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Levels of cigarette availability and exposure in Black and White women and efficient smokers

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Abstract

Purposes of this investigation were to examine differences in smoke exposure and smoking topography across three smoking conditions: usual number of cigarettes, restricted (50%) and increased (167%) simulating restricted and unrestricted cigarette availability. A repeated-measures counterbalanced design with a sample of 25 women (13 African Americans; 12 Caucasians) was implemented with a 6-day inpatient protocol conducted in the General Clinical Research Center (GCRC). There were significantly larger percentage increases in carbon monoxide (CO) postcigarette in the restricted condition compared to usual and increased condition. Women with baseline cotinine/cigarette ratios >20 ng/ml/cigarette, considered efficient smokers, had significantly higher CO increases postcigarette at baseline than participants with lower cotinine/cigarette ratios, yet increased this exposure further during the restricted condition. Efficient smokers had significantly higher nicotine boost in the restricted condition compared to less efficient smokers. Differences by ethnicity were also noted with significantly higher CO percentage increases pre- to postcigarette in African Americans across all conditions, compared to Caucasians. Levels of smoke exposure postcigarette in persons who reduce cigarettes per day in response to restricted cigarette availability may be substantial.

Keywords: Cigarette smoking compensation; Cotinine; Carbon monoxide; Topography; Ethnicity

1. Introduction

There are an estimated 44.3 million adult cigarette smokers in the United States with 70% reporting that they want to quit completely (Centers for Disease Control [CDC], 2002). However, only 4.7% of smokers were able to maintain smoking abstinence for 3 to 12 months in the preceding year. The percentage of ever smokers who had quit smoking was highest among Whites (51%) and lowest among Blacks (37.3%). A variety of factors influence the discrepancy between desire to quit smoking and actual quit rates, because tobacco use is a biobehaviorally mediated activity involving social pressures, individual desires, genetically conferred vulnerabilities, pharmacological utility of nicotine, dependence on nicotine (Kozlowski et al., 2001), lack of access to proven treatments of tobacco dependence, and cost of pharmacotherapy for smoking cessation (CDC, 2002).

Three areas briefly addressed in the introduction are as follows: aspects of women and smoking, smoking behavior in response to restricted cigarette availability, and factors of ethnicity and efficient smoking that may moderate these responses. Smoking prevalence among women was 21% (19.7 million) in the United States (CDC, 2002). Further evidence of the impact of smoking among women is the loss of an estimated 2.1 million years of life each year in the past decade due to smoking-attributable premature deaths from neoplastic, cardiovascular, and respiratory diseases (USDHHS, 2001). Smoking-related influences independent of nicotine may be more important to women than men (Perkins et al., 1994), and the carbon monoxide (CO) cost of obtaining nicotine was higher in women smoking light cigarettes, than in men (Zeman et al., 2002).

Smoker responses to restricted smoking through smoking bans and increased cost have been examined. Fant et al. (1995) reported increased ratings of subjective pleasure after smoking in the condition where fewer, more widely spaced

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cigarettes had been smoked. Increased salience of widely spaced cigarettes could reduce motivation of smokers to quit (Fant et al., 1995). This may apply in workplace nonsmoking policies. In addition, there is a strong, inverse relationship between cigarette price and consumption (USDHHS, 2000). In a time-series study of state cross-sections, it was estimated that a 10% increase in cigarette prices would yield an overall drop of 4.7% in number of cigarettes demanded (Peterson et al., 1992) and Evans and Farrelly (1998) concluded that smokers in high-cigarette-tax states were more likely than smokers in low-cigarette-tax states to smoke higher tar and higher nicotine cigarettes. The effect of pricing on cigarette consumption is likely to be greatest among those with fewer economic resources (USDHHS, 2001) and Blacks were twice as responsive as Whites to changes in cigarette prices (CDC, 1998). Personal economic factors influence cigarette availability and individuals may use downward or upward compensation within a boundary in response to the number of available cigarettes (Kozlowski & Pillitteri, 1996). Key factors in determining per-cigarette smoke exposure were the individual's blocking of filter ventilation with lips or fingers and smoking topography, such as number and size of puffs (Kozlowski & Pillitteri, 1996).

