Overview of 1980 to 1994 Research Related to the Standard Federal Trade Commission Test Method for Cigarettes

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INTRODUCTION This chapter provides an overview of the major studies related to the Federal Trade Commission (FTC) test method for determining tar, nicotine, and carbon monoxide (CO) yields of cigarettes compared with yields experienced by smokers, with special reference to low-tar and low-nicotine cigarettes. Most of the studies reviewed here were published since 1980; studies published prior to 1980 were extensively reviewed in the 1981 Surgeon General's report (U.S. Department of Health and Human Services, 1981).

The apparent differences between stated yields, as measured by the FTC test method, found in cigarette advertising and on some cigarette packs and actual amounts received by smokers appear to be largely attributable to compensation behaviors related to nicotine and possibly other substances in cigarette smoke. For example, when smokers switch to low-tar and low-nicotine cigarettes, they tend to increase the volume of inhaled smoke per cigarette or increase the number of cigarettes smoked so as to maintain a steady-state level of nicotine in their blood. They may also increase the volume by changing their puffing behavior and increase yield by blocking ventilation holes in filters.

Changes in puffing patterns can substantially alter tar and nicotine yields, as reported by Rickert and colleagues (1983), who investigated the impact of varying levels of butt length, puff duration, puff interval, puff volume, and blocking of ventilation holes.

The differences in advertised tar and nicotine yields of cigarettes compared with the amounts received by smokers result largely from differences between the smoking parameters of the FTC test method and actual smoking behaviors. These differences can substantially alter the amounts of tobacco smoke constituents that smokers inhale. The FTC method was devised in 1967, and it is not clear whether these parameters were based on actual human smoking patterns and behavior. Furthermore, cigarettes have undergone substantial changes in design and content over the past 40 years. Also, much more is currently known about smoking behavior; pharmacodynamics and pharmacokinetics; and the measurement of tar, nicotine, CO, and other substances in cigarette smoke as well as in blood, plasma, urine, and expired air in smokers.

Rickert and Robinson (1981, p. 401) emphasize that

> even if compensation [changes in smoking patterns to increase smoke intake per cigarette] did not occur, it is likely that smoking machine parameters fixed about 20 [years] ago no longer represent the average smoker, who probably takes puffs of more than 45 mL every 40 s instead of a 35-mL puff every 58 s.

There are harmful substances in tobacco and tobacco smoke other than tar, nicotine, and CO. These include hydrogen cyanide (HCN), acrolein, total aldehyde, and tobacco-specific nitrosamines (TSNAs). Levels of some of these harmful substances in low-tar and low-nicotine cigarettes probably differ among brands and may also differ within brands when cigarettes are smoked differently.

Smoking patterns may be influenced by factors other than nicotine dependence. Pomerleau and Pomerleau (1984) pointed out that there is substantial evidence that many cigarettes are smoked for reasons other than to receive nicotine. They cite research indicating that smoking patterns are influenced in part by environmental situations, emotions, personality, and motivation.

Robinson and coworkers (1983) found that smoking compensation behaviors may lead to disproportionate increases in CO and HCN when smokers switch to low-nicotine cigarettes.

Thus, research over the past 15 years has created multiple arenas within which scientists and policymakers may reexamine the accuracy and relevance of the FTC testing method and, if necessary, redesign it.

PARAMETERS OF THE FTC TEST METHOD AND CURRENT SMOKING PATTERNS

The current FTC test method is based on four parameters: puff frequency (every 60 seconds), puff volume (35 mL), puff duration (2 seconds), and a butt length that varies with cigarette type. Darrall (1988) noted that these parameters were set as long ago as 1936 and were not based on observed smoking patterns. For individual smokers, puff volume has been reported to range from 23 mL to 60 mL; puff duration is known to vary from 0.8 seconds to 3.0 seconds. Typically, butt length is set at 23 mm, or filter and overwrap plus 3 mm, whichever is longer; however, the FTC reported that, for 135 of 176 brands tested, butt length was more than 30 mm (Kozlowski, 1981).

Cigarette design has undergone significant change over the past several decades. Cigarette manufacturers can influence yields of tar, nicotine, and other substances through changes in wrapping paper porosity; tobacco packing density; and filter-related factors such as ventilation, particulate matter retention, and pressure drop. Benowitz and colleagues (1983) noted that delivery of tobacco substances also may be influenced by how fast the paper burns because this may determine how long a cigarette is smoked. Study results indicate substantial differences in yields when FTC test method parameters are varied (Table 1).

Table 1

Variation of puffs and tar, nicotine, and CO yields with puff frequency

			Puff Frequency (seconds)															
			50				40				30				20			
Brand	Type	Tar Band	P	T	N	CO	P	T	N	CO	P	T	N	CO	P	T	N	CO
Mini	(Pl)	(M)	11	7	10	3	27	30	39	20	69	68	71	40	91	112	114	69
Reg	(Pl)	(M-H)	10	14	12	11	28	31	29	26	62	60	49	38	99	100	71	65
Reg	(Pl)	(M-H)	12	16	13	12	24	33	32	23	52	69	54	42	73	97	72	61
Reg	(Pl)	(M-H)	12	10	4	12	29	29	23	16	57	57	37	32	110	110	72	50
Mini	(V)	(L)	3	4	12	-1	28	24	35	9	54	52	53	23	71	97	91	61
KSUM	(V)	(L)	22	35	10	18	47	55	24	43	90	154	47	67	160	300	143	188
KSEM	(V)	(L)	9	17	14	15	27	31	32	32	52	94	60	64	101	145	104	92
KSEM	(V)	(L)	8	8	6	15	30	21	19	27	69	84	48	79	118	139	96	108
KS	(V)	(L)	14	9	6	8	38	19	19	24	76	54	38	43	118	99	77	65
KS	(NV)	(L-M)	13	25	18	15	31	44	35	33	57	62	61	39	94	122	92	57
KS	(NV)	(M)	13	13	4	4	26	26	16	16	60	60	32	32	93	93	50	50
IS	(NV)	(L-M)	21	22	21	20	38	46	42	39	70	62	58	46	100	129	110	70
Percentage Increase in Machine Puffing Rate			20				50				100				200			

Note: Column numbers denote percentage increases over values obtained with a 60-second puff frequency.

Key: P = puffs count; T = tar yield; N = nicotine yield; CO = carbon monoxide yield; Mini = minicigarette; Reg = nonfilter; KS = king size; UM = ultramild; EM = extra mild; IS = international size; Pl = plain; V = ventilated; NV = nonventilated; M = middle tar; M-H = middle to high tar; L = low tar; L-M = low to middle tar.

Source: Darrall, 1988.

Gori (1990a) noted that machines, unlike humans, smoke each cigarette in exactly the same way. Smokers usually inhale after taking a puff, and inhalation seems to be largely under the influence of nicotine demand. When smoking machines were invented, little was known about inhalation patterns. Today, inhalation can be measured with various biological markers, such as CO and cotinine (an indicator of nicotine intake).

In a study of eight smokers, Gust and colleagues (1983) observed that the number of puffs and the duration, volume, and time between puffs varied with each smoker. All these factors affect the amount of smoke constituents to which the smoker is exposed. Gust and colleagues also noted that smoking patterns can vary as a smoker smokes a single cigarette.

Observations of smoking behavior reveal that smoking patterns are influenced by a wide range of factors, including degree of nicotine dependence, environmental cues, stress levels, and personality variables.

A survey of 1,200 randomly selected smokers and ex-smokers in the United States and Europe showed that consumers believe that the tar yields stated on cigarette packages accurately represent what is received by the smoker (Gori, 1990b). The majority of respondents indicated a belief that the published yield is equal to the amount consumed per cigarette. However, tar intake is related to nicotine intake, and individual intake of tar varies according to the nicotine levels of cigarettes and the level of nicotine dependence of smokers.

Guyatt and coworkers (1989a, p. 192) studied the changes in puffing behavior during the smoking of a cigarette. The researchers reported

> The most important change in puffing behavior during a single cigarette is the reduction in puff volume since this directly affects smoke uptake. Most subjects showed this effect, but the proportional change was independent of the tar level of the cigarette smoked or the sex of the subject and was consistent between sessions. However, there were significant between-subject differences indicating that each individual had [an] idiosyncratic pattern. Most subjects control puff volume by varying the duration, mostly by truncating the latter part of the puff.

