

# Determinants of Puff Duration in Cigarette Smokers: I

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NEMETH-COSLETT, R AND R. R GRIFFITHS. *Determinants of puff duration in cigarette smokers I* PHARMACOL BIOCHEM BEHAV 20(6)965-971, 1984 —This research was undertaken to provide information about variables that might account for the decreases in puff duration that consistently occur as a whole cigarette is smoked. Cigarette smoking was investigated under conditions in which subjects smoked cigarettes which they could not see. In a series of three experiments, the length of the tobacco rod, the length of the cigarette holder, and the cigarette nicotine delivery were systematically manipulated. The results showed that puff duration correlates with the length of the tobacco rod, and that visual stimulus control, satiation, distance from the burning ember to the smoker's mouth, nicotine delivery, particulate build-up during smoking, and subjective acceptability of cigarette smoke do not contribute significantly to the control of puff duration.

Cigarettes    Smoking    Tobacco    Nicotine    Self-administration    Humans

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WHILE it is generally believed that cigarette smoking is a widespread form of human drug self-administration [3, 4, 9], the variables that control this behavior are poorly understood. For example, over the years, the role of nicotine in maintaining cigarette smoking has received extensive attention and investigation, but it has been difficult to isolate nicotine's contribution experimentally [4, 8, 10]. At least part of the reason for relatively slow progress in understanding variables controlling smoking has been the reliance of investigators on relatively gross measures of cigarette smoking (e.g., total number of cigarettes smoked, number of puffs taken, etc.) which provide only crude approximations of smoking behavior. Over the past few years, however, more sophisticated measuring techniques have become available which now allow researchers to assess a much wider variety of potential functionally relevant aspects of smoking topography (cf., [13]).

The duration of individual puffs represents one such measure. Data obtained from surreptitious observation of smokers in a natural environment [11] suggested that puff duration progressively decreases as a cigarette is smoked. Using objective measurement procedures in a laboratory setting, Chait and Griffiths [1] confirmed that puff duration decreased as a function of the ordinal position of the puff within a full length cigarette. By using modified half-length cigarettes and analyzing smoking on a puff-by-puff basis, Chait and Griffiths showed that puff duration was correlated with the distance from the burning tip (ember) of the cigarette to the smoker's mouth, and not correlated with ordinal puff number. They pointed out that a variety of factors (in-

cluding changes in resistance to draw, pharmacological delivery, and temperature) could possibly change as a function of ember-to-mouth distance, and thus account for this effect.

The present series of studies was undertaken to further investigate variables controlling the duration of individual puffs. To eliminate expectational effects, a novel methodology was used throughout the studies in which subjects smoked cigarettes which they could not see. In the first study, smoking was characterized under conditions which eliminated visual stimulus control and by having subjects puff from cigarettes of different lengths. In addition, by studying a series of puffs from each cigarette, the first study provided information concerning the possible role of satiation in controlling puff duration. The second study was a systematic replication of the first in which both tobacco rod length and distance from the burning ember to the smoker's mouth were manipulated. The third study in the series provided information about the role of nicotine in controlling puff duration by using the same methodology to assess smoking of research cigarettes which varied in nicotine delivery.

## METHOD

### *Subjects*

Male and female cigarette smokers were recruited through local newspaper advertisements to serve as subjects. Measurement of carbon monoxide (CO) in samples of expired air [7] indicated that all subjects were inhalers (mean pre-session CO levels ranged from 14 to 58 ppm). The subjects were paid weekly at a mean rate of \$8 per session.

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TABLE 1  
SUBJECT CHARACTERISTICS AND EXPERIMENTAL ASSIGNMENT

Subject	Age (years)	Sex	Years Smoking	Preferred Brand*	Self-Reported Cigarette Consumption (per day)	Experiments
EN	38	M	29	Kent III (12, 0 90)	30	1,2
RJ	50	M	40	Kool (17, 1.1)	50	1,3
TH	34	M	17	Marlboro 100s (17, 1 1)	40	2
JV	30	F	13	Marlboro box (16, 1.1)	40	1,2,3
BR	49	F	33	Kool Super Long (14, 1 0)	50	1,2,3
KD	32	F	15	Marlboro Box (16, 1 1)	30	1,3
DG	24	F	8	Marlboro Box (16, 1 1)	30	1,3
DF	27	F	10	Marlboro 100s (17, 1 1)	30	2
SD	29	F	17	Marlboro 100s (17, 1 1)	20	2

\*Tar (milligrams) and nicotine (milligrams), respectively, are presented in parentheses. Estimates are based on a report of the Federal Trade Commission, March, 1983

Subject characteristics and experimental assignment are presented in Table 1.

