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Effects of Smoking Abstinence and Chain-Smoking on Puffing Topography and Diurnal Nicotine Exposure

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KOLONEN, S., J. TUOMISTO, P. PUUSTINEN AND M. M. AIRAKSINEN. *Effects of smoking abstinence and chain-smoking on puffing topography and diurnal nicotine exposure.* PHARMACOL BIOCHEM BEHAV **42**(2) 327-332, 1992.—Effects of chain-smoking, a 15-h smoking abstinence, and the nicotine yield of cigarettes on puff indices were studied in eight healthy smokers by using a controlled crossover study design. Puff parameters were measured puff by puff with a portable measuring device when 10 or 20 cigarettes, with nicotine yields of 0.3 and 1.0 mg, were smoked per day. The interval between sessions was 1 h, and the 20 cigarettes per day were chain-smoked 2 at a time. Serum cotinine indicated that smokers compensate completely for the lower nicotine delivery from the 0.3-mg cigarette. Smokers almost doubled total puff volume per cigarette and per day mainly by taking more puffs from the low-nicotine cigarettes and slightly prolonging puff duration. However, nicotine deprivation and chain-smoking had a relatively minor effect on puffing indices with both brands, a fact that agrees poorly with the nicotine titration hypothesis. However, in the course of every single cigarette of the day smokers significantly reduced puff duration and puff volume toward the end of the cigarette, which probably involves satiation of the nicotine crave but may also be due to changes in taste of the smoke.

Cigarette smoking Nicotine Cotinine Abstinence Puff parameters Microcomputer Behavior

PUFFING parameters under laboratory conditions have usually been measured by quite solid orifice flowmeters (5,8) or by noninvasive spirometric methods (4). Also, a portable device using a holder-pressure transducer system has been utilized that gives detailed information about puffing frequency (10,11). The device used in the present study was additionally constructed to make volumetric measures.

Puffing behavior of smokers is sensitive to alterations in nicotine/tar availability and more affected by the delivery of nicotine than of tar (12). The important role of nicotine in regulating smoke intake has been shown in various brand-switching studies and by administration of excess nicotine (17). However, to our knowledge the effect of chain-smoking on nicotine intake and puffing pattern has not been studied by other groups, whereas compensatory response to an increased presentation of cigarettes has been investigated by Gritz et al. (7). Also, detailed volumetric data about puff parameter after a long smoking abstinence is rather limited (12,24).

This study was carried out to investigate the effects of nicotine intake on puffing patterns while smoking a single cigarette 1) after a 15-h period of smoking abstinence and 2) after an excess nicotine delivery by chain-smoking cigarettes and 3) the effects of the nicotine yield of the cigarette. The smoking pattern was investigated puff by puff with a microcomputer measuring system developed specifically for this purpose.

METHOD

Subjects and Cigarettes

Eight healthy habitual smokers who had smoked 9.6 ± 9.2 years (mean ± SD) medium-yield cigarettes (15.7 ± 5.1 per day) were admitted to this study. The volunteers, three females and five males, 28.9 ± 8.1 years of age were randomly divided into two groups. Volunteers whose preferred cigarette brand varied (nicotine 0.7–1.0 mg and tar 9.0–15.0 mg/cigarette) smoked in a randomized order both low-yield (nicotine 0.3 mg, tar 4.5 mg) and medium-yield cigarettes (nicotine 1.0 mg, tar 15.6 mg). The test cigarettes were kindly donated by the Finnish tobacco companies and obtained directly from the production line.

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Procedure

The study design was crossover, where subjects smoked both low- and medium-yield cigarettes. The experiment was started with a 2-day nonsmoking period. Thereafter, subjects smoked 10 cigarettes per day for 2 days and 20 cigarettes per day for 2 days (in all, 480 cigarettes/day). The interval between smoking sessions was 1 h, and the 20 cigarettes per day were chain-smoked 2 at a time. One group smoked low-yield and the other medium-yield cigarettes that were provided in coded plastic bags each morning, and the volunteers were not informed as to the strength of their cigarettes. The smoking sessions were arranged in a test room with minimal extraneous disturbance 0800 to 1700 h. Subjects were instructed not to smoke during the remainder of the time (nicotine abstinence) and informed that this would be controlled by analyses. After the first 6-day period, there was a 2-week pause during which subjects smoked their preferred brand in their habitual way. Then, the groups were crossed over and another 6-day experiment was carried out identical to that described above. Special attention was paid to guarantee a relaxed atmosphere in spite of the laboratory conditions.

