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Cigarette Filter Vent Blocking: Effects on Smoking Topography and Carbon Monoxide Exposure[1]

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ZACNY, J. P., M. L. STITZER AND J. E. YINGLING. *Cigarette filter vent blocking: Effects on smoking topography and carbon monoxide exposure*. PHARMACOL BIOCHEM BEHAV 25(6) 1245–1252, 1986.—Two studies were conducted using smokers of unventilated cigarettes to determine the effects of filter vent blocking on smoke exposure (Experiment 1) and smoking topography (Experiment 2). In both studies, subjects were exposed to ultra low yield cigarettes that had 0%, 50%, and 100% of their filter vents blocked with tape. In Experiment 1, carbon monoxide (CO) exposure from eight 60 ml puffs increased in an orderly fashion as a function of filter vent blocking. By blocking filter vents, smoke was no longer diluted with air as it passed through the filter, and hence, exposure to smoke constituents was increased. In Experiment 2, when puff and inhalation parameters were allowed to vary, subjects took significantly more puffs, and larger puffs from unblocked cigarettes than from completely blocked cigarettes, but CO exposure from the completely blocked cigarette was double that from the unblocked cigarette (8.96 ppm vs. 4.32 ppm). The increased number and volume of puffs taken from ultra low yield cigarettes with unblocked filter vents may be due to changes in physical characteristics of the cigarette, and not to smokers actively compensating for reduced smoke constituent yields.

Cigarettes Smoking Tobacco Smoking topography Filter ventilation Hole blocking Carbon monoxide boost

COMMERCIAL cigarettes that are labelled "ultra low yield" have nicotine yields ranging from 0.1–0.4 mg, tar yields of 1–5 mg, and carbon monoxide (CO) yields of 1–7 mg [8]. These low yields are achieved by using less tobacco, increasing filter size, increasing porosity of the cigarette paper, and perforating the filter [29]. By increasing paper porosity, using larger filters, and/or placing perforations in the filter, the mainstream smoke is diluted and smoke dose per puff is reduced. Although smokers cannot influence the paper porosity or filter size of their cigarettes, they can change filter perforation characteristics by blocking the vents with lips or fingers, thereby at least partially negating the risk reduction associated with smoking ultra low yield cigarettes. A number of studies using smoking machines have demonstrated that smoke constituent delivery is increased when filter vents are blocked [11, 12, 20, 26]. For example, when an ultra low yield cigarette with unblocked filter vents was machine smoked according to Federal Trade Commission (FTC) standards, it delivered 0.38 mg of nicotine per cigarette; this same cigarette with tape-blocked filter vents delivered 0.84 mg of nicotine, a 122% increase in nicotine delivery [26]. Although it has been verified that many smokers of ultra low yield cigarettes do block filter vents with their fingers or lips while smoking [12], no studies have examined the effect of vent blocking on biological exposure to smoke constituents in human smokers. The purpose of Experiment 1 was to manipulate degree of vent blocking while holding constant other smoking parameters (e.g., puff volume and number) in order to examine vent blocking effects on tobacco smoke exposure, as measured by expired air carbon monoxide (CO) levels.

Another way smokers might partially negate the risk reduction associated with smoking ultra low yield cigarettes is by puffing and inhaling more smoke from these ventilated cigarettes than from unventilated cigarettes. For example, in one study that examined effects of ventilated cigarette holders, smokers took more puffs as the degree of ventilation and smoke dilution increased [8]. CO exposure levels across ventilation conditions were similar, suggesting that puff number was used by the smokers to compensate for smoke dilution. In Experiment 2, we examined in detail smoking behaviors such as puff number and volume while manipulat-

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ing vent blocking in order to determine which smoking behaviors are influenced by filter ventilation. Breath CO measurement provided an index of biological exposure.

