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# How Does Puffing Behavior Alter During the Smoking of a Single Cigarette?

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GUYATT, A. R., A. J. T. KIRKHAM, A. G. BALDRY, M. DIXON AND G. CUMMING. *How does puffing behavior alter during the smoking of a single cigarette?* PHARMACOL BIOCHEM BEHAV **33**(1) 189–195, 1989.—We examined changes in puffing behavior during the course of a single cigarette in 76 subjects seen on 6 occasions each (456 cigarettes). The puff volume fell on average by 33% during a cigarette and puff duration by 39%, the interpuff interval rose by 75%, but the pressure drop and the maximum flow and pressure achieved during puffing hardly changed. There were highly significant differences between subjects but not between sessions, or when subjects were grouped according to tar yield of the cigarette or by sex. Individual puff volumes with a single cigarette were highly correlated with puff duration (except in a few individuals with irregular puffing patterns), but not generally with maximum flow rate, suggesting that most smokers reduce volume by taking shorter puffs. This is unlikely to reflect mechanical factors or smoke temperature, and may be a response to changing smoke composition. Variation in puffing patterns between individuals may reflect differences in sensitivity to smoke components, and individuals who show little fall in puff volume also show small responses on switching to cigarettes with different tar and nicotine yields. The individual response to smoke might be assessed by an analysis of puffing on a single cigarette.

Cigarette smoking Puff-by-puff analysis Smoke handling behavior Puff volume changes Sensory control Variability of subject sensitivity

THE changes in the way in which a smoker puffs during the course of a single cigarette may provide important information regarding the control of the smoking process. We have examined this possibility using data from a previously described laboratory study (10) comprising 456 separate studies (76 subjects seen 6 times). During each study a cigarette was smoked through a holder incorporating a resistive element (8) and 8 separate measurements were made on each puff.

Many workers have measured puffing behavior on cigarettes using such systems (24), but usually express the data as mean values per cigarette. The references to changes during a cigarette are more limited, normally consisting of brief annotations in other studies. Puff volume has been shown to fall (1, 5, 9, 11, 15, 27), while puff duration either decreased (1, 6, 17, 22, 27) or stayed constant (9). The interpuff interval increased (1, 5, 6, 22), but sometimes decreased again towards the end of the cigarette (9) while the pressure drop across the cigarette varied very little (3,15).

We reexamined these effects by calculating for each study regressions for each measurement against time. We also estimated the correlations between the various measurements and confirmed our earlier observations of a strong correlation between puff volume and duration (15), suggesting the puff volume is controlled by varying duration. However, we found marked individual variations and decided to use the coefficient of the correlation as a criterion for subdividing subjects, with a view to identifying different paterns of puffing.

## METHOD

### *Subjects*

Seventy-six volunteers (30 male, 46 female, smoking at least 10 manufactured cigarettes per day) were seen on 6 occasions each, at monthly intervals, smoking one cigarette of their usual brand. Fifty-nine of the subjects made an additional visit to smoke a cigarette with machine tar and nicotine yields below or above their usual brand. The experimental protocol was approved by the Ethical Committee of the Institute and every subject gave informed consent in writing before beginning.

Although the tests were performed throughout the day and evening, each individual was requested to attend at the same time for each visit, and where possible, on the same day of the week. They were allowed to smoke normally before coming to the laboratory except that they were asked to abstain for at least 30 minutes before the test.

### *Measurements*

Puffing measurements were made with the subject sitting in a comfortable chair, in a special room, smoking through a holder with a 2-mm orifice (8,10). The duration of each puff was recorded together with the interpuff interval. The flow and pressure channels were integrated with time to give puff volume and a pressure integral, this latter index being a function of the work expended during the puff. The maximum flow rate and pressure were recorded, together with the period needed to reach maximum pressure after the beginning of the puff (i.e., latency). The pressure drop across the cigarette was calculated at the standard flow of 17.5 $ml \cdot s^{-1}$(P17.5).

