# Cigarette Design

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## CIGARETTE-YIELD TESTING BY SMOKING MACHINE USING THE FTC PROTOCOL

The modern low-yield cigarette is defined by a standardized smoking-machine test commonly referred to as the FTC method (Peeler, 1996), based on the Federal Trade Commission protocol. This smoking-machine procedure simulates a precise manner of smoking by fixing puff size (35 ml), puffing rate (once per minute), puff duration (2 seconds), and butt length to which the cigarette is smoked (23 mm on an unfiltered cigarette or overwrap, plus 3 mm on a filtered cigarette). The number of puffs to be taken is not specified. The standard yields of tar and nicotine measured are reported in cigarette advertising (according to a cooperative agreement) and on some very low-tar cigarette packs (as measured by the FTC method) at the manufacturer's discretion (Peeler, 1996; Kozlowski *et al.*, 1998c). Carbon monoxide (CO) is also measured, but is not reported in advertising. The same basic methodology is used for cigarette testing in Canada, Australia, and the United Kingdom. In the United States, cigarette brands yielding approximately 1-5 or 6 mg tar by this standard method are generally called 'Ultra-Light'; brands yielding between approximately 6 or 7-15 mg tar are called 'Light'; and brands yielding more than 15 mg tar are called 'Regular' or 'Full Flavor'. By convention, cigarettes yielding 15 mg tar by the FTC method are called 'low tar'.

The origins of the FTC method can be found in the early efforts of tobacco industry researchers to compare cigarettes of the day. They arbitrarily selected the smoking parameters of a 35-ml puff volume, a 2-second puff duration, and a one-puff-per-minute frequency (Bradford *et al.*, 1936). At the time, nearly all cigarettes were unfiltered, lacked overwraps, and were of similar length, weight, and circumference; presumably, most had similar burn times, a characteristic closely related to the number of puffs taken. The past 30 years has seen dramatic growth of variation in the physical characteristics of cigarettes, with differences in circumference ('slims' to 'wides'), length (70-120 mm), and weights.

## CHANGES IN FTC MACHINE-SMOKED YIELDS OVER TIME

Each year since 1968, the FTC has reported sales-weighted yields of tar and nicotine based on the FTC protocol (Table 2-1). Average sales-weighted standard tar yield decreased from 21.6 mg in 1968 to 12.0 mg in 1997 (44.4 percent), while average sales-weighted nicotine yield decreased from 1.35 mg to 0.89 mg (34.1 percent). Though standard tar and nicotine yields have the status of official FTC data, it would be wrong to assume that these numbers have any bearing on smoker exposure to tar and nicotine.

Table 2-1
**Sales-Weighted Tar and Nicotine Yields: 1968-1997**

| Year | Tar(mg) | Nicotine (mg) | Tar/Nicotine |
|---|---|---|---|
| 1968 | 21.6 | 1.35 | 16.00 |
| 1969 | 20.7 | 1.38 | 15.00 |
| 1970 | 20.0 | 1.31 | 15.27 |
| 1971 | 20.2 | 1.32 | 15.30 |
| 1972 | 19.9 | 1.39 | 14.32 |
| 1973 | 19.3 | 1.32 | 14.62 |
| 1974 | 18.4 | 1.24 | 14.84 |
| 1975 | 18.6 | 1.21 | 15.37 |
| 1976 | 18.1 | 1.16 | 15.60 |
| 1977 | 16.8 | 1.12 | 15.00 |
| 1978 | 16.1 | 1.11 | 14.50 |
| 1979 | 15.1 | 1.07 | 14.11 |
| 1980 | 14.1 | 1.04 | 13.56 |
| 1981 | 13.2 | 0.92 | 14.35 |
| 1982 | 13.5 | 0.89 | 15.17 |
| 1983 | 13.4 | 0.88 | 15.23 |
| 1984 | 13.0 | 0.89 | 14.61 |
| 1985 | 13.0 | 0.95 | 13.68 |
| 1986 | 13.4 | 0.93 | 14.41 |
| 1987 | 13.3 | 0.94 | 14.15 |
| 1988 | 13.3 | 0.94 | 14.15 |
| 1989 | 13.1 | 0.96 | 13.65 |
| 1990 | 12.5 | 0.93 | 13.44 |
| 1991 | 12.6 | 0.94 | 13.40 |
| 1992 | 12.4 | 0.92 | 13.48 |
| 1993 | 12.4 | 0.90 | 13.78 |
| 1994 | 12.1 | 0.90 | 13.44 |
| 1995 | 12.0 | 0.87 | 13.79 |
| 1996 | 12.0 | 0.88 | 13.64 |
| 1997 | 12.0 | 0.89 | 13.48 |

## DESIGN CHANGES THAT REDUCE STANDARD YIELDS

Changes in cigarette design have produced the reductions in standard yields of tar and nicotine measured over the past several decades. Although it is unlikely that decreases in FTC tar yields of only a few milligrams are toxicologically consequential, cigarette manufacturers can manipulate variables that combine to make small changes in yields or in the sensory effects of cigarettes. Such reformulations can have important policy implications. For example, changing a cigarette slightly to reduce the standard tar yield from 16 mg to 15 mg would increase the percentage of low-tar cigarettes on the market, and thereby reduce sales-weighted tar levels. However, even without compensatory smoking, such a small change would likely have negligible effects on health.

Cigarette design manipulations intended to decrease standard yields can be divided into those having two broad functional effects: 1) reducing the number of puffs per cigarette, and 2) reducing the tar and nicotine concentration in smoke per puff (Kozlowski, 1983). Table 2-2 provides a summary

Table 2-2
**Main Ways to Reduce Standard Tar and Nicotine Yields**

**A. Reduce the number of puffs taken by:**

- 1) decreasing the length of the available tobacco column with
  - a. longer filter overwraps,
  - b. longer filters;
- 2) increasing the burn rate of the column with
  - a. chemical additives in paper or tobacco,
  - b. higher porosity paper,
  - c. less tobacco (by weight),
  - d. lower diameter tobacco column.

**B. Reduce concentration of tar and nicotine per puff by:**

- 1) increasing filter efficiency with
  - a. ventilated filters (by reducing tobacco amount/puff),
  - b. longer filters,
  - c. denser filters,
  - d. 'active' filters;
- 2) increasing air dilution of mainstream smoke with
  - a. ventilated filters,
  - b. higher porosity paper;
- 3) decreasing the density of tobacco with
  - a. reconstituted sheet tobacco,
  - b. puffed or expanded tobaccos,
  - c. flavorings (casings) and additives,
  - d. smaller circumference cigarettes;
- 4) tobacco blending with
  - a. use of lower nicotine yield tobacco strains,
  - b. flue-cured, burley, oriental tobaccos,
  - c. different parts/leaf positions of plants.

of these factors. Manufacturing cigarettes that produce lower FTC tar and nicotine yields is a complex, multi-factorial process—a complicated recipe. Manipulating one variable also affects other variables. Cigarette design involves alteration of elements within a complex system. For example, if one simply increased filter ventilation greatly, this would cause less tobacco to be consumed with each standard puff, and thereby cause an increased number of puffs. Altering design to increase the inter-puff burn rate (*e.g.*, chemical treatments of the cigarette paper or using less tobacco) deals with this issue (Philip Morris, 1980).

The design features listed in Table 2-2 should not be considered 'secrets' of cigarette manufacture. Many of these design characteristics were discussed in a classic book on tobacco and tobacco smoke by Wynder and Hoffman (1967) and more recently by Browne (1990). Journals such as *Beitrage Zur Tabakforschung* and *Tobacco Science* have been available in research libraries for decades. Research articles on such design features have been published by various industry scientists (*e.g.*, Parker and Montgomery,

1979; Shoffner and Ireland, 1982). What is secret, however, is the exact formulation of a particular brand at any given time. Even if details are supplied in some of the formerly secret tobacco company documents, there is no guarantee, for example, that the Marlboro Light® brand of 1985 is the same in all attributes as the same named brand in 2000.