METHOD

Subjects

Our subjects were seven cigarette smokers: mean age, 32.4 years (range 22 to 46 years); mean years smoking, 16.6 years (range 5 to 26 years); mean number of cigarettes smoked per day, 33.6 (range 30 to 45). Their usual brand cigarettes delivered medium to high levels of nicotine, tar, and CO (FTC levels: mean nicotine, 1.0 mg per cigarette; mean tar, 15.7 mg per cigarette; mean CO, 15 mg per cigarette). Three subjects were women (C.W., D.W., P.T.); four were men (R.H., M.D., B.E., J.W.). Five subjects (B.E., J.W., M.D., D.W., C.W.) participated in Experiment 1 and five subjects (J.W., R.H., C.W., D.W., P.T.) participated in Experiment 2.

Cigarettes

During sessions, subjects smoked ultra low yield cigarettes (0.1 mg nicotine, 1 mg tar, 1 mg CO, 1984 FTC levels) through a flowmeter cigarette holder. Subjects smoked mentholated low yield cigarettes if their usual brand was mentholated, and nonmentholated cigarettes if their usual brand was nonmentholated. Four brands of cigarettes, two mentholated (Carlton and Now) and two nonmentholated (Cambridge and Now), fit the yield criteria. Subjects were randomly assigned to one of the two possible brands and smoked that brand during the entire study. Subjects were not aware of what brand they were smoking because of a lightweight cardboard barrier situated on the cigarette holder preventing them from seeing the cigarette.

General Procedures

Subjects were smoke deprived for at least 20 min prior to each experimental session. At the start of each session, subjects were seated in a room housing the smoking measurement equipment. The experimenter was present in the room during the smoking sessions to light the cigarettes and place them in the holder, and to carry out other procedures pertinent to the experimental protocol.

Three vent blocking conditions were studied in which 0%, 50%, or 100% of filter vents were blocked. In the unblocked (0%) condition, unaltered cigarettes were used. In the partially blocked (50%) condition, two 6 mm^2 pieces of cellophane tape were placed opposite to one another directly on the filter vents so that 50% of the vents were blocked. In the completely blocked (100%) condition, a strip of tape, 24 mm long, was wound around the filter vents, completely covering them.

Experiment 1 Procedures

In Experiment 1, each subject participated in three 1.5 hour sessions on consecutive days. During each session, subjects took single puffs from each of eight freshly lit full length cigarettes under each of the three vent conditions. Twenty minutes elapsed between the last puff under one experimental condition, and the first puff under the next experimental condition. Order of conditions within each session was determined by a randomized block. While the percentage of blocked filter vents was varied, the following parameters were held constant: (1) puff number at 8, (2) interpuff interval at 50 sec, (3) puff volume (amount of smoky air drawn from a cigarette) at 60 ml, (4) inhalation volume (amount of smoky air inhaled after a puff) at 50% of a subject's vital capacity, and (5) breathhold duration (temporal period from maximum inhalation to exhalation onset) at 3.5 sec. By holding cigarette, puff, and inhalation variables constant, any differences in CO boost across conditions could be attributed to the experimental vent blocking manipulation.

Puff volume, inhalation volume, and breathhold duration were controlled through the use of microcomputer-based feedback delivered to the subjects. The computer measured topography events in real time. That is, while the subject was puffing, inhaling, breathholding, and exhaling, the computer was continually updating puff volume, inhalation volume, and breathhold duration values. The computer was programmed to generate auditory stimuli, in the form of beeps, when a specified puff volume, inhalation volume, or breathhold duration had been reached. Puffing was initiated with a verbal signal from the experimenter. The first beep cued the subject to stop puffing and start inhaling. The second beep was a cue to stop inhaling and start breathholding, and the third beep was a cue to stop breathholding and start exhaling. Before each puff, the experimenter could change the values at which the auditory stimuli were generated. In this way, transient undershooting or overshooting of the three variables within each 8 puff experimental condition could be counteracted. Criteria were established for average puff volume (±5 ml), inhalation volume (±100 ml), and breathhold duration (±1 sec) of each experimental condition. If average values did not fall within the prescribed range, the experimental condition would have been repeated, but no conditions had to be repeated by these subjects who had received some practice with the smoking feedback procedure prior to the experiment.

