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A Comparative Evaluation of Self-Report and Biological Measures of Cigarette Use in Non-Daily Smokers

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Abstract

A large subset of individuals who smoke cigarettes do not smoke regularly, but the assessments used to collect data on cigarette consumption in non-daily smokers have not been rigorously evaluated. The current study examined several self-report and biomarker approaches to the assessment of cigarette use in a sample of non-daily smokers (n=176). Participants were randomly assigned to a Daily Monitoring condition (n=89), requiring a Daily Report of the number of cigarettes smoked in the previous 24 hours, or a No Monitoring condition (n=87). Number of cigarettes smoked over the first 28 days of the study was assessed using two Quantity Frequency measures, a Graduated Frequency measure, and a Timeline Follow Back (TLFB) interview at the Session 5 study visit. Hair nicotine (NIC), hair cotinine (COT), and expired-air carbon monoxide (CO) were collected from each participant. Total cigarettes reported via Daily Report were strongly correlated with all Session 5 measures of total cigarettes, but were most strongly

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associated with TLFB total cigarettes. Collapsed CO across five sessions was the biomarker most strongly correlated with Daily Report total cigarettes. The results support the use of DR and TLFB methods of assessing cigarette use in non-daily smokers. Results also support the use of CO as appropriate biological markers of exposure in non-daily smokers, and point to some limitations in the use of hair biomarkers in this population.

Keywords

Non-daily smokers; self-report measures; hair toxicology; assessment

Introduction

The prototypical smoker is depicted as using cigarettes daily and at high rates throughout the day, but many smokers do not fit this profile. Approximately 40% of persons in the United States who endorse cigarette smoking over a one year period report nondaily smoking (Substance Abuse and Mental Health Services Administration, 2012), and while daily smoking is on the decline, nondaily use is becoming more prevalent (Schane, Glantz, & Ling, 2009). Further, just over half of individuals endorsing smoking in the past 30 days are not nicotine dependent (Goedeker and Tiffany, 2008). The study of nondaily smokers is a burgeoning area of interest in the tobacco use field, and work to date has focused on many domains, including describing intermittent or nondaily smokers (Shiffman et al., 2012), comparing aspects of their smoking with daily smokers (Coggins, Murrelle, Carchman, & Heidbreder, 2009), investigating the health effects of nondaily smoking (Schane, Ling, & Glantz, 2010), and examining attempts at cessation in this population (Tindle & Shiffman, 2011).

An area that has received minimal attention is the assessment of cigarette use in this subset of smokers (Fagan & Rigotti, 2009). Examination of the assessment of cigarette use in non-daily smokers, including self-report measurement and biomarkers of use, is important for a number of reasons. Even low rates of smoking carry significant health risks (Bjartveit & Tverdal, 2005; Schane, Ling, & Glantz, 2010), and these smokers still report considerable difficulty quitting smoking (Tindle & Shiffman, 2011). Accurate assessment of smoking amount is crucial, given that smoking rate may be an important factor in the shift from nondependent to dependent smoking (Colby et al., 2000; Tiffany, Conklin, Shiffman, & Clayton, 2004). Further, precise estimates of smoking are important in quantifying the amount of exposure to toxins and the level of risk for associated health problems (Joseph et al., 2005; US Department of Health and Human Services, 2004). Accurate quantification is also necessary for well-informed treatment strategies (Fiore et al., 2000), and total amount smoked may be important as a predictor of future cessation (Hughes & Carpenter, 2006).

Various self-report measures have been used to assess cigarette use in dependent smokers. *Quantity Frequency (QF)* measures require participants to identify the number of days smoked over a certain period of time and the number of cigarettes smoked on an average smoking day. In *QF Closed* surveys, participants are asked to choose from a range of a number of cigarettes smoked on an average day (e.g., 2-5 cigarettes, 6-10 cigarettes). This

measure can also be administered such that participants are asked to provide an exact number of cigarettes smoked on an average smoking day (*QF Open survey*). The *Graduated Frequency* measure asks participants to report the number of days that they used multiple ranges of amount of drug (e.g., Makela & Mustonen, 2007). The *Timeline Follow Back* interview (Sobell & Sobell, 1996) uses calendar pages to help guide recall of drug use on a day-by-day basis. Finally, *Daily Report* assessments include a variety of collection strategies including daily diaries (e.g., Windham, Mitchell, Anderson, & Lasley, 2005), nightly phone calls (e.g., Ershoff et al., 1999), and real time logging of drug-use events (e.g., Stone & Shiffman, 1994).

