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# Blocking Filter Vents Increases Carbon Monoxide Levels From Ultralight, But Not Light Cigarettes

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SWEENEY, C. T. AND L. T. KOZLOWSKI. *Blocking filter vents increases carbon monoxide levels from ultralight but not light cigarettes*. PHARMACOL BIOCHEM BEHAV **59**(3) 767–773, 1998.—Effect of vent blocking on carbon monoxide (CO) exposure from a best-selling light cigarette was examined in 12 daily cigarette smokers. Mean CO boosts were not different from each other with (a) 0% filter vents blocked (5.0 ppm), (b) vents covered with lips (4.9 ppm), (c) 50% of vents covered with tape (4.8 ppm), and (d) vents covered with a pinch of the fingertips (4.9 ppm). A second study in another 12 smokers was conducted to replicate these findings as well as earlier findings that blocking vents doubles CO intake from 1-mg tar cigarettes. While blocking half the vents with fingers significantly increased CO boost from ultralight cigarettes (2.8 vs. 5.4 ppm, $p < 0.001$), it did not influence boosts from light cigarettes (6.3 vs. 6.5 ppm, $p = 0.8$). The lowest yield cigarettes (1 mg tar) may be special. Smoking machine simulations provide poor models of human smoke intake. It is unclear whether tar and nicotine intake from light cigarettes was influenced by vent blocking. © 1998 Elsevier Science Inc.

Cigarettes Smoking Carbon monoxide Filter ventilation Vent blocking Low-yield cigarettes

SO-CALLED "ultralight" cigarettes [about 1–5 mg tar by the Federal Trade Commission (FTC) Method (2)], reduce standard yields of tar, nicotine, and carbon monoxide (CO) on smoking machines largely by means of small holes or vents on the filter that serve to dilute the smoke with air (9). Although manufacturing changes such as the use of both longer filters and highly porous cigarette paper have also contributed to reducing standard yields, filter ventilation has been the major change behind the modern "low-yield" cigarettes (7). In addition to ultralight cigarettes, so-called "light" cigarettes (about 6–15 mg tar) are also vented, but to a lesser extent than ultralight cigarettes [each puff of a light cigarette is diluted about 16–30% with ambient air vs. about 70–90% for ultralight cigarettes (14)]. The function of these filter vents can be easily compromised in the hands and mouths of smokers: Observational and interview studies have shown that some smokers, knowingly and unknowingly, cover these holes with their lips, fingers, or even with tape (6,10).

Smoking machine estimates used to simulate the effect of vent blocking on smoke exposure have demonstrated that yields of tar, nicotine, and CO increase dramatically when filter vents are blocked (8,11,15). A study exploring the effect of vent blocking on smoke exposure in human smokers found that blocking 0, 50, and 100% of the filter vents on a 1-mg tar cigarette with tape, while holding all other smoking parameters as constant as possible, increased CO exposure in an orderly fashion (20). This research was extended to assess directly the effect of a behavioral vent blocking maneuver (i.e., blocking vents with lips) on smoke exposure from a 1-mg tar cigarette (12). Using CO boost (postcigarette expired air CO level minus precigarette expired air CO level) as an estimate of the effects of vent blocking on smoke exposure, lip blockade was compared with two additional experimental conditions in which 0% of the filter vents were blocked, and 100% of the filter vents were covered with tape. Blocking filter vents with lips more than doubled the CO exposure from

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these cigarettes. Mean CO boosts for the unblocked, lip-blocked, and tape-blocked conditions were 2.7 ppm (SE = 0.52), 6.7 ppm (SE = 1.0), and 12.9 ppm (SE = 2.2), respectively. Additional analyses indicated that lip-blockade effectively blocked approximately 50% of the filter vents.

The majority of research thus far has assessed the effect of vent blocking in cigarettes in the 1–5-mg tar category. Light cigarettes, however, are much more popular, making their use of greater public health significance. In 1995, 47.8% of the cigarettes sold in the United States were in the "light" (7–15 mg tar) range compared with only 11.9% in the "ultralight" (6 mg tar or less) range (13). Like ultralight cigarettes, best-selling light cigarettes are also subject to vent blocking. Using an objective, unobtrusive indicator of vent blocking, one study found that some vent blocking was found in 53% of 158 light filters collected (10). The purpose of the present study was to further extend the research on vent blocking in best-selling "light" cigarettes.

