APPLICATIONS OF SOME PHYSICAL INDICATORS OF CIGARETTE SMOKING

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Abstract—Since abstinence may be an unrealistic goal for some smokers, the use of presumably less-hazardous, low-yield cigarettes has been recommended. A cigarette is called low-yield if it delivers small amounts of tar and nicotine in a standard smoking-machine assay. Unfortunately, machine-smoked yields are poor predictors of a smoker's exposure to the toxic ingredients in tobacco. Many smokers who smoke low-yield cigarettes are not actually low-yield smokers, in that they use any of a number of compensatory smoking techniques to increase the yields of their cigarettes. Compensatory smoking often takes place without the awareness of the smoker and can be very difficult for the smoker to monitor, even if trying to do so. Physical indicators of tobacco use should be applied by smokers who are trying to reduce their exposure to tobacco. In particular, the application of information to be found in heart-rate changes and in changes in the appearance of spent filters is discussed. The smoking of low-yield cigarettes should be recommended only when low-yield smoking has been confirmed in the individual smoker.

My assignment, as I understood it, was to propose applications for some of the findings of basic research on cigarette smoking. Speculation was encouraged. I have decided to avoid talking about the use of those physical indicators of tobacco use that have some history of application (e.g., alveolar carbon monoxide, plasma thiocyanate; see Frederiksen & Martin, 1979; Jarvik, 1979; for reviews) and even those indicators that are just beginning to be applied (e.g., plasma cotinine and nicotine; see Hill & Marquardt, 1980). Instead, I will argue that smokers and scientists can find important and inexpensive indicators of cigarette smoking in the appearance of spent cigarette butts and in the effects of cigarettes on pulse rate.

These indicators are not meant to discriminate true abstainers from bogus abstainers, rather they are proposed as an accompaniment to a smoker's attempt to decrease the risks of smoking by limiting intake of toxic smoke products. The discussion that follows should not be construed as support for the recommendation that smokers who are unable or unwilling to give up cigarettes should smoke "low-yield" cigarettes (Gori, 1976; Gori & Lynch, 1978). There are many unanswered questions about the safety of reduced-yield cigarettes (Kozlowski, in press-a). If the physical indicators described herein were actually applied by would-be "less-hazardous" smokers, I suspect that many would be confronted with evidence that the reduced yields are more apparent than real and that for them this tempting therapy is much more dangerous than the rigors of cigarette abstinence.

With many drugs, it is relatively easy to know one's limits. Two bottles of beer supply a fixed dose of alcohol just about as reliably as two tablets of aspirin deliver a quantity of acetylsalicylic acid. Cigarette smoking, however, is a drug-delivery system for nicotine, "tar" and carbon monoxide that affords no such straightforward way of monitoring dose. Although the words on cigarette packs and advertisements appear to indicate the dose of tar and nicotine to be found in a cigarette, smokers can easily double or triple yields beyond the nominal levels by taking more frequent, larger, or higher velocity puffs (Creighton & Lewis, 1978; Kozlowski, in press-b; Sutton, Feyerabend, Cole, & Russell, 1978). Even the lowest-yield cigarettes on the market (i.e., $\leq$ 6 mg tar, 0.6 mg nicotine) can deliver two times as much nicotine, three times as much tar, and about four times as much

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carbon monoxide, if a smoker simply holds [illegible] filter cigarette [illegible] farther back in the mouth, thereby defeating the purpose of the vents with his or her lips (Kozlowski, Frecker, Khouw, & Pope, 1980a).

Low-yield cigarettes are defined by standard smoking-machine assays of tar and nicotine yield. Smoking machines are puffing machines that take a 2 sec, 35 ml puff on a cigarette every minute until a fixed butt length is reached. The standard smoking-machine assay provides an inadequate model of human smoking behavior for three main reasons. First, as has been alluded to above, smokers tend to compensate for low-yields by altering their way of smoking low-yield cigarettes (e.g., Ashton, Stepney, & Thompson, 1979; Kozlowski, Jarvik, & Gritz, 1975). Second, though the standard parameters are meant to represent the *average* smoker, the standard settings underestimate how the average smoker smokes a modern cigarette (e.g., Creighton & Lewis, 1978; Moody, Averitt, & Griffith, 1973). Third, human smoking behavior is too variable to be adequately represented by an "average" smoking regimen. This point should be expanded, in part because it is not usually mentioned as a problem with the machine assays.