Three design features that can influence standard yield will be discussed. They are: available length of tobacco (which relates to burn rate), tobacco column nicotine content, and filter ventilation.

**Available Length of Tobacco**

Because the last few puffs on a cigarette have higher deliveries than the first few puffs, eliminating the last puff by increasing the burn rate has a relatively large effect on reducing tar and nicotine yields. The FTC test method has never required the recording or reporting of the number of puffs taken by the smoking machine, yet industry testing of cigarettes has routinely done so. The official Canadian cigarette testing laboratory (Labstat Incorporated, Kitchener, Ontario) has customarily collected the number of puffs taken by the machine for each cigarette smoked. In one study, 12 best-selling Canadian cigarette brands were shown to have decreased from 9.8 to 8.8 puffs per cigarette (a 10 percent reduction) between 1969 and 1974; during the same period, tar yield decreased 13.6 percent, from 22 mg to 19 mg (Kozlowski *et al.*, 1980b).

There is some evidence that increases in the length of the overwrap (the distinctive paper wrap covering the outside of the filter) have been used to decrease the number of puffs taken (Grunberg *et al.*, 1985). Other things being equal, a longer "filter plus overwrap" will result in a longer butt being left in the smoking machine. However, tobacco exists under the overwrap that is still available to be smoked by the human smoker. This additional tobacco would not be burned in the FTC test, resulting in a lower standard yield, but a potentially higher yield for the actual smoker.

**Nicotine Content of Tobacco**

Different types of tobacco can contain different amounts of nicotine, with burley being the highest and flue-cured tobacco being somewhat lower. Oriental tobaccos and reconstituted tobacco sheet have substantially lower nicotine contents. Different parts of the same tobacco plant can contain different nicotine levels based on stalk position, soil nitrogen, and the curing process. Blends of tobacco strains and tobacco from particular segments can contribute to the blend of a particular cigarette brand. These blends, combined with the use of fillers, additives, and reconstituted sheet tobacco in the tobacco column of cigarettes, can lead to differences in nicotine contents among brands. Kozlowski and colleagues (1998b) measured the nicotine content of the "tobacco column" (a complex of tobacco, reconstituted sheet, flavorings, and casings) in American, British, and Canadian cigarette brands. On the whole, American cigarette brands contained less nicotine per cigarette (10.2 mg ± 0.25 SEM) than either British (12.5 mg ± 0.33 SEM) or Canadian (13.5 mg ± 0.49 SEM) brands ($p < 0.008$). Among American brands, nicotine contents ranged from a high of 13.4 mg (Newport Full-Flavor®) to a low of 7.3 mg (GPC Lights®). The nicotine content of Canadian brands ranged from a high of 18.3 mg (Players Extra Light®) to a low of 8.0 mg (Players Full Flavour®), while

British brands ranged from a high of 15.9 mg (Knightsbridge® Super King) to a low of 9.0 mg (Dorchester®). Brands with the lowest standard nicotine yield (0.1 mg), such as Carlton®, Carlton® 100, Merit Ultima®, and Craven Ultra-Mild®, contained between 8.7-11.2 mg nicotine per cigarette (Kozlowski *et al.*, 1998b).

These same authors found a significant positive correlation (r = 0.51 [95% CI = 0.20–0.73]) between brand FTC nicotine yield and the nicotine content of tobacco. In 1997, the state of Massachusetts required testing of the best-selling cigarettes (*N* = 15 brand groups) for nicotine content of whole tobacco (American Cancer Society, 2000). This testing showed no significant differences between brand categories (Full Flavor, Light, or Ultra-Light). This discrepancy in the relationship between standard yields and nicotine content may be due to the exclusion of poor-selling, very low FTC tar brands from the Massachusetts sample. But substantial differences in nicotine content of tobacco were nonetheless found between some brands. Values ranged from a low of 8.3 mg for GPC Lights® King Size to a high of 15.48 mg for Marlboro® 100 Soft Pack (an 87 percent difference—low to high), which cannot be viewed as a small difference. Note that Kozlowski and associates (1998b) found an 84 percent difference between the lowest and highest nicotine content observed (see above).

**Filter Ventilation** Although each of the manufacturing changes listed in Table 2-2 (including those intended to reduce the number of puffs per cigarette) has contributed to the development of lower tar and nicotine cigarettes, filter ventilation has been the major innovation behind the modern low-yield cigarette (Kozlowski, 1983; Kozlowski *et al.*, 1998b). Filter vents, which usually are one or more rings of small holes or perforations, serve to dilute smoke with air, thereby reducing standard yields of tar, nicotine, and CO.

A 1956 Philip Morris memo to the company's most senior executives maintained that ventilation could serve as a "counter-attack" to negative health claims about smoking because it reduced "smoke solids," CO, and irritation (DuPuis, 1956).

Vents are placed in the filter by one of three main processes: electrostatic perforation, mechanical perforation, or laser perforation (Helms, 1983; Helms and Lorenzen, 1984). The method of perforation can influence actual tar and nicotine delivery to the smoker (this issue will be addressed further in the next section). Whatever the method of perforation, the location of filter vents generally ranges from 11 to 15 mm from the mouth end of the filter. In a recent study, the filter ventilation levels of 32 U.S. cigarette brands were tested and found to range from 0 to 83 percent (Kozlowski *et al.*, 1998b). A cigarette with 0 percent filter ventilation would produce a puff of smoke undiluted by air from filter vents. A cigarette with 83 percent filter ventilation would produce a puff that is 83 percent air from vents and 17 percent smoke undiluted by air from vents.

Increases in ventilation appear to have been important in meeting the tar-yield maximum in the European Economic Community. Internal Philip Morris documents indicated that the company's strategy for reducing the

smoke deliveries of its Marlboro® brands in Europe rested primarily on increasing filter ventilation (Stolt, 1977). Tests have shown that Full-Flavor Marlboro® cigarettes are now twice as ventilated in the United Kingdom as in the United States (19.5 versus 10.2 percent); similar differences are seen for Marlboro Light® (44.9 versus 22.5 percent) (Kozlowski *et al.*, 1998b).

## COMPENSATION AND CIGARETTE DESIGN: DIFFERENCE IN YIELD WITH DIFFERENT SMOKING PATTERNS

The observed decreases in standardized yields of tar and nicotine that have occurred since 1968 do not seem to translate into reduced exposures for smokers. Smokers can consciously or unconsciously compensate for lower standard yields in a number of easy and effective ways.

**Increasing Puff Number** Of course, smokers are not limited in the number of puffs they may take from a cigarette. Smokers can counteract yield reduction methods that reduce puff number simply by taking more puffs per cigarette. If smokers receive less tar and nicotine per puff from lower yield products, they can easily compensate by taking more puffs or, of course, smoking more cigarettes per day. Across 32 studies cited by the Surgeon General (U.S. DHHS, 1988), the average of the mean inter-puff intervals was 34 seconds, with a range of 18-64 seconds. This contrasts with the 58-second inter-puff interval used with the FTC method. Naturally, the actual range of inter-puff intervals would be much larger than this range of means. Results from a recent laboratory study revealed that smokers of low-yield (≤ 0.8 mg nicotine by FTC method) and high-yield (0.9-1.2 mg nicotine by FTC method) cigarette brands had significantly shorter inter-puff intervals (about 20 seconds) than those of the FTC protocol (Djordjevic *et al.*, 2000). Clearly, smokers often take more than one puff per minute and can thereby increase their actual yield.