IMPACT OF CHANGING PARAMETERS OF THE FTC TEST METHOD ON ABSOLUTE YIELDS OF A CIGARETTE BRAND AND RELATIVE YIELDS OF DIFFERENT BRANDS

Schlotzhauer and Chortyk (1983) examined the influence of varying smoking machine parameters on yields of tar, nicotine, and other selected smoke constituents from an ultralow-tar cigarette. The smoking machine parameters were changed to reflect the deeper inhalation, more frequent puffs, and vent blocking evident among smokers of lower yield cigarettes. Specifically, volume was varied from the standard 35 mL to 45 mL and 55 mL; frequency of puffs was doubled; and puff duration was increased from 2.0 to 3.0 seconds. Only one parameter was varied at a time; yields were measured with vent holes both unblocked and completely blocked.

As shown in Tables 2 through 4, changing one parameter at a time produces substantial increases in yields, and when cigarettes were machine smoked at the average of the parameters used in Tables 2 through 4, as shown in Table 5, total particulate matter (TPM) yields were approximately doubled, and increases of 96 to 271 percent in the individual components were observed.

TAR AND NICOTINE YIELD BY THE FTC TEST METHOD AND AMOUNTS DELIVERED TO SMOKER

The issue of compensation has become a central concern in assessing intake of tar, nicotine, CO, and other constituents constituents of tobacco smoke, particularly with regard to cigarettes described as low tar and low nicotine. Various researchers have reported no correlation between cigarette brand yield and actual exposure and substantially higher relative exposures from low-delivery cigarettes than indicated by quantitative differences in stated yields (Rickert and Robinson, 1981).

The current primary measurement of the carcinogenic potential of a cigarette is its tar yield. Kozlowski and colleagues (1980a) noted that tar yield depends in part on the number of puffs per cigarette and that a major factor in tar reduction has been reduced cigarette length, which results in fewer puffs per cigarette during standard FTC testing. Increasing the number of puffs can lead to substantial increases in tar yields.

Table 2
Effect of increased puff volumes on cigarette mainstream smoke under FTC conditions of puff frequency (60 seconds) and puff duration (2 seconds)

Results	35-mL Volume	45-mL Volume	Change (±%) From FTC Values	55-mL Volume	Change (±%) From FTC Values
Cigarettes Smoked	20	20	—	20	—
Total Puffs	152	150	-1	150	-1
Puffs/Cigarette (average)	7.6	7.5	-1	7.5	-1
Total Volume Inhaled (mL)	5,320	6,750	+27	8,250	+55
TPM (mg)	86	95	+10	135	+57
TPM/Cigarette (mg)	4.3	4.7	+10	6.7	+56
TPM/Puff (μg)	566	633	+11	900	+59
Phenol/Cigarette (μg)	12	17	+41	23	+92
Glycerol/Cigarette (μg)	327	624	+91	1,000	+206
Catechol/Cigarette (μg)	28	28	0	43	+54
Hydroquinone/Cigarette (μg)	23	27	+17	41	+61
Nicotine/Cigarette (μg)	378	502	+33	713	+88
Neophytadiene/Cigarette (μg)	15	32	+113	39	+160
Palmitic Acid/Cigarette (μg)	35	63	+80	64	+83
C_{18} Acids/Cigarette (μg)	33	61	+85	55	+67

Key: TPM = total particulate matter.

Source: Schlotzhauer and Chortyk, 1983.

Table 3

Effect of increased puff frequency and increased puff duration on cigarette mainstream smoke composition

Results	60-Second Frequency	30-Second Frequency	Change (+%)	3-Second Puff Duration	Change (±%)
Cigarettes Smoked	20	20	0	20	0
Total Puffs	152	281	+85	150	-5
Puffs/Cigarette (average)	7.6	14.0	+85	7.5	-5
Total Volume Inhaled (mL)	5,320	9,835	+85	7,800	+47
TPM (mg)	86	205	+138	166	+93
TPM/Cigarette (mg)	4.3	10.2	+138	8.3	+93
TPM/Puff (μg)	566	728	+29	1,106	+93
Phenol/Cigarette (μg)	12	20	+67	13	+8
Glycerol/Cigarette (μg)	327	1,542	+371	795	+143
Catechol/Cigarette (μg)	28	66	+136	70	+150
Hydroquinone/Cigarette (μg)	23	50	+117	40	+74
Nicotine/Cigarette (μg)	378	961	+154	618	+63
Neophytadiene/Cigarette (μg)	15	29	+93	53	+253
Palmitic Acid/Cigarette (μg)	35	41	+17	39	+11
C_{18} Acids/Cigarette (μg)	33	34	+3	30	-10

Key: TPM = total particulate matter.

Source: Schlotzhauer and Chortyk, 1983.

Table 4

Effect of obstructing tipping paper ventilations on cigarette mainstream smoke composition

Results	FTC Conditions[a]	FTC With Obstructed Perforations	Change (±%)
Cigarettes Smoked	20	20	0
Total Puffs	152	131	-14
Puffs/Cigarette (average)	7.6	6.5	-14
Total Volume Inhaled (mL)	5,320	4,584	-14
TPM (mg)	86	256	+198
TPM/Cigarette (mg)	4.3	12.8	+198
TPM/Puff (μg)	566	1,969	+248
Phenol/Cigarette (μg)	12	19	+58
Glycerol/Cigarette (μg)	327	1,001	+206
Catechol/Cigarette (μg)	28	58	+107
Hydroquinone/Cigarette (μg)	23	53	+130
Nicotine/Cigarette (μg)	378	839	+122
Neophytadiene/Cigarette (μg)	15	50	+233
Palmitic Acid/Cigarette (μg)	35	85	+143
C_{18} Acids/Cigarette (μg)	33	76	+130

[a] *35-mL puff volume, 60-second puff frequency, 2-second puff duration.*

Key: TPM = total particulate matter.

Source: Schlotzhauer and Chortyk, 1983.

Table 5
Effect of combined compensatory parameters on yields of mainstream smoke components

Results	FTC Conditions	New Conditions[a]	Change (±%)
Cigarettes Smoked	20	20	0
Total Puffs	152	236	+55
Puffs/Cigarette (average)	7.6	11.8	+55
Total Volume Inhaled (mL)	5,320	11,564	+117
TPM (mg)	86	169	+97
TPM/Cigarette (mg)	4.3	8.4	+95
TPM/Puff (μg)	566	716	+27
Phenol/Cigarette (μg)	12	30	+150
Glycerol/Cigarette (μg)	327	1,212	+271
Catechol/Cigarette (μg)	28	55	+96
Hydroquinone/Cigarette (μg)	23	53	+130
Nicotine/Cigarette (μg)	378	850	+125
Neophytadiene/Cigarette (μg)	15	52	+247
Palmitic Acid/Cigarette (μg)	35	86	+142
C_{18} Acids/Cigarette (μg)	33	71	+115

[a] *Averaged, reported compensatory smoking parameters (49-mL puff, 38-second frequency, 2.5-second puff duration) set on smoking machine.*

Key: TPM = total particulate matter.

Source: Schlotzhauer and Chortyk, 1983.

In a subsequent study of four popular king size cigarettes (see Table 6), Kozlowski (1981, p. 159) found that

> the same cigarette can easily rise from a low-tar to a high-tar category [through an increase in] the number of puffs taken from it, within the range of puffs per minute consistent with human smoking behavior. Based on the standard assay, brand B has 17 percent more tar than brand C; however, based on a 10-puff estimate, their tar deliveries are identical. Those smokers who take 14 puffs per cigarette are getting 58 percent more tar than would be expected from the standard yields.

Rawbone (1984), in a study of 400 middle-tar and low-tar smokers in the United Kingdom, found that tar delivery varied significantly between middle- and low-tar cigarettes but noticeably less than expected. That is, where a 46-percent lower tar delivery was expected with the low-tar cigarettes, a 32-percent reduction was observed. Furthermore, with regard to tar delivery, 98 percent of the middle-tar cigarette smokers fell within the established bounds of 16.50 to 22.49 mg delivery, whereas only 70 percent

Table 6
Tar yields (mg) as a function of number of puffs taken by smoking machines

	Number of Puffs			
Brand[a]	6	8.7[b]	10	14
A	13	18	21	30
B	13	21	22	31
C[c]	13	18	22	31
D[c]	12	17	19	27

[a] Four of the most popular brands of king-size filter cigarettes.
[b] Mean number of puffs for the standard assay for these cigarettes: A, 8.6 puffs; B, 9.3; C, 8.1; D, 8.9.
[c] These brands are mentholated.