Because light cigarettes are generally less ventilated than ultralight cigarettes, blocking vents on lights, it might be argued, would not produce noticeable effects. A secondary analysis of data previously published (15), however, indicated that blocking 50% of the filter vents has at least an equal, if not greater effect, on tar, nicotine, and CO yields for light cigarettes than for ultralight cigarettes, as measured by change in yields. Thirty-six brands of Canadian cigarettes (including 28 brands that had ventilated filters), were tested on a smoking machine under three experimental conditions to simulate how smoker's exposure to toxic substances would be affected by smoking patterns of differing intensities. In the "standard" condition, a puff volume of 35 ml and of 2-s duration was taken every 60 s until a fixed butt length was reached. In the "moderate" condition (which was used to represent more typical smoking behavior), puff volume was increased to 48 ml, puff duration was increased to 2.4 s, and puff interval was decreased to 44 s. The parameters of the "intense" condition were exactly the same as the "moderate" condition with the exception that 50% of the vent holes were covered with tape. Comparing results obtained under the moderate and intense conditions shows the effect of blocking 50% of filter vents on tar, nicotine, and CO yields. The standard tar yields of the 36 brands of cigarettes tested ranged from 0.5 mg to 14.4 mg. We chose to examine 10 specific brands: four that represented the lowest of the ultralight cigarettes (range: 0.5–1.5 mg tar) and six that had standard tar yields closest to that of a best-selling cigarette brand in the United States, Marlboro Lights® (range: 8.2–10.2 mg). Comparing yields obtained under both the moderate and intense conditions showed that blocking half the filter vents resulted in greater increases in CO yields for the six light brands than for the four ultralight brands (4.7 mg CO vs. 2.6 mg CO, respectively). Because a smaller difference in CO yields had led to a difference in alveolar CO levels from a 1-mg tar cigarette, it seemed possible that an even larger difference in CO yield for lights might be reflected in noteworthy differences in CO intake from these cigarettes.

The purpose of the present study was to assess the effects of vent blocking on smoke exposure and subjective effects in human smokers from a best-selling light cigarette. In our earlier research we studied blocking with lips, a maneuver that resulted in blockage of approximately 50% of the vent holes. In this study we wanted to additionally look at the effects of (a) blocking with a pinch of the fingertips, a maneuver likely to also block about half the filter vents, and (b) covering 50% of the filter vents with tape. This study examined how these three vent blocking maneuvers compared with one another and with an unblocked condition with respect to CO boost and subjective effects.

## METHOD—STUDY 1

### *Participants*

Twelve cigarette smokers (seven women and five men) were recruited through fliers and newspaper advertisements. The average participant was 21 years old (range 20–24, SD = 1.0), smoked 21 cigarettes per day (range 10–30, SD = 5.0), and had been smoking regularly for 6.5 years (range 2–12, SD = 2.4). Three participants reported their usual brand as being Marlboro Lights, three Marlboro Full-Flavor, two Parliament Lights, one Marlboro Medium, one Sebring Full-Flavor, one Newport Full-Flavor, and one Camel Lights.

### *Cigarettes*

During the session participants smoked Marlboro Lights® (0.8 mg nicotine, 10 mg tar, 10 mg CO) (2). Participants smoked mentholated cigarettes if their usual brand was mentholated and nonmentholated cigarettes if their usual brand was nonmentholated. The CO yield of mentholated and nonmentholated cigarettes did not differ. Two participants smoked mentholated cigarettes.

### *Procedure*

Participants were initially screened through a brief telephone interview. Meeting times were arranged with those eligible to participate. Eligible participants were daily cigarette smokers who were at least 18 years of age or older. Each participant was scheduled for one 2.5-h session. Because sessions were scheduled at the convenience of the participants, they were conducted at various times throughout the day, ranging from 0900 to 1900 h. Participants were instructed to maintain their normal smoking patterns prior to each session.

The following four vent blocking conditions were studied: (a) 0% of the filter vents were blocked (i.e., unaltered cigarettes were used); (b) 50% of the filter vents were blocked with tape (i.e., two 6 × 6-mm pieces of cellophane tape were placed opposite to one another centered over the vents that were approximately 12 mm from the proximal end of the cigarette); (c) as many vents as possible were blocked with the participant's lips (i.e., participants were instructed to place the cigarette as far into their mouth as necessary to cover all the filter vents); and (d) as many vents as possible were blocked with the participant's fingers (i.e., participants were instructed to hold the cigarette between their thumb and forefinger when taking a puff, covering as many of the vents as possible). The experimenter observed all participants while smoking to ensure that these conditions were met.