**Increasing Puff Volume** A major and easy way for the smoker to increase smoke intake is to increase the volume of each puff. Total puff volume per cigarette is a function of puff number and volume per puff. In terms of overall exposure, total volume per cigarette is a better index and gives insight into how much 'work' the smoker performed in smoking the cigarette. Smokers are free to take large or small puffs on their cigarettes. The 32 studies summarized in the Surgeon General report (U.S. DHHS, 1988) confirmed that puff volumes often deviate from the FTC standard. The average of mean puff volumes across the studies was 43 ml, with a range of 22-66 ml. Again, because these represent ranges of means, the actual ranges of individual scores would be broader.

Published studies confirm that smokers will change their puff sizes in response to the type of cigarette that they smoke. Herning and associates (1981) studied smokers who were smoking the first cigarette of the day. These smokers showed larger puff volumes on the low-nicotine cigarettes (47.8 ml) than on either the medium- or high-nicotine cigarettes (35.9 ml and 36.9 ml, respectively). Among 10 participants studied by Tobin and Sackner (1982), larger puff volumes were taken from the low-tar cigarettes (52 ml) than from the high-tar cigarettes (39 ml) ($P < 0.001$). A study by Moody (1980) reported a mean puff volume of 43.5 ml. Djordjevic and col-

leagues (2000) recently reported that the average volumes of smoke per puff for smokers of low-yield and medium-yield cigarette brands were 48.6 ml and 44.1 ml, respectively. Other investigators have noted similar findings (*e.g.*, Zacny *et al*., 1986, 1987; Zacny and Stitzer, 1988). These studies showed that the FTC test underestimates the volume of smoke taken from lower tar cigarettes. Industry studies show that smokers often take far more in total volume of smoke than is predicted by the FTC test. In two separate Philip Morris studies, smokers (one in each study) independently took nearly 1,400 ml of smoke from Carlton® cigarettes, in both cases nearly five times the expected FTC value for a whole cigarette (Wakeham, 1974; Kelley, 1977).

Additionally, unpublished industry research revealed that puff volumes increase as standard yields decrease (see Norman and Ihrig, 1980a & b, at Lorillard, discussed later in the chapter). Clearly, puff volume changes represent a significant and easy mode of compensation for low-yield products.

**Dilution and Puff Volume** As discussed earlier, filter ventilation dilutes smoke with air. One way for the smoker to compensate for the reduced nicotine delivery that results from air dilution is to increase puff volume. If a smoker increases puff volume, he or she will receive more smoke from the cigarette along with more air. This larger puff might feel 'lighter' to the smoker than if they had taken a smaller, more concentrated puff of equivalent yield from an unventilated or less-ventilated cigarette. This effect of 'softening' the taste or reducing the harshness of taste may be an important reason for the perception of 'lightness' in lower standard-yield cigarettes (Kozlowski *et al*., 1998a, 1999, 2000).

Consider a simplified model of ventilation and puff volume. A curvilinear relationship exists between the level of dilution and the puff volume needed to compensate for reduced yield (Sutton *et al*., 1978). The formula for puff volume percentage increase needed to compensate is as follows: percentage increase in puff volume = (% dilution/[100 – % dilution]) x 100. As dilution increases, puff volume to compensate increases exponentially. According to Kozlowski and colleagues (1998b), for a cigarette with 13 percent dilution (*e.g.*, Marlboro® Full Flavor), a small puff volume increase (15 percent, from 35 ml to 40 ml) would provide full compensation for the dilution. To compensate fully for a 40 percent diluted cigarette (*e.g.*, Virginia Slims Light® 100), a puff volume of 58 ml (a 67 percent increase) would be needed. In contrast, with a highly ventilated cigarette such as Carlton® 100 (83 percent diluted), a large and generally impractical puff volume of 206 ml would be required. These estimates assume a 35 ml base puff (the base puff is what is assumed to occur with no ventilation). For those with a 45 ml base puff, a heroic puff of 265 ml would be required to compensate for the 83 percent dilution on the 1 mg tar cigarette. The best-selling Marlboro Light® cigarette is just 23 percent diluted, and an easy puff of about 60 ml (from a 45 ml base) or only 45 ml (from a 35 ml base) would fully compensate. Increased puff volume is a very likely mode of compensation when it can be performed without significant additional effort (*i.e.*, for a Light cigarette with low-to-moderate air dilution). For a

heavily ventilated cigarette (*e.g.*, 83 percent diluted, 1 mg tar), increasing per-puff volume within acceptable bounds of comfort and effort alone will not generally provide full or even substantial compensation. (Of course, smokers are not constrained to simply take bigger puffs; they may also take more puffs; for more, see Kozlowski *et al.*, 1998b.)

The phenomenon of compensating with bigger puffs is well known to industry scientists. For example, Norman and Ihrig (1980a) of Lorillard conducted a series of studies concerning puff volumes and puff velocities on lower tar cigarettes being greater than those for higher tar cigarettes. These authors assumed that ultralow-tar brands were more palatable to the smoker if compensatory smoking required a modest amount of additional effort. To describe this effort, they derived the "puffing power function" (Norman and Ihrig, 1980b), defined as the product of the flow rate through the cigarette and pressure drop required to produce that flow.

These authors examined the relationship between puffing power functions (expressed in 'puffing power units' or PPU) and puffing regimens (at standard FTC 35 ml as well as 50 ml puffs). The increase in PPU represented the "extra effort needed to obtain a given amount of additional [tar] from the cigarette" (Norman and Ihrig, 1980b). They thought that an understanding of puffing effort is critical for very low-yield brands, since these are most likely to be smoked with extra effort to obtain more smoke.

Increasing puff volume can have additional effects, especially if puff velocity also increases. Other things being equal, a higher velocity puff (*i.e.*, > 17.5 ml/sec) will reduce filter efficiency (*i.e.*, the percentage of what enters the filter that remains in the filter). Further, filter tip ventilation decreases as flow rate increases. If the cigarette is ventilated with high-porosity paper, however, the opposite is true—dilution increases with increasing flow rate:

> ". . . [A] cigarette constructed with low paper porosity but with filter tip ventilation would more readily allow a smoker to take a higher delivery of smoke by increasing the velocity of puffing. Such a cigarette construction would provide a marketing opportunity to offer a LOW to LOW TO MIDDLE delivery product when smoked by machine, which could be a LOW TO MIDDLE to MIDDLE delivery product when smoked by the smoker."
>
> . . . "Alternatively, if a cigarette is manufactured to have no filter tip ventilation, but high paper porosity, the smoker would not be able to compensate for reduced delivery by puffing harder; in fact, the higher the velocity of the puff, the lower the delivery. Theoretically the smoker would be able to increase delivery by reducing his puffing velocity and increasing the duration of the puff. This is unlikely to occur to any marked extent as it would require a marked change of habit that would probably feel uncomfortable to the smoker." (See Creighton, 1978a.)

Air drawn through the vents dilutes the smoke, but also generally reduces the draw resistance through the filter and tobacco rod (Creighton, 1978a). For example, Zacny and associates (1986) found that the average "resistance to draw" (RTD—the amount of pressure that must be exerted on the filter for inhalation) of an unblocked (*i.e.,* fully ventilated) Now® cigarette was 92.5 mm H2O (for Kozlowski *et al.*, 1998b, Now® was 66.3 percent diluted). In contrast, the same cigarette fully blocked (*i.e.*, unventilated) had an RTD of 184.4 mm H2O, a 100 percent increase. This lower RTD for the ventilated cigarette means the smoker can easily take a larger puff on the cigarette with little added effort and receive more smoke from the cigarette. Lower RTD, in effect, promotes the use of increased puff volume as a compensation method. Industry studies bear this observation out (Long, 1955; Goodman, 1977; Creighton and Watts, 1972; Mendell, 1983). The air-diluted smoke would also be less irritating than the same smoke undiluted, and thereby would also facilitate increased puff volumes because inhibitory oral and respiratory cues would be milder.

