5% were within 3 cigarettes, and among those reporting fewer CPD BL than filters collected, 89.4% were within 2 cigarettes. The mean initial CO for day 0 was 22.70 ppm ($SD = 11.38$) and for day 5, 22.56 ppm ($SD = 11.17$); these values were not significantly different from one another ($p = .73$). Because sessions occurred at the same time of day, this suggests that actual smoking level did not change significantly while enrolled in the baseline period.

Heaping in CPD Measures

We examined frequencies to understand how often multiples of 10 were reported by participants for CPD PS compared with CPD BL (Figure 2). During the phone screen, participants reported CPD more often in multiples of 10 than they did during the baseline period (phone screen reporting any multiple of 10 = 54.7%, baseline reporting any multiple of 10 = 17.2%, $p < .001$).

Predictors of Initial CO

Results from the mixed models regression show that both measures of CPD were significantly associated with CO (CPD PS: coefficient = 0.53, $p < .001$; CPD BL: coefficient = 0.64, $p < .001$). *Post hoc* analyses indicate that CPD BL was a better fit in the model with CO as the dependent variable (CPD BL: AIC = 7527.159 versus CPD PS: AIC = 7556.258). The final linear regression model, using CPD BL (Table 1), shows that CPD BL ($\beta = .43$, 95% CI = .28–.58), number of cigarettes smoked today ($\beta = 0.41$, 95% CI = 0.16 to 0.67), time since last cigarette ($\beta = -1.05$, 95% CI = -1.40 to -.70), and self-rated FTND score ($\beta = .89$, 95% CI = .42 to 1.36) were significantly associated with initial CO (Table 1). The addition of the following independent variables (number of cigarettes smoked today, time since last cigarette, and FTND score) increased the R^2 of the regression model with only CPD BL as an independent variable, by nearly 7.0% (R^2 increased from 12.9% to 20.2%).

DISCUSSION

Daily cigarette consumption has been found previously to be the most important factor in models examining daily exposure to nicotine and CO;³⁷ thus, correctly measuring CPD is critical. Our findings suggest the importance of a short baseline period, occurring prior to any study manipulation, which includes measuring CPD on multiple days to capture true daily cigarette consumption. In addition to this, our study demonstrates that reports of CPD during a baseline period, verified by filter collection, offer a more accurate measure of daily consumption among smokers, compared with a single self-reported CPD assessment during a phone screen. Collecting cigarette filters may serve as a self-monitoring technique, similar to EMA, although less costly, and lead to more accurate TLFB reporting of CPD. While also self-monitoring cigarette consumption using EMA methods, Shiffman² found that TLFB reports were less biased than either global reports or TLFB reports alone.³⁸ The collection of filters provides a physical tracking of cigarette consumption, which may reduce recall bias; this method could be compared with the use of EMA methods when looking to reduce bias.³⁹ The awareness of smoking behavior that is prompted by self-monitoring could be compared with the use of fitness tracking devices; individuals wear a device that counts steps or monitors physical activity, making one more attentive to activity levels (or lack thereof).^{40,41}

There are conflicting viewpoints regarding the use of self-reported smoking,^{3,4,42,43} as they may be sources of participant bias.^{42,44} Self-reported CPD are often rounded to a preferred number,^{9–12} usually multiples of 5 or 10, and most often, 20 CPD. When self-reporting CPD, smokers may not recall an exact amount, and report a rounded estimation, often based on pack size.¹⁴ Consistent with previous research indicating that self-reported CPD (both

global reports and TLFB alone) were subject to heaping,² smokers in the present study more often rounded to multiples of 10 when self-reporting CPD during a phone screen, compared with TLFB reports coupled with self-monitoring through filter collection methods.

Initial phone screen self-reports were nearly 3 CPD greater than what was consistently reported each day during the baseline period. For each full day that smokers were enrolled in the baseline period, their reports of CPD did not vary significantly from one day to the next. This finding is supportive of how essential a baseline period may be in establishing a true measure of CPD. This is further exemplified by the difference found between a single self-reported measure of CPD (occurring at phone screen) and multiple, highly reliable reports of CPD over several days. In addition to this, CO measured at the start of each session (prior to any cigarettes being smoked in the lab) did not differ from day 0 to day 5 (first and last baseline visits); this offers biochemical support that smoking levels did not change during the baseline period. The finding that these 2 CO measures are not significantly different speaks to concerns about potential changes in cigarette consumption due to being asked to monitor (collect filters) smoking behavior. Day 0 CO was collected at the start of the first visit, along with other measures such as height and weight, without participants having prior knowledge of the collection of these measures. Furthermore, prior to their first study visit, participants were unaware they would be asked to collect cigarette filters throughout the study; therefore, the initial CO measure on the first baseline day, is likely a true representation of usual cigarette consumption.

In addition to the discrepancy found between phone screen self-report and average baseline CPD, being enrolled in a smoking study, in which smoking behaviors are being manipulated in some way, may contribute to one's awareness of daily cigarette consumption, leading to changes in smoking behavior that are unrelated to the study. Due to this possibility, a short baseline period similar to what has been described here, in which smokers are enrolled in a study, but are asked to continue their usual smoking behaviors for a short time, allows for observation of typical behavior or, any changes in behavior. Further, baseline measures of smoking behavior could then serve as the comparison with study outcomes, rather than using a single self-reported measure as a comparison. A comparison baseline period may be especially important in cessation and reduction interventions to classify true reductions in CPD, rather than changes in behavior that may occur due to bias or enrollment in a study.