*Change With Time*

For each of the 456 studies, indices of change were derived for the 8 separate measurements. Linear regressions equations were derived of the form:

$$y = a + b \cdot t$$

where y is one of the 8 measurements and t is the elapsed time from lighting up. The data from the first and last puffs were ignored; the lighting puff tends to be irregular while the final puff is often very small, probably because the subject senses a rise in temperature (10). A count was made of the individual regression equations which gave significant negative or positive slopes ($p<0.05$). The linearity of the relationships was examined by analysis of covariance to see if the second order polynomial gave a significantly better fit (23). This was tested for all 456 tests separately or for the 76 subjects after pooling all the data on their 6 visits.

A "change index" was derived from the regression equation for each cigarette and each of the 8 measurements of the form:

$$(Y_2 - Y_{n-1})/\text{mean } Y$$

where $Y_2$ and $Y_{n-1}$ are the values of the variable in question at the start of the second and penultimate puffs as estimated using the regression equation, and mean Y is averaged over the same data. The normality of data was tested for each index by calculating the index of skewness on all 456 studies (23), but in no case was the skewness index significant, and parametric tests have been applied throughout. We also examined the effect of alinearity by recalculating the "change index" using the second order polynomial rather than the linear regression.

No measurements were made of smoke temperature, but we estimated it using a model derived from an in vitro study (10). Temperature was derived for each puff using an equation incorporating the volume, elapsed time and pre- and postsmoking cigarette lengths. Corrected volumes were calculated using this estimate and the "change index" obtained from these.

The data were examined by two-way analysis of variance to see if there were significant "between-subject" and "between-session" differences. The former effect indicates systematic differences between individuals and the second some effect of time such as a training effect. The data were also subdivided according to the tar yield of the cigarette smoked (below and above 10 mg) and by sex, and examined for significant differences.

*Interrelationship of Measurements*

An alternative method of examining the data was to see if there were interrelationships between the various measurements within a single cigarette, between, for example, puff volume and duration or pressure integral and pressure drop. With 8 measurements there are 28 ways in which two values can be chosen, and correlations were obtained for each case, again ignoring the first and last puffs and pooling the data for each subject. The percentage of significant negative and positive slopes were recorded for each of the 28 cases, and the data are presented as a matrix.

*Variations in Puffing Behavior*

We estimated the mean coefficient of correlation for the puff volume, puff duration correlation, and used this as a criterion to subdivide the data into 8 groups. With values of r below .45, less than 20% of the variance could be explained by the relationship while if it exceeded .89, over 80% of the variance can be attributed to it.

TABLE 1

SUMMARY OF ANALYSES ON EIGHT MEASUREMENTS OF PUFFING

| Index | Significant Regressions Negative % | Positive % | 2nd Order Significance Better Fit n=456 % | n=76 % | Between Subjects F sig. | Between Sessions F sig. |
|---|---|---|---|---|---|---|
| Puff duration | 65.6 | 0.2 | 13.8 | 36.8 | 6.16† | 1.74NS |
| Interpuff interval | 0.2 | 69.3 | 18.4 | 67.1 | 4.71† | 2.56* |
| Puff volume | 64.5 | 1.1 | 7.7 | 31.6 | 6.47† | 1.36NS |
| Maximum flow | 8.6 | 12.9 | 8.6 | 13.2 | 3.07† | 1.55NS |
| Pressure integral | 66.9 | 0.7 | 10.5 | 31.6 | 6.05† | 2.44* |
| Maximum pressure | 13.4 | 9.9 | 8.1 | 17.1 | 3.12† | 1.92NS |
| Latency | 22.6 | 2.2 | 3.7 | 13.2 | 2.93† | 1.17NS |
| P17.5 | 20.8 | 14.3 | 14.9 | 17.1 | 2.34† | 1.75NS |

Percentage of significant regression equations negative and positive shown in columns 1 and 2. Percentage of analyses where second order equation gave significantly better fit, in column 3 all studies, in column 4 after pooling data for each subject. Analysis of variance on "change indices" between subjects (column 5, degrees of freedom 75 and 375) and between sessions (column 6, degrees of freedom 5 and 375). Codes for significance levels, NS=$p>0.05$, *$p<0.05$, †$p<0.01$.