Source: Kozlowski, 1981.

of the low-tar cigarette smokers were experiencing a delivery at or below the upper limit of 10.49 mg set for low-tar cigarettes (with 30 percent experiencing a higher-than-expected tar delivery).

Rickert and colleagues (1986) machine-analyzed the nicotine, tar, and CO yields of 10 cigarette brands under 27 different conditions (the standard condition and 26 variations). Tar, nicotine, and CO yields increased with volume of smoke produced per cigarette, but yields per liter of smoke were relatively constant across the 27 conditions.

Woodward and Tunstall-Pedoe (1992) investigated the smoking patterns of 2,754 smokers (1,133 males and 1,621 females) to determine intake of smoke components by smokers of low-tar cigarettes. This study, perhaps the largest naturalistic investigation of smoking behavior ever undertaken, included smokers of low-, middle-, and high-tar cigarettes. The researchers concluded that tar yield does not accurately reflect the amount of smoke components consumed by the smoker. Specifically, tar intake increased with tar yield but much less than anticipated; expired-air CO and cotinine seemed to peak among middle-tar smokers. For women, thiocyanate increased from low- to middle-tar smokers, and for men, from middle- to high-tar smokers. The researchers found that smokers of middle-tar cigarettes may consume more of some smoke components than smokers of high-tar cigarettes. Middle-tar smokers were noted to have higher levels of expired-air CO and cotinine.

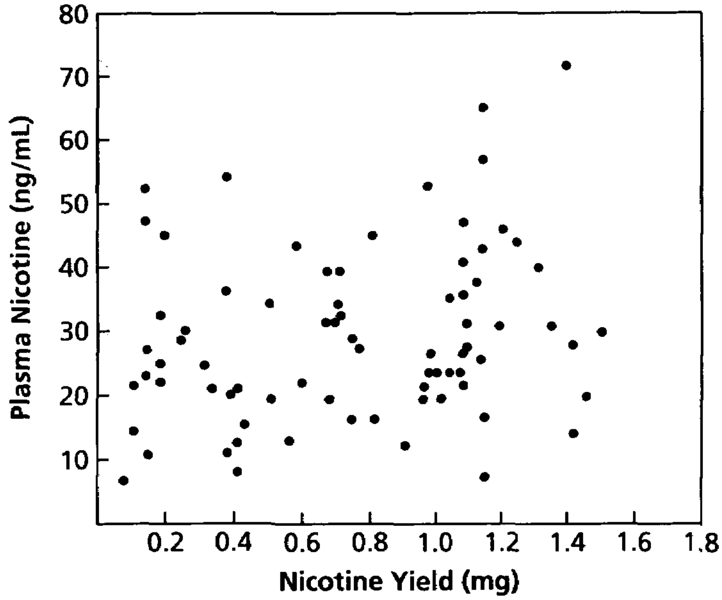
Armitage and colleagues (1988) investigated the influence of changes in tar yield when nicotine yield was maintained. Twenty-one smokers of middle-tar cigarettes were studied, with randomization to three categories: low tar and low nicotine, low tar and medium nicotine, and medium yields of tar and nicotine. With regard to nicotine uptake, there were no significant differences noted between middle-tar and nicotine-maintained cigarettes, but there were significant differences between low-tar and nicotine-maintained cigarettes. The mean total puff volume of the nicotine-maintained cigarette was significantly greater than that recorded for middle-tar cigarettes. There was no difference in mean total puff volume between low-tar cigarettes and nicotine-maintained cigarettes.

RELATIVE YIELDS OF DIFFERENT BRANDS BY THE FTC TEST METHOD AND AMOUNT OF NICOTINE ABSORBED BY SMOKERS

Ebert and colleagues (1983) undertook a study of 76 smokers to determine correlations between levels of plasma nicotine and alveolar CO and the nicotine and CO yields of cigarettes. The correlations were found to be poor (Figures 1 and 2). For the 24 smokers of low-nicotine, low-tar cigarettes, nicotine levels were statistically lower for smokers of low-nicotine cigarettes, but the levels were only slightly lower and there was great overlap in individual plasma nicotine values; there was no difference in the mean alveolar CO levels between the low-nicotine smokers and smokers of regular cigarettes.

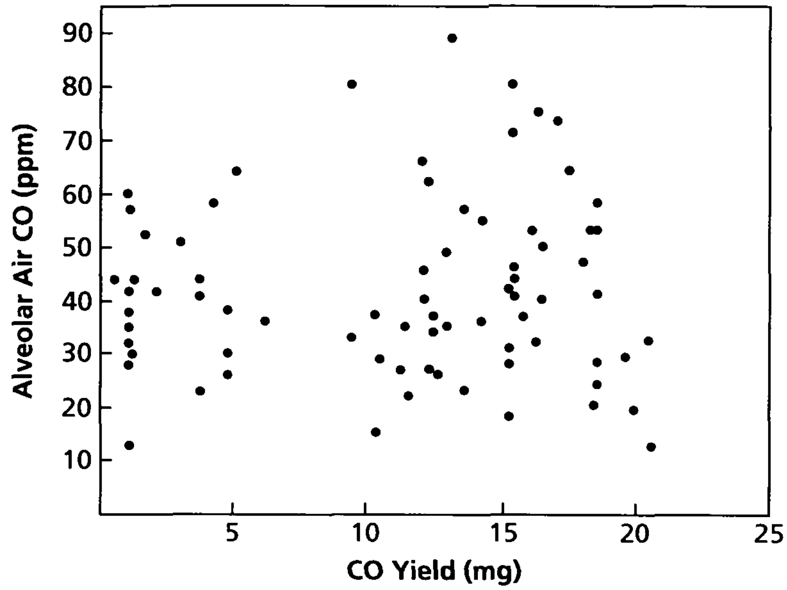
Research by Benowitz and colleagues (1983) on 272 subjects about to enter a smoking treatment program revealed that the correlation between stated nicotine yield and actual blood cotinine levels was not significant. Furthermore, it was determined that nicotine concentration in the unburned tobacco and amount of nicotine in an unburned cigarette are not correlated positively with FTC-determined yields and that tobacco in low-yield cigarettes did not contain less nicotine than tobacco in higher yield cigarettes.

Figure 1
Relationship between plasma nicotine concentration in smokers and nicotine yield of cigarettes smoked



Source: Ebert et al., 1983.

Figure 2
Relationship between carbon monoxide (CO) concentration of alveolar air in smokers and CO yield of cigarettes smoked



Source: Ebert et al., 1983.

Ventilation and burning characteristics are the primary determinants of machine-measured yields, and these characteristics can be controlled by smokers. Benowitz and colleagues acknowledged that blood cotinine is not a "perfect marker," but a full range of cigarettes was included in the study and there is no reason to suspect that brand is related to nicotine and cotinine metabolism.

Russell and colleagues (1986) examined blood nicotine, cotinine, and carboxyhemoglobin (COHb) levels among 392 smokers whose regular brands varied from low tar to middle tar. Tar levels were estimated from blood nicotine levels and cigarette tar yields. The authors reported

> Smokers of LT [low-tar] cigarettes had a lower intake of tar, nicotine, and CO than the smokers of higher yielding brands. On average, their estimated intake of tar was about 25 percent lower, their intake of nicotine was about 15 percent lower (17 percent and 12 percent, as measured by blood nicotine and cotinine, respectively), and their intake of CO was about 10 percent lower. These differences are substantially less than the reductions in the standard machine-smoked yields of their cigarettes (47 percent, 39 percent, and 34 percent for tar, nicotine, and CO yields, respectively), and this indicates the extent to which the LT smokers were smoking and inhaling more intensively, presumably to compensate for the lower yields. However, it is clear that

> despite such compensatory changes in smoking behavior, their intake of the three major smoke components was still lower to a statistically and clinically significant degree (Russell et al., 1986, p. 83).

Maron and Fortmann (1987) examined the relationship of FTC machine-estimated nicotine yield by cigarette brand with the level of cigarette consumption and two biochemical measures of smoke exposure (expired-air CO and plasma thiocyanate) in a population of 713 smokers. These investigators found that the lower the nicotine yield, the greater the number of cigarettes smoked per day. Smokers of ultralow-nicotine cigarettes experienced smoke exposures that were not significantly different from those of smokers of higher yield brands. Only after adjustment for number of cigarettes smoked daily did nicotine yield become significantly related to expired-air CO and plasma thiocyanate. The number of cigarettes smoked per day accounted for 28 and 22 percent of the variance in observed expired-air CO and plasma thiocyanate levels, respectively, whereas nicotine yield accounted for only 1 and 2 percent of the variance, respectively. The authors concluded that machine estimates suggesting low nicotine yield underrepresent actual human consumption of harmful cigarette constituents.