Additional industry research has looked at interactions between the type of ventilation used and puff volume. A. B. Norman and others at R. J. Reynolds Tobacco Co. compared laser, mechanical, and electrostatic perforation types (Norman *et al.*, 1984). Laser perforations were found to promote compensation with increased puff volumes. That is, as puff volumes increased, filter air dilution decreased most significantly with laser perforations. W. I. Casey (1994) at R. J. Reynolds explored yields from different tobacco blends with perforations as "holes" versus "slots" (hole versus slot is not defined). Cigarettes were tested according to FTC procedures as well as "50/30" procedures (50 ml puff, every 30 seconds); brands had approximately equal air-dilution levels (80-85 percent). Two rows of slots gave the same nicotine (0.11 mg) as did two rows of holes under FTC conditions, but gave more nicotine under the 50/30 condition: 0.67 versus 0.53 mg. Ventilation holes increased yield by 382 percent and ventilation slots increased yield by 509 percent over FTC estimates, simply by increasing puff volume and puff number. This effect of slots versus holes was not found for another tobacco blend. Here, one can see that design features (*e.g.*, filter ventilation and tobacco blend) can interact dramatically with smoker behavior (puff volume/puff interval) to produce more elastic products (*i.e.*, giving low values to the smoking machine, but higher values to smokers).

**Blocking Filter Vents** Another technique smokers can use to increase smoke concentration is the blocking of filter vents. Research has found that the majority of smokers are unaware of the presence of vents in general or even on their own brands (Kozlowski *et al.*, 1996, 1998d). At best, filter vents are placed just millimeters from lips or fingers, and they are often not noticed by smokers (Kozlowski *et al.*, 1998d). Smokers can and do obstruct the vents with either their lips or fingers, thereby diminishing or defeating the air-dilution effect. The ease with which smokers can unknowingly compensate for low standard yields by interfering with this important design feature has long been known within the cigarette industry. Internal company documents from the British American Tobacco Co. indicate that the industry acknowledges the importance of filter ventilation for designing products to

be compensatable or elastic. For example, in one document, this question was asked—"Which product/design properties influence elasticity?" The answer—"1. Tip ventilation: bigger effects at higher degree of ventilation. . . 2. Delivery of the blend . . ." (Brown & Williamson, 1984).

**Effects of Vent Blocking on Smoke Exposure**

The earliest of the published studies to examine the effects of vent blocking used smoking machine estimates to simulate the effect of vent blocking. Blocking half the vents of a 4 mg tar cigarette, for example, increased the smoking-machine yields of tar by 60 percent (from 4.40 to 7.03 mg), nicotine by 62 percent (from 0.45 to 0.73 mg), and CO by 73 percent (from 4.50 to 7.80 mg) (Kozlowski *et al*., 1980a & b). Blocking all of the filter vents of these same cigarettes with tape increased yields of tar by 186 percent (from 4.40 to 12.60 mg), nicotine by 118 percent (from 0.45 to 0.98 mg), and CO by 293 percent (from 4.50 to 17.70 mg). In another study, Kozlowski and colleagues (1982) completely tape-blocked the vents on different brands of 1 mg tar cigarettes from Canada, the United States, and the United Kingdom. Cigarettes were smoked more intensely in the blocked condition (2.4 second puff duration; 44 second puff interval; 47 ml puff volume). Tar yield increased from 1,360 percent (Cambridge® [0.8-11.7 mg]) to 3,800 percent (Viscount No. 1® [0.3-11.7 mg]). Nicotine yield increased from 720 percent (Cambridge® [0.1-0.82 mg]) to 1,767 percent (John Player Ultra Mild® King Size [0.12-2.24 mg]). Similarly, CO yield increased from 870 percent (Cambridge® [1.8-17.5 mg]) to 4,180 percent (John Player Ultra Mild® King Size [0.50-21.4 mg]) under the more intense smoking conditions. Compare this to an unventilated reference cigarette, which saw yield increases of 46 percent for tar, 35.8 percent for nicotine, and 35.7 percent for CO under these intense conditions.

In a 1983 study, Rickert and associates tested 36 brands of Canadian cigarettes (including 28 brands that had ventilated filters) on a smoking machine under three experimental conditions to simulate how smokers' exposure to toxic substances would be affected by smoking patterns of different intensities. 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 seconds, and puff interval was reduced to 44 seconds. The parameters of the 'intense' condition were exactly the same as the 'moderate' condition, except that 50 percent of the vent holes were covered with tape. Comparing yields obtained under the moderate and intense conditions, then, shows the effect of blocking 50 percent of filter vents (Rickert *et al*., 1983).

A secondary analysis of these data was performed on the 28 ventilated-filter brands. These were divided into three standard yield bands: 1-2 mg tar ($n$ = 4), 3-5 mg tar ($n$ = 11), and 6-14 mg tar ($n$ = 13), roughly corresponding to Lowest Tar, Ultra-Light, and Light designations. Lowest Tar cigarettes showed a nicotine yield increase of 0.22 mg (130 percent), Ultra-Light cigarettes showed an increase of 0.31 mg (57 percent), and Light cigarettes showed an increase of 0.43 mg (36 percent). Lowest Tar cigarettes showed an increase of 2.5 mg tar (160 percent), compared to a 4.0 mg tar (63 per-

cent) increase in Ultra-Light and a 5.5 mg tar (38 percent) increase in Lights. CO yields in Lights were increased by 4.7 mg (36 percent), while Ultra-Light brands increased 4.9 mg (75 percent) and Lowest Tar brands increased 2.6 g (150 percent).

Baker and colleagues (1998) presented an industry experiment on the effects of differing degrees of vent blocking on smoke yields. Both Light (9.3 mg tar, 0.89 mg nicotine, 8.7 mg CO at FTC conditions) and Ultra-Light (4.1 mg tar, 0.35 mg nicotine, 4.0 mg CO at FTC conditions) cigarettes were tested for the effect of vent blocking on yield under the FTC protocol. The Light cigarette showed an increase of 0.8 mg tar (8.6 percent), 0.08 mg nicotine (9.0 percent), and 1.4 mg CO (16 percent) when smoked with 50 percent of the vents blocked. The Ultra-Light cigarette showed an increase of 1.1 mg tar (27 percent), 0.09 mg nicotine (26 percent), and 2.3 mg CO (57.5 percent) with 50 percent vent blockage (Baker *et al.*, 1998).

Baker and Lewis (1997) provided the results of previously unreleased industry reports in which smoking machines were used to simulate the effect of vent blocking with lips and fingers on tar yields. These estimates were calculated assuming that the maximum coverage of filter vents is approximately 50 percent for lips and 25 percent for fingers. These researchers reported that blocking filter vents with fingers would increase the total particulate matter (TPM—tar plus nicotine, minus water) of a 1.3 mg tar cigarette by 23 percent to 1.6; blocking vents on the same brand with lips would increase the TPM by 92 percent to 2.5. Blocking filter vents with fingers would increase the TPM of a 2.2 mg tar cigarette by 32 percent to 2.9; blocking vents on the same brand with lips would increase the TPM by 59 percent to 3.5. Blocking filter vents with fingers would increase the TPM of a 6.7 mg tar cigarette by 10 percent to 7.4; blocking vents on the same brand with lips would increase the TPM by 21 percent to 8.1. Note that a negative relationship exists between tar yield and percentage of increase in TPM (Baker and Lewis, 1997).