*Brand Switching*

For the 59 subjects in whom brand switching data were available, a "switch index" was derived to express the changes in mean puff volume of the form:

$$(V_A - V_B) \times 100/(V_A + V_B)/2$$

where $V_A$ and $V_B$ are the mean puff volumes before and after switching. A correlation was then calculated between these data and the corresponding "change index" for puff volume on the same visits. (The "change index" values were combined for each subject as there was no significant difference between the pre- and postswitch data sets.) The change in machine nicotine yields on switching ("nicotine change") varied according to the brands smoked so a multiple regression was also calculated with the "change index" as the independent variable and the "switch index" and "nicotine change" as the dependent variables.

## RESULTS

*Change With Time*

For each index the percentage of the 456 studies in which the individual regression slopes were significantly negative or positive is shown in Table 1, colums 1 and 2. The majority of the puff volume, puff duration and pressure integral regressions showed significant negative slopes, while most interpuff interval slopes were positive. The other measurements showed a minority of

TABLE 2

SUMMARY OF ANALYSES ON EIGHT MEASUREMENTS OF PUFFING

| Index<br>Number | Average Value for Cigarette<br>All<br>76 | "Change Index" (%)<br>All<br>76 | <10 mg<br>19 | >10 mg<br>57 | Male<br>30 | Female<br>46 |
|---|---|---|---|---|---|---|
| Puff duration (sec) | 2.10 ±0.62 | −39.0 ±19.2 | −42.6 ±3.5 | −37.7 ±2.7 | −41.9 ±3.8 | −37.1 ±2.7 |
| Interpuff Interval (sec) | 32.9 ±12.8 | 75.8 ±31.4 | 80.9 ±5.8 | 74.2 ±4.4 | 72.5 ±6.0 | 78.0 ±4.5 |
| Puff volume (ml) | 47.2 ±14.6 | −33.0 ±19.2 | −34.2 ±3.9 | −32.6 ±2.6 | −32.7 ±3.6 | −33.2 ±2.8 |
| Maximum flow (ml/sec) | 40.4 ±10.6 | 1.0 ±11.2 | 0.5 ±2.9 | 1.1 ±1.4 | 3.4 ±1.8 | −0.6 ±1.8 |
| Pressure integral (kPa·sec) | 3.73 ±0.13 | −34.6 ±19.1 | −35.4 ±3.4 | −34.3 ±2.7 | −35.5 ±3.6 | −33.9 ±2.8 |
| Maximum pressure (kPa) | 3.21 ±0.10 | −2.1 ±13.8 | −1.8 ±3.7 | −2.2 ±1.7 | −0.1 ±2.1 | −3.4 ±2.2 |
| Latency (sec) | 0.69 ±0.32 | −24.9 ±24.8 | −24.2 ±5.9 | −25.1 ±3.3 | −27.2 ±4.5 | −23.4 ±3.7 |
| P17.5 (kPa) | 1.38 ±0.15 | −1.5 ±6.1 | −1.2 ±1.3 | −1.6 ±0.8 | −3.0 ±1.1 | −0.6 ±0.9 |

Mean values per cigarette, column 1, "change indices" columns 2 to 6 for all subjects, those smoking cigarettes with less or more than 10 mg tar and male and female. Data averaged for each subject before analysis with mean and standard deviation (columns 1 and 2) or standard error of the mean (columns 3–6).

significant regressions, these being presumably due to chance.

The next two columns consider the percentage of studies in which the second order polynomial gave a significantly better fit. In column 3, the data from each cigarette was considered separately and in most cases the second order polynomial did not produce significant improvements. When the data were pooled first (column 4), the only relationship which showed significant alinearity in most subjects was the interpuff interval time comparison. For most individuals the interval increased rapidly over the first few puffs then more slowly thereafter.

On substituting the second order polynomial equation for the linear regression in the "change index" for puff volume, we obtained a mean value of −33.7% on 456 studies as opposed to −33.0 for the linear equation. Although this difference is highly significant ($p<0.001$), it is very small. A bigger difference was produced by correcting for temperature, giving an average fall of −39.2%, similar to the "change index" for puff duration, −39.8%. We repeated all the analyses involving puff volume using these corrected values but found no material differences from those involving the uncorrected data. Accordingly we have used the uncorrected linear data throughout.