During each session, participants took eight 2-s puffs from cigarettes under each of the four vent-blocking conditions. Time between puffs was restricted to 50 s. Participants heard taperecorded tones indicating when to start and stop puffing. To ensure that the cigarette did not extinguish itself before the eighth puff, the eight puffs were equally divided between two cigarettes. Because the last few puffs of a cigarette produce greater yields than the first few puffs (17), dividing the puffs in this way could result in an underestimate of exposure levels.

During each session participants took four puffs from each of eight cigarettes, two cigarettes per vent blocking condition. Thirty minutes elapsed between the last puff under one experimental condition and the first puff under the next experimental condition. Order of presentation was balanced for the 12 participants using an orthogonal Latin square design (4). All cigarettes were lit by the experimenter using a 50-cc syringe to take the lighting puff. All participants were paid $15.00 at the conclusion of the session.

### *Measurement Procedures*

*CO boost measure.* Two expired air CO samples were collected from each participant immediately prior to smoking the first cigarette under each experimental condition using a Vitalograph BreathCO machine (McNeil International, Inc., Lenexa, KS). Participants were instructed to inhale deeply, hold their breath for 15 s, and exhale slowly and steadily through the mouthpiece for about 15 s. The highest CO reading in parts per million was taken from the digital display.

The two expired air CO samples collected prior to smoking the first cigarette under each experimental condition were averaged to obtain the mean precigarette CO. Exactly 2 min after the last puff from the second cigarette under each experimental condition, two additional expired air CO samples were collected. These two values were averaged to obtain the mean postcigarette CO. The CO boost measure was calculated as the difference between the mean postcigarette CO and the mean precigarette CO.

*Subjective reports.* Immediately following the eighth puff from each cigarette (i.e., the fourth puff from the second cigarette under each experimental condition), participants were asked to rate six characteristics of the cigarette using a 100-mm visual analog scale. The characteristics rated were strength ("very weak"/"very strong"), harshness ("very mild"/"very harsh"), heat ("no heat"/"very hot"), draw ("easy"/"hard"), taste ("very bad"/"very good"), and satisfaction derived from smoking ("very unsatisfying"/"very satisfying"). Data from a previous study (12) indicated that subjective ratings of strength and harshness behave in a similar manner. Analyses of this data indicated that the combination of these two characteristics was more reliable (reliability estimate = 0.915) than either of the two characteristics alone (reliability estimate = 0.844). We, therefore, created a strength/harshness index by taking the mean of the responses for these two characteristics for each of the experimental conditions. This index, rather than the separate characteristics, was used in analyses.

### *Data Analysis*

Effects of vent blocking on CO boost and cigarette characteristics were analyzed using a repeated measures analysis of variance (ANOVA). We hypothesized that the lip-blocked, tape-blocked, and finger-blocked conditions would not differ significantly from one another. We further hypothesized that there would be a significant difference between the unblocked condition and the combination of the three remaining blocking conditions with respect to CO boost and subjective characteristics, for a total of four planned comparisons. Because the number of planned comparisons (i.e., 4) exceeded the number of degrees of freedom associated with the overall treatment mean square (i.e., 3), we used a modified Bonferroni test to help control for the increased probability of type I errors as a result of multiple testing (5). The adjusted significance level for each individual comparison was calculated as alpha = 0.04.

## RESULTS—STUDY 1

Mean pretrial CO readings were 25.0 ppm (SE = 3.8), 26.4 ppm (SE = 3.5), 24.8 ppm (SE = 3.9), and 25.8 ppm (SE = 3.8) for the unblocked, lip-blocked, tape-blocked, and finger-blocked conditions, respectively, $F(3, 33) = 0.52$, NS. There was, therefore, no reason to expect that pretrial CO readings would influence the CO boosts for the four conditions. Mean CO boosts for the unblocked, lip-blocked, tape-blocked, and finger-blocked conditions were remarkably similar: 5.0 ppm (SE = 0.47), 4.9 ppm (SE = 0.86), 4.8 ppm (SE = 0.47), and 4.9 ppm (SE = 0.50), respectively. The comparison between the unblocked condition and the remaining three conditions with respect to CO boost was not significant, $F(1, 11) = 0.13$, NS.