Several factors may moderate the response to smoking restrictions including ethnicity and smoking efficiency. In comparison to Caucasian women, African American women had higher cotinine levels and smoked fewer cigarettes per day (Wagenknecht et al., 1990) and African American women had significantly higher cotinine/cigarette ratios of 20.1 ng/ml/cigarette $\pm$ 11.7 compared to Caucasians at 10.9 ng/ml/cigarette $\pm$ 6.0 (Ahijevych and Parsley, 1999). While nicotine and cotinine metabolism differences influence these values, the issue of efficient smokers being able to compensate in the presence of smoking restrictions is an important consideration (Benowitz, 2002; Perez-Stable et al., 1998). An efficient smoker has been described as one whose cotinine/cigarette ratio is relatively high. Shiffman et al. (1990) reported an average of 14.0 ng/ml cotinine/cigarette among light smokers and 12.5 ng/ml/cigarette among heavy smokers. Persons exceeding these levels could be considered efficient smokers (Perez-Stable et al., 1990).

Therefore, the purpose of this study was to determine if there were differences in levels of smoke constituent exposure and smoking topography behaviors in response to changes in nicotine availability in African American and Caucasian women cigarette smokers. Research questions were the following: What are the differences in cigarette-smoke constituent exposure and smoking topography across three conditions of usual, increased and restricted number of cigarettes per day? Can efficient smokers, defined by baseline cotinine/cigarette ratio, increase their efficiency in the restricted condition? And secondarily, do African American and Caucasian women differ across conditions in smoking topography or exposure?

2. Method

2.1. Subjects

Participants were 25 women recruited through neighborhood advertisement and snowball technique for a 6-day inpatient cigarette smoking study. Recruitment was stratified by race to yield similar representation and resulted in 13 African American and 12 Caucasian women participants. Inclusion criteria were African American or Caucasian woman by self-report; 18 to 50 years of age; regular smoking for at least 1 year and a minimum of 10 cigarettes per day (cpd); no regular prescribed medications; no other tobacco use; no history of liver, endocrine or pulmonary disease; and not pregnant. Power analysis for a repeated-measures design with α=.05, power = 0.8, average correlation=.8, medium effect size, and three treatment conditions required a total sample size of 14 (Stevens, 1996). Sample size of 25 exceeds these requirements. Within-subject variation across all conditions was analyzed with the participant serving as their own control.

2.2. Procedure

A counterbalanced crossover repeated-measures design with a sample of 25 women was used to describe and contrast cigarette-smoke constituent exposure and smoking topography across three different daily smoking rates. Each participant experienced all conditions. Manipulating nicotine availability to a rate of cigarettes greater than usual simulated unrestricted cigarette availability. The restricted dose condition (a simulation of restricted smoking) tested the ability of women who were already efficient smokers to increase their efficiency further. Beginning at 0730 h on Day 1 and following written, informed consent, women were admitted for six consecutive days and nights to the General Clinical Research Center (GCRC) in a private room with reverse ventilation. A history and physical examination and admission blood work were completed to screen for exclusion criteria not identified in the initial interview. Participants were provided their usual preferred brand of cigarettes throughout the 6-day protocol. On Day 1, women smoked at their usual rate (ad libitum). Beginning on Day 2 and continuing through Day 3, they were randomly assigned to smoke their usual brand at either 167% or 50% of the usual rate established on Day 1. On Day 4, participants returned to the usual smoking rate condition of Day 1 to prevent carry-over from the previous condition. During Days 5 and 6, women were assigned to the opposite condition (see Fig. 1). Data collection in increased and restricted conditions occurred on the second day of the condition to permit adjustment. Women were paid US$450 upon completion of the 6-day study. The university Institutional Review Committee for the Use of Human Subjects approved the protocol. Upon conclusion of the

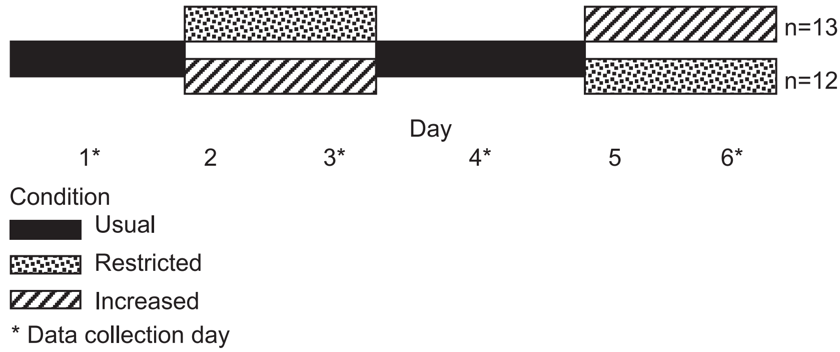

Fig. 1. Counterbalanced study design of usual, increased, and restricted smoking rates in cigarettes per day ($n = 25$).

study, women were provided smoking cessation information and materials.