These self-report measures capture rates of cigarette use relatively well in regular, heavy smokers, as evidenced by (1) the self-report measures being highly correlated with biomarkers of smoking (Patrick et al., 1994) or (2) the less intensive self-report measures being highly correlated with more intensive measures of smoking behavior (e.g., daily reporting of cigarette use; Brown et al., 1998; Shiffman, 2009; but see Griffith, Shiffman, & Heitjan, 2009 for an exception). Similar research using nondaily smokers has begun; work by Shiffman, Dunbar, & Benowitz (2014) that found the relationship between self-reported cigarette smoking and urinary cotinine was significant in a sample of intermittent smokers, and Harris et al. (2009) demonstrated that global measures of smoking behavior and TLFB data were highly correlated in a sample of nondaily smokers.

Self-report measures are quick, straightforward, and inexpensive methods of assessment, but are limited by factors such as recall bias (Ehrman & Robbins, 1994). Further, lower level smokers may under-report their cigarette use due to the growing stigma around smoking or because they belong to certain groups in which cigarette use is especially discouraged (Al-Delaimy & Willett, 2008, Patrick et al., 1994). Biomarkers of smoking, including carbon monoxide (CO), nicotine, and cotinine (a major metabolite of nicotine), are often viewed as the gold standard for assessing nicotine exposure due to the objectivity of these measures and the decreased susceptibility to reporting bias (Benowitz, 1996).

CO shows reasonable specificity for cigarette use in dependent smokers (Benowitz, 1999), but is highly dependent on time since last cigarette and therefore may be of limited utility in quantifying cigarette use in non-daily smokers (Benowitz et al., 2002). Biomarkers of smoke constituents (e.g., nicotine) or direct metabolites of nicotine (e.g., cotinine) are the best markers currently identified for measuring smoke exposure (Benowitz, 1999; Haley & Hoffman, 1985; Rebagliato, 2002), with cotinine having the advantage of being able to detect use that occurs over a longer period of time than nicotine (Al-Delaimy, Crane, & Woodward, 2002). However, measurement of nicotine and cotinine collected via traditional assays (i.e., blood plasma, urine, and saliva) may be poor indices of smoking levels in irregular users, as the detection period is limited to recent use.

Nicotine and cotinine concentrations in hair may be more useful measures of tobacco exposure in non-daily smokers. Biomarkers found in hair are good indicators of *long-term* drug use, as nicotine is continuously incorporated into the growing hair shaft and remains very stable over time (Eliopoulos, Klein, & Koren, 1996). Modern techniques such as liquid chromatography-tandem mass spectrometry (LC-MS/MS) allow for the detection of

extremely low (picogram) levels of nicotine and cotinine in hair samples (Miller, Murray, Rollins, Tiffany, & Wilkins, 2011). Hair analysis is limited by cost and, in some cases, the feasibility of hair collection, which highlights the importance of identifying the self-report measure(s) most strongly associated with these biomarkers.

Study aims and hypotheses

The primary aim of this research was to evaluate a set of self-report measures of cigarette use in a sample of non-daily smokers. The current study adds to the literature by evaluating a number of different self-report measures of smoking behavior in comparison to one another and against state-of-the-art biomarkers of smoking in this population. We hypothesized that total cigarettes derived from the TLFB measure would be most strongly correlated with Daily Report data, followed by Graduated Frequency, QF Open, and QF Closed, respectively. Further, we hypothesized that administering the QF measure in an open ended format would have advantages over the traditional close ended format. We also hypothesized that hair biomarkers (hair nicotine and hair cotinine) would be more strongly related to self-report measures of cigarette use than CO, due to the shorter half-life of the latter.

Methods

Participants were recruited from Buffalo, NY via television and radio ads and flyers posted in the community. Individuals were invited to participate if they were 18-45 years old, smoked between 1-29 of the past 30 days (≤ 15 cigarettes on an average smoking day), smoked ≥ 25 lifetime cigarettes, and had no current plans to quit smoking. Participants were excluded if they used non-cigarette tobacco products more than once in the past year, if they had a past year drug abuse/dependence diagnosis, if they had predominately grey or white (non-pigmented) hair, if their hair was < 3 cm in length, or if they were unwilling to forgo chemical hair treatment during the course of the study. Women were excluded if they were currently pregnant, nursing, or planning to become pregnant during the course of the study. Eligible participants were randomly assigned to the Daily Monitoring or No Monitoring group (matched on gender).