The two-way analyses of variance are also summarised in Table 1. There were highly significant between-subject differences for all indices, but the only significant between-session changes were for the interpuff interval and pressure integral, significant at the 5% level only. The largest changes with time for the interpuff interval occurred on sessions 1 and 6, while the pressure integral showed the smallest fall on the first visit. Since there were only fairly small differences between sessions, in the rest of this presentation we have combined the data from each subject before analysis, so that the standard deviation (SD) or standard error of the mean (SEM) corresponds to 76 observations.

The actual magnitude of the various measurements is shown in Table 2, column 1, representing the mean value for the cigarette excluding the first and last puffs. The remaining 5 columns correspond to the "change indices," with all the subjects together, subdivided according to the type of cigarette (less or more than 10 mg machine tar yield) and by sex. There were no significant differences between measurements in either subdivision. The largest "change index" was seen with the interpuff interval which nearly doubled. Puff duration, puff volume and pressure integral decreased between 30% to 40% but there was virtually no change in P17.5, maximum flow or maximum pressure. The latency fell about 24%, that is the point of maximum pressure was reached earlier in the puff, equivalent overall to 0.17 sec, but the average fall in puff duration was 0.81 sec (39% fall), so that the main effect is a truncation of the last part of the puff.

### *Interrelationship of Measurements*

The individual correlations calculated for the data pooled for each subject are summarised in Table 3 as a matrix showing the

TABLE 3

SUMMARY OF CORRELATIONS BETWEEN 8 INDICES FOR DATA WITHIN INDIVIDUAL CIGARETTES

| | Puff Duration | Maximum Flow | Pressure Integral | Maximum Pressure | Latency | P17.5 | Interpuff Interval |
|---|---|---|---|---|---|---|---|
| Puff volume | +80.3<br>−0.0 | +27.6<br>−0.0 | +94.7<br>−0.0 | +21.0<br>−0.0 | +0.0<br>−19.7 | +0.0<br>−13.2 | +0.0<br>−3.9 |
| Puff duration | | +0.0<br>−7.9 | +76.3<br>−0.0 | +0.0<br>−5.3 | +0.0<br>−17.1 | +2.6<br>−0.0 | +0.0<br>−9.2 |
| Maximum flow | | | +21.0<br>−0.0 | +96.0<br>−0.0 | +0.0<br>−1.3 | +0.0<br>−3.9 | +0.0<br>−0.0 |
| Pressure integral | | | | +42.1<br>−0.0 | +0.0<br>−13.2 | +21.0<br>−0.0 | +0.0<br>−3.9 |
| Maximum pressure | | | | | 0.0<br>−3.9 | +19.7<br>−0.0 | +0.0<br>−0.0 |
| Latency | | | | | | +1.3<br>−0.0 | +0.0<br>−0.0 |
| P17.5 | | | | | | | +0.0<br>−0.0 |

Percentage of regressions of pooled data (total 76) significant at 5% level or less (+ and − indicate positive and negative correlations).

percentage of the 76 studies yielding respectively significant positive and negative correlation coefficients. Puff volume and the pressure integral were correlated in almost all subjects, and in most cases, with puff duration. In a few subjects puff volume was correlated with maximum flow and inversely with latency, while in a minority of subjects the pressure integral was correlated with maximum pressure and flow and P17.5. The only other correlation shown by most subjects was between maximum pressure and flow.

### *Variation in Puffing Behavior*

The subdivision of the subjects according to the coefficient of correlation for puff volume against puff duration within each study is shown in Table 4 with the data divided into 8 groups. For each subgroup, the range of r values are shown, with the extent to which the correlation explains the variance shown in brackets. Group 1, for example, represents 7 subjects in whom there is virtually no relationship between puff volume and duration while group 8 includes 10 in whom the two measurements seem directly proportional. The subjects were evenly spread throughout the groups irrespective of sex or tar level of the cigarette. In the fifth column the r values for the correlation between puff volume and maximum flow are shown as the mean and SEM values for each subgroup. The highest values were found in the first few groups where the correlation between puff volume and duration is weak, but the values were normally less than for the puff volume duration correlations. The change index for puff volume (column 6) became progressively more negative as the correlation between puff volume and duration increased.