Data collection on Days 1, 3, 4, and 6 included specific cigarette-related measurements at established time points throughout the day for comparability across participants: the first cigarette bout of the day, and an observation bout during each of the three periods between 1000 and 1200, between 1500 and 1700, and between 2000 and 2200 h. Measures included smoking topography during the smoking bout. Smoke constituent exposure measures were CO in exhaled air measured 2 min pre- and postcigarette, as well as blood samples for plasma nicotine that were obtained 1 min prior to smoking and 1 min after cigarette completion. Nicotine and CO boost and percent increase were calculated from these values. Plasma for cotinine assay was collected at each time point precigarette. The average of measurements of four bouts for a given condition were computed and used in further analyses. Similarly, average percentage increase in CO pre- to postcigarette for each day was the average CO change of four cigarettes in each condition. Topography measures included daily total puff volume for each of the four testing days that was extrapolated from the average of puff volumes from four cigarettes each day multiplied by the number of recorded cigarettes that day. Average butt length for each day was computed from the diary recording of length of butt remaining for each cigarette smoked. GCRC nursing staff measured length of remaining cigarette rods in millimeters, including the filter of each cigarette. Baseline cotinine/cigarette ratio was calculated with plasma cotinine from a sample obtained on Day 1 between 2000 and 2200 h and the recorded number of cigarettes smoked that day. An efficient smoker was defined as a person with a cotinine/cigarette ratio greater than 20 ng/ml cotinine/cigarette at the end of Day 1, a conservative definition of efficient smoker based on a ratio of 14 ng/ml/cigarette in light smokers (Shiffman et al., 1990).

2.3. Measures

Smoking topography variables included puff volume (ml), puff duration (s), interpuff interval (s), and peak flow rate (ml/s) as measured by the Clinical Research Support System (CReSS; Plowshare Technologies, Baltimore, MD). Briefly, this equipment included a flowmeter cigarette holder attached to a differential pressure transducer and connected with tubing to an interface box. After a 15-min warm-up period, the system was calibrated by attaching a 60-ml syringe to the mouthpiece and puffs of 30–50 ml were simulated, which were then compared to the CReSS volume digital read-out. Computed volumes ranged within ± 1 ml of the syringe volume. Maximum peak flow rate measured with the CReSS system is 200 ml/s and time tag accuracy is ± 5 ms (www.plowshare.com). Puff clean-up utility software (Plowshare Technologies) was used to remove nonpuff artifacts with parameters set to eliminate puffs < 0.3 s in duration and < 5 ml volume.

Plasma nicotine and cotinine were assayed by gas chromatography–mass spectrometry on a GC-65 solid phase extraction column (Biochemical Diagnostics, Edgewood, NY). A Hewlett-Packard gas chromatograph model 6890, equipped with a 6890 autosampler and a capillary column (length: 30 m, ID: 0.25 mm, film thickness: 0.25 um methyl silicon, supplied by Alltech) interfaced with a Hewlett-Packard 5972 model mass selective detector.

Exposure to CO was measured in a sample of expired air in parts per million using the Bedfont Mini-Smokerlyzer (Innovative Marketing, Medford, NJ) calibrated with a 50 ppm CO standard per equipment instructions and participants were instructed on the 15-s breath-hold technique before exhaling completely into the mouthpiece.

Nicotine dependence, depressive symptomatology, and body composition were measured at baseline as potential influencing factors on the primary dependent variables. Nicotine dependence was assessed on admission with self-reported latency in minutes to the first cigarette of the day (Heatherton et al., 1989) and the Fagerström Test for Nicotine Dependence (FTND; Heatherton et al., 1991), a 6-item instrument, with potential scores ranging from 0 to 10, and higher scores indicating greater dependence (Heatherton et al., 1991). Current depressive symptomatology was assessed on admission with the Center for Epidemiological Studies Depression (CES-D) scale, a 20-item instrument with higher scores indicating greater levels of depressive symptomatology (Radloff, 1977). Sociodemographic and smoking history data were collected as described in previous studies (Ahijevych et al., 1996). Body composition was determined by tetrapolar bioelectrical impedance analysis (BIA) with a Spectrum II analyzer system (RJL Systems, Clinton Township, MI). Adipose and lean body mass in kilograms were computed.