#### Setting and Apparatus

The setting and apparatus have been described in detail [1,5]. The test rooms were equipped with a comfortable armchair for the subject, a chair for a research technician, a television set, a smoking console and a one-way observation window. The console contained a session light, a depository for cigarette butts and a pressure transducer. During experimental sessions, subjects smoked all cigarettes through a plastic cigarette holder. The holder was connected via a 2-m length of tube (2 mm, o.d.) to the pressure transducer which operated a relay following a decrease in pressure ( $>5$  mm Hg) induced by puffing on a cigarette. The pressure transducer and the other components of the console were interfaced with a computer that recorded and controlled experimental events.

#### General Procedures

Each subject was run individually at the same time each day, five days a week. During sessions they were required to smoke through the plastic holder. They were not permitted to eat or drink while in the test room, but they were allowed to watch television or read a daily newspaper. In order to acclimate the subjects to this test environment, for each of the first five sessions they were provided with cigarettes of their preferred brand and allowed to smoke as much or as little as they desired.

All of the subsequent experimental sessions were conducted in an identical fashion. Upon arrival to the laboratory, the subject was seated in the test room and required not to smoke. Fifteen minutes later, an expired air CO sample was taken. A research technician who was seated in a chair directly behind the subject then lit a cigarette, and placed it in the plastic holder which was now mounted in a funnel-like apparatus. With the exception of changes in Experiment 2, all holders were a standard length of 35 mm. The funnel-like apparatus allowed the subjects to hold the cigarette without seeing the cigarette. A stopwatch was started, and every 45

seconds the funnel was handed to the subject, who took one puff and returned the funnel to the research technician. The cigarette could be removed and replaced without the subject's knowledge if the conditions of the study warranted such a change. The procedure was continued until eight puffs (Experiments 1 and 2) or two puffs (Experiment 3) had been taken. This series of puffs constituted a trial-block. Fifteen minutes (Experiments 1 and 2) or 45 seconds (Experiment 3) later, the procedure was repeated. Daily sessions consisted of two (Experiment 1), three (Experiment 2) or eight (Experiment 3) trial-blocks.

Following each trial-block, subjects were required to rate: The taste of the cigarette (very bad/very good); the strength of the cigarette (very weak/very strong); how "hot" the cigarette was (no heat/very hot); the harshness of the cigarette (very mild/very harsh); the draw of the cigarette (easy/hard); the satisfaction they derived from the cigarette (very unsatisfying/very satisfying). These measures were obtained by having the subjects mark vertical lines along a 100 mm bipolar visual analog scale for each of the six questions. Although time limits for completion of these ratings were not imposed, all subjects readily made their assessments within 30 seconds after the last puff.

#### Experiment 1. Manipulation of Cigarette Length

Daily sessions consisted of two trial-blocks involving eight puffs each. For the first (Baseline I) and last (Baseline II) five days of the study, each block consisted of eight puffs spaced approximately 45 seconds apart from the subject's preferred cigarette brand—the cigarette was not replaced between puffs. This Baseline condition was conducted to determine whether smoking a whole cigarette through a funnel would produce topographical changes similar to those reported previously during ad lib smoking (cf., [1]). Following Baseline I, each session continued to consist of two blocks, with eight puffs in each block. However, one block now consisted of one puff from each of eight full length cigarettes (Full Length) while the second block consisted of one puff from each of eight cigarettes which had been precut to produce just 5 mm of smokable tobacco (Butt). For all con-

ditions, the cigarette filters were left intact. Full Length and Butt blocks were quasi-randomized daily, and this experimental phase continued until data from 10 blocks, or 80 puffs in each condition has been obtained

#### Experiment 2: Manipulation of Cigarette Length and Distance From the Mouth

The second experiment was designed to provide information about cigarette length versus the distance from the smoker's mouth to the burning ember as controlling variables for puff duration. In a systematic replication of Experiment 1, subjects were now presented daily with the funnel for three trial-blocks, consisting of eight puffs each. Two of the three blocks were identical to the conditions of Experiment 1 (i.e., the Full Length and Butt conditions), except the holder was shortened to approximately 15 mm. The third condition (Butt Long Holder) consisted of cigarettes which had been precut to produce 5 mm of smokable tobacco and which were placed in a long plastic holder (approximately 70 mm). For all conditions, the cigarette filters were left intact. While the length of the tobacco rod in this Butt Long Holder condition was comparable to the Butt condition, the distance from the smoker's mouth to the burning end of the cigarette was comparable with the Full Length condition. The funnel blocked from the subject's view both the length of the holder and the length of the rod. As in Experiment 1, trial-blocks were quasi-randomized and were continued until 10 blocks or 80 puffs in each condition had been completed.