Study procedures

Study participants attended weekly lab sessions, which occurred at the same time each week for 5 weeks (Sessions 1-5). Participants returned for a final session (Session 6) 12 weeks after Session 1. During Session 1, participants provided written informed consent, provided CO and hair samples, and completed demographic and smoking history questionnaires. A 400 mg dose of ofloxacin was administered[1]. The Nicotine Addiction Taxon Scale (NATS; Goedeker & Tiffany, 2008) was administered to assess nicotine dependence. Four assessments of past 28 day smoking behavior were administered by trained interviewers in a fixed order: QF Closed, QF Open, Graduated Frequency, and TLFB.

[1]We intended to use ofloxacin to identify the exact segment of hair corresponding with the 28-day period of self-report assessment of smoking behavior. Participants were administered one dose at study Session 1 and a second dose at study Session 5, thus marking the period of smoking between Days 0 and 28. However, hair toxicology procedures were unable to detect discrete peaks representing a spike in ofloxacin in the hair on days that this medication was ingested. As such, we were unable to use the exact segment of hair corresponding with the days of interest, and instead used the well-established method of approximating one month's worth of exposure by segmenting 1 cm of hair (Al-Delaimy et al., 2002; Miyazawa & Uematsu, 1992; Uematsu et al., 1995).

During the QF Closed assessment, participants were asked the number of days in the past 28 they had smoked cigarettes and the number of cigarettes smoked on an average smoking occasion; participants chose the number of cigarettes smoked on average from a list (0, < 1,1, 2-5, 6-15, 16-25, 26-35, or >35). During the QF Open assessment, participants were asked the number of days in the past 28 they had smoked cigarettes and were then asked to estimate the exact number of cigarettes (up to 35) that they smoked on an average smoking occasion. During the Graduated Frequency assessment, participants were asked the number of days of the past 28 they smoked 0, <1, 1, 2-5, 6-15, 16-25, 26-35, and >35 cigarettes. During the TLFB assessment (Sobell & Sobell, 1996; modified for cigarette smoking), participants were presented with calendar pages depicting the past 28 days and were asked to indicate the number of cigarettes smoked on each of these days. Those in the Daily Monitoring group were required to call the lab each evening over the first 28 days of the study to report the number of cigarettes they had smoked in the past 24 hours (Daily Report). Participants in the No Monitoring group did not make a Daily Report but otherwise went through the same study procedures.

Participants provided an expired CO sample and completed cue reactivity trials (see Wray, Gass, & Tiffany, 2014) during Sessions 2-4. At Session 5, expired CO was collected and a 400 mg dose of ofloxacin was administered. The QF Closed, QF Open, Graduated Frequency, and TLFB measures were administered in this fixed order to assess self-reported smoking behavior over the first 28 days of the study.

A second hair sample was collected during the final visit (Session 6). This allowed us to quantify hair nicotine (NIC) and hair cotinine (COT) in a segment of hair that had been below the scalp during the Session 5 visit, thus generating values of NIC and COT from a time point as close to the assessment of self-reported smoking as possible.

Hair samples were collected by cutting 50-100 strands of hair (a “pencil thickness” width) from the crown of the head and as close to the scalp as possible. Hair samples were sent to the Center for Human Toxicology in Salt Lake City, UT for analysis. A liquid chromatography-electrospray ionization-tandem mass spectrometry (LC-ESI-MS/MS) procedure was used for the analysis of NIC and COT according to the method of Miller et al. (2011) with minor modifications. Hair strands were aligned, and the 1-cm of hair[2] closest to the scalp was cut from the bundle, placed into silanized vials, and weighed. The hair segments were then washed sequentially with solvents to reduce the potential influence of environmental nicotine. The hair segments were cut in segments 2-3mm in length and fortified with internal standards nicotine-d3 and cotinine-d3. A solvent was then used to extract the compounds of interest. The hair samples were cleaned using solid-phase extraction before LC-MS/MS analysis (Acquity UPLC® system coupled to a Quattro Premier XE™ triple quadrupole mass spectrometer). The procedure allowed for the detection of the presence of NIC and COT at levels ≥ 0.025 ng/mg and for precise quantification of levels ≥ 0.05 ng/mg.