2.4. Data analysis

Repeated-measures analyses were conducted with dependent variables of smoking topography and smoke constituent exposure across the conditions: usual smoking rate condition (Days 1 and 4), and conditions increased to 153% and restricted by 51% of baseline rate. Post hoc analyses were conducted using a Bonferroni correction of $P<.008$. Analysis of variance and covariance were used to compare efficient and less efficient smokers and African American and Caucasian women. These analyses were accomplished using SAS.JMP software (Statistical Analysis Systems, SAS Institute, Carey, NC).

3. Results

The sample of 13 African American and 12 Caucasian women had an average age of 32.1 years (S.D. = 7.9; range = 19–50), 72% were single, divorced or separated, and 60% had an annual household income < US$20,000. Participants had smoked 16.0 years on average (S.D. = 9.0) with an average of 19.3 cpd (S.D. = 8.7; range = 10–38). Average Federal Trade Commission (FTC, 2000) levels of their usual cigarette brands were 13.92 mg tar (S.D. = 3.5), 1.04 mg nicotine (S.D. = 0.26), and 14.12 mg CO (S.D. = 2.9). Sixty-eight percent ($n=17$) of the participants smoked menthol cigarettes and only 28% smoked light cigarettes. Sixty-five percent of the sample smoked cigarettes with 0% ventilation or air dilution and the cigarette brands of the remaining participants had an average of 18.8% air dilution (Kozlowski et al., 1998). The average time to first cigarette after awakening was 7.8 min (S.D. = 7.8) and the average FTND score was 5.9 (S.D. = 1.6; range = 2–10) with a score of 6 to 7 indicating high dependence (Fagerström et al., 1992). Cotinine/cigarette ratio was computed with precigarette cotinine concentration obtained between 2000 and 2200 h on Day 1 and the number of cigarettes recorded during ad lib smoking on Day 1. The average was 20.0 ng/ml cotinine/cigarette (S.D. = 18.0). Fifteen women (60%) reported alcohol use for an average of 9.5 years (S.D. = 5.4) and the average CES-D score was 15.7 (S.D. = 10.2) with a score ≥ 16 interpreted as "at risk" of depression.

Demographic and smoking history characteristics by ethnicity are presented in Table 1 with significant differences noted for education, annual household income, cigarettes per day and menthol and light cigarette brands.

Table 1
Demographic and smoking history characteristics in women by ethnicity (average and S.D., where applicable)

	Black ($n=13$)	White ($n=12$)
Age	29.5 (6.4)	35 (8.7)
Education (years) *	11.4 (1.0)	12.3 (1.2)
Percent single marital status	77	25
Percent unemployed	62	55
Percent with annual household income < US$15,000 *	91	50
Age of smoking initiation	15.5 (4.7)	15.7 (1.4)
Years of smoking	12.8 (8.1)	19.3 (9.0)
Cigarettes per day *	13.6 (4.3)	25.4 (8.1)
Percent smoking menthol cigarettes *	100	33
Percent smoking light cigarettes *	0	50
Lifetime quit attempts	3.2 (3.4)	2.6 (2.1)
Time to first cigarette (min)	8.9 (7.5)	13.5 (17.9)

* $P<.05$.

Body fat composition for the total sample ranged from 13.4% to 66.8% with an average of 40.0% (S.D. = 13.7) and average lean body mass was 42.4 kg (S.D. = 6.2). Average weight was 74.8 kg (S.D. = 22.1) and body mass index (BMI) ranged from 16.9 to 64.2 (mean = 28.7, S.D. = 10.5). Urine pH was measured three times per day with averages ranging from 5.8 to 6.5 (within normal limits) over the 6-day period. Cotinine clearance was significantly greater in acidified urine (pH = 4.4; Benowitz et al., 1983) and could be a potentially confounding variable. Admission blood work revealed normal red and white blood cell counts, hemoglobin, hematocrit, platelets, and gamma-glutamyl transferase.