Experiment 2 Procedures

In Experiment 2, subjects participated in five daily sessions of 1.5 hr duration. During each session, subjects smoked one cigarette under each of the vent block conditions. Puff and inhalation parameters were free to vary. Twenty minutes elapsed between completion of one experimental condition and the start of the next experimental condition. Order of conditions was determined by a randomized block.

Measurement Procedures

Resistance-to-draw (RTD). Our vent blocking manipulation altered cigarette filter characteristics, and by doing so, may have also altered the resistance to gas flow through the cigarette. Because cigarette resistance to gas flow, or RTD, can affect smoking topography [4,15], we examined the effects of vent blocking on RTD, using a vacuum pump, rotameter, and water manometer. RTD measures were taken from five unlit cigarettes of each brand under each vent blocking experimental condition using a standard flow rate of 17.5 ml/sec.

Filter stain pattern assessment. As a validity check on our vent blocking procedure, a research assistant, blind to the experimental conditions, rated each of the spent filters into one of three categories based on the stain pattern of the filters [11]: vents not blocked, vents partially blocked, and vents completely blocked. For each of the two experiments, filter stain templates were used for reference purposes in assigning the spent filters into one of the three categories [13]. The templates were prepared by taking lit cigarettes with filter vents untaped, partially taped, and completely taped, and extracting smoke from them (via a 44 ml bulb syringe) either once (for the Experiment 1 template) or at 60 sec intervals until the cigarettes had been smoked down to the butts (for the Experiment 2 template).

CO boost measure. Before and after smoking, an expired air CO sample was obtained from the subjects. Subjects exhaled residual air from their lungs into the atmosphere before taking a deep breath and holding it for 20 sec. They then exhaled successively into two 1 l polyvinyl bags; the second bag containing alveolar air was analyzed for CO content, using an Ecolyzer 2000 (Energetics Science, Elmsford, NY). The increase in CO levels from immediately before the smoking bout to two minutes after the smoking bout constituted the CO boost measure.

Puffing topography. The five puffing topography variables measured were (1) puff number, (2) interpuff interval, (3) puff duration, (4) puff volume, and (5) average flow rate/puff. A pressure-sensitive switch (Micropneumatics Logic, Inc. No. 502-V-3.3) was activated and deactivated by the onset and offset of puffs. Puff number was measured by counting the number of switch closures. Puff duration was measured by timing the interval between onset and offset of the switch. Interpuff interval was measured by timing the interval between the offset of the switch and its next onset. Puff volume was measured by continuously sampling pressure differences across a small orifice in a modified plastic cigarette holder modeled after an ADL Smoke Dosimeter (Arthur D. Little, Inc., Cambridge, MA). A pressure transducer (Grass Model PT5) transformed the pressure differential into an electrical signal that was directly proportional to the rate of smoke flow through the orifice, after appropriate calibration procedures. The electrical signal representing flow rates was sent, via an amplifier and analog-to-digital converter, to a microcomputer (Apple IIe) which integrated the flow rates over the duration of the puff to obtain puff volume. Validation of the puff volume measure was assessed on a daily basis by syringe-drawing known volumes of smoke from a lit cigarette; if the average puff volume obtained by the flowmeter deviated more than 3 ml from the average puff volume obtained by the syringe, the gain on the amplifier was adjusted accordingly. Average flow rate/puff was obtained by dividing puff duration into puff volume, and was a measure of the average rate of smoke flow through the holder orifice, during a puff.

Inhalation topography. Two inhalation topography variables were measured in these studies: inhalation volume, and lung exposure duration. Inhalation volume was measured with a respiratory inductive plethysmograph (Respitrace; Non-Invasive Monitoring Systems, Inc.; Ardsley, NY), designed to record thoracic and abdominal movements which could be transformed into meaningful inhalation and exhalation measures. Elastic cloth bands containing folds of wires were placed around the thoracic and abdominal areas of the subject, and then connected, via an oscillator module, to the Respitrace. The expansion and contraction of the bands created by normal breathing changed the cross sectional areas of the bands, and produced a constantly changing electrical signal which was converted into a digital signal output. The digital signal was summed from start to peak of the electrical potential rise that represented an inhalation. Breath volumes were calibrated for each subject prior to each experimental condition using an 800 ml known volume of air. In order to control for the different lung sizes of subjects, inhalation volume was expressed for each subject as a percentage of their vital capacity. Vital capacity, a measure of lung volume, was obtained for each subject at the start of the experiment by having them take a deep breath then exhale as much air as possible into a water spirometer (Collins Vitalometer; Braintree, MA). Mean vital capacity for the seven subjects was 3606 ml, with a range of 2825 ml to 5263 ml. Lung exposure duration (the temporal period from inhalation onset to exhalation offset) was measured by timing the interval between the onset of the rise in the electrical signal generated by an inhalation and the trough of the electrical signal generated by the end of an exhalation.