In a study of 289 smokers of cigarettes in the 1-mg FTC tar class, Gori and Lynch (1983) observed that nicotine intake (measured by plasma cotinine) varied widely, from undetectable to about 800 ng/mL. The findings indicated that smokers of low-yield brands tend to take in more nicotine than posted FTC values. This observation is illustrated in Figure 3. Brand A was .9 tar and .18 nicotine, whereas brand B was .5 tar and .10 nicotine.

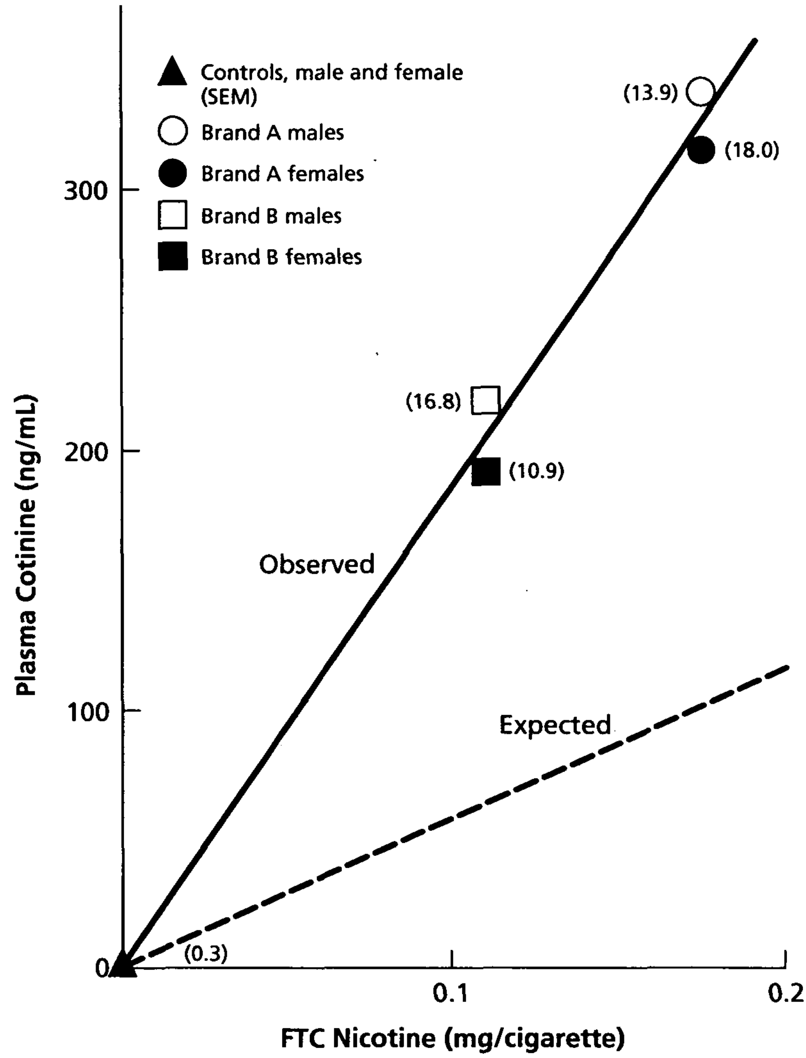
Coultas and colleagues (1993), working with a population of 298 mostly Hispanic smokers, studied the relationship between yields of cigarettes currently smoked and levels of salivary cotinine and expired-air CO. Spearman's correlation coefficients (Snedecor and Cochran, 1980) between the current number of cigarettes smoked and cotinine or CO were higher than correlations between the FTC nicotine data and these same markers. In multiple linear regression models, the current number of cigarettes smoked was the most important predictor of cotinine and CO levels ($p < 0.0001$), and the addition of FTC tar, nicotine, and CO to the models explained little about the variability in cotinine and CO levels.

In a large-scale study of 2,455 cigarette smokers who smoked their usual brands, Wald and colleagues (1984) observed that nicotine and CO intake was relatively constant across brands, regardless of stated yield, although tar intake appeared related to tar yield.

YIELD BY THE FTC TEST METHOD AND ABSORPTION OF NICOTINE IN SWITCHERS

As pointed out by many researchers, cigarette smoking has the hallmarks of drug-dependent behavior, with strong evidence that nicotine is the dependence-producing component (Benowitz et al., 1989). Nicotine is rapidly absorbed into the blood and quickly delivered to the brain, where

Figure 3
Observed and expected baseline plasma cotinine values as a function of FTC nicotine delivery of brands A and B



Key: SEM = standard error of the mean.
Source: Gori and Lynch, 1983.

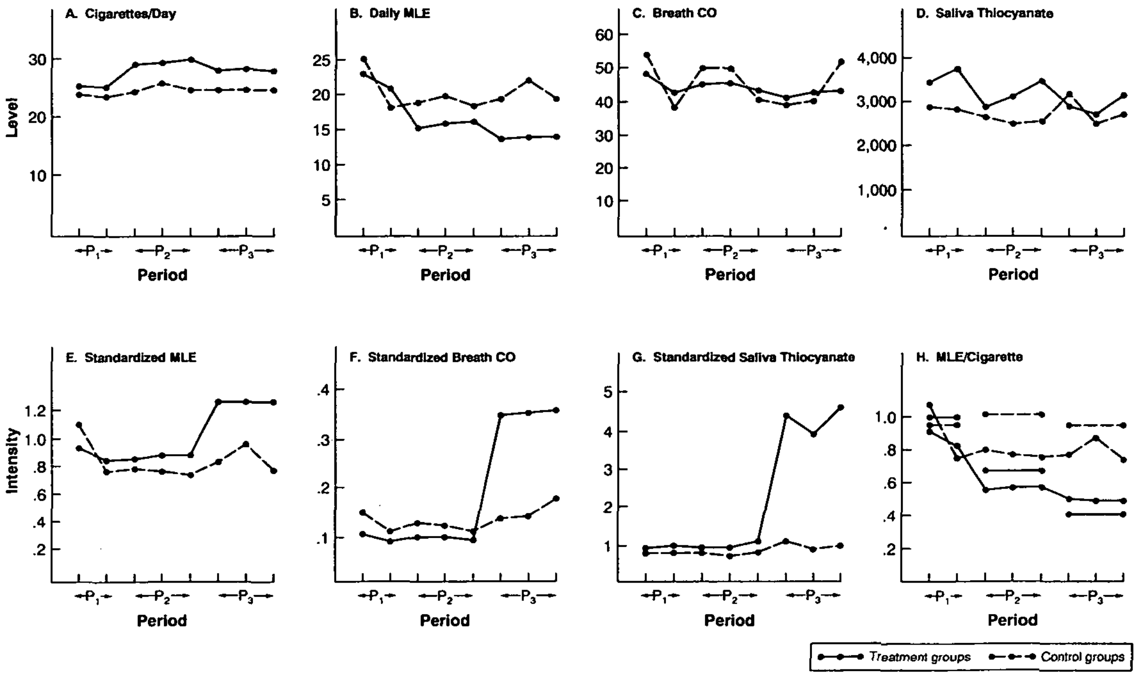
it produces a range of mental effects on the smoker. This quick absorption and effect permit the smoker to control the nicotine level carefully; however, nicotine is rapidly eliminated from the body, which means the smoker has to deliver regular doses to the blood.

Robinson and colleagues (1982 and 1983) studied the smoking patterns of 22 cigarette smokers divided into treatment and control groups, with the treatment group switching twice to cigarettes of successively lower nicotine yields. Compensation behavior was measured noninvasively (average number of daily cigarettes, daily mouth-level nicotine exposure, butt length, expired-air CO, and saliva thiocyanate) and invasively (COHb, serum cotinine, and plasma thiocyanate). As shown in Figure 4, there were no major differences between smokers in treatment and control groups. The near-complete compensation was attributed to upward changes in smoking intensity, depth of inhalation, and cigarette consumption. In addition, there was an observed tendency of smokers of lower delivery cigarettes to smoke cigarettes down closer to the overwrap and to block ventilation holes.