All cigarettes smoked on the second and fourth smoking days were puffed through a holder connected to the flowmeter unit, which measured puff duration, flow rate of smoke, single puff volume, puff volume per cigarette and day, interpuff interval, and number of puffs.

Venous blood samples were drawn at 0800 before smoking and at 1500 after the eighth, or sixteenth, cigarette of the day. Samples were stored at −20°C until analyzed by high-performance liquid chromatography (HPLC) (14).

Recording and Analyzing System

Analysis of puffing parameters was performed by a portable microcomputer-assisted device (16). Briefly, the measurement system was based on the Bernoulli equation, which states that the pressure difference is proportional to the square of flow. The measuring device consisted of a portable microcomputer (Epson HX-20, GmbH, Düsseldorf, FRG) with a microcassete unit and an IBM-compatible personal computer (Medikro 386-33C, Medikro Ltd, Kuopio, Finland). Subjects smoked cigarettes through a holder having an orifice flowmeter that measured pressure difference as an analogy signal by a differential type transducer (Micro Switch 142PC01D, Honeywell Div., Brussels, Belgium) that was transformed to numerical data by an analogy-digital converter (ADC0844, National Semiconductor GmbH, Munich, FRG).

After smoking a cigarette, the data was automatically stored on microcassette (max. puff curves of 20–30 cigarettes per cassette). On the following day, the data were transferred from cassette to the hard disc through an RS-232C interface. The portable microcomputer was programmed by the extended version of Microsoft Basic, and statistical programs (Stats+™, StatSoft, Inc., Tulsa, OK) were used for handling the ASCII characters and performing the statistical tests. All six devices used in this study were calibrated with a syringe (60 ml) before and after measurements on the test days. Subjects were personally trained to use the device on the day preceding the first test day.

Puff-by-puff analyses with both brands were made for selected cigarettes along the test day in the following way: 10 cigarettes/day—first, second, fifth, sixth, ninth, and tenth cigarette; 20 cigarettes/day—first, second, tenth, eleventh, nineteenth, and twentieth cigarette. Within a cigarette, the three first, three middle, and three last puffs were used for the statistical analyses.

Data Analysis

Calculations and statistical analyses were performed with Stats+ microcomputer programs. Differences between groups were analyzed by repeated-measures analysis of variance (ANOVA) with posthoc comparisons by the Scheffè multiple-comparison test (21). The differences within the three groups while smoking different test cigarettes were examined using the Friedman two-way ANOVA by ranks followed with multiple comparisons between the smoking blocks (18). Specific comparisons between the habitual brand of subjects and the test brands are not given in the text because the cigarette brands used by different individuals had different tar/nicotine yields.

RESULTS

Effects of Nicotine Yield and Smoking Deprivation on Puff Parameters

Serum cotinine concentrations varied according to the number of cigarettes smoked but there were no significant differences between the test cigarettes (Fig. 1A). However, the difference in puff volume between brands was almost two-fold ($p < 0.01$, Fig. 1B). Total puff volume with 10 low-yield cigarettes was (mean ± SEM) 642 ± 69 ml and for medium-yield cigarettes 335 ± 51 ml, $F(1, 14) = 12.86$, $p < 0.01$, with 20 low-yield cigarettes 603 ± 63 ml and medium yield cigarettes 349 ± 55, $F(1, 14) = 9.32$, $p < 0.01$ (Table 1).

The mean puff volume varied notably without any clear trend when measured cigarette by cigarette. Puff volumes with medium-yield cigarettes were smaller in every cigarette smoked but the difference was only occasionally statistically significant ($p < 0.05$). Smokers increased the total puff volume during the course of the day when smoking low-yield cigarettes, but they decreased it when smoking 20 medium-yield cigarettes ($p < 0.001$, Table 1).