Subjective reports. After completion of a smoking bout (8 puffs in Experiment 1, one cigarette in Experiment 2), subjects were asked to rate six characteristics of the cigarette. Subjects made their subjective estimations for each of the six measures by placing a vertical hatch mark at some point along a 100 mm bipolar scale. Subjects rated the cigarettes on strength (very weak/very strong), harshness (very mild/very harsh), heat (no heat/very hot), draw (easy/hard), taste (very bad/very good), and the satisfaction derived from smoking (very unsatisfying/very satisfying).

Data Analysis

Effects of vent blocking on CO boost, five puff topography measures, two inhalation topography measures, and six ratings of cigarette characteristics were assessed using a repeated measures analysis of variance (ANOVA). Each subject contributed three (Experiment 1) or five (Experiment 2) observations at each vent blocking condition. Also, the effect of vent blocking on RTD was assessed using a repeated measures ANOVA, with vent blocking and cigarette brand as factors. Tukey post-hoc comparison tests were used, when appropriate. From the filter stain pattern analysis, the percentage of butts assigned to the appropriate stain pattern category was calculated.

RESULTS

Resistance-to-Draw

Table 1 shows RTD for four cigarette types used under each of the filter vent block conditions. RTD was significantly influenced by filter vent blocking, $F(2,6)=200.3$, $p<0.001$, but there were no differences in RTD across the four cigarette brands used, nor any interactions between vent blocking and brands. Compared with unblocked cigarettes, average RTD increased by 19% when half of the vents were blocked, and increased by 98% when all the vents were blocked.

Experiment 1. Effects of Filter Vent Blocking on Smoke Exposure

In Experiment 1, puff number and volume, inhalation volume, and breathhold duration were controlled to examine effects of vent blocking on biological exposure, as measured by CO boost.

Smoking topography measures. Table 2 (left side) shows that puff number, puff volume, inhalation volume, and lung exposure duration (incorporating breathhold duration) were

TABLE 1

MEAN RESISTANCE TO DRAW (RTD)† VALUES

Cigarette Brand	Percent of Filter Vents Blocked 0%	50%	100%
Now-NM‡	92.5	115.3	184.4
Cambridge-NM	88.9	106.2	163.1
Now-M	83.8	103.1	183.4
Carlton-M	95.5	105.7	181.9
Mean	90.2	107.8	178.2*
S.E.M.	1.3	1.6	2.5

*$p<0.001$.
†Average RTD in mm of H_2O for 5 cigarettes.
‡NM=Non-mentholated, M=Mentholated.

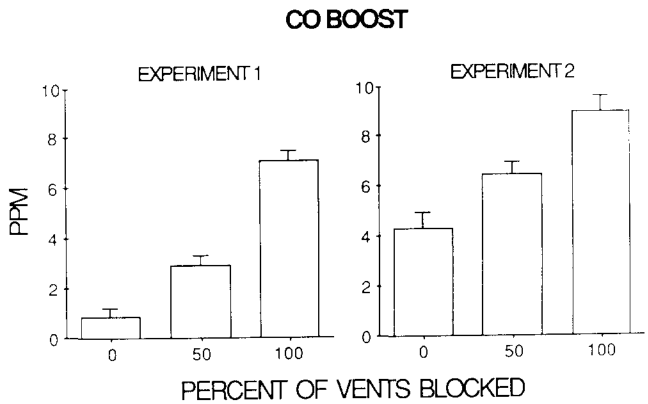

FIG. 1. The effect of vent blocking on CO boost under controlled conditions, Experiment 1 (left frame), and ad lib conditions, Experiment 2 (right frame). Brackets indicate standard error of the mean.

equivalent across experimental conditions, as dictated by the experimental design. There were also no significant differences in interpuff interval. However, two uncontrolled parameters, puff duration, $F(2,8)=22.3$, $p<0.001$, and average flow rate/puff, $F(2,8)=33.6$, $p<0.001$, differed across conditions. Post hoc tests revealed that mean puff duration and average flow rate/puff in each condition was significantly different from the others.