Interestingly, the yield increases seen as a result of 50 percent blocking were significantly different between the Rickert and associates' (1983) and the industry's (Baker and Lewis, 1997; Baker *et al.*, 1998) studies. For example, nicotine yield in Ultra-Light cigarettes increased 57 percent in the Rickert and associates (1983) study, but only 26 percent in the Baker and colleagues (1998) study. Similarly, Rickert and associates found a 63 percent increase in tar, while Baker and colleagues found only a 27 percent increase. Baker and Lewis (who downplayed the effects of vent blocking) found that blocking 50 percent of vents caused a TPM increase of 59 percent, comparable to the Rickert results. However, they found a smaller effect for Lights (38 percent versus 22 percent increase in tar).

Why are there such discrepancies in the effects of vent blocking in these studies? Perhaps smoking conditions contribute to the effect of vent blocking. In the Rickert and associates (1983) study, cigarettes were smoked at a larger puff volume with shorter intervals than the FTC conditions used by Baker and colleagues (1998) and Baker and Lewis (1997). For example, to approach the 57 percent increase in nicotine yield at 50 percent blockage of

Ultra-Lights seen by Rickert and associates, Baker and colleagues tested their Ultra-Lights with 100 percent of vents blocked, and even here the yield increase was only 51 percent. An alternative explanation is that the cigarette designs selected for use in the Baker and colleagues study may be more resistant to the effect of vent blocking.

Zacny and associates (1986) evaluated the effect of vent blocking on smoke exposure in smokers. They found that blocking 0 percent, 50 percent, and 100 percent 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. Mean CO boosts (post-cigarette expired air CO level minus pre-cigarette expired air CO level) were 0.83 ppm, 2.87 ppm, and 7.07 ppm when 0 percent, 50 percent, and 100 percent of the filter vents were blocked.

This research was extended by Kozlowski and colleagues (1996b) to assess the effect of a behavioral vent blocking maneuver (*i.e.*, blocking vents with lips) on smoke exposure from the 1 mg tar Ultra-Light brand, Now®. Blocking filter vents with lips (estimated to be about 50 percent blockage) more than doubled the CO exposure from these cigarettes: CO boosts for the unblocked, lip-blocked, and 100 percent tape-blocked conditions averaged 2.7 ppm (SE = 0.52), 6.7 ppm (SE = 1.0), and 12.9 ppm (SE = 2.2), respectively.

Sweeney and Kozlowski (1998) examined the effect of blocking the filter vents of the best-selling cigarette brand, Marlboro Light®. CO boosts for the unblocked, lip-blocked, tape-blocked (50 percent coverage), 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. This "no-effect" finding for Marlboro Light® was subsequently replicated in a second study comparing the effects of finger-blocking and not blocking: the mean CO boosts for the unblocked and finger-blocked conditions were nearly identical: 6.3 ppm (SE = 0.50) and 6.5 ppm (SE = 0.52). In this same study, finger-blocking the vents on the 1 mg tar brand Now® led to a significantly higher (P = 0.0004) CO boost (5.4 ppm, SE = 0.64) than when filter vents were not blocked (2.8 ppm, SE = 0.34).

Puff number, puff duration, and puff interval were all controlled in these studies to examine the independent effects of vent blocking on smoke exposure. What type of an effect does vent blocking have on smoke exposure under more naturalistic conditions when parameters such as puff number and puff duration are free to vary? Zacny and associates (1986) explored this question with five smokers who smoked 1 mg tar cigarettes ad lib (*i.e.*, puff and inhalation parameters were free to vary) under each of three vent blocking conditions: 0 percent of the filter vents blocked; 50 percent of filter vents blocked with tape; and 100 percent of filter vents blocked with tape. Participants took significantly more puffs with significantly shorter interpuff intervals from cigarettes with unblocked filter vents than from cigarettes with blocked filter vents. Puff durations were similar across conditions, but puff volumes were larger when subjects smoked cigarettes with

unblocked filter vents than when smoking cigarettes with blocked filter vents. Smokers were trying to compensate for smoke dilution by smoking the unblocked cigarettes more intensely. Nevertheless, participants still had greater CO exposure when smoking vent-blocked as compared with unblocked cigarettes, indicating that compensation was not complete. Mean CO boosts were 4.32 ppm, 6.44 ppm, and 8.96 ppm, when 0 percent, 50 percent, and 100 percent of filter vents were blocked, respectively (standard errors of the mean were not reported).

The two most recent studies in this area (Sweeney and Kozlowski, 1998; Sweeney *et al.*, 1999) further extended this research by examining the effects of behavioral vent-blocking maneuvers under ad lib smoking conditions. In the first study, participants smoked cigarettes from the brands Now® (1 mg tar by FTC method) and Marlboro Light® (10 mg tar by FTC method) under each of two vent-blocking conditions: unblocked and finger blocked. Blocking filter vents with fingers led to an 85 percent increase in CO exposure from Now®, but had no added effect on CO exposure from Marlboro Light®. The generalizability of these findings to all brands of Ultra-Light and Light cigarettes is limited, however, given that only one brand from each category was examined. A second study examined the effects of vent blocking using several cigarette brands of varying ventilation levels and standard tar yields. In a repeated-measures study with female daily cigarette smokers, the effect of lip-blocking on CO exposure was examined using four cigarette brands: Carlton® (1 mg FTC tar; 83 percent ventilated), Now® (2 mg FTC tar; 66 percent ventilated), Virginia Slims Ultra-Light® (5 mg FTC tar; 56 percent ventilated), and Virginia Slims Light® (8 mg FTC tar; 40 percent ventilated). Results showed that behavioral blocking caused all four brands to produce similar CO exposures. Blocking vents increased smokers' exposure to CO by 239 percent when smoking Carlton® and by 44 percent when smoking Now®. No significant increases in CO exposure with blocking were found for either of the Virginia Slims® brands.

The previous studies have used CO measures as an index of vent blocking because they are more practical and easy to obtain. However, one study has obtained salivary cotinine levels from self-selected 1 mg tar cigarette smokers (Kozlowski *et al.*, 1989). Here, large cotinine values were found in smokers who blocked the vents of 1 mg tar cigarettes; these values are larger than would be expected given the standard yield of their product and appear to compensate fully for that reduced yield. No other studies have been identified that investigated the effects of vent blocking on nicotine or cotinine levels. Obviously, further studies must be conducted on nicotine intake before concluding that vent blocking in Light cigarettes is inconsequential to exposure.

**Prevalence of Vent Blocking**

Published, peer-reviewed research has shown that a substantial proportion of smokers block vents. Using an unobtrusive indicator of vent blocking (stain pattern; discussed below), one study found that 58 percent of 135 cigarette filters from various Ultra-Light brands (4 mg tar or less) gave evidence of at least some vent blocking (Kozlowski *et al.*, 1988). Using similar procedures, another study found evidence of vent blocking in

53 percent of 158 filters of Light brands that were collected (Kozlowski *et al.*, 1994). In a study of 'high-risk' smoking practices used by the homeless, Aloot and colleagues (1993) found that 24 percent reported blocking filter vents (Aloot *et al.*, 1993).

The stain pattern technique for determining vent-blocking is straightforward. Trained raters observe the mouth ends of cigarette butts and judge whether or not vent blocking has occurred based on the extent of the tar stain on the filter. A "bull's eye" pattern on the filter indicates that little or no vent blocking occurred, while a more uniform pattern across the filter would indicate that filter vents had been blocked. This technique has been validated and has been shown reliable on a number of brands (*e.g.*, Carlton®, Now®, Merit Ultima®, Camel Light®) through numerous refinements (Kozlowski *et al.*, 1980a & b; Pillitteri *et al.*, 1994; Sweeney, 1998). It must be stressed that this technique detects the presence or absence of any vent blocking with either fingers or lips. It should not be used to indicate the extent of vent blocking.