[2]Because hair grows at a rate of approximately one centimeter per month, one month’s worth of exposure can be approximated by measuring levels of nicotine and cotinine found in one centimeter of hair (Al-Delaimy et al., 2002).

Participants were compensated for each completed session (Sessions 1-4, $30 each, Session 5, $70, and Session 6, $110). In addition, participants in the Daily Monitoring group were compensated for nightly phone calls according to the following schedule: $0.25 for the first call with payment increasing by $0.25 per night until a maximum of $1.50 was reached. If participants missed a phone call, the payment schedule restarted at $0.25. Participants who did not call for 7 consecutive days were excused from the study (n=2).

Data Reduction

The total number of cigarettes generated by each self-report measure of smoking corresponding with the first 28 days of the study (i.e., Session 5 assessments) was calculated and used for analyses. Missing days of daily report data were imputed using the mean number of cigarettes for that participant. NIC and COT values from the Session 6 hair sample collection were used for analyses. In some cases, an exact value of NIC or COT was not identified because NIC (or COT) was above the limit of detection but below the limit of precise quantification. A value of 0.037, i.e., the midpoint of the limit of detection (0.025 ng/mg) and the limit of quantification (0.05 ng/mg) was assigned in these cases. CO levels from the first five study sessions were averaged to provide a mean CO rating over the first 28 days of the study. Log transformations were used to improve the normality of the data.

Our inclusion criteria for quantity and frequency of baseline smoking was intended to be broad in order to capture smokers at a wide range of non-daily use. Although we recruited participants who smoked 1-29 of the past 30 days (≤ 15 cigarettes on an average smoking day), some participants reported daily smoking during the 28 day assessment period. Due to the irregular patterns of cigarette use in this population, we did not exclude data from participants who reported daily smoking during the 28-day assessment period. However, in order to focus this report on non-dependent smokers, we excluded participants if they were classified as nicotine dependent based on their NATS score (≥ 14.33; n=28). Of the remaining participants, those who completed each of the first five study sessions were retained for analyses.

Data analysis

Correlational analyses were used to assess the relationship among total cigarettes generated via self-report measures over the first 28 days of the study and between self-report measures and biomarkers. Spearman's correlation coefficients were reported for associations between self-report measures and biomarkers of smoking. Steiger's Z-test (Steiger, 1980) for comparing correlated correlation coefficients was used to determine if correlations were significantly different from one another.

Biomarkers were predicted in sequential multiple regression models (controlling for gender and hair color when predicting hair biomarkers, as hair color influences the binding of nicotine to hair; Kelly, Mieczkowski, Sweeney, & Bourland, 2000) to determine the added benefit of utilizing more intensive data collection methods. In another set of models, CO values were regressed out of NIC (COT) levels to determine if self-reported total cigarettes still predicted CO once the shared variance between CO and NIC (COT) was removed from the NIC (COT) values.

We first report comparisons across groups to determine if Daily Monitoring influence participants' report of smoking behavior. Given that only half of the sample had Daily Report data, we then present analyses run in the Daily Monitoring Group only, and finally present analyses run in the full sample (e.g., analyses focused on Timeline Follow Back and QF data).

Results

Participant characteristics

Participants (n=176) were 52% male (n=92), 66% White (n=116), averaged 25 years of age (range 18-45, *SD* 6.1), and had been smoking for an average of 9 years (range 0-30, *SD* 7.1). Most were employed (77%), and had at least some college education (85%). According to Session 1 TLFB data, participants smoked 16.5 days of the past 28 (range 0-28, *SD* 8.7*)* and 2.6 cigarettes on an average smoking day (range 0-15.3, *SD* 1.6*)*. Session 1 CO averaged 4.9 ppm (*SD* 6.1), Session 1 NIC averaged 2.6 ng/mg (*SD* 7.2), and Session 1 COT averaged 0.3 ng/mg (*SD* 0.9). There was no significant difference between Session 1 and Session 5 levels of CO, NIC, or COT in the Daily Monitoring or No Monitoring group.