Biological exposure measure. Mean pre-trial carbon monoxide readings were 34.2, 34.7, and 32.5 ppm for the 0%, 50%, and 100% vent-block conditions, respectively, $F(2,8)=2.65$, ns. Figure 1 (left frame) shows that carbon monoxide boost (from the pre-trial levels) increased as a greater percentage of filter vents were blocked, $F(2,8)=143.4$, $p<0.001$. Mean CO boosts were 0.83 ppm, 2.87 ppm, and 7.07 ppm, when 0%, 50%, and 100% of the filter vents were blocked, respectively. Post hoc tests revealed that each CO boost was significantly different from the others.

Subjective report measures. Table 3 shows the effects of vent blocking on subjective estimates of cigarette characteristics. Subjects rated the completely blocked cigarettes as stronger, $F(2,8)=8.0$, $p<0.01$, harsher, $F(2,8)=7.0$, $p<0.01$, and hotter, $F(2,8)=4.3$, $p<0.05$, than the partially blocked and unblocked cigarettes. There was also a trend for higher draw, taste, and satisfaction ratings as a greater percentage of filter vents were blocked, but between-condition differences were not significant.

Filter stain pattern assessment. A single puff was taken from each of 360 cigarettes (8 cigarettes × 3 conditions × 3 sessions × 5 subjects), of which 343 were available for analysis. Overall, 311 out of the 343 spent filters were placed in the appropriate category for a 91% accuracy rate.

Experiment 2. Effects of Filter Vent Blocking on Smoking Topography

In Experiment 2, puffing and inhalation parameters were allowed to vary in order to examine the effects of filter ventilation on smoking topography.

Smoking topography measures. The effects of vent blocking on puff and inhalation parameters are shown in Table 2 (right side). Subjects took significantly more puffs, $F(2,8)=7.9$, $p<0.01$, with significantly shorter interpuff intervals, $F(2,8)=4.3$, $p<0.05$, from cigarettes with unblocked filter vents than from cigarettes with blocked filter vents. Puff durations were similar across conditions, but puff volumes were larger, $F(2,8)=36.2$, $p<0.001$, and average flow rate/puff was higher, $F(2,8)=59.9$, $p<0.001$, when subjects smoked cigarettes with unblocked filter vents than when smoking cigarettes with blocked vents. Post hoc tests revealed that the puff volumes and the average flow rate/puff from the three vent blocking conditions were significantly different from each other. Inhalation volume was not affected by vent blocking, but lung exposure durations were significantly shorter when subjects smoked unblocked as compared with vent blocked cigarettes, $F(2,8)=12.9$, $p<0.005$. However, absolute differences in lung exposure duration across conditions were less than one second.

Biological exposure measure. Mean pre-trial carbon monoxide readings were 40.8, 38.8, and 39.6 ppm for the 0%, 50%, and 100% vent-block conditions, respectively, $F(2,8)=1.66$, ns. Figure 1 (right frame) shows that CO boost (from the pre-trial levels) increased as a greater pecentage of filter vents were blocked, $F(2,8)=23.8$, $p<0.001$. Mean CO boosts were 4.32 ppm, 6.44 ppm, and 8.96 ppm when 0%, 50%, and 100% of filter vents were blocked. Post hoc tests revealed that each CO boost was significantly different from the others.