With respect to the strength/harshness index, ANOVA indicated that the lip-blocked (mean = 47.5, SE = 5.6), tape-blocked (mean = 52.3, SE = 4.1), and finger-blocked (mean = 52.3, SE = 5.1) conditions did not differ significantly from one another. The combination of the three vent blocking conditions was, however, significantly different from the unblocked condition [mean = 37.3; SE = 5.4; $F(1, 11) = 9.4$, $p = 0.004$]. The lip-blocked, tape-blocked, and finger-blocked cigarettes were also not rated differently with respect to heat (mean = 25.5, SE = 7.2; mean = 26.3, SE = 6.0; mean = 31.0, SE = 7.0, respectively.) Cigarettes under the three blocking conditions were rated as significantly hotter than cigarettes that were not blocked [mean = 18.1, SE = 5.2; $F(1, 11) = 5.7$, $p = 0.02$]. Whether cigarettes were blocked or not blocked did not have a significant effect on ratings of cigarette draw, $F(1, 11) = 1.5$, NS, or satisfaction, $F(1, 11) = 0.16$, NS. Analyses of cigarette taste yielded somewhat anomalous results. Initial pairwise comparisons of the three vent blocking conditions revealed that cigarettes under the tape-blocked condition were rated as tasting significantly better than cigarettes under the lip-blocked condition, $F(1, 11) = 8.1$, $p = 0.008$. Subsequent comparison of the unblocked condition with the three blocked conditions indicated that there was no significant difference with respect to taste, $F(1, 11) = 0.24$, NS.

## DISCUSSION—STUDY 1

The results of Study 1 suggest that blocking the filter vents on a 10-mg tar cigarette (i.e., a "light" cigarette) has no added effect on smoke exposure in human smokers, as measured by expired air CO levels. It should be noted that the exact placement of the filter vents can vary from cigarette to cigarette, but their location generally ranges from 12–15 mm from the proximal end of the cigarette. Individual differences in smoking behavior on CO levels were minimized in this study by employing smoking control procedures. The participants in our study were analogous to smoking machines: puff number, puff duration, and interpuff interval were the same for all participants for all experimental conditions. The results were somewhat unexpected, given previous research with 1-mg tar cigarettes demonstrating that CO exposure increased in a linear fashion as a greater percentage of vents were blocked (12,20).

Previous research has estimated that covering filter vents with the lips results in blockage of approximately 50% of vent holes (12). In the present study, it was assumed that blocking filter vents with a pinch of the fingertips would also result in covering about half of the vent holes. With respect to subjective ratings of strength/harshness and heat, both the lip-blocked and finger-blocked conditions did not differ from the condition in which 50% of vent holes were known to be blocked. Additionally, these three blocking conditions were found to be significantly different from the unblocked condition with respect to these variables. These findings support our estimates that fingers or lips can block around half the vents.

The results of this study suggest that filter vents on light cigarettes may influence yields determined from smoking machines, but have no meaningful effect in human smokers. Previous research examining the effect of vent blocking on smoking machine yields found that blocking half the vents on various brands of low-yield cigarettes led to increases in yields of tar, nicotine, and CO—increases that were even higher for the "light" brands than the "ultralight" brands (15). This finding obtained with smoking machines was not replicated in our sample of human smokers.

In light of similar research previously done with 1-mg tar cigarettes (12), it appears that behavioral blocking of filter vents results in an increase in CO exposure for ultralight cigarettes, but not for light cigarettes. The existence of a "no-effect" finding in this study, however, makes it difficult to draw any firm conclusions from these results. These findings, therefore, need to be replicated in another sample of smokers. An experimental design that allows for direct comparisons between ultralight and light cigarettes would be most powerful and was, therefore, used in Study 2.

## STUDY 2

The purpose of Study 2 was to attempt to replicate the findings of both Study 1 and previous work done with ultralight cigarettes (12), while at the same time allowing for direct experimental comparisons between ultralight and light cigarettes. We also wanted to examine an additional vent blocking maneuver not previously studied with ultralight cigarettes (i.e., finger blocking).

## METHOD—STUDY 2

### *Participants*

Twelve cigarette smokers (six women and six men) were recruited through fliers posted around the Penn State campus. The average participant was 23 years old (range 20–29, SD = 3.0), smoked 22 cigarettes per day (range 10–45, SD = 10.0), and had been smoking regularly for 7.4 years (range 2.5–15, SD = 4.7). Three participants reported that they usually smoked Marlboro Lights, two Camel Lights, two Camel Filters, one Marlboro Full-Flavor, one Marlboro Medium, one Parliament Lights, one Merit Ultra-Lights, and one Now Ultra-Lights.

### *Cigarettes*

During the session participants smoked both Marlboro Lights® and the ultralow-yield cigarette brand Now® (0.1 mg nicotine, 1 mg tar, 2 mg CO) (2). Participants smoked mentholated cigarettes if their usual brand was mentholated and nonmentholated cigarettes if their usual brand was nonmentholated. Two participants smoked mentholated cigarettes.