The differences found between CPD PS (self-report) and CPD BL in the present study suggest that bias in self-reported CPD may impact categorization of nicotine dependence among smokers, particularly with use of the FTND. On average, smokers misreported CPD by about 3 cigarettes, a figure similar to what Shiffman found.² Although this seems minimal, it could lead to misclassification of FTND scores due to the FTND breakpoints, which occur at counts of 10 (eg, 10 or fewer, 11–20, 21–30, 31+). As an example, if a smoker self-reports smoking ten CPD, but actually smokes 12 CPD, they would be classified differently using the FTND for each measurement, despite the small difference in CPD.

CO measures are used to evaluate smoke intake,⁴⁵ and in smoking research studies to verify smoking status,^{46–48} overnight abstinence,^{49,50} and changes in exposure.²⁶ Due to the noted differences found between self-reported phone screen CPD and baseline CPD, verified by

filter collection, we examined differences in these 2 measures when predicting CO measured at the start of study sessions. Average baseline CPD better predicted CO than did self-reported CPD. In addition, variables such as FTND score, the number of cigarettes smoked today (prior to study session) and time since last cigarette predicted initial CO and increased the variance when added to a CPD-only analysis. These results indicate the importance of collecting cigarette-related measures, in addition to TLFB reports of CPD and filter collection.

Some limitations to the study should be considered. Participants may have over-reported CPD at phone screen to ensure eligibility. Although this may be possible, callers were not made aware of the inclusion criteria, and the mean CPD reported during the phone screen was greater than study requirements (mean = 19.1 CPD at phone screen). A person with a strong desire to enroll would ostensibly report a few cigarettes more than a half-pack or a pack to ensure eligibility (for example, reporting 12 or 22 CPD), however, the largest frequency of reporting occurred at exactly 20 CPD. A second limitation may be that participants could simply count their filters prior to their session and report this number during the TLFB interview. Although this concern exists, even though minimal, differences did exist between TLFB reports and filters returned (Figure 1), indicating that participants were aware if they had misplaced any filters, and they reported this. Strengths include 99.2% retention of smokers who attended the first baseline visit, identical procedures for the baseline period of all 5 studies, and a demographically diverse sample of smokers.

IMPLICATIONS FOR TOBACCO REGULATION

Our results provide important suggestions for study design and methodology in smoking research. They highlight differences between self-reported CPD during a phone screen and multiple, consistent TLFB reports of CPD verified by filter collection during a baseline period. Our findings suggest that a 3- to 4-day baseline observational period (including both CPD and filter collection) would provide a more precise assessment of CPD. CPD reported on each baseline day, verified by filter collection did not differ significantly from one day to the next. The consistency of baseline CPD reports are further verified by the observation of CO measures taken on the first and last baseline visits; these were also not significantly different from one another, suggesting a true stability of consumption over the 5-day period. A baseline period provides a snapshot of a smoker's usual smoking behavior, prior to any study manipulation, and data collected during this time period serve as a comparison of measures with later outcomes, this may be especially important in studies measuring cessation or reduction in cigarette consumption, as changes in use frequency may related to biased self-reports of CPD.

Additionally, our study highlights the benefit of filter collection as a means of self-monitoring, which increases smokers' awareness of their daily cigarette consumption, resulting in more accurate recall during TLFB interviews. Because heaping is common in self-reported CPD and often occurs in multiples of 5 or 10, assessing nicotine dependence based on self-reported CPD may incorrectly classify dependence levels in smokers, particularly when using the FTND, a widely accepted and validated measure of dependence.^{51–53} Cut-offs for the FTND occur at counts of 10; thus, if smokers heap their cigarette

consumption at counts of 10, even if the misreporting is only the difference of a few cigarettes, smokers may be categorized as more or less dependent than they actually are. In the present study, 32.2% of FTND scores using the baseline CPD measure changed (10.5% higher and 21.7% lower) than the FTND score using self-reported CPD at phone screen.

Finally, our results show that in addition to baseline CPD, FTND score, time since last cigarette, and the number of cigarettes smoked prior to session, also are predictive of initial CO, a direct measure of smoke exposure. These measures are easily collected during study sessions in addition to CPD reports and add value to the assessment of cigarette consumption and smoke exposure.

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Human Subjects Statement

All participants provided signed informed consent. The University of Pennsylvania Institutional Review Board approved the study protocol.

Figure 1. Mean CPD and Filters Collected during Baseline Period

Note.

Day 1 = first baseline visit; participants did not begin collecting filters on Day 1 until after they attended their first baseline session. Final baseline day not shown, participants switched to study cigarettes on final day.

Figure 2.
Percentage of "Heaped" Reports when Reporting Cigarette Consumption

Table 1

Linear Regression Model Predicting Initial CO

Initial CO (N = 1043)			
Independent Variables	Coefficient (95% CI)	p-value	Effect size (η^2)
Baseline Cigarettes per Day	.43 (.28 to .58)	< .001	0.046
Number Cigarettes Today	.41 (.16 to .67)	.002	0.011
Time Since Last Cigarette	-1.05 (-1.40 to -.70)	< .001	0.018
FTND score	.89 (.42 to 1.36)	< .001	0.017

Note.Model $R^2 = .2017$