3.1. Differences by condition

The first research question examined differences in cigarette-smoke constituent exposure and topography across three conditions of usual, increased and restricted number of cigarettes per day. Random assignment to order of conditions resulted in 12 participants experiencing increased condition on Days 2 and 3, while 13 participants were assigned the restricted condition on those days. The average of 153% of baseline cigarettes per day is slightly less than the target of 167% for the increased condition. Baseline self-reported cigarettes per day was 19.3 cigarettes on average compared to an average of 17.7 cpd in the usual condition (r=.90). Topography, cigarette butt lengths, and CO exposures on Days 1 and 4, both usual smoking rate conditions, were similar. Therefore, in the counterbalanced crossover design, the increased or restricted condition was preceded by a similar condition (Day 1 or Day 4) and allowed for appropriate comparisons. Repeated-measures analyses of total puff volume, percentage increase in CO, butt lengths, and cotinine/cigarette were significant ($P<.001$). Post hoc analyses of significant differences with Bonferroni correction of $P<.008$ are identified in Table 2. Significantly higher puff volume per cigarette and shorter butt length occurred in the restricted condition compared to usual and increased conditions, with

Table 2
Selected smoke constituent exposure and smoking topography parameters in usual, restricted and increased conditions and ratios to usual condition (Mean and S.D.)

	Cigarettes per day	Puff volume (ml)	Number of puffs per cigarette	Puff volume per cigarette (ml)	Total puff volume (ml)	Butt length remaining (mm)	Cotinine per cigarette (ng/ml/cigarette)
Usual	17.7 (6.7)	41.9 (11.8)	13.4[a] (3.2)	542[a] (147)	9145.7[a,b] (977.2)	37.2[b] (7.7)	20[b] (18.0)
Restricted	9.3 (3.4)	43.2 (12.0)	13.4[a] (3.7)	558[a] (187)	5018.4[a,c] (582.0)	33.6[a,c] (5.7)	31.9[a,c] (22)
Increased	26.5 (9.7)	41.5 (9.9)	12.4[b,c] (3.8)	504[b,c] (167)	13758.0[b,c] (1747.0)	39.0[b] (8.2)	12 (9.7)[b]
Restricted/usual (%)	51	103	100	105	54	90	200
Increased/usual (%)	153	99	93	93	142	105	68

Usual = ad lib smoking at usual rate (Day 1).
Restricted = 50% of cigarettes of usual rate.
Increased = 167% of cigarettes of usual rate.
[a] Significantly different from increased condition.
[b] Significantly different from restricted condition.
[c] Significantly different from usual condition.

significantly higher cotinine/cigarette ratios in the restricted condition compared to the increased condition. There were significantly larger percentage increases in CO pre- to postcigarette in the restricted condition (174%) compared to the increased condition (140%). There were no significant differences in puff peak flow average (ml/s) or puff duration (s) across the conditions.

Strong inverse correlations were evident between number of cigarettes per day and the CO percentage increase postcigarette with $r = -.66$ in the increased condition and $r = -.80$ in the restricted condition, $P < .0006$. FTC CO was correlated with CO percentage increases in only the increased condition (r=.49, P=.018). In a hierarchical multiple regression, ethnicity was entered first and accounted for 35% of the variance in CO percentage increase (P=.0025) in the restricted condition. Number of cigarettes per day was entered next and accounted for an additional 30% of the variance (r^2=.65, P=.0003). Being African American and smoking fewer cigarettes per day in the restricted condition were associated with greater CO percentage increases postcigarette.

3.2. Efficient and less efficient smokers

The second research question examined if efficient smokers were able to increase their efficiency in the restricted condition (50% of usual rate of cigarettes per day). There were seven efficient smokers. Eighteen participants had cotinine/cigarette ratios < 20 ng/ml/cigarette. Eighty-six percent of the high-cotinine/cigarette ratio group was African American, while 39% of the low ratio group was African American. Use of menthol cigarettes was 61% and 86% in the lower and higher ratio groups, respectively. Efficient smokers had significantly higher CO% increases in all three conditions compared to less efficient smokers ($P < .03$, Fig. 2). In the decreased availability condition, CO self-administration per cigarette in efficient smokers was 203% of precigarette level, although total CO exposure in the restricted condition was 58% relative to the usual availability condition.