### *Procedure*

The procedure for Study 2 was the same as described in Study 1, the only exception being the number and type of vent blocking conditions that were studied: only the unblocked and finger-blocked conditions were examined in Study 2. Because these two manipulations were examined using two types of cigarettes (i.e., ultralight and light), four experimental conditions were used: ultralight unblocked, ultralight finger-blocked, light unblocked, and light finger-blocked.

### *Measurement Procedures*

CO boost and subjective reports were measured exactly as in Study 1.

### *Data Analysis*

Effects of vent blocking on CO boost and cigarette characteristics were analyzed using a 2 × 2 (cigarette × blocking) analysis of variance (ANOVA) with repeated measures on both factors. Cigarette refers to ultralight and light cigarettes and blocking refers to the unblocked and finger-blocked manipulations. To determine whether our results replicate those from Study 1 and previous work (12), the key analyses are those assessing the significance of the interaction between the two repeated factors (cigarette × blocking). We hypothesized that the ultralight finger-blocked cigarette would have a significantly higher CO boost than the ultralight unblocked cigarette. We further hypothesized that there would no significant difference between the two light cigarette conditions. We also planned to test if the CO boost from the ultralight finger blocked cigarette differed from the boost from the light unblocked cigarette. With respect to the cigarette characteristics, we did post hoc comparisons when warranted by significant interaction effects, using an adjusted Bonferroni alpha level (5). The adjusted significance level for each individual pairwise comparison was calculated as alpha = 0.03.

## RESULTS—STUDY 2

Average pretrial expired air CO levels were similar across the four experimental conditions: 25.4 ppm (SE = 3.1), 25.4 ppm (SE = 1.9), 24.9 ppm (SE = 2.5), and 24.8 ppm (SE = 3.0) for the ultralight unblocked, ultralight finger-blocked, light unblocked, and light finger-blocked conditions, respectively, $F(1, 11) = 0.001$, NS. There was, therefore, no reason to expect that pretrial CO readings would influence the CO boosts for the four conditions.

Both cigarette and blocking main effects were significant with respect to CO boost, $F(1, 11) = 39.5$, $p = 0.0001$; $F(1, 11) = 11.5$, $p = 0.006$, respectively. The cigarette × blocking interaction also had a statistically reliable effect on CO boost, $F(1, 11) = 11.4$, $p = 0.006$. Figure 1 shows the mean CO boosts with standard errors for both the ultralight and light cigarettes under both blocking conditions.

Mean CO boosts for the ultralight unblocked, ultralight finger-blocked, light unblocked, and light finger-blocked conditions were 2.8 ppm (SE = 0.34), 5.4 ppm (SE = 0.64), 6.3 ppm (SE = 0.50), and 6.5 ppm (SE = 0.52), respectively. Consistent with previous findings (12), the CO boost from the ultralight finger-blocked cigarette was significantly higher than the boost from the ultralight unblocked cigarette, $F(1, 11) = 25.3$, $p = 0.0004$. Consistent with the results of Study 1, the CO boost from the light finger-blocked cigarette was not statistically different from the light-unblocked cigarette boost, $F(1, 11) = 0.06$, NS). The difference between the CO boost from the ultralight finger-blocked cigarette and the combination of both light cigarette conditions did not reach an acceptable level of significance according to the adjusted Bonferroni alpha level, $F(1, 11) = 5.3$, $p = 0.04$.

Figure 2 shows the mean subjective ratings of strength/harshness with standard errors for both the ultralight and light cigarettes under both blocking conditions.

Both cigarette and blocking main effects were significant, $F(1, 11) = 11.7$, $p = 0.006$; $F(1, 11) = 8.7$, $p = 0.01$, respectively, with respect to strength/harshness ratings. The interac-