In a different approach, Gritz and colleagues (1983) looked at the puffing behavior of eight smokers presented with cigarettes at two and four times

Figure 4

Average daily exposure and standardized exposure measures by period for treatment and control groups



Note: Average nominal nicotine deliveries are shown as horizontal lines in Panel H. Abbreviated variable names have been used. The increase of "standardized" exposure measure for the treatment group (Panels F and G) during period three (P_3) does not represent an increase in exposure. The exposure remains fairly constant during the entire study, as Panels C and D indicate. Panels F and G illustrate the extent of compensation necessary to maintain this constant exposure. See text for details.

Key: MLE = mouth-level exposure; CO = carbon monoxide.

Source: Robinson et al., 1982.

their normal smoking rates. All eight smokers compensated to some degree. Despite being presented with twice the usual number of cigarettes, the smokers titrated their nicotine intake down, largely by changing their number of puffs, puff volume, and puff duration per cigarette. Gritz and coworkers disputed the view that some smokers may be compensators and others may be noncompensators, arguing that these two groups of smokers represent the opposite ends of a continuum.

Henningfield and Griffiths (1980) studied the effect of tobacco product concentration on puffing rate and total number of puffs. Tobacco concentration levels were set at 100, 50, 25, and 10 percent by means of ventilated holders (identified in Figures 5 and 6 as holders 0, 1, 2, and 4). As shown, puffs at holder 4 were about double those of holder 0. In addition, there were substantial increases in puff rate.

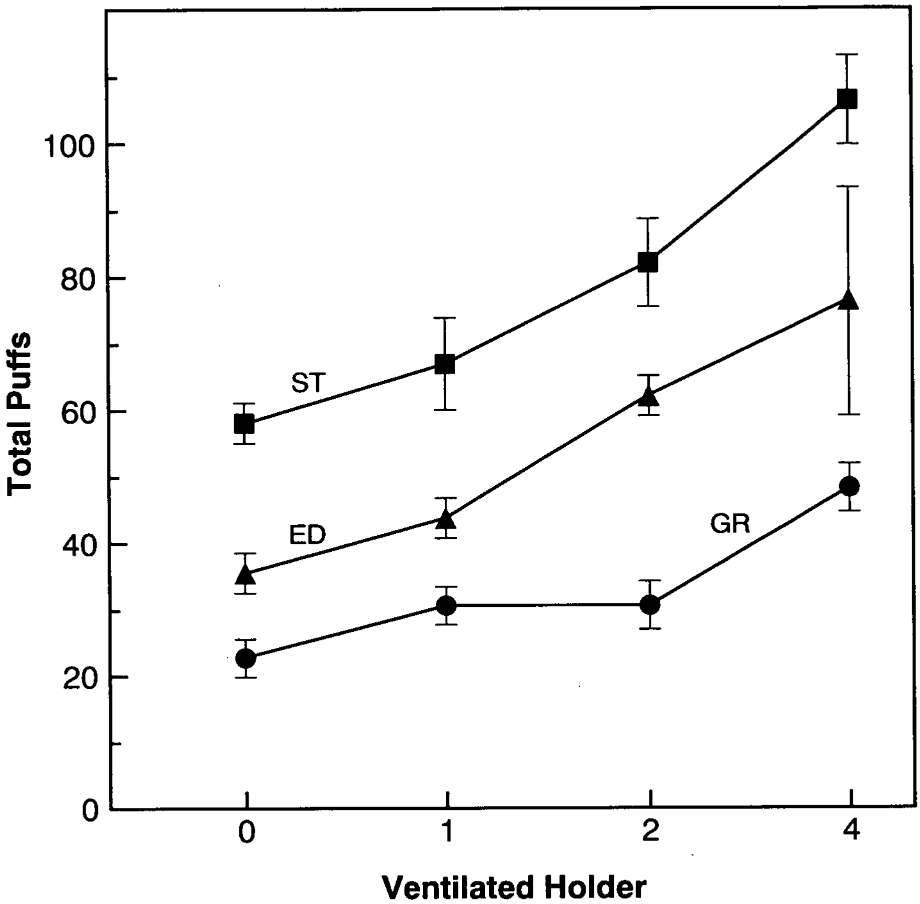
Compensation via alterations in puffing patterns does not explain all observed changes, however. In their investigation of puffing and inhalation patterns and yields, Nil and colleagues (1986) found that changes in puff volume account for only about one-fifth of the difference in smoke yields; no significant changes were found in inhalation patterns. On the other hand, with lower yield cigarettes, there was nearly complete compensation based on alveolar CO uptake, and the degree of increased heart rate was viewed as a nearly complete compensation for nicotine intake.

McBride and colleagues (1984) measured changes in smoking behavior and ventilation when subjects smoked cigarettes of varying nicotine yields. Nine smokers were studied, and the test order was randomized. Puff volume was noted to increase significantly during the smoking of low-nicotine cigarettes. In a study of 170 male smokers and 170 age-matched male nonsmokers, Bridges and colleagues (1986) observed that total puff volume was significantly greater for smokers of cigarettes lower in nicotine yields. As shown in Figures 7 and 8, total puff volume was significantly correlated with nicotine yield and plasma cotinine.

Researchers have observed that smokers can substantially alter tar, nicotine, and CO delivery of cigarettes by blocking the ventilation holes in the filters. In a two-part study of smokers of low-yield cigarettes, Kozlowski et al. (1982a) observed hole-blocking behavior and measured tar, nicotine, and CO levels. The investigators reported that 44 percent of 39 smokers of low-yield cigarettes blocked the ventilation holes to various degrees with their fingers or lips; 5 of 33 females left hole-blocking lipstick on the filters.

In the second part of their study, Kozlowski and colleagues (1982a) evaluated the effect of hole blocking on the tar, nicotine, and CO yields of American, British, and Canadian cigarettes of lowest or near-lowest yields. After videotaping 48 smokers, the researchers defined actual smoking behaviors and reset smoking machine parameters to reflect these real-life patterns for puff interval (44 seconds) and puff duration (2.4 seconds). Machine puff volume was set at 47 mL (2 to 13 mL below the smokers' estimated average) because this is the maximum obtainable from most

Figure 5
Mean total puffs per session (N = 4) and standard error values for each subject as a function of cigarette holder number



Note: The approximate concentrations of delivered tobacco product are indicated by the holder number in which 0 = 100 percent, 1 = 75 percent, 2 = 50 percent, and 4 = 10 percent. The abbreviations ST, ED, and GR represent three paid female volunteers who participated in the study.

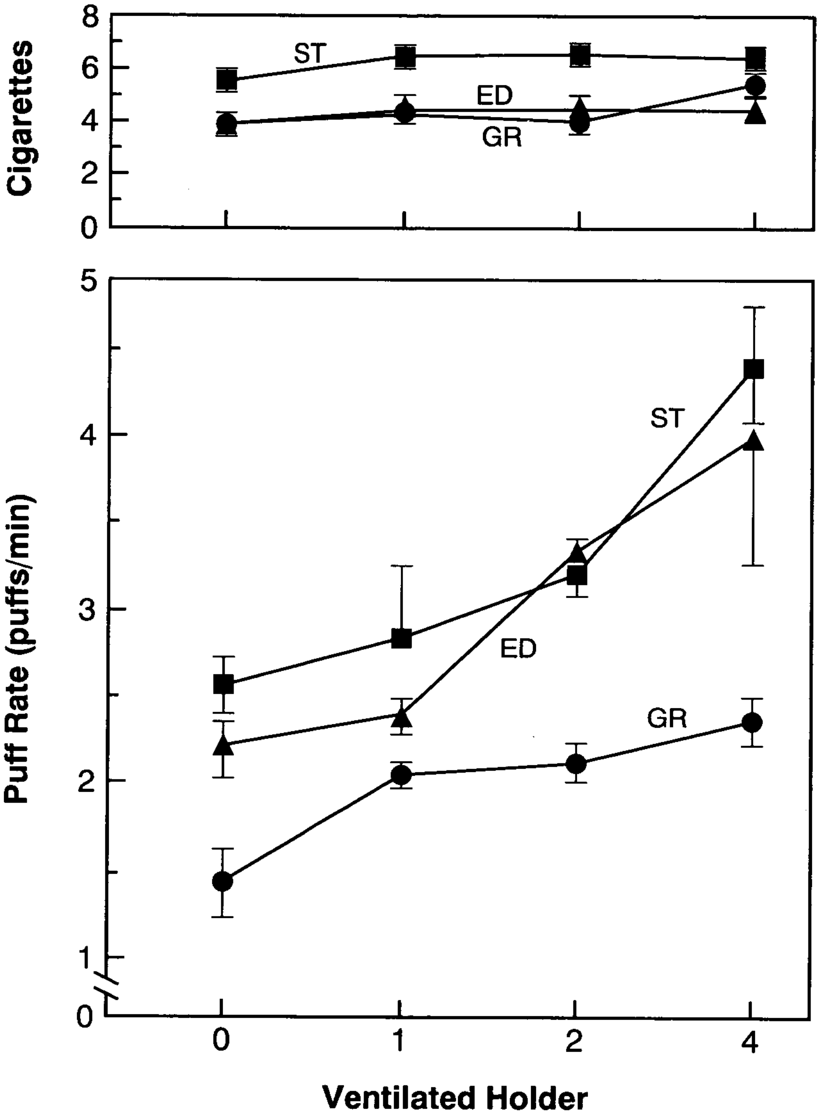
Source: Henningfield and Griffiths, 1980.