Table 1 shows cigarette by cigarette that smokers took considerably fewer puffs from the medium-yield brand than the low-yield brand during the day when they smoked either 10 cigarettes, $F(1, 14) = 8.91$, $p < 0.01$ or 20 cigarettes, $F(1, 14) = 7.30$, $p < 0.025$.

When the first two "morning" cigarettes (first and second) and last two "evening" cigarettes (nineteenth and twentieth) were smoked sequentially, no substantial changes in volumetric measures were observed between the chain-smoked cigarettes of the same brand (Table 1). Also, the number of puffs taken from the cigarettes were quite stable when 10 or 20 low-yield cigarettes were smoked. However, smokers took significantly more puffs from the last 2 of the 10 medium-yield cigarettes, $\chi^2 = 10.38$, $p < 0.001$, when compared with the previous cigarettes of the day. With the dose of 20 medium-yield cigarettes a day, the results were opposite, $\chi^2 = 10.36$, $p < 0.001$.

Puff-by-Puff Changes Within Single Cigarettes

Puff duration shortened during the smoking of a single cigarette so that the three last puffs were 16–22% shorter than the three first puffs, $\chi^2 = 9.00$, $p < 0.001$. However, no significant difference in puff duration was found between the 10- and 20-cigarette days or the two brands (Figs. 2 A and B).

The flow rate was quite stable, although it tended to be higher during the last puffs from a cigarette than from the middle. The trend was significant when 20 medium-yield cigarettes were smoked per day, $\chi^2 = 4.75$, $p < 0.01$ (Figs. 2 C and D).

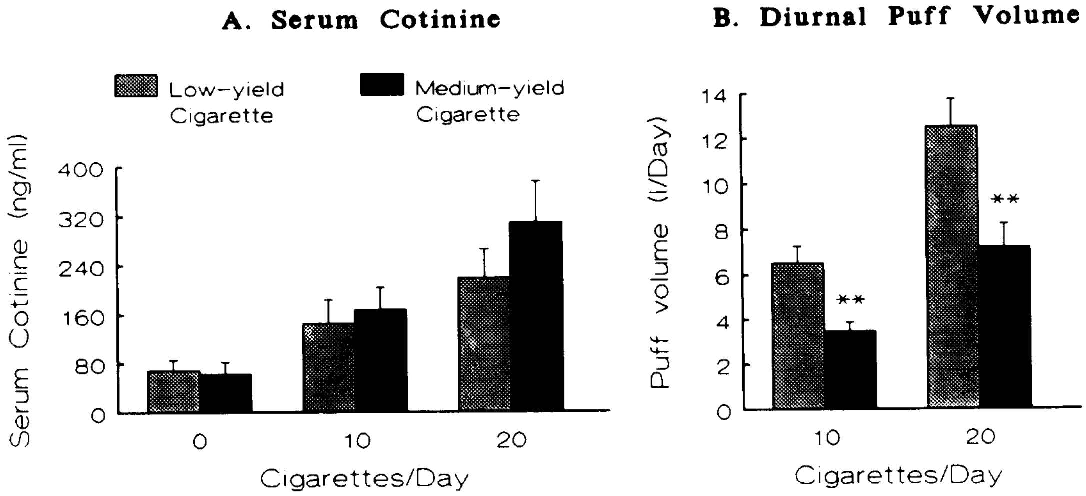

FIG. 1. (A) Serum cotinine concentrations before smoking and after 10 or 20 cigarettes per day and (B) total puff volumes per day with both cigarette brands. Mean ± SEM (eight subjects). $^{**}p < 0.01$ (ANOVA).

Puff interval (interpuff interval) measured puff by puff varied in the same way with both cigarette types. Intervals between the three puffs taken in the middle of the cigarette were longer than between the first three and the last three puffs, $\chi^2 = 12.25, p < 0.001$ (Fig. 2 D and F).

Puff volumes from single cigarettes reflected differences in puff duration and flow rate. The results suggest that smokers take smaller puffs at the end of a cigarette (Figs. 2 and 3). In spite of the variation in single puffs and between subjects, this trend was rather obvious. The drop in puff volume along the cigarette was found to be significant ($p < 0.01$) with the dose of 10 ($\chi^2 = 4.75$) and 20 ($\chi^2 = 5.00$) low-yield cigarettes. With the medium-yield cigarettes, a decreasing trend was constantly observed with 10 cigarettes per day, $\chi^2 = 3.25, p < 0.05$, but only occasionally with 20 cigarettes per day (Fig. 3).