Even if one assumes that the smoking-machine assay gives precise estimates of yields to the "average smoker," this average smoker is only one important summary statistic for the distribution of smoking habits. The other important summary statistic is the population variance, and the variability of smoking parameters is high (Creighton & Lewis, 1978). In an overall sample of 499 smokers, the average number of puffs taken on a cigarette was 9.0 and the standard deviations for the various sub-samples were at least 3.5 (Moody et al., 1973). If other variables are assumed to be constant, these figures can be used to estimate the yields of an average 1.0 mg nicotine cigarette (0.11 mg nicotine/puff for 9 puffs); the change of plus or minus one SD in number of puffs could cause the 1.0 mg nicotine cigarette to yield from 0.6 mg to 1.4 mg nicotine. Under these circumstances the coefficient of variation for nicotine yield to smokers would be 40%. If a standard assay is used, not to discriminate differences in machine-smoked cigarette yields, but rather to discriminate differences in human-smoked cigarette yields, the variability in human smoking behavior needs to be considered, as one would in applying statistical tests to determine if means are significantly different from each other. Table 1 demonstrates some of the implications of taking an estimate of human smoking variability into account. It is assumed that 3.5 is the population standard deviation for numbers of puffs taken on cigarettes. Table 1, Column 1 treats the estimation of nicotine yields to smokers as a problem of statistical estimation of mean nicotine yields given different sample sizes (Dixon & Massey, 1969). The last row shows that, if an individual smoker were to smoke a 1.0 mg nicotine cigarette, his yields would have a 95% chance of falling within the interval from .2 to 1.8 mg nicotine. As the sample size increases, the precision of the estimate increases. Note that if one cares to be as precise with human smokers as one is with smoking machines, a sample of 246 smokers, each smoking the same brand, would be needed. Column 2 shows a *one-tailed confidence interval* ($p < .05$) for a test for differences between means. If a smoker wondered if she were getting less nicotine from her usual brand (e.g., 0.8 mg nicotine) than a friend was getting from his usual brand, it would be likely to be true (95% confidence), only if her friend's brand delivered 1.7 or more mg of nicotine per cigarette. Columns 3 and 4 present a power analysis for the statistical test to detect a difference of .1 mg and .4 mg nicotine, respectively. A power of at least .80 has been recommended as a standard confidence level (Cohen, 1969). Power is defined as the probability that the statistical test will result in the conclusion that a significant difference exists; power is a function of the size of the difference being tested, the reliability of the sample (n), and the significance criterion (here $p < .05$, one-tailed).

This exercise is meant only to illustrate the problems involved. I know of no suitable, public data base that allows one to go beyond the simplifying assumption that only one parameter (here, number of puffs) is varying and provide a composite estimate (based on puff-volume, -velocity and -number) of variability in exposure to smoke from the same cigarette. (For a discussion of other problems with the standard assay, see Kozlowski, Rickert, Robinson, & Grunberg, 1980b.)

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Table 1. Confidence limits for [illegible]

n	Mean[a]	Difference[b]	Power [illegible]	[illegible]
240	±.05	[illegible]	[illegible]	[illegible]
61	±.10	[illegible]	[illegible]	[illegible]
15	±.20	[illegible]	[illegible]	[illegible]
10	±.25	[illegible]	[illegible]	[illegible]
5	±.35	[illegible]	[illegible]	[illegible]
1	±.70	[illegible]	[illegible]	[illegible]

[a] $p = .95$ that a random sample from a [illegible] population will fall within [illegible] population mean.
[b] $p = .95$ that a one-tailed difference between sample means will be at least this large.