We identified the four subjects with the weakest and strongest correlations between puff volume and duration, and show typical chart records of draw pressure they developed during smoking (Fig. 1). The first two subjects, with an insignificant correlation, gave a very irregular puffing pattern with the maximum flow rate varying unpredictably from puff to puff. By contrast, the two subjects with the strongest correlation were much more consistent in their puffing pattern. We expressed this effect by deriving for each study the coefficient of variation for maximum flow rate (SD/mean) and this is shown in Table 4 last column. (Maximum flow was chosen since it shows no marked change during smoking, Table 2.) The coefficient of variance tended to decrease as the correlation between puff volume and duration improved. In a group of 151 smokers, including 75 additional individuals with incomplete records, there was a significant negative correlation between the two coefficients ($r = -.51$).

### *Comparison With Switch Data*

The absolute difference in the machine nicotine yield on switching was $0.419 \pm 0.161$ mg for 59 subjects. The simple correlation showed a significant negative correlation between the "change index" for puff volume and the "switch index" (coefficient $-.341$, $p<0.01$). The multiple regression analysis showed a significant negative correlation comparing the "change index" with the "switch index" and "nicotine change" together, F ratio of 3.73 on 2 and 56 degrees of freedom ($p<0.05$), but there was no significant correlation between the "change index" and the "nicotine change" ($F=0.08$ on 1 and 56 degrees of freedom).

## DISCUSSION

The most important change in puffing behavior during a single cigarette is the reduction in puff volume since this directly effects smoke uptake (28). 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 their own idiosyncratic pattern. Most subjects control puff volume by varying the duration [(6,15) and present study], mostly by truncating the later part of the puff. The maximum flow rate hardly altered during smoking, although a few subjects showed a significant correlation

TABLE 4

SUBDIVISION OF SUBJECTS ACCORDING TO THE DEGREE OF CORRELATION BETWEEN PUFF VOLUME AND DURATION MEASURED WITHIN AN INDIVIDUAL CIGARETTE

| Range of r values | Number of Subjects Sex | | <10 mg Tar | >10 mg Tar | r for puff vol vs. max flow | Change Index for Puff Volume | | Coefficient Variation Max Flow | |
|---|---|---|---|---|---|---|---|---|---|
| 0–0.45 (0–20%) | 5M | 2F | 2 | 5 | .354 ± .121 | −13.1% | ±4.3 | 20.0% | ±3.5 |
| .45–.55 (20–30%) | 1M | 3F | 2 | 2 | .528 ± .109 | −33.9% | ±9.2 | 17.0% | ±3.2 |
| .55–.63 (30–40%) | 2M | 6F | 0 | 8 | .273 ± .077 | −20.5% | ±5.1 | 13.2% | ±1.9 |
| .63–.71 (40–50%) | 4M | 8F | 3 | 9 | .285 ± .080 | −26.6% | ±5.8 | 13.5% | ±1.5 |
| .71–.77 (50–60%) | 3M | 2F | 3 | 2 | .300 ± .079 | −27.8% | ±2.2 | 11.5% | ±1.0 |
| .77–.84 (60–70%) | 6M | 8F | 3 | 11 | .201 ± .046 | −31.6% | ±3.0 | 11.9% | ±0.7 |
| .84–.89 (70–80%) | 6M | 10F | 2 | 14 | .081 ± .069 | −43.1% | ±4.9 | 11.9% | ±0.7 |
| .89–1.0 (80–100%) | 3M | 7F | 4 | 6 | .116 ± .088 | −52.5% | ±5.0 | 10.2% | ±0.8 |

For each category, the numbers of each sex and those smoking cigarettes with less or more than 10 mg tar; the mean and SEM for coefficient of correlation between puff volume and maximum flow; the slope of puff volume against time and the coefficient of variation for maximum flow measurements during each cigarette.