DISCUSSION

Nicotine is the essential physically addictive substance in tobacco, and serious smokers smoke to prevent withdrawal

TABLE 1

MEAN VALUES OF SOME PUFF PARAMETERS OF THE SINGLE CIGARETTES DURING THE TEST DAYS WHEN 10 OR 20 LOW- AND MEDIUM-YIELD CIGARETTES WERE SMOKED

	Number of Puffs		Puff Volume (ml)		Total Puff Volume/Cigarette (ml)	
Order of Cigarettes	L-Y	M-Y	L-Y	M-Y	L-Y	M-Y
10 Cigarettes/day						
1st	19.0*	12.3	32.9	25.6	611*	289
2nd	18.5†	13.6	33.5	30.5	652*	364
5th	18.9†	13.5	38.0†	25.9	710*	336
6th	18.0*	12.1	35.2	24.0	616*	283
9th	18.3*	13.0	37.5	26.4	659‡	334
10th	17.8	14.8	34.7	27.8	604†	403
X§	18.4	13.2	35.3‡	26.7‡	642‡	335‡
SE	1.5	1.1	3.9	4.5	69	52
20 Cigarettes/day						
1st	18.5	14.0	32.8	29.7	559†	396
2nd	17.6	13.4	36.8	28.1	544†	393
10th	18.4†	12.1	33.6	30.0	577*	323
11th	18.5	14.4	39.4†	22.5	670*	317
19th	19.5*	11.9	35.5	35.6	652*	361
20th	18.5*	11.6	35.5	30.8	629*	304
X§	18.5*	12.9‡	35.6†	29.5*	605‡	349‡
SE	1.9	1.5	5.0	5.9	63	52

Values are mean ± SE. LY and MY, low- and medium-yield (tar/nicotine) cigarettes.

$^*p < 0.01$, $^\dagger p < 0.05$, $^\ddagger p < 0.001$ between cigarette brands (ANOVA), §between cigarettes across the day (Friedman ANOVA by ranks).