machines. Ventilation holes were blocked with tape. The researchers compared standard yields of cigarettes to yields resulting from the study-determined parameters and blocked ventilation holes; they observed that "tar increases from 15- to 39-fold, nicotine from 8- to 19-fold and CO from 10- to 43-fold" (Kozlowski et al., 1982a, p. 159). Five cigarette brands similar in tar yield were found to differ substantially when parameters were changed and holes blocked.

In a later study of 14 subjects, Kozlowski (1989) detected hole blocking by half the sample. Subjects blocking the ventilation holes of ultralow-yield

Figure 6

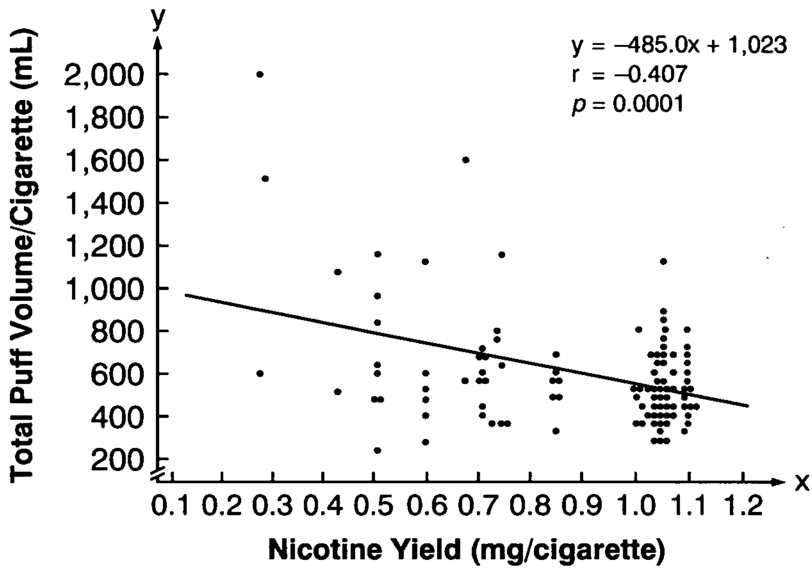
Mean number (N = 4) of cigarettes smoked by each subject during 3-hour sessions as a function of holder number (upper frame) and mean rate of puffing (puffs/minute) per cigarette (lower frame)



Note: Standard error values for each subject, in both frames, are indicated by the brackets. The approximate concentrations of delivered tobacco product are indicated by the holder number in which 0 = 100 percent, 1 = 75 percent, 2 = 50 percent, and 4 = 10 percent. The abbreviations ST, ED, and GR represent three paid female volunteers who participated in the study.

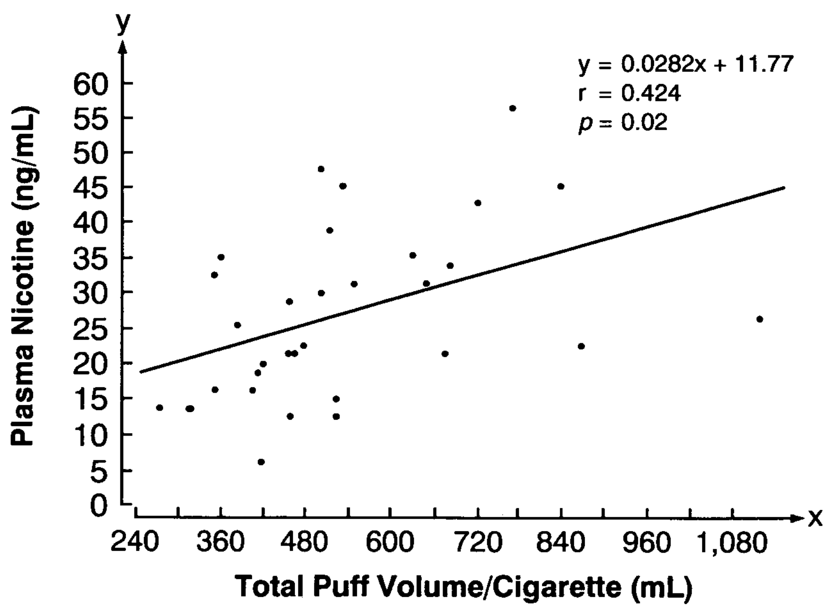
Source: Henningfield and Griffiths, 1980.

Figure 7
Relationship of total puff volume per cigarette with the nicotine yield of the cigarette smoked



Source: Bridges et al., 1986.

Figure 8
Relationship between plasma nicotine concentration and total volume puffed per cigarette in a population smoking a single brand of cigarette (nicotine yield = 1.05 mg/cigarette)



Source: Bridges et al., 1986.

cigarettes were found to have higher CO and salivary cotinine levels. Rickert and colleagues (1983) found that blocking half the ventilation holes increased the delivery of TPM by 60 percent, and full occlusion increased TPM delivery by 150 percent.

The effect of blocking on perforation ventilation (ventilation holes in the filter) and channel ventilation (longitudinal air channels around the filter) was studied by Höfer and colleagues (1991). The researchers compared results of lip smoking and holder smoking of cigarettes among 72 smokers, divided equally by ventilation type of cigarette smoked. Höfer and colleagues (1991, p. 910) found that

> under normal lip contact conditions, the CO and nicotine deliveries of the channel-ventilated cigarettes were higher than those of the perforation-ventilated cigarettes and higher than with holder smoking. With holder smoking, both types of cigarettes delivered comparable amounts of CO and nicotine (*t*-tests, n.s.).

It appeared that the nicotine boost from channel-ventilated cigarettes was twice that of perforation-ventilated cigarettes; differences in CO exposure were less well defined. The researchers judged that there was evidence of blocking in 86 percent of the channel filter cigarette smokers and in 33 percent of the perforated filter cigarette smokers.

In a novel approach to the study of hole blocking among smokers of ultralow-tar cigarettes, Kozlowski and colleagues (1988) collected 135 discarded filters from ashtrays in shopping malls. It was found that 58 percent of the filters showed some evidence of hole blocking (as measured by tar stain patterns); 19 percent showed evidence of extreme hole blocking; and 42 percent showed no signs of hole blocking. Kozlowski and colleagues (1994) extended this research to "light" cigarettes (about 9 to 12 mg tar, about 15 to 30 percent vented): Twenty-seven percent of collected filters indicated extreme blockage; 26 percent showed some blocking; and 47 percent showed no vent blocking. Although defeat of the air vents will have a relatively small effect on light rather than ultralight cigarettes, the greater sales of light cigarettes contribute to its significance for public health. In an earlier report, Kozlowski and colleagues (1980b) examined the effect of hole blocking on nicotine, tar, CO, and puffs (Table 7), noting that ventilated filters have been developed primarily as a way to make less toxic cigarettes but that smoking behavior can sabotage the benefits of these filters.

Kozlowski and colleagues (1989) demonstrated that some smokers of vented filter cigarettes are lighter smokers who appear to be seeking lower smoke doses and do not block vents, whereas others are generally heavier smokers who block vents and derive high daily doses of nicotine. Two smokers, who were vent blockers, of a 1-mg tar, 0.1-mg nicotine cigarette achieved salivary cotinine levels (303 and 385 ng/mL) consistent with smoking a high-yield cigarette.