Industry scientists have objected to the use of the stain pattern technique (Baker and Lewis, 1997). They criticize raters' accuracy in judging the presence or absence of blocking and allege that the properties of laser-perforated filter vents produce variant patterns. Instead, the industry touts saliva-based measurements of lip placement around the ventilation zone as a better gauge of vent blocking. These techniques use ninhydrin and other biochemical stains to detect remnants of saliva in filters. These saliva-based techniques can detect vent blocking, but are impaired by factors such as lip dryness and so may underestimate its extent. Advocates of saliva-based measures admit that the technique often can fail to give a lip imprint stain for up to 20 percent of butts (Baker *et al.*, 1998). Another limitation of the saliva-based measures is that they will only detect lip blocking, totally ignoring finger blocking (unless the fingers have saliva on them).

During more than 15 years of published research on vent blocking, no formal response from the industry was put forth. In 1997, Baker and Lewis, two industry scientists, published their critique of peer-reviewed work on the subject. Their assertions were that: 1) vent blocking is not a significant mode of compensation because it does not occur often; 2) when vent blocking does occur, it hardly increases yields; and 3) mouth insertion depths of cigarettes do not differ greatly for ventilated and unventilated cigarettes.

Between 1974 and 1997, 10 studies were conducted by the tobacco industry in an attempt to measure the depth to which smokers insert cigarettes into their mouths by examining spent cigarette filters from public areas, such as shopping malls (Baker and Lewis, 1997). In these studies, a visible imprint of the lip marks on the filter was obtained by spraying the filter with either iodine or ninhydrin solutions to detect certain enzymes and amino acids in dried saliva on the filter. Across 10 studies, insertion depth measures ranged from 3 to 25 mm, with mean values ranging between 10.1 and 11.5 mm. Using both mouth insertion data based on 2,232 cigarette butts from a pair of 1997 Canadian studies, as well as information on ventilation zone location for leading U.S. brands, Baker and

Lewis (1997) estimated the proportion of smokers that would cover filter vents while smoking. They concluded that 36 percent of smokers will cover vents for at least one puff when they are placed at 11 mm, versus 6 percent of smokers who will cover the vent holes in at least one puff with ventilation zones positioned 17 mm from the mouth end of the filter.

Brands vary greatly in the placement of vents on the filter, and vent placement can bear little relationship to the standard yield of the cigarette. For example, a Marlboro® Full Flavor (16 mg tar) has vents at 12.5 mm from the mouth end, whereas a Carlton® (1 mg tar) has vents at 15 mm. Merit Ultima® (1 mg tar) has vents at 11.0 mm, whereas Camel® Full Flavor (17 mg tar) has vents at 14.5 mm (Kozlowksi *et al.*, 1997).

In an unpublished study by Röper (cited in Baker and Lewis, 1997), an attempt was made to assess more directly the prevalence of lip blocking by having 52 smokers take 1 puff on 5 cigarettes from each of 3 ventilated-filter brands. Of the 735 visible lip imprints that were obtained, 48 percent had at least some coverage of the ventilation zone.

Baker and colleagues (1998) examined 900 British smokers' filters for evidence of vent blocking using saliva-based techniques. They report that 15 percent of butts had at least partial vent coverage, while 85 percent showed no vent zone coverage. More interesting, however, are differences in coverage and insertion depth among standard (unventilated), Light, and Ultra-Light cigarettes. Light cigarettes showed partial coverage in 11.5 percent of cases and complete coverage in 1.5 percent of cases. In contrast, Ultra-Light cigarettes showed partial coverage in 9.6 percent of cases and complete coverage in 6.5 percent of cases. Further, standard cigarettes were inserted a mean of 7.8 mm (SD = 3.6) into a smoker's mouth, whereas Ultra-Light cigarettes were inserted a mean of 9.5 mm (SD = 5.0) into the mouth; in these cigarettes, the vents were placed 13.5-14.5 mm from the mouth end (Baker *et al.*, 1998).

Porter and Dunn (1998) of Imperial Tobacco examined butts collected in Montreal, Toronto, and Vancouver, Canada, for signs of vent blocking by examining mouth insertion depths. They found that the difference in insertion depths between ventilated and unventilated cigarettes was negligible (10.6 ± 3.6 mm versus 11.0 ± 3.6 mm). Further, they found that between 14 percent and 20 percent showed some evidence of partial vent coverage, whereas between 4 and 10 percent showed evidence of complete blockage (Porter and Dunn, 1998). In a similar study, McBride (1985), also of Imperial Tobacco, found that there were no significant differences in insertion depths between ventilated and unventilated cigarettes. However, McBride noted that "insertion depths were greatest for cigarettes in the very low delivery category." (McBride, 1985)

A study by British American Tobacco/Suisse (1984) examined the depths to which smokers inserted cigarettes into their mouths. Baker and Lewis (1997) cited this study along with several others as evidence that insertion depths are not large enough to interfere with ventilation in most cases. However, further examination of the results revealed that an interesting effect was obscured—insertion depths were greatest for the lowest yield cig-

arettes. The researchers concluded that "highly ventilated cigarettes are inserted deeply into the smokers mouth and consequently the ventilation level is reduced during normal smoking" (British American Tobacco/Suisse, 1984). For example, an Ultra-Low delivery cigarette (1 mg tar, 0.1 mg nicotine, 78 percent diluted) showed 43 percent of insertions beyond the vents, whereas a Full-Flavor brand (16 mg tar, 1.2 mg nicotine, 17 percent diluted) had only 22 percent of insertions beyond the vents; both brands had vents at 11-13 mm. By this technique, lip imprints beyond the vents were taken as evidence of vent blockage.

Large insertion depths seem to be about twice as common among less-popular 1 mg tar cigarettes. Given the relative disparity in sales (much greater for higher yield cigarettes), the 'few' blocked 1 mg tar cigarettes can be 'hidden' among the shallow insertion depths of more popular higher yielding brands. This causes average insertion depths to appear low enough not to interfere very much with vents. Furthermore, this permits the industry to argue (based on average insertion depths) that vent hole covering is not a major problem, when, in fact, their data suggest it is a significant problem for the lowest yield cigarettes. Porter and Dunn (1998) cited McBride's prior work, but made no mention of that researcher's finding of greater insertion depths for lower yield cigarettes (McBride, 1985), nor did they address the similar findings of the British American Tobacco/Suisse study (1984).

Ferris of the British American Tobacco Co. (cited by Baker and Lewis, 1997) conducted a study in 3 British cities in which 133 smokers of ventilated-filter cigarettes were videotaped. A total of 798 puffs were individually assessed from the video recordings: during 12 percent of the puffs, smokers' fingers were in contact with the cigarette for all or part of a puff. During 81 percent of the puffs, there was no finger contact with the cigarette. Ten percent of the puffs could not be assessed. During 29 percent of the final puffs, however, smokers' fingers were at least partially in contact with the cigarette. Eleven percent of participants had their fingers in contact with the cigarette for one or more puffs. However, since finger and lip blocking are mutually exclusive, it is noteworthy that lip blocking was not included in this study.

Baker and Lewis (1997) noted that when smoking an Ultra-Light cigarette (2.2 mg FTC tar), 45 percent of smokers blocked vents to some degree with their lips. Further, 21 percent of smokers (or nearly half of those who blocked vents) increased tar yields to at least 3.3 mg tar (50 percent). It was estimated that approximately 1 in 10 smokers doubled their tar yield from lip blocking alone; this is not insignificant, yet Baker and Lewis seemed to downplay these results.

Table 2-3 outlines the conditions under which different modes of compensation will be likely to occur. Reviewing the literature, vent blocking appears to be a significant mode of compensation for reduced yield among smokers of Lowest Tar cigarettes (*e.g.*, 1 mg FTC tar), but not likely among most smokers of Light and Ultra-Light cigarette brands.