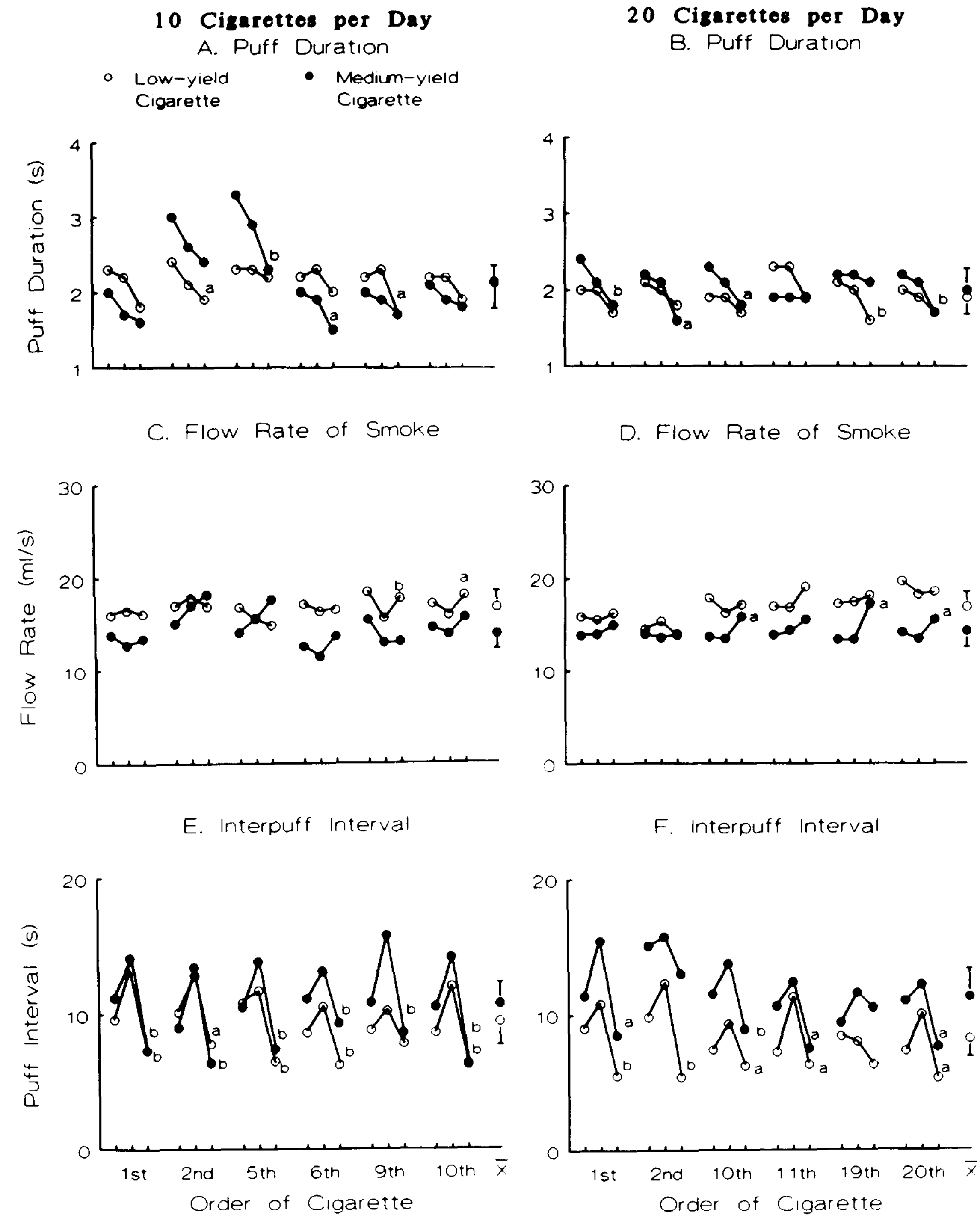

FIG. 2. Average puff durations, flow rates, and puff intervals of the three first, middle, and last puffs in six single cigarettes during the various test days under laboratory conditions. X, mean ± SE (eight subjects); a, $p < 0.05$; b, $p < 0.01$; c, $p < 0.001$ (Friedman ANOVA) between first and last three puffs (puff duration) or middle and last three puffs (flow rate and interpuff interval).

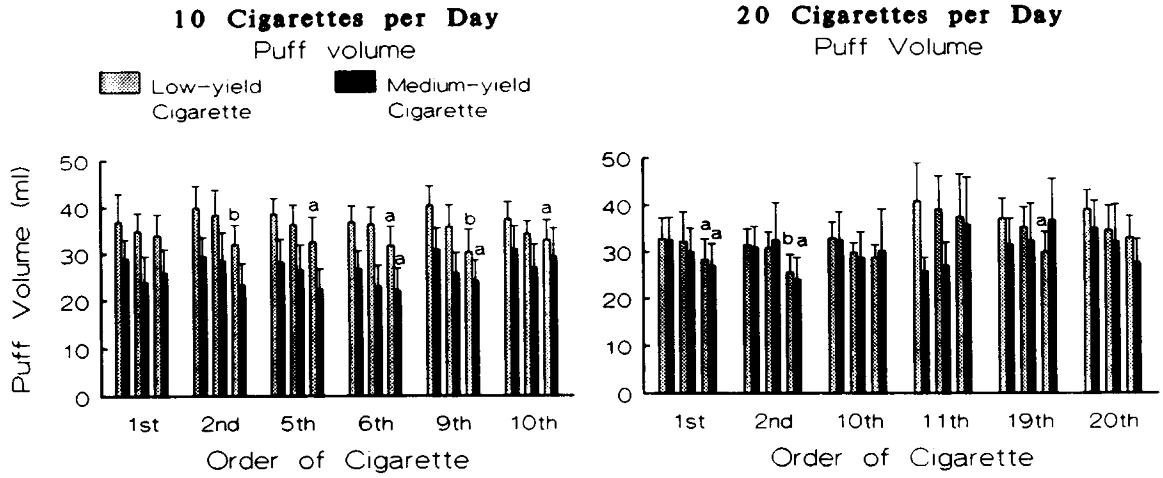

FIG. 3. Puff volume of the three first, middle, and last puffs in six cigarettes during the smoking day under laboratory conditions. Mean ± SE (eight subjects). a, $p < 0.05$; b, $p < 0.01$ (Friedman ANOVA).