Some smokers probably do benefit from switching to low-yield brands or from reducing the number of cigarettes smoked per day, but the nominal yields or a simple count of cigarettes smoked are inadequate indicators of individual exposures—notwithstanding their use by some researchers (e.g., Foxx & Brown, 1979). Diagnostic tests are needed to determine which smokers do benefit from trying to limit their smoke exposure. If one accepts Gori's (1976) metaphor that low-yield cigarettes are a "prescription" for safer smoking, it should be added that this prescription drug requires careful monitoring (as does cortisone), before it is applied in long-term therapy.

EVIDENCE FROM THE APPEARANCE OF SPENT FILTERS

Using the pattern of tar stain to detect hole-blocking of ventilated-filter cigarettes

Ventilated-filter cigarettes have become increasingly popular in recent years. These filters are used in moderate-yield as well as extremely low-yield cigarettes as air-dilution devices, and they cause each puff of smoke to be diluted by up to 75% with air (Brown, Keith, & Allen, 1980). Perforated filters have become a critical factor in the production of low carbon monoxide cigarettes.

We have found that around 40% of low-tar smokers block these ventilation holes with their fingers or lips and, therefore, increase their exposure to toxic products from these cigarettes (Kozlowski et al., 1980a; Kozlowski, Rickert, Pope, Robinson, & Frecker, in press). Most of the individuals who misused the ventilated cigarettes in this way were unaware that they were blocking the holes. So, lecturing to a group of smokers about this problem usually results in skepticism or denial rather than repentance and promises to do better. Luckily, insofar as the perforations have been blocked, the stain pattern on the smoker end of the filter changes. In an unblocked filter, air, rather than smoke, passes through the periphery of the filter and a discrete "bull's-eye" of stain is found in the center of the filter. When a smoker blocks the vents, smoke, rather than air, is drawn through the periphery of the filter, and a more uniform field of tar stain can be seen on the entire end of the filter. (See Kozlowski et al., 1980a, for more on this and for a chemical analysis that can be used to confirm hole-blocking.)

Smokers should be taught to inspect their filters regularly, to make sure that they are not interfering with the ventilation holes. (Lipstick over the holes is another useful sign of hole-blocking.) The technique is most useful for categorizing cigarettes (smokers) into only three categories: (1) vents probably not blocked at all, (2) unable to judge, and (3) vents probably blocked completely. Any finer quantification is prevented by imperfections in cigarette construction that can cause variation in the stain pattern. For example, sometimes the seam on the filter wrapping blocks a few holes and gives the appearance that one finger may have blocked the holes. In effect, then, this technique will catch only very extensive hole-blocking (as the lips might accomplish). Since occasionally a filter has not been vented properly at the factory and will produce a stain pattern indicative of complete hole-blocking, collecting a sample of several cigarettes is necessary, before making judgements about a smoker's habits.

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[illegible] reliable information about partial hole blocking may be [illegible]

The stain-pattern technique can also be used to discover if a cigarette is [illegible] brands (e.g., *Merits* in the United States and *Accord* in Canada) are ventilated [illegible] not at all obvious from looking at the filter wrapping. All smokers should be [illegible] their brand (especially if it delivers 10 mg or less tar in the standard assay), by [illegible] to minimize how far the cigarette is placed in the mouth and how often the [illegible] filter wrapper. Dissecting the filter and holding the wrapper up to the light [illegible] used to reveal rows of vent holes on cigarettes that do not look vented. If [illegible] know that their brand is ventilated and exactly where the vent holes are found, [illegible] they be expected to avoid blocking them?

Using intensity of tar stain to detect intensive smoking

The term "intensive" has been employed to describe smoking a cigarette so as to derive high yields, for example, by taking larger or more frequent puffs (Sutton et al., 1978). If smokers decided to stay with their usual brand, but, as a health measure, decided to cut down on the number of cigarettes smoked per day, more intensive smoking could eliminate the benefits of the reduction. The intensity or "darkness" of the tar stain on the end of the filter could be used as an indicator of changes in the intensiveness of smoking: The darker the stain, the more tar and nicotine have reached the smoker's mouth.