between this and puff volume. This effect could represent an alternative but weaker control mechanism for volume or just be the result of random variations in flow rate. Most subjects showed a smooth decrease in puff volume and puff duration during smoking as might be expected for an ingrained habit with constant reinforcement. A minority, however, have a very variable pattern

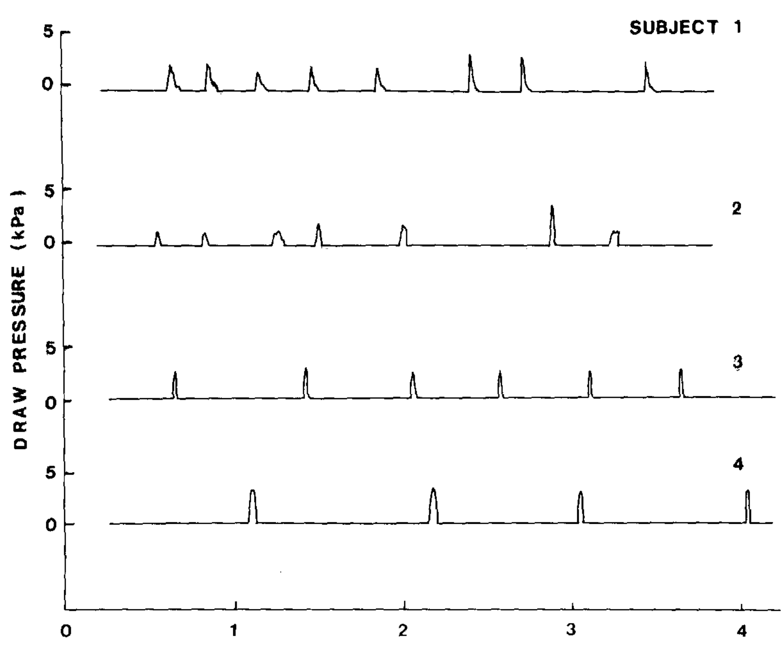


FIG. 1. Chart recordings of draw pressure during smoking in two subjects showing a very weak correlation between puff volume and duration (top two panels) and two showing a very strong correlation (bottom two panels).

almost as if they had either never learnt to smoke evenly or were not responding consistently to the cigarette.

Before seeking to explain this effect, it is necessary to consider instrumental and statistical factors and the physics of smoking. The use of a holder to monitor puffing behavior must inevitably distort smoking to some extent, but without such a device most of the measurements would be impossible. However the analyses of variance (Table 1) suggest that the different subjects smoked consistently on the different occasions since few of the between session comparisons were significant. A holder does have the advantage of preventing the subject blocking the ventilation holes on low tar cigarettes and increasing the tar and nicotine deliveries (21).

A basic limitation in this type of investigation is the small number of data points per cigarette (the mean number of puffs in this study was 14.25, range 8 to 28). This predisposed us to use simple statistical methods, primarily the linear regression against time, permitting the use of a single index to represent change. We justified this by showing that the second order polynomial equation only gave a significantly better fit to the data in a small minority of cases (Table 1) and that its use had very little effect on the puff volume "change index."

Some of these relationships may be truly curvilinear, but the higher order equations needed to demonstrate them require more data to establish them unequivocally. Pooling data from six cigarettes did increase the proportion of studies where the second order equation gave a significantly better fit (Table 1), but in only one measurement, the interpuff interval, did this occur in a majority of subjects. A complex analytical method has been described (5) to examine alinear relationships between the cumulative puff volume and time. It uses a third order polynomial (equivalent to the second order puff volume, time equation) on data from a single cigarette, but in view of the foregoing discussion, we question the validity of this approach and believe our methods to be more statistically realistic.

There is a very close resemblance between the flow and pressure records during puffing; records on a chart recorder of the two signals look almost identical. There is a high correlation between the equivalent values, maximum flow and pressure and puff volume and pressure integral and they change in a similar way with time. This is consistent with the observation that the tobacco rod acts a linear resistance (13) which stays constant throughout the course of smoking the cigarette. We found the pressure drop only fell on average by 1.52% (P17.5, Table 1), similar to our earlier observations (15) and an in vitro study (3). (In the latter work, a terminal rise may reflect the use of constant suction rather than discrete puffs.)