symptoms. Brand-switching studies have shown that smokers up- or downregulate their smoke intake by changing volume of puff and inhalation to maintain their desired levels of nicotine (11,14,17). As serum cotinine in the present study and smoke exposure indicators in some other experiments suggest, smokers seem to compensate for the lower delivery of nicotine and tar almost completely (11,14,19). Primarily, smokers seem to change their puff volume by changing the number of puffs, puff duration, and puff interval according to the nicotine yield of the cigarette. Nevertheless, the regulation measured by puff volume has usually remained incomplete if compared against the standardized machine-smoking deliveries for the brands; this was found also in this study. However, one should note that we do not know the true delivery of nicotine and tar in the real smoking situation. Further, it is also important to notice that smokers inhale only 46–85% of the puffed smoke (22) and may vary the percentage according to nicotine crave.

The role of nicotine in puffing behavior is important but its role on the puff-by-puff level is rather obscure. The present and previous (8,9,22,23) results have shown that smokers reduce puff duration and puff volume and change puff interval during the course of every single cigarette. Furthermore, results suggest that the interpuff interval first increases (3,9) and then decreases toward the end of the cigarette while the pressure drop across the cigarette remains fairly constant (9,15). Also, inhaled smoke volume seems to decrease as the cigarette is smoked (22). Puff duration seemed to be the primary mechanism of control, but interpuff interval is also important as Bridges et al. (2) recently proposed. The fall in puff duration and volume is in agreement with puff-to-puff increases in nicotine and tar deliveries (20) due to deposition of these substances in the unburnt cigarette and its subsequential revaporization partially as the cigarette burns. Thus, smokers may down-regulate by taking smaller puffs when the delivery of nicotine levels increase near the end of the cigarette. The results agree with earlier studies. However, it should also be taken into account that the rest of the cigarette also contains many pyrolytic and pyrosynthetic products of tobacco that may effect the taste of the smoke and therefore its desirability. The flow rate stayed rather constant during the smoking, and it may well be that subjects found it simple to control puff volume by curtailing puff duration rather than by altering flow rate (15).

The present results show that an overnight abstinence of smoking (the nicotine deprivation condition) does not change puffing behavior significantly during the smoking of a single cigarette, which has also been found via puff parameters during the first cigarette of the day (12), Also, Zacny and Stitzer (24) found that smokers do not increase puff volume after a deprivation of 300 min. Further, it has been shown that smokers have quite a high blood level of nicotine in the morning due to the accumulation of nicotine by day (1), and for that reason they may not have a great need to change puff intensity. Furthermore, in an experimental setting smokers took significantly more puffs after 30 min deprivation than after overnight deprivation, which was explained to be due to a lack of acute tolerance to nicotine's effects after longer deprivation (13).

During chain-smoking (the nicotine satiation condition), puff volumes of two sequential cigarettes were almost similar, which is poorly fitting with the nicotine hypothesis. However, one cigarette pacing study (7) has shown that in the quadruple rate condition compared to the ordinary rate smokers decreased puff volume per cigarette but it was not as substantial as in the present study. In another study where the experimental deprivation interval was either 3, 30, or 300 min from the last puff of the baseline, cigarette smokers took, on the average, 904, 1041, and 1304 ml smoke per cigarette, respectively, and there were no differences in mean puff volumes (24). The results suggest that only the general trend is influenced by blood nicotine, but at the level of a single cigarette learned and indirect determinants may be more important. Also, other factors such as cigarette design, taste, and flavor are probably involved (6).

In conclusion, the present study suggested that smokers compensate almost completely for lower nicotine delivery of the cigarette. Smokers increase puff volume by prolonging puff duration and taking more puffs from the low-nicotine cigarettes. However, nicotine deprivation and chain-smoking had only a minor effect on puffing indices, which fits poorly with the nicotine titration hypothesis. On the other hand, in the course of every single cigarette smokers significantly reduce puff duration possibly due to condensation and revaporization of nicotine and tar on the remaining tobacco. Also, taste of the smoke may not be so pleasing nearer the end.

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