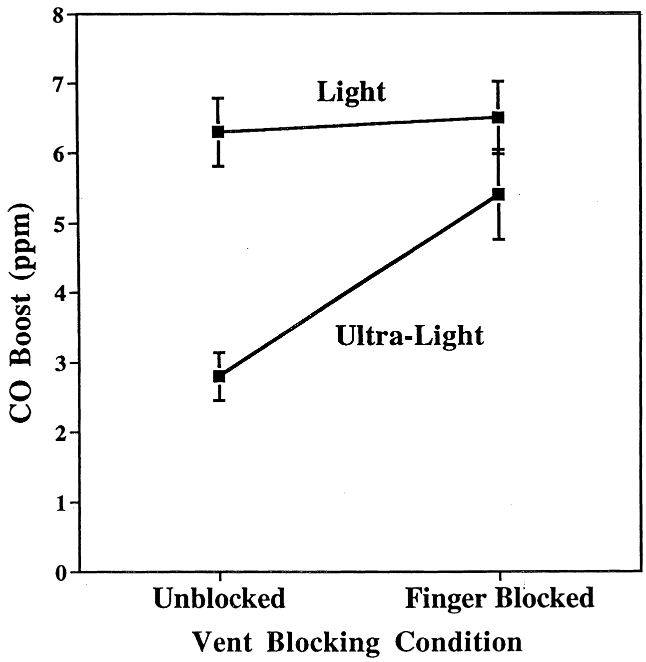


FIG. 1. Mean CO boosts with standard errors for both ultralight (0.1 mg nicotine, 1 mg tar, 2 mg CO) and light (0.8 mg nicotine, 10 mg tar, 10 mg CO) cigarettes under both blocking conditions.

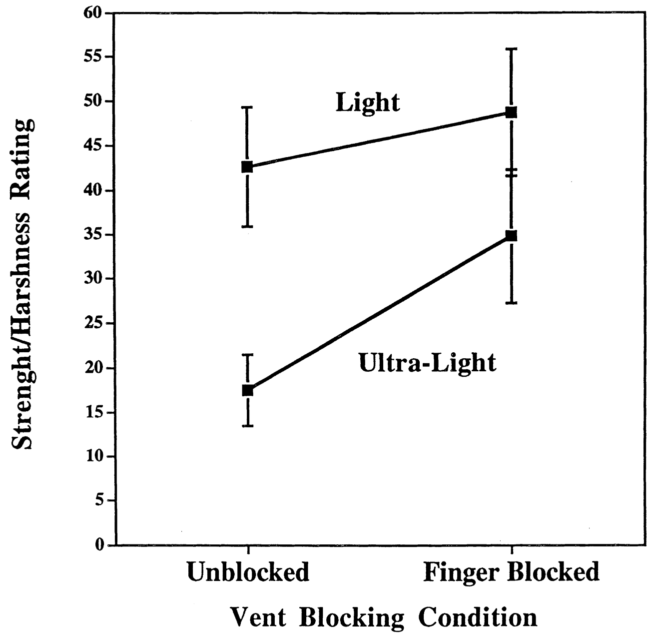


FIG. 2. Mean subjective ratings of strength/harshness with standard errors for both ultralight (0.1 mg nicotine, 1 mg tar, 2 mg CO) and light (0.8 mg nicotine, 10 mg tar, 10 mg CO) cigarettes under both blocking conditions.

tion, however, did not achieve statistical significance, $F(1, 11) = 3.1, p = 0.11$). Figure 3 shows the mean subjective ratings of heat with standard errors for both the ultralight and light cigarettes under both blocking conditions. Once again, both cigarette and blocking main effects were significant, $F(1, 11) = 5.7, p = 0.03$; $F(1, 11) = 10.2, p = 0.008$, respectively, but the interaction was not significant, $F(1, 11) = 0.07$, NS.

No significant main effects or interactions were obtained for ratings of both cigarette draw and taste. With respect to ratings of satisfaction, both a significant cigarette main effect, $F(1, 11) = 5.3, p = 0.04$, and a significant blocking main effect, $F(1, 11) = 6.3, p = 0.03$, were found. A significant interaction effect was also found, $F(1, 11) = 8.2, p = 0.02$. Paired comparisons revealed that the ultralight finger-blocked cigarette was rated as being significantly more satisfying than the ultralight unblocked cigarette, $F(1, 11) = 11.9, p = 0.005$. There was no reported difference in satisfaction, however, between the blocked and unblocked light cigarettes, $F(1, 11) = 0.333$, NS. There was also no reported difference in satisfaction between the ultralight finger-blocked cigarette and the light unblocked cigarette, $F(1, 11) = 2.1$, NS.

## DISCUSSION—STUDY 2

The CO boost results from Study 2 replicate quite well both those results from Study 1 with light cigarettes and those results previously obtained using ultralight cigarettes (12). While covering half the filter vents on a 1-mg tar cigarette results in a doubling of CO exposure, the same manipulation with a light cigarette appears to have no effect on CO exposure in human smokers. Several of the trends that did not reach an acceptable level of significance according to the adjusted Bonferroni alpha level (e.g., comparison of the CO boost from the ultralight finger-blocked cigarette with both light cigarettes) may have been statistically significant given a larger sample size. Increasing the sample size would not likely show an effect of blocking on CO boost from light cigarettes, given the small effect sizes that were found.