Table 7
Effects of blocking the ventilation holes on the yields of a popular, low-yield cigarette[a]

Characteristics	Unblocked Holes	Half-Blocked Holes	Fully Blocked Holes
Constituents			
Nicotine (mg)	0.45	0.73 ± .06	0.98 ± .06[a]
Tar (mg)	4.40	7.03 ± .04	12.60 ± .20[a]
Carbon Monoxide (mg)	4.50	7.80 ± .24	17.70 ± .40[a]
Puffs	11.10	10.50 ± .20	9.20 ± .40[a]

[a] *Half-blocked vs. fully blocked comparison (t-test, 2-tailed)* $p < .01$. *Values are means ± standard deviations. Government figures for the June-July 1979 assay were used as the unblocked control; variances were not reported, but those found in similar analyses imply that all within-row comparisons would be statistically significant. All analyses in the table were performed by the same laboratory employing the same techniques.*

Source: Kozlowski et al., 1980b.

Bridges and colleagues (1990) studied 170 male smokers to determine the influence on yield of smoking topography (i.e., total smoking time per cigarette, number of puffs, interpuff interval, puff duration, volume per puff, total duration per cigarette, total volume per cigarette, flow rate). The smokers were divided into six groups according to stated nicotine yields of their cigarettes. The first four groups were most similar in age, smoking history, and alcohol and coffee consumption. There were significant negative correlations between nicotine yield and mean puff volume, total duration and volume, and flow rate. That is, as nicotine yield decreased, mean puff volume, total duration and volume, and flow rate increased significantly. These statistical relationships are shown in Figure 9. Multiple regression analysis showed that nicotine yield, alone or in combination with other factors, is a significant predictor of number of puffs or total puff volume per cigarette.

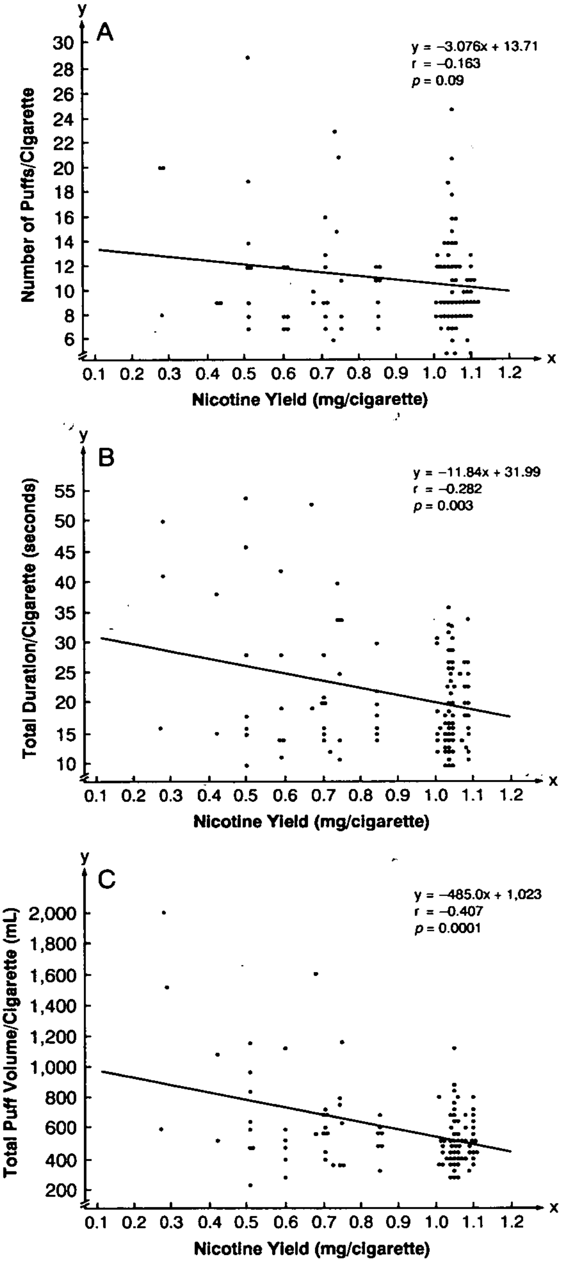
Figure 9 is of special interest because it represents smoking topography changes in a subpopulation for which nicotine yield was held constant to control for the possible confounding effects of nicotine on smoking behavior. Cumulative puff volume for a cigarette is significantly correlated with plasma nicotine, an indication that increased inhalation results in increased absorption. For the same group, the interpuff interval was negatively correlated with plasma nicotine levels (i.e., when time between puffs went down, plasma nicotine level went up).

According to Bridges and colleagues (1990, p. 31)

> Smokers smoking the lowest yield cigarettes (Group 1) had significantly higher total puff volume per cigarette than did the other groups, and significantly higher mean puff volume and flow rate . . . than Groups 3 and 4. Smokers of lower yield

Figure 9

Linear relationships between nicotine yield and puffing topography measures: (A) number of puffs per cigarette, (B) total puff duration per cigarette, (C) total puff volume per cigarette



Note: The graphical representation for each of these relationships includes the equation for the inserted least-squares best fit line, the correlation coefficient (r), and the level of significance for the correlation. The data are for groups 1-4, n = 108.

Source: Bridges et al., 1990.

cigarettes also tended to have higher numbers of puffs per cigarette, decreased interpuff interval, increased duration per puff, and increased duration per cigarette, but these differences did not reach statistical significance. These results are consistent with changes in puffing topography to compensate for lower yield cigarettes.

In addition, there were significant negative correlations between nicotine yield and mean puff volume, total duration and volume, and flow rate. That is, as nicotine yield decreased, mean puff volume, total duration and volume, and flow rate increased significantly. In addition, multiple regression analysis showed that nicotine yield, alone or in combination with other factors, is a significant predictor of number of puffs or total puff volume per cigarette.

Creighton and Lewis (1978) examined changes in smoking patterns when cigarettes were varied according to nicotine delivery. Specifically, 16 smokers were monitored for 3 months. The first month, they all smoked medium-delivery cigarettes of about 1.4 mg nicotine; then the group was split for 1 month, with half smoking lower delivery cigarettes (about 1.0 mg nicotine) and half smoking higher delivery cigarettes (about 1.8 mg nicotine). During the third month, the panel of 16 smokers returned to the 1.4 mg nicotine cigarettes. Significant changes were found in smoking patterns among the 16 smokers: either the increased smoking intensity when smoking lower delivery cigarettes or decreased intensity when smoking higher delivery cigarettes. However, the researchers reported that the smokers did not equalize nicotine and TPM delivery when they switched to lower delivery cigarettes, as was the case when they switched to higher delivery cigarettes. The number of cigarettes smoked per day remained about the same throughout the study.

Russell and colleagues (1982) looked at changes in nicotine, cotinine, COHb, thiocyanate, and tar when 12 smokers switched to low-tar, low-nicotine cigarettes for 12 weeks. Plasma nicotine and cotinine were both reduced by about 30 percent and tar by 15 percent; plasma thiocyanate and COHb did not change significantly. Although mouth level of nicotine intake from low-tar, low-nicotine cigarettes was similar to the standard machine yield, the blood levels of 30 percent were substantially less than the anticipated level of 46 percent based on machine yields. There was no compensatory increase in smoke intake at the mouth level, but blood measures showed the increase in inhalation between 32.1 and 40.8 percent.

Similarly, Ashton and coworkers (1979) found that, when switched from medium- to high- or low-nicotine brands, smokers compensated for about two-thirds of the difference in standard yields. Specifically, when nicotine yield was reduced by 50 percent, nicotine intake was about 15 percent lower. Furthermore, based on machine yields, it was anticipated that the nicotine yield of low-nicotine cigarettes would be 32.6 percent that of high-nicotine cigarettes; however, in the laboratory the observed yield was 59 percent that of high-nicotine cigarettes.

Benowitz and colleagues (1986) looked at differences in tar, nicotine, and CO exposure when smokers switched from their regular brand to high-, low-, and ultralow-yield cigarettes. The researchers detected no differences in exposure among the high- and low-yield smokers. However, for smokers of ultralow-yield cigarettes, there were substantial reductions in exposure to tar (49 percent), nicotine (56 percent), and CO (36 percent). Despite these reductions, the investigators reported that the relative exposure to tar and nicotine from ultralow-yield compared with higher yield cigarettes was much greater than predicted by FTC machine-determined yields.