Brand selection is usually not forced upon smokers. The self-selected choice of brands is due to many factors. It should be noted that some

Table 2-3
**Major Compensatory Behaviors in Relation to Cigarette Designs That Increase Total Smoke Volume per Cigarette**

**A. For more-popular lightly and moderately diluted cigarettes (*i.e.*, <60% ventilated, >4 mg FTC tar yield—"Light" and "Ultra-Light")**

1) Increase volume per puff.
   Probably the easiest, most common method; for example, the smoke intake from a 45 ml puff on a 23% ventilated cigarette can be equivalent to the smoke intake from a 35 ml puff on an unventilated cigarette.
2) Increase number of puffs taken.
3) Reduce air dilution (as in Section B below).
   This likely will be a lesser-to-negligible compensation mode because (a) the effect is relatively small for these brands, and (b) increased puff volume and number can achieve all needed/desired compensation.

**B. For less-popular heavily diluted cigarettes (*i.e.*, 60-85% ventilated, 1-2 mg FTC tar yield—"Ultra-Low Tar")**

1) Reduce air diluation by blocking filter vents with lips or fingers.
   Filter designs that promote ventilation 'compromise' (*e.g.*, Actron®) avoid the need to behaviorally block vents.
2) Increase volume per puff.
   This technique would be more effective when coupled with some dilution reduction. Laser filter vents become relatively less effective with increased puff volumes.
3) Increase number of puffs taken.

smokers of the lowest yield cigarettes appear to have very low nicotine needs and are disinclined to over-smoke these cigarettes, while other smokers of the lowest yield cigarettes have high nicotine needs and can fully compensate using these brands (Kozlowski *et al.*, 1989).

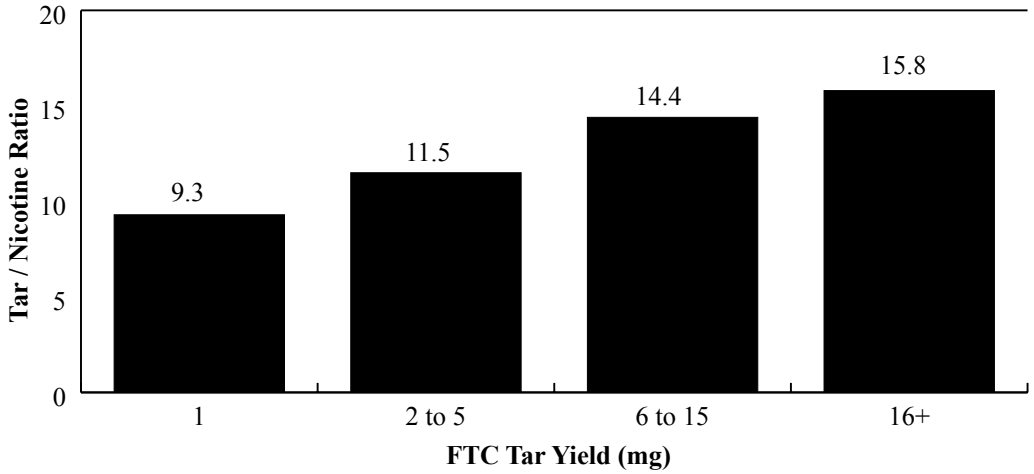
In summary, published, peer-reviewed research has shown that a substantial proportion of smokers block vents and that it is a common mechanism used by smokers to compensate for the reduced nicotine yield of ventilated cigarettes.

## Tar/Nicotine Ratios Depend on Smoking Conditions

During the period 1968-1997, the average sales-weighted ratio of tar to nicotine (T/N ratio) decreased 15.8 percent. Generally, the higher the yield, the higher the T/N ratio (see Figure 2-1). However, compensatory smoking behaviors (taking more frequent puffs, taking larger puffs, or vent blocking) can have dramatic effects on T/N ratios (Creighton and Lewis, 1978; Kozlowski *et al.*, 1980b; Rickert *et al.*, 1983). Given that some researchers have indicated an interest in using these ratios in the governmental regulation of cigarettes (*e.g.*, Russell, 1976; Gori, 1990; Bates *et al.*, 1999), this issue takes on greater importance.

In their study, Rickert and associates (1983) demonstrated that as intensity of smoking increased, T/N ratios increased. Intensely smoked Ultra-Light cigarettes provided a nearly identical T/N ratio (12.2) as Light ciga-

Figure 2-1
**FTC Tar/Nicotine Ratios for 2,052 Brands Tested as a Function of FTC Tar Yield Categories (FTC, 1999)**




*Note: Figure 2-1 shows the T/N ratios for all 2,052 brands tested by the FTC method in 1997 (FTC, 1999) as a function of FTC tar yield categories. One-way analysis of variance shows that T/N ratios increase as tar yield increases (P<0.0001, all pairwise comparisons significant P<0.001, Bonferroni t-tests) (Ns, SEMs: 15, 0.50; 159, 0.22; 922, 0.07; 156, 0.17).*

rettes smoked under standard conditions (11.9). The difference between standard and intense condition T/N ratios across all brands is significant (P< 0.0001). The blocking of vents has a greater effect on the change in T/N ratios in Lowest Tar brands (1.90 or 20.5 percent) than in Lights (0.78 or 6.5 percent) (P = 0.0146).

Internal tobacco company studies revealed that there is great variability in the T/N ratios of otherwise equivalent cigarettes. An R. J. Reynolds study tested the yields of Now® brand cigarettes and comparable experimental cigarettes (both 1 mg tar/FTC) smoked under two conditions, the standard FTC method and the previously mentioned "50/30" condition (a 50 ml puff taken every 30 seconds) (Casey, 1994). The T/N ratio of the Now® blend under standard conditions was 8.33; however, under 50/30 conditions, the ratio rose to 10.98 (an increase of 31.8 percent). At the same time, an experimental blend saw its T/N ratio increase from 6.36 at standard conditions to 6.72 at 50/30 conditions (an increase of only 5.7 percent) (Casey, 1994). It would appear that the trends for reduced "standardized smoking-machine" T/N ratios may have little relation to the ratios delivered to actual smokers. Empirical evidence for this proposition is presented in Chapter 3.

**Elastic Cigarette Designs** The rules or constraints of the FTC measurement regimen can be viewed as obstacles to be overcome by manufacturers that wish to design cigarettes that deliver lower yields during the course of the stan-

dardized smoking-machine test, while enabling smokers to achieve yields higher than would be predicted by smoking machines. A design that gives a low value to smoking machines but can potentially give higher values to smokers is termed 'elastic'. Internal tobacco industry documents revealed a concern for cigarette elasticity:

> "Smokers have disappointed us in that they have not chosen to smoke twice as many 10mg cigarettes if they changed from 20mg products. Thus in order to reinforce the primary pleasures of smoking, I have proposed to make it easier for smokers to take what they want from a cigarette which might well have a low delivery when smoked by machine which overcomes current legal constraints and to enhance the sensations from the first few puffs." (See Creighton, 1980s.)

> "Irrespective of the ethics involved, we should develop alternative designs (that do not invite obvious criticism) which will allow the smoker to obtain significant enhanced deliveries should he so wish" (See British American Tobacco Company, 1984.)

> "Compensation - It exists; most smokers practice it, but we need to understand it better before advantage can be taken in the marketplace. Here, I believe designing to the subconscious is preferred to requiring the smoker to commit a conscious act." (See Sandford, 1985.)

In a presentation given to marketers at the British American Tobacco Co., scientist D. E. Creighton described advances in the design of "compensatable" filter products:

> "The design of a cigarette with a compensatable filter will have a high taste to tar ratio. . . . This [the HH filter] was designed in BAT Hamburg and has been tested on consumers, who found the cigarettes too strong. As the sample cigarettes had a machine smoked delivery of about 1mg tar, the product must be very compensatable. Our own tests both subjective and objective suggested that it is a compensatable filter, when smoked against conventionally constructed controls. The objective test we have used is to smoke at 35 and 50ml puff volumes and to see if the increase in delivery at the higher puff volume is pro-rata or more. With HH, the delivery was more than pro-rata." [This paper goes on to compare the HH filter to the Actron filter used in Barclay®, discussed below.] (See Creighton, 1980s.)