Participant responses on ultralight cigarette characteristics for the most part replicate previous findings (12,20). Compared with unblocked cigarettes, ultralight cigarettes with filter vents blocked are generally rated as stronger, harsher, and hotter. Participants in the present study also rated ultralight cigarettes as more satisfying when filter vents are blocked, a finding not previously reported. Participant responses are generally not as consistent for the light cigarettes: blocking filter vents resulted in higher ratings on the strength/harsh index in Study 1, but not in Study 2. Light cigarettes with filter vents blocked were, however, rated as hotter than unblocked cigarettes, consistent with Study 1. Ratings of cigarette draw, taste, and satisfaction did not differ between blocked and unblocked cigarettes, also as in Study 1. These three characteristics have been repeatedly shown to have no relation to vent blocking manipulations. Researchers might consider replacing them with alternative questions that may prove to be more informative.

## GENERAL DISCUSSION

Since the early 1980s, researchers have been well aware of the discrepancy between advertised cigarette yields, as determined by standard smoking machine assays, and smoke exposure levels in human smokers (3). This discrepancy has been attributed to people smoking more intensively than smoking machines. They generally take a greater number of higher volume puffs in shorter intervals of time than is specified by smoking machine parameters. In an attempt to reduce this discrepancy and thereby provide smokers with more mean-

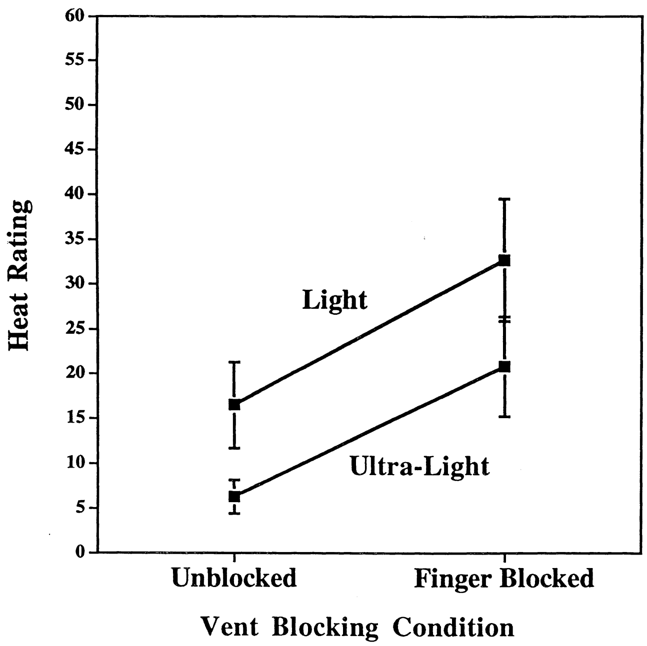


FIG. 3. Mean subjective ratings of heat with standard errors for both ultralight (0.1 mg nicotine, 1 mg tar, 2 mg CO) and light (0.8 mg nicotine, 10 mg tar, 10 mg CO) cigarettes under both blocking conditions.

ingful and accurate yield information, it has been suggested that current testing procedures be modified so that parameters are better based on how people actually smoke (3). For cigarettes in which ventilation holes are incorporated, for example (today such cigarettes account for approximately 70% of the cigarettes sold in the US), it has been recommended that occluding filter vents during testing will more accurately reflect human smoking behavior. The findings from Studies 1 and 2 suggest that although such recommendations may be appropriate for ultralight cigarettes, they are probably unwarranted for light cigarettes, most particularly for measuring CO yields.

*Further Evidence of the Inadequacy of the Standard Machine Testing Procedure*

Our results indicate that the increased yields that result from blocking vents on smoking machines are reflected in increases in human smoke exposure from 1-mg tar cigarettes, but not from 10-mg tar "light" cigarettes. The discrepancy between machine-smoked CO yields and smoker's CO exposure from light cigarettes might best be explained by pharmacokinetic factors. Machines simulate behavior, not pharmacokinetics. When CO yields are determined by smoking machines, all of the CO available in the drawn smoke is measured. Because CO absorption is time dependent, however, smokers may not necessarily absorb all the available CO from a smoke bolus (18). It has been shown that CO exposure levels increase as lung exposure duration increases (19). However, under natural smoking conditions lung exposure durations are relatively short, thus limiting CO absorption and exposure. Though blocking the filter vents on light cigarettes may increase the dose of CO, these increased doses are not reflected in increased exposure because of the relatively short time available for maximal CO absorption.