The consistancy of P17.5 during smoking is due mainly to the concentration of resistance in two regions, the burning coal where the hot gases have a high viscosity (3) and in the filter. The impedance in both regions remains fairly constant, and will tend to mask small fluctuations elsewhere. The resistance of the tobacco rod might be expected to fall as it shortens to a third or less of its original length, but this is probably counteracted by the deposition of tar on the unburnt tobacco. Also the area through which air enters the cigarette will decrease substantially as the porous paper is burnt away, thus increasing impedance. [This picture is slightly complicated since the paper just behind the burning coal is much more porous than the rest (4).]

It is therefore difficult to explain puff volume changes during smoking by mechanical factors. An inverse relationship has been shown between puff volume and pressure drop using various filter rods and special cigarettes (20), and under carefully controlled conditions a direct relationship between puff duration and pressure drop (18). However, in the present study, puff volume and duration changed in the same direction during smoking, while, as already noted, neither pressure drop or maximum pressure altered appreciably.

There might be a response to the rise in smoke temperature towards the end of the cigarette (18,26). In a separate analysis of the present data (10), we showed that the final puff was much smaller than expected when the cigarette was smoked down within 5 mm of the butt, although the maximum flow rate hardly changed. This suggests that if the subjects sensed an excessive temperature, they responded by curtailing the puff immediately. However, by itself, this will not explain the steady reduction in puff duration during the course of smoking [(18) and current study] which will begin well before any temperature rise would be expected. As noted above, temperature changes will affect the volume measurements leading to an underestimate of the "change index." In future studies it would be advantageous to record temperature to correct for these effects, but it is unlikely that this will materially alter the conclusions since, as noted above, the uncorrected and corrected data gave similar results in the various analyses used here.

Another possible mechanism for reducing puff volume during a cigarette concerns the rise in arterial levels of nicotine (2). Buzzi *et al.* considered evidence that this might produce a satiation effect (5), although they themselves discounted it. We cannot make direct investigations since the study was not designed for the purpose; no additional nicotine was administered, nor was smoking controlled except for a restriction of half an hour before the test. (Since each subject came at the same time of day and the same day for each visit, their presmoking status was fairly constant, but varied widely between individuals.) However, the maintenance of such a critical arterial level of nicotine would require control of both the size and timing of individual puffs and we find no evidence of this; the interpuff interval is not correlated with puff volume, or indeed any of the other measurements we considered.

The most likely explanation of fall in puff volume during the cigarette relates to the puff-by-puff increases in tar and nicotine deliveries (25) due to deposition of tar in the unburnt tobacco and its subsequent revaporization as the cigarette shortens. [Similar increases have been shown in the number of particles per unit volume (12, 14, 16, 19) and carbon monoxide (7).] As the delivery of nicotine increases through the cigarette the smoker may compensate by taking smaller puffs. This effect has been shown repeatedly in brand switching experiments (24) where the mean puff volume per cigarette increases when a cigarette with a lower nicotine yield is smoked or falls with a higher yield cigarette.

Individuals may vary in their sensitivity to changes in smoke composition. A "responder" would show a marked fall in puff volume during a cigarette (negative "change index"), while a "nonresponder" might show no change at all (zero "change index"). Similarly the "responder" would increase mean puff volume on brand switching much more than the "nonresponder," (larger "switch index"). This would explain the significant negative correlation we found between the "switch index" and "change index" for puff volume in 59 subjects.

Our analyses suggest that "nonresponders" might be recognised by their irregular puffing patterns, and although we have no formal proof we have a little anecdotal support. One subject with an irregular pattern kept changing brands indiscriminately over the full range available as if he was quite indifferent to what he was smoking while another man was prepared to smoke any cigarettes offered including some left in an opened packet for several months.

We conclude that future studies of puffing behavior should consider the changes occurring during the course of a cigarette as well as mean values. We observed a considerable variation in smoking behavior among established smokers, and believe that this should be allowed for in future smoking studies. It may prove possible to distinguish the response of any individual to tobacco smoke from the puffing pattern on a single cigarette.

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