Daily Report compliance was high, with data collected on 94% of possible days in the Daily Monitoring group. There were no significant differences between the Daily Monitoring and No Monitoring groups on participant characteristic variables, baseline total cigarettes smoked over the previous 28 days, or baseline NIC or COT levels. Participants in the Daily Monitoring condition had slightly higher baseline CO levels than participants in the No Monitoring condition (t=2.50, $p<.05$).

Comparisons between Daily Monitoring and No Monitoring groups

Self-report measures: Past 28 day total cigarettes as assessed by each of the self-report measures (TLFB, Graduated Frequency, QF Open, and QF Closed) were significantly higher in the Daily Monitoring group than in the No Monitoring group (Table 1).

Biomarkers: All self-report assessments of cigarette use were significantly correlated with all biomarkers of smoking (Table 2). There were several instances in which biomarkers were more strongly correlated with self-report measures in the Daily Monitoring group than in the No Monitoring group; i.e, TLFB, GF, and QF Open measures were more strongly associated with carbon monoxide levels in the Daily Monitoring group than in the No Monitoring group.

Analyses using Daily Report data (Daily Monitoring group only)

Self-report measures: As Daily Report was the most rigorous self-report measure used to collect data on total number of cigarettes, we compared total cigarettes derived from Daily Report to total cigarettes derived from all other self-report measures administered. All measures of total cigarettes were strongly correlated with Daily Report total cigarettes; these correlations followed the predicted pattern, such that Daily Report total cigarettes were most strongly correlated with TLFB total cigarettes ($r=.96$), followed by Graduated Frequency ($r=.93$), QF Open ($r=.92$), and QF Closed ($r=.88$) total cigarettes. The correlation between

Daily Report and TLFB total cigarettes was significantly higher than correlation between Daily Report and all other self-report measures (Steiger's zs ≥ 3.37; *p*s<.001).

Regression analyses were conducted to evaluate the relative predictive validity of total cigarettes derived from the Daily Monitoring methodology above and beyond total cigarettes generated from TLFB methodology. When predicting NIC, COT, or CO from total cigarettes assessed by TLFB total cigarettes in the Daily Monitoring group, the addition of DR total cigarette data did not significantly improved the prediction models (*p*s= .21−.72).

Biomarkers: We also evaluated each biomarker against total number of cigarettes generated by the Daily Report. Aggregated CO (collapsed across the first five sessions) was significantly more highly correlated with DR total cigarettes than hair NIC, hair COT, and CO measured at a single session (Steiger's z > 2.20; *ps*<.05). CO measured at a single session (Session 5) was significantly more strongly correlated with Daily Report total cigarettes than was hair COT (Steiger's z=2.09, *p*<.05) but not significantly different than hair NIC (Steiger's z= 1.03, *p*=.30). There was no significant difference in the correlation between DR total cigarettes and hair NIC or hair COT (Steiger's z= 1.47, *p*=.14).

We also evaluated whether NIC was uniquely predicted by self-report measures of smoking behavior once the variance of CO was removed from the NIC values. Total cigarettes across all measures (using the Daily Monitoring group only) no longer predicted NIC values in these models; however, in a parallel analysis predicting COT, self-report total cigarettes continued to predict COT once the shared variance between CO and COT levels was removed from the COT variable (*ps*<.05).

Analyses using full sample

Self-report measures: We compared variables generated from the commonly used QF measures with those generated from the TLFB measure (we used TLFB data instead of Daily Report data for this analysis since we could not determine whether participants smoked on days when they did not call in to report number of cigarettes smoked). TLFB total smoking days was significantly correlated with QF total smoking days (*r*=0.94). TLFB number of cigarettes on an average smoking day was also highly correlated with QF Open number of cigarettes on an average smoking day (*r*=0.88), but significantly less strongly correlated with QF Closed number of cigarettes on an average smoking day (*r*=0.74; Steiger's z= 7.22, *p*<.001).

We also created a total number of cigarettes variable from TLFB data by "binning" average number of cigarettes reported into categories consistent with the QF Closed measure and multiplying this with total number of days the participant reported smoking. This was done to distinguish the statistical effect of binning from the cognitive self-report issues of the subjects' own binning. We found that the correlations between TLFB "binned" data and COT, NIC, and CO at session 5 were not significantly different than the correlations between QF closed data and these biomarkers (Steiger's z's < .96, *p*s >.34). However, the correlation between TLFB binned data and aggregated CO (Sessions 1-5) was significantly higher (*r*=.62) than the correlation between QF Closed data and aggregated CO (*r*=.57, Steiger's z=2.01, *p*<.05).