Subjective report measures. Table 3 shows the effects of vent blocking on subjective estimates of cigarette characteristics. Subjects rated the completely blocked cigarette as stronger, $F(2,8)=10.8$, $p<0.005$, harsher, $F(2,8)=8.6$, $p<0.01$, hotter, $F(2,8)=12.6$, $p<0.003$, tastier, $F(2,8)=5.7$, $p<0.03$, and more satisfying, $F(2,8)=6.0$, $p<0.03$, than the unblocked cigarette.

Filter stain pattern assessment. Filter stain ratings were made for 75 cigarettes (5 cigarettes/condition × 3 conditions × 5 subjects). Overall, 72 out of 75 spent filters were placed in the appropriate category for a 96.0% accuracy rate.

DISCUSSION

Our vent blocking procedure, using tape to obstruct 50% or 100% of the filter vents, was validated by the stain pattern

TABLE 2

MEAN VALUES OF PUFF AND INHALATION PARAMETERS‡

	Percent of Filter Vents Blocked					
	Experiment 1§			Experiment 2#		
	0%	50%	100%	0%	50%	100%
Puffing Topography						
Puff number	8.0	8.0	8.0	13.2	11.1	9.0†
	0	0	0	1.0	0.7	0.4
Interpuff interval (sec)	51.4	55.2	53.7	20.6	22.1	23.3*
	1.0	2.2	2.6	1.8	1.9	1.8
Puff duration (sec)	1.6	1.8	2.1†	2.0	1.9	1.8
	0.1	0.1	0.1	0.1	0.1	0.1
Puff volume (ml)	61.1	61.4	60.2	63.3	54.8	42.8†
	0.3	0.3	0.3	1.7	2.0	2.2
Average flow rate (ml/sec)	39.4	35.8	30.0†	32.3	29.4	24.0†
	4.1	4.4	3.1	1.4	1.7	1.6
Inhalation Topography						
Inhalation volume (% of VC)¶	50.0	49.6	49.8	18.3	19.9	19.0
	0.4	0.5	0.3	1.3	1.2	1.1
Lung exposure duration (sec)	8.21	8.36	7.81	4.50	4.90	5.40†
	0.21	0.16	0.22	0.32	0.30	0.35

*$p<0.05$.
†$p<0.01$.
‡Data are Mean ± S.E.
§Single puffs from full length cigarettes.
#Ad lib smoking of a whole cigarette.
¶VC=vital capacity.

TABLE 3

MEAN SUBJECTIVE RATINGS OF CIGARETTE CHARACTERISTICS‡§

	Percent of Filter Vents Blocked					
	Experiment 1			Experiment 2		
	0%	50%	100%	0%	50%	100%
Strength	16.8	32.3	51.4†	29.8	44.8	55.4†
	4.1	6.2	7.3	4.8	5.2	4.2
Harshness	17.8	26.9	43.5†	32.3	43.7	54.0†
	4.6	6.8	7.5	5.7	5.5	4.9
Heat	15.1	28.8	36.1*	29.1	38.8	50.8†
	5.2	8.1	9.2	5.0	5.0	4.5
Draw	21.8	21.2	34.9	50.6	52.2	51.1
	5.3	4.8	8.4	6.1	5.2	4.9
Taste	31.6	37.1	50.1	34.4	47.6	63.0*
	8.4	7.3	6.3	5.1	5.2	4.2
Satisfaction	24.8	33.6	46.0	35.0	50.0	66.4*
	5.3	6.8	6.0	6.1	5.7	3.7

*$p<0.05$.
†$p<0.01$.
‡Data are Mean ± S.E.
§Response range 0–100 mm on a visual analogue scale.

assessments. Cigarette butts, after being compared to a filter stain template, were accurately categorized 90% of the time in both experiments, indicating that the characteristic stain pattern left by unblocked, partially blocked, and completely blocked vents were clearly evident in a majority of rated butts. Our stain pattern accuracy rates are similar to those rates obtained in a previous vent blocking study [13], in which completely blocked and unblocked filters of ultra low yield cigarettes were categorized according to their stain pattern after both human and machine smoking.