Before discounting such an approximate measure of tar and nicotine yield, note how modest my aspirations are for it and consider that some information under the circumstances, is probably better than none. First, this technique does not seem appropriate for most smoker-to-smoker comparisons, but should be reserved for measuring changes in the smoking habits of individual smokers. Second, it can provide only a rough, ordinal scale (decrease, no change, increase) of changes in yield from the same brand of cigarette. Filter efficiency (i.e., the percentage of material presented to the filter that remains in the filter) is decreased by high-velocity puffing (Creighton & Lewis, 1978). As a result, some increases in exposures would not be detected by this technique. The more sensitive butt-nicotine analyses (e.g., Forbes, Robinson, Hanley, & Colburn, 1976; Kozlowski, 1976; Schulz & Seehofer, 1978) are equally prone to this failing, since they do depend upon the often unwarranted assumption of constant filter efficiency (Creighton & Lewis, 1978) to predict mouth level exposures from the amount of nicotine found in the filter.

We know from a pilot study that individuals can faultlessly discriminate a cigarette filter that has had six puffs taken on it from one that has had 12 puffs taken on it, simply by judging which has the darker stain. We do not know how fine the discriminations can get, but we are confident that smokers can use this system to provide a benchmark of smoking intensiveness that they can try to stay at or below.

A smoker might try to learn how his or her filters look, after they have been smoked under controlled conditions; then, as the number of [illegible]rettes smoked per day is reduced, an effort should be made to keep the intensity of the sta[illegible] at or below this threshold level. From time to time, a cigarette might be smoked in [illegible]y specific manner (e.g., one puff every 40 seconds or every minute) and the stain intensity of this cigarette could be used for comparison with other cigarettes that had been recently smoked. (Due primarily to oxidation, the color of the stain will vary as a function of how long ago the cigarette was smoked.)

Some additional points

In the case of vented cigarettes, both the intensity and pattern of stain should be used to help the smoker control the yields from these cigarettes. One hopes that, just as many drivers develop the habit of glancing at the speedometer to monitor speed, smokers will develop the habit of regularly glancing at their spent filters to monitor their intake of smoke.

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EVIDENCE FROM CHANGES IN HEART RATE

The first physiological fact that most researchers learn about nicotine [illegible] heart rate (e.g., Jarvik, 1979). I propose that this fact be used as the basis for [illegible] nicotine. One recent study in humans (to pick one of several) supports this pro[illegible] et al., 1979). The effects of two high nicotine cigarettes (1.5 mg per cigarette) [illegible] compared with those of two low nicotine cigarettes (0.08 mg per cigarette). M[illegible] plasma nicotine and heart-rate were taken at 1, 10, 20, 45, and 120 min after smoking. The high nicotine cigarettes increased heart-rate by an average of 22 beats/min; the low nicotine cigarettes caused an increase of 10 beats/min. Almost exactly congruent curves were found for plasma levels of nicotine and heart-rate (r = .96).

The use of heart rate as an indicator of smoking should be subject to most of the same restrictions as the other indicators that I have discussed. Since there are large individual differences in the tolerance to the heart rate effects of nicotine, the measure will be of little use in comparing smokers. Smokers should test for themselves the efficacy of this indicator, by checking if a cigarette does increase their heart rate. The most sensitive procedure would be to, either first thing in the morning or after at least one hour's abstinence, have the smoker take a precigarette pulse rate (a 15 or 30 sec sample should do) and a pulse rate approximately one min after smoking. The test should be repeated three or four times on separate occasions, before any conclusions are made. (A counselor might provide some statistical support at this point.) The heart rate effects of a low-yield cigarette could be tested in each individual who wanted to try reduced-yield smoking. If there were not smaller heart rate increases from these cigarettes, it would suggest that an even lower-yield cigarette should be tried, or that intensive smoking was such a problem that it might prevent the success of this form of therapy.