Biomarkers: Regression analyses were conducted to evaluate the relative predictive validity of the QF Open and Closed measures. When predicting NIC, COT, or CO from total cigarettes assessed by the QF Closed measure in the full sample, the addition of QF Open data significantly improved the prediction models (R^2 change= .06-.09, *p*s<.01).

Discussion

Biomarkers of cigarette use are often considered the "gold standard" for assessment of smoking behavior, but come with limitations including cost and invasiveness. Further, traditional biomarkers can only measure recent smoking, which is potentially problematic for use in non-daily smokers. Therefore, identification of the most valid self-report measures of cigarette use is essential in order to accurately study rates of smoking in this subsample of smokers.

Self-report measure findings

Results indicate that total cigarettes as assessed by the TLFB measure were most strongly associated with cigarette totals generated from a daily report measure (this is not surprising, given that the ability to aggregate daily data over a one month period enhances reliability, which in turn allows for a stronger correlation with biomarkers of smoking). However, it is important to note that all self-report measures were highly and significantly correlated with DR total cigarettes. As such, although more intensive measures generally performed better than less intensive measures, use of each of the self-report measures investigated in this study are likely to be appropriate for use with non-daily smokers.

Our results indicate that participants in the Daily Monitoring group reported significantly more total cigarettes than participants in the No Monitoring group. Given that there was no significant change in biomarker values from Session 1 to Session 5 in this group, we conclude that the increase in number of cigarettes reported are not due to increases in cigarette consumption from baseline to the Session 5 follow up. Higher correlations between several self-report measures and biomarkers in the Daily Monitoring versus no Monitoring group also provide evidence that, although the Daily Monitoring group reported more cigarettes, this increase in reporting was likely a function of daily monitoring subsequently improving retrospective recall of smoking behavior.

Given that QF measures are commonly administered to minimize time and cost of assessment, we compared the use of a QF Open versus Closed measure. These two measures share the "frequency" question (On how many days of the past 28 did you smoke part or all of a cigarette?") and differ only in the response options to the "quantity" question. We expected that the QF Open measure would outperform the QF Closed measure, given that “binning" the cigarette quantity necessarily limits the variance and the potential correlation with other measures. As predicted, the QF Open measure demonstrated advantages over the QF Closed measure; QF Open total cigarettes added predictive ability above and beyond that of QF Closed total cigarettes when predicting biomarkers of smoking, and the correlation between TLFB and QF Open cigarettes per smoking day was significantly higher than the correlation between TLFB and QF Closed cigarettes per smoking day. Several national surveys use the closed format when assessing cigarette use (e.g., National Survey on Drug

Use and Health, Youth Risk Behavior Surveillance System, National Youth Tobacco Survey) while others do not ask a quantity question at all (e.g., Behavioral Risk Factor Surveillance System Questionnaire). Data from the current study support the use of an open-ended format of the QF measure when assessment Quantity Frequency measure is selected.

Biomarker findings

We anticipated that, due to a short half-life, CO would not be strongly associated with levels of cigarette use in this sample of non-daily smokers. Contrary to our hypothesis, CO levels measured across five time points were significantly more strongly correlated with total cigarettes than both hair biomarkers. Further, CO measured at a single session was more strongly correlated with self-reported smoking than hair COT. These results are promising for the use of CO (especially measured across multiple time points) as a relatively good biomarker of smoking in non-daily smokers, especially as a low cost and noninvasive measure of cigarette use that provides immediate feedback about smoking behavior.

The relationship between smoking level and hair biomarker concentrations in dependent smokers is similar to what was found in our sample of non-daily smokers (*r*'s ranging from 0.48-0.69; Eliopoulos et al., 1996, Mizuno et al., 1993). However, we expect that we would have seen even stronger relationships between the self-report data and biomarkers if we had been able to identify the exact segment of hair corresponding with the 28-day self-report assessment period. Despite these limitations, several strengths of the methods used to quantify hair biomarkers in this study should be noted. The LC-MS/MS procedure allowed for the assessment of extremely small concentrations of NIC and COT. In addition, hair samples were washed using a newly validated procedure, thus providing a significant reduction in nicotine that may have been present from environmental exposure (Miller et al., 2011).