Experiment 1 showed that filter vent blocking of ultra low yield cigarettes increased tobacco smoke exposure in human subjects. CO boost increased from 0.83 ppm to 2.87 and 7.07 ppm, respectively, when subjects took 8 puffs from an ultra low yield cigarette with 0%, 50%, and 100% of the filter vents blocked. By blocking the filter vents, which are designed to dilute smoke, the tobacco smoke bolus clearly became more concentrated. In fact, CO exposure from the completely blocked cigarette condition (7.07 ppm) was very similar to the CO exposure from unventilated, high yield cigarettes smoked under similar controlled conditions (8.70 ppm) [16]. CO exposure results from Experiment 1 obtained with smokers under controlled smoking conditions are consistent with previous reports utilizing smoking machines [11, 20, 26]. For example, in one of these studies [11], taping 50% and 100% of the filter vents of an ultra low yield cigarette increased nicotine yield from 0.45 mg to 0.73 mg and 0.98 mg, tar yield from 4.4 mg to 7.0 mg and 12.6 mg, and CO yield from 4.5 mg to 7.8 mg and 17.7 mg. The same functional relationship was demonstrated with human smokers in the present study when CO boost was used as a measure of smoke constituent absorption. However, direct quantitative comparisons between human and machine smoking studies are not possible because of differences in puffing parameters and measurement procedures.

Puff duration and flow rate, as measured by average flow rate/puff, were not under experimental control, and changed across conditions in Experiment 1. Although it is possible that the flow rate and/or puff duration changes in our study affected CO boost [21], the overriding influence of vent blocking on CO boost is suggested from the smoking machine studies that have held flow rate and puff duration constant and still found large differences in CO deliveries across vent blocking conditions [11, 20, 26]. The most likely variable responsible for the changes in puff duration and flow rate across experimental conditions was RTD: RTD increased as a function of vent blocking (see Table 1), thereby decreasing the rate of smoke flow, which in turn increased the amount of time it took to pull the prescribed 60 ml puff volume from the cigarette (see Table 2). Similar results were obtained in a study in which syringe-drawn puffs of a fixed volume were taken from a lit cigarette [15]. As the tobacco rod burned, resistance to air flow decreased, and the amount of time it took to pull the fixed volume puffs from the cigarette decreased in a linear fashion.

The second experiment investigated effects of filter ventilation under more naturalistic conditions when smokers could adjust their puff and inhalation parameters. Subjects took an average of 13 puffs from unblocked cigarettes, 11 from partially blocked cigarettes, and 9 puffs from completely blocked cigarettes. The volume and rate of smoke flow was also greater when subjects smoked unblocked as opposed to vent-blocked cigarettes. The across-condition differences in puff number and volume suggest that smokers were compensating for smoke dilution by smoking the unblocked cigarettes more intensively. However, subjects still had greater CO exposure when smoking vent-blocked, as compared with unblocked cigarettes, suggesting that compensation was not complete.

The generality of findings from Experiment 2 may be limited by the fact that heavy smokers were used as subjects. That is, heavy dependent smokers may have increased their puff number and puff volume when switched to ultra low yield cigarettes, whereas this may not be typical for the general population of smokers who use ultra low yield cigarettes. Unfortunately, there are no detailed smoking topography data (puff number per cigarette, puff volume) available for regular smokers of ultra low yield cigarettes that could be used in a direct comparison. However, the population data that are available suggest that smokers of ultra low yield cigarettes manage to maintain biological levels of tobacco smoke constituents that are clearly above levels predicted by package yields and only slightly below those observed in smokers of higher yield brands. This is true for carbon monoxide [10], plasma cotinine [2,7] and plasma thiocyanate [2] exposure levels. For example, Benowitz and coworkers [2] found plasma cotinine levels of about 200 ng/ml in ultra low yield smokers and levels of about 300 ng/ml in smokers of higher yield brands; cotinine levels in nonsmokers are close to 0 ng/ml. These data suggest that smokers of ultra low yield cigarettes are not by and large "light" smokers who are successfully reducing their biological exposure levels. In part, these substantial biological exposure levels are due to consumption of large numbers of cigarettes per day. Two studies have shown that ultra low yield smokers consume at least as many cigarettes or more cigarettes per day as do smokers of higher yield brands [2,10], with an average daily consumption of about 30 cigarettes per day. In addition to smoking more cigarettes per day, it seems likely that regular smokers of ultra low yield brands also take more puffs per cigarette and draw larger puffs from their cigarettes than do smokers of higher yield brands, as suggested by the results of Experiment 2.