If these preliminary tests were encouraging, smokers should establish solid baselines on their usual brand, that is, one to two weeks of heart rate measures (before and after the first cigarette, a midday cigarette and an evening cigarette), before switching to the low-yield brand. For the first few weeks and periodically thereafter, heart rate tests should be performed. Obviously, the data-analytical chores can become considerable and the "patients" would need to be provided with kits to help them record and evaluate this information. (Perhaps the ability to balance a checkbook or to fill out income tax forms should be a prerequisite for those who could use this technique on their own.)

Of course, the smokers should be warned that changes in cardiovascular conditioning, for example, as the result of an exercise program or weight gain, could confound this procedure. The results of the periodical tests of resting heart rate could be used to help prevent misleading conclusions.

Some general benefits

The bookkeeping involved with this procedure may be cumbersome, but the procedure has some important nonspecific effects. Personal acquaintance with the heart rate effects of cigarettes may provide additional incentive to cut down or give up smoking. The performance of the heart has emotional significance, and if acute "benefits" to the heart can be felt immediately under the fingertips, it may add to the smoker's conviction to decrease risks.

PERSONAL RESPONSIBILITY AND LOW-RISK SMOKING

The application of these indicators does not require special equipment or blood-letting. These indicators could easily be applied as a package, and they have the advantage of placing the responsibility for less-hazardous smoking where it should reside, not in government regulations or manufacturer's promises, but in the individual smoker's concern for promoting his or her own health. Since the individual smoker is the primary benefactor or victim of the low-yield therapy, the individual should be motivated to monitor his or her exposure to cigarette smoke. This recommendation is consistent with the growing movement toward medical self-care.

Most smokers tell us that they have decided to smoke low-yield brands because they believe them to be "safer" (Kozlowski [illegible]). Unless the low-yield [illegible] [illegible] seriously mistaken about how [illegible] low-yield smoking, however, the smoker [illegible]. The application of [illegible] she is in control of the risks of cigarette [illegible] educated consumers who [illegible] discussed here (and others) can help smokers [illegible] control over their smoking behavior.

The goal of the applications of these physical indicators is to reduce smoke intake [illegible] minimum. There are likely to be large individual differences in the level at which [illegible] minimum occurs. We have argued (Herman & Kozlowski, 1979; Kozlowski, 1980) that there is an above-zero, biologically-based threshold in dependent smokers (the exact threshold varies from smoker to smoker) that causes them to suffer when they try to reduce their consumption below that level (cf. the stuck-points in Shapiro, Schwartz, Tursky, & Shnidman, 1971.) Reductions below this lower boundary are believed to be equivalent to complete abstinence. Psychosocial factors (e.g., living or working with heavy smokers) can cause an individual's smoke intake to be well above this lower boundary or, alternatively, (e.g., a long-standing effort to keep smoke intake to a minimum) just above this lower boundary (cf. Kozlowski, 1980). At best, low-yield therapies can help the smoker minimize exposure to needless excesses of the toxic ingredients in cigarette smoke. If an individual smoker's lower boundary is relatively high, there may be substantial risks to maintaining consumption even at that level. Even so, if the psychosocial context is contributing greatly to surplus dosing (i.e., smoking more than one "needs" to), then, the application of the self-monitoring techniques may be helpful in reducing risks.

A closing note on applications

I have stressed the use of these techniques by smokers. Some researchers may have need for these methods. After all, standard yields and simple counts of cigarettes smoked can be misleading indicators of smoking behavior—even to those researchers who already employ some of the chemical procedures for evaluating exposure. For example, ventilated-filter cigarettes have been found to deliver relatively high levels of carbon monoxide to smokers (Wald, Idle, Smith, & Bailey, 1977); one wishes that the stain-pattern technique had been available, to determine if hole-blocking, rather than some other change in smoking behavior, were responsible for this effect.

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