Limitations

Exclusion criteria related to hair analyses restricted our sample in a number of ways; these restrictions likely created some selection bias regarding the smokers who participated in this study, such that our sample was younger than seen in other smoking research. However, despite the relatively younger age of our sample, participants in this study represented a wide range of smoking levels. A second limitation was the inability to identify the precise segment of hair corresponding with the 28-day period of self-report assessment. Although we intended to advance procedures beyond what is typically used, the practice of using a 1-cm segment of hair to represent one month's worth of exposure is commonly accepted (e.g., Miyazawa & Uematsu, 1992, Uematsu et al., 1995). We administered the self-report measures in a fixed order, which may have influenced participants' responses as they went through the sequence of assessments; although counterbalancing the order of measures would have allowed us to assess order effects, we chose to keep the order fixed to minimize potential carryover effects, as measurement order effects were not a question of interest in this research project. Finally, the participants in the current study were not treatment seeking smokers who were aware of the fact that biomarkers were being collected to verify their smoking status. We do not know the extent to which these results will generalize to

treatment seeking samples, given that smokers trying to quit may have more incentive to underreport their smoking.

Future research in this area may answer more detailed questions related to the patterning of cigarette use (i.e., the day-to-day variations in smoking) in this population. For example, future work might examine how well biomarkers of use are able to capture variations in smoking patterns.

Summary

Results indicated that all self-report measures of smoking were highly correlated with daily reports of smoking, but that total cigarettes generated via TLFB methodology were most strongly associated with daily reports. Administering the QF measure in an open-ended format had distinct advantages over administering this measure in a close-ended format. CO aggregated across multiple collections was a valid measure of smoke exposure, offering the advantages of being a less expensive, less invasive, and more immediate biological indicator of cigarette use. Hair biomarkers demonstrated some promise for use in this sample, but several limitations should be addressed before continuing with this type of assessment in non-daily smokers.

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Table 1

Total cigarettes smoked in 28 days generated from self-report measures of cigarette use;

	Daily Monitoring group (n=89)		**No Monitoring group (n=87)**	
	Mean (*SD*)	**Range**	**Mean (*SD*)**	**Range**
Daily Report	65.9 (*53.0*)	4-190	n/a	n/a
Session 5 Timeline Follow Back	61.0 (*50.9*)*†	4-191	46.7 (*41.3*)*	4-199
Session 5 Graduated Frequency	70.8 (*60.5*)*	2-273	50.9 (*45.8*)*	3-214
Session 5 Quantity Frequency Open	63.0 (*51.4*)*	2-208	45.7 (*42.3*)*	3-216
Session 5 Quantity Frequency Closed	73.7 (*67.7*)*	2-294	55.2 (*52.0*)*	3-284

*indicates significant between group difference, p<.05 ,

†indicates measure generated significantly different number of cigarettes from Daily Report, p<.05

Table 2

Correlations (Spearman's rho) Between Self-Report Measures of Total Cigarettes And Biomarkers of Smoking

	Daily Monitoring Group					No Monitoring Group				
	DR	**TLFB**	**GF**	**QF Open**	**QF Closed**	**DR**	**TLFB**	**GF**	**QF Open**	**QF Closed**
Session 6 NIC	0.57**	0.58**	0.56**	0.59**	0.55**	n/a	0.47**	0.44**	0.39*	0.43**
Session 6 COT	0.45**	0.42**	0.37*	0.41**	0.36*	n/a	0.43**	0.45**	0.42**	0.46**
Session 5 CO	0.65**	**0.66****	**0.66****	0.63**	0.62**	n/a	**0.44****	**0.42****	0.46**	0.46**
Sessions 1-5 CO	0.74**	**0.75****	**0.69****	**0.73****	0.65**	n/a	**0.52****	**0.48****	**0.46****	0.46**

Note. CO = Carbon Monoxide, COT= Hair Cotinine, DR= Daily Report, GF= Graduated Frequency, NIC= Hair Nicotine, QF= Quantity Frequency, TLFB=Timeline Follow Back;

* p=.001,

** p=.000, **bold** indicates that the correlation was significantly different between Daily Monitoring and No Monitoring groups (p<.05)