Differences in puff volumes observed across filter vent conditions in Experiment 2 could have been caused by the differences in RTD across the three cigarette conditions: unblocked cigarettes provided less resistance to smoke flow and therefore produced higher flow rates. Because subjects did not shorten their puff durations to compensate for the higher flow rates when smoking unblocked cigarettes, puff volumes were also higher. A previous experiment using cigarettes with similar nicotine yields but dissimilar RTDs also found larger puff volumes from the cigarettes that had the lower RTD [4].

The differences in puff number across experimental conditions might also be explained primarily by differences in physical characteristics of the cigarettes. This is suggested from results of smoking machine studies in which more puffs were extracted from ultra low yield cigarettes with unblocked filter vents than from cigarettes with tape-blocked filter vents [11,26]. A likely reason for the greater number of puffs is that less tobacco is burned per puff when the filter vents are left unblocked. These results and the results of studies examining the effects of physical characteristics on smoking topography [3, 4, 14–16] suggest that in yield reduction studies which utilize commercial brand cigarettes [17, 18, 24, 28], measured changes in either puff volume or puff number might not necessarily be a function of the efforts of subjects to increase smoke constituent uptake, but may be merely a function of changes in physical characteristics of the cigarettes being tested. Nevertheless, these smoking behavior changes may contribute to greater than predicted smoke exposure levels.

Subjects were not informed about the characteristics of cigarettes that they would be smoking, and could not see the cigarettes, yet the majority of subjects in both experiments reported that the unblocked cigarette was weaker, cooler, milder, less tasty, and less satisfying to smoke than the blocked cigarette. These results are consistent with yield reduction studies in which low yield cigarettes are rated as weaker and/or less satisfying than high yield usual-brand cigarettes [24,25]. When comparing the subjective report measures of Experiments 1 and 2, it is apparent that cigarette length affected the measures: when puffs were taken from freshly lit cigarettes (Experiment 1), cigarettes were rated as weaker, milder, cooler, less tasty, and less satisfying, than when cigarettes were smoked down to the butt (Experiment 2). These results are consistent with those of previous studies which have used whole- and full-length cigarettes [14–16]. Puffs from freshly lit cigarettes most likely delivered a less concentrated bolus of smoke than the average puff from a cigarette smoked down to the butt [30]. Interestingly, in neither Experiment 1 nor Experiment 2 were draw characteristics rated differently across the three cigarette conditions, even though the vent blocking manipulation affected RTD. This may have been due to inconsistent interpretation of the draw question, some subjects equating draw with the difficulty of obtaining a concentrated bolus of smoke from the rod, and others equating the phrase with the difficulty of sucking an air/smoke mixture (regardless of smoke concentration) from the cigarette into the mouth. These intersubject differences, then, are thought to be responsible for the draw level rating being insensitive to the experimental manipulation.

Ultra low yield cigarettes are marketed with claims that these cigarettes are "safer" than moderately high yield cigarettes. Studies have confirmed, however, that nicotine exposure levels are not related to nicotine yields [1, 5, 19, 23]. Also, a large body of research (e.g., [9, 22, 27]) has determined that when smokers switch from high to low yield cigarettes, reductions in smoke exposure levels are often not proportional to the reductions in cigarette yields. Results of Experiment 1 demonstrate that one of the ways smokers can effectively compensate for large yield reductions is by blocking filter vents. Results of Experiment 2 demonstrate that unblocked cigarettes generate different puffing patterns than do vent-blocked cigarettes. Puff volume and puff number are increased by filter ventilation in a direction that leads to enhanced smoke constituent exposure. Smokers who switch to ultra low yield cigarettes may therefore partially negate the expected risk reduction benefits of these cigarettes by blocking some or all of the filter vents, by increasing their puff volumes and/or by taking a greater number of puffs from each cigarette, as well as by smoking a greater number of cigarettes per day.

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