The ventilated Actron filter makes use of plastic channels to feed air from vent holes back to the end of the filter. It appears that this channel system dramatically increased the likelihood of vent blocking because, in addition to blocking air intake holes, one could also subvert the ventilation system by either causing the fragile plastic channels to collapse or by blocking air exit holes with lips. This filter design caused competing manufactur-

ers to complain to the FTC that this cigarette design was classified as 1 mg but gave much higher actual deliveries. The courts ruled that the FTC test could not properly provide tar and nicotine numbers for this type of filter (FTC v. Brown & Williamson Tobacco Corporation, 1985). The Actron filter can still be found on Brown & Williamson's Barclay® and Kool Ultra® brands.

With some brands, elasticity arose from the ease with which a smoker could alter their smoking patterns on the product. Internal tobacco company documents show an industry aware that some lower yield products were smoked more intensely than higher yield products:

> "The smoker profile data reported earlier indicated that Marlboro Lights cigarettes were not smoked like regular Marlboros. In effect, the Marlboro 85 smokers in this study did not achieve any reduction in smoke intake by smoking a cigarette (Marlboro Lights) normally considered lower in delivery." (See Goodman, 1975.)

> "Numerous experiments have been carried out in Hamburg, Montreal and Southampton within the company, as well as many other experiments by research workers in independent organisations, that show that generally smokers do change their smoking patterns in response to changes in the machine smoked deliveries of cigarettes." (See Creighton, 1978b.)

**Cigarette Length** In the late 1960s, Philip Morris undertook the Smoke Exposure Study, termed SEX-1 in their internal documents. While the actual report is currently unavailable in the company's Internet document archive, references to the results are available in other documents. In a memo discussing reasons to publish the SEX-1 report, the effect of cigarette length on exposure is discussed. It appears that smokers of 100 mm cigarettes showed an increased intake of tar and nicotine compared to 85 mm cigarette smokers. However, it is noted that this increase was "not as great as would have been predicted from the increase in available tar" (Dunn, 1971). This issue of cigarette length and exposure was evidently significant, because the design of a subsequent study (SEX-2) was modified to include smokers who switched from 85 mm to 100 mm cigarettes to determine changes in daily smoke intake (Dunn, 1969). While the results of the SEX-1 study are far from clear, no other findings related to cigarette length are known to exist. Interestingly, the percentage of cigarettes sold ranging in length from 94 to 101 mm increased from 9 to 39 percent during the period 1967-1997 (FTC, 1999).

In summary, the tobacco industry has a stake in smokers' continued use of their products. Cigarette designs that promote compensation and/or elasticity of yield have been used, both in the research and development laboratories and in the marketplace. These designs allow the smoker to obtain more smoke (tar, nicotine, and CO) from each cigarette than would be indicated by the FTC testing method.

## MORE EVIDENCE FROM INDUSTRY DOCUMENTS RELATED TO COMPENSATION, CIGARETTE DESIGN, AND THE FTC TESTING METHOD

As shown in previous sections, considerable evidence exists in tobacco industry documents of knowledge regarding compensation and elasticity. Also revealed in industry documents are discussions about whether smokers might be misled by FTC tar and nicotine ratings used in advertisements and league tables. Particularly of concern were those customers who switched to a lower yield brand due to health concerns:

> "Should we market cigarettes intended to re-assure the smoker that they are safer without assuring ourselves that indeed they are so or are not less safe? For example should we 'cheat' smokers by 'cheating' League Tables? If we are prepared to accept that government has created league tables to encourage lower delivery cigarette smoking and further if we make league table claims as implied health claims—or allow health claims to be so implied—should we use our superior knowledge of our products to design them so that they give low league table positions but higher deliveries on human smoking?"
>
> . . . "Are smokers entitled to expect that cigarettes shown as lower delivery in league tables will in fact deliver less to their lungs than cigarettes shown higher?" (See British American Tobacco Company, 1977.)
>
> "It is difficult to ignore the advice of Health Authorities who advise smokers to give up smoking or change to a lower delivery brand but there is now sufficient evidence to challenge the advice to change to a lower delivery brand, at least in the short term. In general a majority of habitual smokers compensate for changed delivery, if they change to a lower delivery brand." (See Creighton, 1978b.)
>
> "1) Some concern has been expressed concerning the moral obligation of Philip Morris (and perhaps the tobacco industry) to reveal to the FTC the fact that some cigarette smokers may be getting more tar than the FTC rating of that cigarette. . . . 2) I believe that there need be no such concern, at least from a position of morality. It is obvious that HEW [Department of Health, Education, and Welfare; now the Department of Health and Human Services] knows that smokers vary their intake. Otherwise they would not urge smokers to take fewer puffs. There are published papers which show that different puffing patterns on the same cigarette will yield different amounts of tar." (See Fagan, 1974)

**SUMMARY** Many smokers switch to cigarette brands advertised as delivering lower yields out of concerns for their health, believing them to be less risky or a step toward quitting (Kozlowski *et al.*, 1998a, 1999; Giovino *et al.*, 1996). These decisions are often based on the FTC tar ratings, which can be inaccurate in assessing human smoking conditions. Through compensation

behaviors (*i.e.*, vent blocking on Ultra-Low FTC tar cigarettes, larger puff volumes, or more frequent puffs), many smokers can obtain adequate nicotine from their new lower yield brand to sustain their addiction.

Published research results, supplemented by previously unavailable industry data, show that the 44 percent reduction in standard tar yield and 34 percent reduction in standard nicotine yield seen since 1968 do not necessarily mean that smokers have been receiving less tar and nicotine from their cigarettes with each passing year. Smokers can and do compensate for reduced tar and nicotine yield by altering their smoking patterns. Compensation behaviors can range from simple maneuvers such as taking more puffs per cigarette, to increasing volume per puff, to blocking filter vents with fingers or lips. Changes in cigarette design have engineered cigarettes that have an elasticity of delivery, which allows smokers to derive markedly different amounts of nicotine from the same cigarette by changing the way that they smoke it. This designed elasticity is intrinsic to the process of compensation when smokers switch to lower yield cigarettes. Elastic products such as the Actron filter, laser-perforated filters, and invisible filter vents on cigarettes facilitate compensation behaviors in smokers. Larger puff volumes, increasing puff frequency, and other changes in smoking behavior allow smokers to derive doses of nicotine from cigarettes with low machine-measured yields sufficient to fully satisfy their addiction. Smokers are increasingly likely to engage in compensation as the machine-measured yields of cigarettes fall and the percentages of ventilation increase.

## CONCLUSIONS

1. Several design changes in the way that cigarettes are manufactured have led to a substantial reduction in the machine-measured tar and nicotine yields of U.S. cigarettes over the last several decades.

2. Many of the same design changes that have reduced machine-measured tar yields, particularly placing ventilation holes in the cigarette filters, also create an elasticity of delivery for the cigarette, allowing a wide range of tar and nicotine deliveries from the same cigarette when a smoker alters his or her smoking behavior.

3. Increasing puff volume and frequency, covering the ventilation holes with fingers or lips, and other changes in smoking behavior known to occur with use of low machine-measured-tar cigarettes can dramatically increase the tar and nicotine delivery of low- and ultralow-yield brands.

4. Variations in the tar and nicotine delivery that result from the known compensatory alterations in smoking behaviors make the current U.S. cigarette tar and nicotine yields as measured by the FTC method not useful to the smoker either for understanding how much tar and nicotine he or she is likely to inhale from smoking a given cigarette or for comparing the tar and nicotine intake that is likely to result from smoking different brands of cigarettes.

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