Given that inhalation variables were not controlled in this study, it is also possible that the greater perceived harshness of the vent-blocked cigarettes may have resulted in more shallow or shorter inhalation of these cigarettes when compared with unblocked cigarettes, thus affecting exposure levels. However, previous research does not support this explanation. It has been shown that inhalation volume is not affected by vent blocking, and lung exposure duration is, in fact, shorter with unblocked as compared with vent-blocked cigarettes (20).

*Consistency of Present Findings With Other Published Results*

Our CO boost values are similar to those of other studies, lending support to the overall validity of our results. For example, CO boosts of 2.10, 5.76, and 7.38 ppm, for ultralow-yield (1.3 mg tar), low-yield (4.7 mg tar), and high-yield (15.6 mg tar) cigarettes, respectively, smoked under controlled conditions have been reported (18). If one imagined these boost values plotted on a graph, our CO boosts (i.e., 2.8 ppm for the unblocked 1-mg tar cigarette in Study 2 and 5.0 ppm and 6.3 ppm for the unblocked 10-mg tar cigarette in Studies 1 and 2, respectively) would fit well with these data points.

*Are 1-mg tar cigarettes different from other cigarettes?* Our data indicate that at least with respect to their susceptibility to increased yields as a result of vent blocking, 1-mg tar cigarettes do differ from other cigarettes. There is also data to suggest that the toxic exposures from ultralow-yield cigarettes differ from other cigarettes. In one study smokers achieved significantly higher increases in CO levels from both the low (5 mg tar) and high-yield (15 mg tar) cigarettes than from the ultralow-yield (1 mg tar) cigarettes (18). The increased levels of CO from the low and high-yield cigarettes, however, were not different from each other. Similarly, another study (1) showed that exposures to tar (reflected in urine mutagenicity), nicotine, and CO were substantially less in subjects switched to or self-selecting ultralow (1 mg tar) compared with the low (5 mg tar)- and high-yield (15 mg tar) cigarettes. They consumed the same levels of nicotine, CO, and tar, however, from the low- as the high-yield cigarettes. This suggests that rather than the three-way classification of cigarettes that presently exists (i.e., cigarettes delivering about 1–5 mg tar by the FTC method classified as ultralight, those delivering about 6–15 mg tar classified as light, and those delivering >15 mg tar classified as regular or full flavor), a dichotomous classification would be more accurate (i.e., 1-mg tar brands and all others). Under the present system, 5-mg tar cigarettes are classified as ultralight, despite evidence of their being no different from 15-mg tar cigarettes with respect to tar, nicotine, and CO exposures (1).

*Does no change in CO exposure mean no change in tar and nicotine exposure?* Some might argue that the results of Studies 1 and 2 imply that it is not necessary to warn smokers of light cigarettes of the presence of filter vents. However, the present studies assessed the effects of vent blocking on CO exposure only. We do not know how tar and nicotine exposures were affected by our vent blocking manipulations. Other studies, although not directly related to vent blocking, provide conflicting data on this point.

On the one hand, there has been research to show that upon switching to 10-mg tar cigarettes, tar, nicotine, and CO yields are reduced disproportionally, with reductions in CO being smaller than those of tar or nicotine. In one study tar and nicotine were reduced by 15 and 30%, respectively, with no accompanying decrease in COHb levels (16). In other words, the smokers compensated fully for the reduced CO yields. This suggests that changes in nicotine and tar exposures can occur in the absence of any CO exposure change.

There is also, however, research to show that tar, nicotine, and CO exposures are equally unchanged when smokers switch from 15- to 5-mg tar cigarettes (1). This would lead one to assume that the absence of any CO exposure change would indicate no likely change in tar and nicotine exposures as well.

Although we do not have direct data on tar and nicotine exposures from our studies, participant responses regarding cigarette characteristics suggest that exposures to tar and nicotine may have increased as a result of vent blocking. Strength/harshness ratings, which may be assumed to be positively related to tar and nicotine yields, were significantly greater for the three blocked cigarettes than for the unblocked cigarette in Study 1. Ratings of cigarette heat, a characteristic also positively related to smoke intake, were significantly higher for blocked cigarettes than for unblocked cigarettes in both Studies 1 and 2. Further research is necessary to resolve these conflicting findings.

The observation of previous studies that levels of tar, nicotine, and CO from low- and high-yield cigarettes (or light and regular cigarettes) do not differ (1,18) and of the current studies that blocking the filter vents on light cigarettes has negligible consequences for CO intake suggests that the only cigarettes that can truly be considered low-yield are the 1-mg tar cigarettes. Whether reduced exposure to toxic products from these cigarettes translates into meaningful reductions in the health hazards of smoking, however, has yet to be determined.

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