In addition, efficient smokers had shorter remaining cigarette butts than less efficient smokers in both usual and restricted smoking conditions ($P < .04$). Cigarette butt lengths for efficient smokers were 32 and 30 mm in the usual and restricted condition, respectively, while the less efficient smokers had 39 and 35 mm remaining cigarette butt lengths, respectively. Interestingly, there was a trend for higher nicotine boost pre- to postcigarette in efficient smokers in the restricted condition compared to less efficient smokers. Less efficient smokers had similar nicotine boosts across the two conditions (Fig. 3). Usual brands of efficient and less efficient smokers were similar in FTC levels of tar, CO, and nicotine. In addition, there were no significant differences between the two groups on average puff peak flow, interpuff interval, or total puff volume across the conditions, except on Day 1 ad lib smoking, where the total puff volume for the high-cotinine/cigarette ratio group was significantly lower than the group with < 20

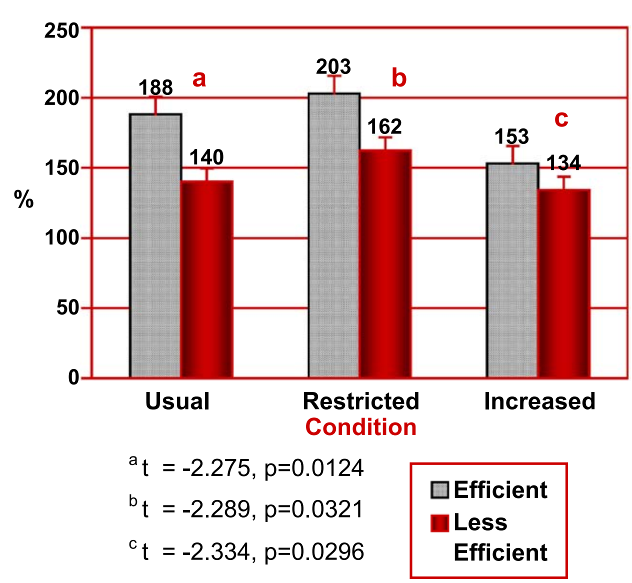

Fig. 2. Average (S.E.) postcigarette CO percentage of precigarette levels in efficient ($n = 7$) and less efficient smokers ($n = 18$) by condition.

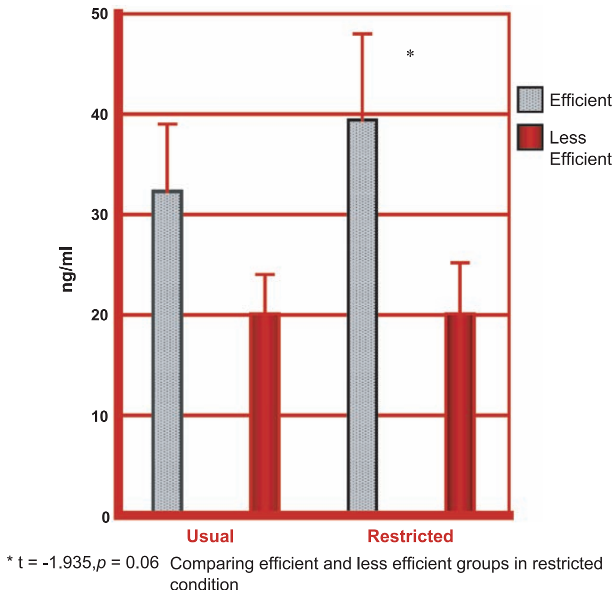

Fig. 3. Average (S.E.) plasma nicotine boost by efficient and less efficient smokers in usual and restricted smoking conditions.

ng/ml cotinine/cigarette (6268 vs. 10,537 ml, P=.006). Baseline cigarettes per day were 19.4 ± 7.1 and 13.4 ± 3.1 for less efficient and efficient groups, respectively, while cotinine concentrations were consistently higher in efficient smokers across all three conditions. For example, in the usual condition, between 2000 and 2200 h (8–10 pm), plasma cotinine concentrations were 536 (efficient) and 195 ng/ml (less efficient smokers).

Using standard least squares regression, 52% of variance in cotinine/cigarette ratio at the end of Day 1 was explained by average puff duration and total puff volume for the day (P=.0018). Longer puff duration and lower puff volume were associated with a higher cotinine/cigarette ratio.