Kolonen and colleagues (1991) examined puffing patterns of 36 smoking students, with different smoking histories, in a natural environment. The subjects included 18 smokers of low-yield cigarettes, 10 smokers of medium-yield cigarettes, and 8 smokers who had switched from medium- to low-yield cigarettes. Subjects smoked their regular brand for the first week, a low-yield brand for the second week, and a medium-yield brand for the third week. All three groups had the highest daily puff volumes when smoking low-yield cigarettes, and the correlations between urine cotinine concentration and daily puffing in the three groups were poor. However, the urinary cotinine concentration was significantly lower for low-yield smokers compared with the switchers. The investigators concluded that cotinine excretion results in the switchers' group were in line with earlier reports showing that long-term switchers have no significant decreases in plasma and urine cotinine.

In a longer study of switching effects, Guyatt and coworkers (1989b) monitored 28 smokers who switched to cigarettes with lower tar and nicotine yields. The researchers concluded, after monitoring subjects for about 1 year, that most effects of the switch to lower yield cigarettes did not persist beyond 36 weeks. The drop in cotinine levels was only 40 percent of what was expected from stated nicotine yields; mean puff volume increased by 16 percent; and smokers seemed to achieve about 60 percent compensation when smoking lower tar cigarettes.

YIELDS BY THE FTC TEST METHOD AND OTHER CONSTITUENTS USING FTC PUFF PROFILE

Carbon monoxide yields follow somewhat surprising dynamics. For example, as Rickert and colleagues (1980) reported, efficient filters may substantially reduce tar yields of cigarettes but lead to increased delivery of CO.

In a study of reduced-draw-resistance cigarettes, Dunn (1978) found that smokers can substantially vary their inhalation patterns, leading to marked changes in the amount of smoke that reaches the lungs as measured by alveolar CO levels. Although increased levels of alveolar CO were expected with reduced draw resistance, CO levels decreased, possibly because of increased delivery of nicotine. Dunn proposed that the level of CO in exhaled air may be a good measure of depth of inhalation.

There appears to be substantial natural variation in the amount of CO inhaled by smokers, even when numbers of cigarettes smoked are approximately equal. Burling and colleagues (1985) studied 12 matched pairs of smokers, each pair smoking a similar number of cigarettes but with different levels of CO (one high-CO-level subject and one low-CO-level subject). The CO boost per cigarette was found to be significantly different for the matched pairs of smokers. The CO boost for the high-CO group was 6.9 ppm per cigarette and for the low CO group 4.4 ppm.

The study found no differences between the high-CO and low-CO groups in terms of number and duration of puffs. Given the significant differences in CO levels, the researchers speculate that the difference may reside in puff intensity, puff volume, or inhalation characteristics. These influences on CO levels are relevant to low-nicotine yields and changes in smoking behavior; Herning and colleagues (1983) reported that CO boost appears correlated to blood nicotine levels.

In an earlier study, Burling and coworkers (1983) found that a smoker's CO level is influenced by factors other than the FTC-determined CO yield of cigarettes. The researchers reported that the CO level is significantly related to interpuff interval, cigarette duration, time since last cigarette, and self-rated estimate of depth of inhalation. This research underscores the likelihood that CO levels may be determined by multiple factors, not just stated yield. However, the finding suggests that, when numbers of cigarettes are held equal, a person smoking cigarettes with a higher CO yield will likely have higher CO levels than a person smoking cigarettes of lower CO yield. Furthermore, Wald and colleagues (1984) reported that smokers of filter cigarettes have a 60-percent higher intake of CO than do those who smoke nonfilter cigarettes.

Russell and colleagues (1982), in a study of long-term switching to low-tar, low-nicotine cigarettes, observed complete compensation as measured by CO uptake, and Robinson and coworkers (1983) reported that COHb levels did not change significantly after smokers switched to cigarettes with 15- and 72-percent lower CO deliveries.

Robinson and colleagues (1984) examined exposure among 22 smokers of high-nicotine cigarettes who switched to cigarettes of similar nicotine yield but with reduced yields for tar, CO, and hydrogen cyanide. Cotinine levels remained about the same; however, although reductions of 40 to 50 percent in CO and HCN were expected, the measured reductions were 5.3 percent for expired-air CO, 12.2 percent for COHb, 2 percent for saliva thiocyanate, and 1 percent for plasma thiocyanate.

Darrall (1988) found that a 50-percent blockage of ventilation holes produced small changes in tar and nicotine yields but greater changes in CO. Nil and coworkers (1986), in a study of 117 regular smokers, reported that the CO boost of cigarettes appeared to remain steady among smokers despite controlled switching to cigarettes of higher or lower yields.

Fischer and colleagues (1989), in an investigation of six different cigarette brands (filter and nonfilter and very low to medium tar yields), found that puff volume and puff frequency, the key determinants of total volume inhaled, significantly affect the smoker's exposure to tobacco-specific nitrosamines. According to the investigators,

> The medium-tar cigarette using standard smoking conditions delivered TSNA values that were close to the calculated average intake by smokers. The calculated average TSNA intake for the low-tar cigarette, however, was about double the value determined under standard smoking conditions (Fischer et al., 1989, p. 1065).

The researchers concluded that

> since the standard smoking conditions cannot reflect the real behavior for low- and very-low-tar cigarettes, especially with respect to the total inhalation volume, risk evaluation has to consider the increase in TSNA intake with increasing total volume (Fischer et al., 1989, p. 1065).

In a subsequent study, Fischer and colleagues (1991) investigated 170 types of American, European, and Russian cigarettes. The findings revealed that the amounts of two TSNAs—NNN (*N*-nitrosonornicotine) and NNK (4-methylnitrosamino-1-[3-pyridinyl]-1-butanone)—in cigarette smoke are not correlated with tar or nicotine delivery and the amounts of TSNAs in mainstream smoke are related to the amount of preformed nitrosamine in the tobacco.

In an investigation of compensation behaviors among smokers switching to lower delivery cigarettes, Robinson and coworkers (1983) noted disproportionate increases in HCN levels. The researchers concluded that machine-determined "standardized" deliveries do not reflect potential exposure to HCN.

Rickert and Robinson (1981), in a study of delivery by low-hazard and high-hazard brands and actual levels, found that differences in HCN and CO yields of the two different delivery types varied much more widely than actual levels of COHb and plasma thiocyanate obtained from smokers of each. High-hazard cigarette smokers had nearly four times the HCN of low-hazard cigarette smokers; however, the actual levels differed by only 20 percent. These differences were not statistically significant, possibly due to small sample size (n = 31).

Rickert and colleagues (1983) looked at variations in smoking patterns and reported that HCN delivery is influenced by blocking of ventilation holes and, to a lesser degree, by puff duration, puff volume, and butt length. Blocking half the ventilation holes increased HCN yield by 70 percent; covering all the holes produced a 250-percent increase in yield. These investigators determined that HCN yield for the cigarette brand investigated ranged from 5 to 241 μg, depending on variations in smoking parameters, although the mean HCN yield was 39 μg. For 115 Canadian cigarettes, the average HCN yield varied from 2 to 233 μg. This impact of smoking pattern on HCN yield was cited by Rickert and colleagues as a possible explanation for the poor correlation between HCN yield and levels of plasma thiocyanate and saliva thiocyanate.

Rickert and colleagues (1980) indicated that aldehydes, gas-phase constituents of tobacco smoke, are known to be ciliatoxic and may not be removed to a substantial degree from cigarette smoke by filters. Acrolein, a toxin restricted in occupational and industrial settings, also may contribute to the chemical toxicity of tobacco smoke. In a study of 102 brands of Canadian cigarettes, Rickert and colleagues found that tar level was a poor predictor of total aldehydes and acrolein delivery. The effect of changes in smoking patterns on phenol, glycerol, catechol, hydroquinone, palmitic acid, and neophytadiene are shown in Tables 2 through 5 (Schlotzhauer and Chortyk, 1983).

PROPOSALS TO CHANGE THE FTC TEST METHOD

At least three proposals have been published for changes in the FTC cigarette test method. Kozlowski and colleagues (1982b) made a proposal addressing the issue of the variability in human smoking behavior. These investigators suggested a three-level (i.e., light, average, and heavy) machine regimen linked to a color-matching technique to help smokers gauge the extent of puffing on a given cigarette—the darker the stain, the greater the exposure, with the tar stains keyed to a range of tar doses. Rickert and colleagues (1986) proposed an estimate based on average yields of tar, nicotine, and carbon monoxide per liter of smoke. Henningfield and coworkers (1994) proposed that multiple tests be used: an average smoking test and a heavy smoking test. The heavy smoking test would include vent-blocking conditions for those cigarettes incorporating ventilation holes and if it is possible for those holes to be blocked by the smoker's lips or fingers.

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