3.3. Ethnicity

In addition to the major focus of differences by condition, differences by ethnicity were characterized. African American women smoked cigarettes with significantly higher FTC tar, nicotine, and CO ($P<.0005$) than Caucasian women; they had higher CES-D scores (20.6 vs. 11.1, P=.02), and smoked fewer cigarettes per day on Day 1 ad lib smoking (13.7 vs. 22.1) with similar cigarette butt lengths (34.8 and 39.9 mm, respectively). Cotinine/cigarette ratios at the end of Day 1 were significantly higher in African American women compared to Caucasian women (28.8 vs. 10.5 ng/ml/cigarette, P=.008) and African American women experienced significantly higher CO percentage increases postcigarette in all four conditions as indicated in Fig. 4. After controlling for FTC CO levels, African Americans were still significantly higher on CO percentage increase in the restricted and increased condition. However, there was an overlap of race and menthol preference in that all African American women smoked menthol, while only 1/3 of Caucasian women smoked menthol cigarettes. CO percentage increases postcigarette are presented for White menthol smokers, White nonmenthol smokers, and Black menthol smokers (Table 3). There were significantly higher CO percentage increases in menthol smokers compared to nonmenthol smokers in the increased and restricted condition for the total sample. Among menthol smokers, Black menthol smokers had significantly higher CO percentage increases than White menthol smokers in the restricted condition. Daily total puff volume was significantly less in African Americans across conditions, primarily as a function of fewer cigarettes per day. There were no significant differences by ethnicity regarding time to first cigarette, FTND, interpuff interval, puff duration, or puff peak flow.

4. Discussion

Smoking fewer cigarettes per day increased CO exposure pre- to postcigarette, and even more so among African American and efficient smokers. A strong inverse relationship between cigarettes per day and CO increase postcigarette further illustrates the importance of determining an individual's change in number of cigarettes smoked per day. In addition, there were significant inverse correlations

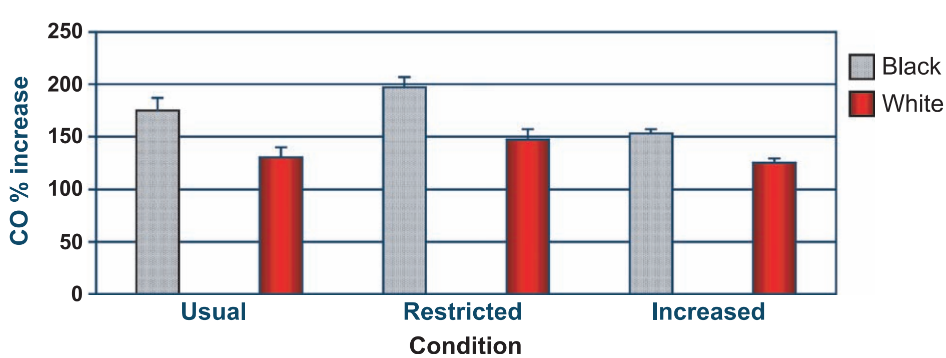

Fig. 4. Average percentage increase (S.E.) in carbon monoxide pre- to postcigarette by condition and race/ethnicity ($P<.01$).

Table 3
Average (S.D.) postcigarette CO percentage increases by race and menthol cigarette preference

Condition	Black menthol smokers ($n=13$)	White menthol smokers ($n=4$)	White nonmenthol smokers ($n=8$)
Usual	175 (49)	134 (22)	128 (21)
Restricted	197 (38)	152 (34)*	144 (36)[†]
Increased	152 (15)	132 (22)	121 (5)[†]

* White menthol smokers significantly ($P<.05$) lower than black menthol smokers.

[†] Nonmenthol smokers significantly lower ($P<.05$) than menthol smokers.

between CO percentage increases postcigarette and body weight and BMI in all three conditions, with highest correlations occurring in the restricted condition ($r=-.72$ and $-.65$, respectively). Zacny et al. (1987) identified that cigarette smokers experienced increasingly higher CO levels postcigarette with longer breathholds. Lung-exposure time was not measured in the current study and may have been an influencing factor. In relation to the cardiovascular effects of CO, Zevin et al. (2001) reported that participants who inhaled CO in amounts similar to smoking conditions did not have the cardiovascular effects they experienced when they smoked cigarettes. They concluded that effects of cigarette smoking on heart rate, catecholamine secretion, or platelet activation were most likely due to cigarette-smoke constituents other than CO. However, CO and CO boost may serve as markers of exposure to smoke constituents and health risk (Frederiksen and Martin, 1979; Zeman et al., 2002). As puff volume increased, the amount of CO absorbed from a cigarette increased systematically (Zacny et al., 1987). Furthermore, an important determinant of tobacco-specific nitrosamine exposure is total volume drawn through a cigarette while smoking (Fischer et al., 1991). Studies have shown a relationship between tobacco smoke exposure, tumor specific mutations, and cancer risk (Shields, 2000). Therefore, it is relevant to consider acute CO exposures postcigarette in those who decrease their cigarettes per day in response to restrictions.

Significantly larger puff volumes and shorter remaining cigarette butt lengths occurred in the restricted condition, corroborated by a conclusion in a review of compensation studies that changing puff volume is the most probable mechanism of compensational smoking (Scherer, 1999).

Efficient smokers may have unique health issues beyond increased CO exposure postcigarette, as they also demonstrated a significantly greater increase in plasma nicotine postcigarette in the restricted condition, compared to less efficient smokers. In contrast, less efficient smokers had similar plasma nicotine boosts of 20.1 ng/ml in both usual and restricted conditions, similar to the average of 24.01 ng/ml previously reported for 10 participants in ad libitum smoking, half of whom were women (Hatsukami et al., 1988). Efficient smokers' nicotine boosts were 32.3 ± 18.8 and 47.2 ± 19.4 ng/ml in usual and restricted conditions, respectively, which is not incongruent with participants who tripled their intake of nicotine per cigarette when number of cigarettes were limited (Benowitz et al., 1986). Hatsukami et al. (1988) reported that longer intercigarette periods were significantly related to greater nicotine increases postcigarette. However, in the current study, both groups experienced longer intercigarette intervals in the restricted condition with a similar number of cigarettes per day (7 ± 1.7 for efficient and 9.8 ± 3.6 for less efficient smokers). Nicotine and cotinine metabolism clearly affect the ratio of cotinine per cigarette used in determining efficient and less efficient smokers. While clearance of nicotine was similar in African Americans and Caucasians in a study using dual-labeled nicotine and cotinine infusions, the clearance of cotinine was significantly slower in African Americans (Perez-Stable et al., 1998). However, the cutpoint of 20 ng/ml/cigarette implemented in this study is conservative, because the ratio reported for a heavy smoker was 12.5 ng/ml/cigarette (Shiffman et al., 1990). Longer puff duration was significantly associated with higher cotinine/cigarette ratio at baseline and thus, smoking topography may also be a component of the ratio determination.

African American women smokers had significantly higher CO increases postcigarette compared to Caucasian women, after controlling for FTC CO levels in their usual brands. In addition, African American and Caucasian women in the study who smoked menthol cigarettes had higher percentages of CO increases postcigarette than Caucasian nonmenthol smokers. This is similar to findings reported by Gori and Lynch (1985) of virtually no relationship between expired air CO levels and FTC CO yields (2–20 mg/cigarette) where average expired CO levels in 865 smokers were 35–40 ppm for a one-time measurement. There is limited published information regarding topography and smoke constituent exposures by ethnicity and gender with which to compare findings of the current study.

Strengths of the study included a repeated-measures design with participants as their own control for factors, such as metabolism and usual cigarette brand. In addition, there were four measures within each condition instead of only one measure to improve validity. A washout period on Day 4 provided a similar baseline for the two counterbalanced conditions of increased and restricted conditions. Finally, the CRC staff and environment ensured accurate implementation of the protocol.

Limitations of the study were the overlap of African American women all smoking menthol cigarettes and potential influence of cotinine metabolism differences by ethnicity. Phase of the menstrual cycle was not an inclusion criterion. The CRC environment may have been less stressful and therefore modified smoking behavior. However, participants maintained contact with family and friends by phone and visits throughout their stay.

Increased cost of cigarettes is one form of restriction of cigarette availability for a segment of cigarette smokers, in addition to policies restricting locations of cigarette smoking. There is a body of past evidence to suggest that increased cost (e.g., taxation) is an effective strategy for reducing smoking prevalence, average cigarette consumption among continuing smokers and improving public health (USDHHS, 2000). While restrictions may increase acute exposure per cigarette compared to unrestricted conditions, overall exposure in a given day would be reduced providing the individual maintains fewer number of cigarettes per day and does not switch to higher tar and nicotine products (Evans and Farrelly, 1998). An area of research that deserves further consideration is whether restriction of cigarette availability, via cost, will be successful among a highly recidivist group of smokers. As an alternative to availability, these "hard-core" smokers may modify consumption, yet increase exposure, and thus not achieve the intended public health benefits.

In summary, reduction of cigarettes per day related to financial or other restrictions has clinical implications concerning increased CO postcigarette exposure, as well as nicotine boost among certain smokers who may be inherently efficient. This study adds to the traditional smoking compensation literature with increased detail on the efficient smoker and African American women regarding changes in cigarettes per day consumed. Tobacco dependence treatment requires consideration of the unique needs of persons smoking what may seem to be a low number of cigarettes per day.

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