#### Experiment 3. Manipulation of Nicotine Delivery

In order to assess the relative contribution of nicotine concentration to changes in puff duration, three different nicotine concentrations from each of two different brands of research cigarettes were tested. Cigarettes from each brand were designed to vary in nicotine yields while being similar to yield of other tobacco components (e.g., tar; carbon monoxide), as well as in other physical characteristics (e.g., length; burn rate; resistance to draw). All cigarettes were unfiltered, and 85 mm in length. The cigarettes were stored frozen; they were conditioned at room temperature and 60% relative humidity for at least 48 hours before use. With regard to the different brands, a series of cigarettes manufactured for the National Cancer Institute (NCI) had nicotine deliveries of 0.16, 0.89 and 2.02 mg [2], while a series of cigarettes supplied by the Tobacco and Health Research Institute at the University of Kentucky (Kentucky) had nicotine deliveries of 0.48, 1.17 and 2.46 mg [12].

The design was similar to that of Experiments 1 and 2. Since there were no differences in puff duration across the eight sequential puffs of same-length cigarettes in the previous experiments, the trial-block size was reduced from eight to two puffs. Four experimental conditions were examined for each of the two cigarette brands: 1. Low Nicotine Full Length; 2. Middle Nicotine Full Length, 3. High Nicotine Full Length; 4. Middle Nicotine Half Length. The two cigarette brands were quasi-randomized over days. Daily sessions consisted of eight trial-blocks consisting of two presentations of each of the four experimental conditions in a quasi-random order. As in previous experiments, subjective ratings were obtained after each trial block. This experiment continued until 20 puffs in each of the eight experimental conditions had been obtained.

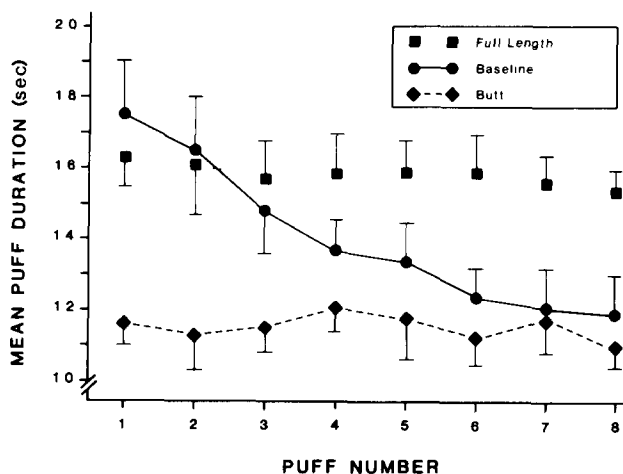


FIG. 1. Group mean puff duration as a function of sequential puff number for the Baseline (Baseline I and II collapsed), Full Length, and Butt conditions of Experiment 1. Data points represent means and brackets show 1 S.E.M. for mean data from six subjects ( $n=6$ ).

#### Data Analysis

For each of the three experiments, mean puff duration for each sequential puff and mean subjective rating scores were computed for individual subjects. These data were analyzed using a two-factor repeated measures analysis of variance. Unless otherwise stated, all reported differences were significant at or below the 0.05 level. The Newman-Keuls test was employed for post-hoc comparisons.

## RESULTS

#### Experiment 1: Manipulation of Cigarette Length

Puff duration during Baseline I and II in which whole cigarettes were smoked reliably and consistently decreased across eight puffs:  $F(7,35)=10.56$  for Baseline I;  $F(7,35)=15.15$  for Baseline II. Since there were no significant differences between Baseline I and II  $F(1,5)<1$ , the data were collapsed and group means are presented in Fig. 1. Also depicted in Fig. 1 are the mean puff durations in the Full Length and Butt conditions. Puff durations in the Full Length condition were significantly greater than in the Butt condition  $F(1,5)=40.23$ . In contrast to the decreases obtained during the Baseline condition, there was no significant decrease in puff duration across the eight puffs in the Full Length  $F(7,35)<1$  or the Butt  $F(7,35)=2.05$ ,  $p>0.05$  condition. Furthermore, each of these treatment conditions was significantly different from the Baseline condition  $F(2,15)=16.19$ .

Figure 2 shows that while there were substantial differences across the six subjects both in absolute puff durations and the magnitude of experimental effects, the effects revealed in the group data are apparent within each individual subject.

Mean ratings of cigarette characteristics are presented in Fig. 3. Subjects rated the Butt condition as significantly stronger, hotter, harsher, worse tasting and less satisfying than either the Full Length or Baseline conditions, which

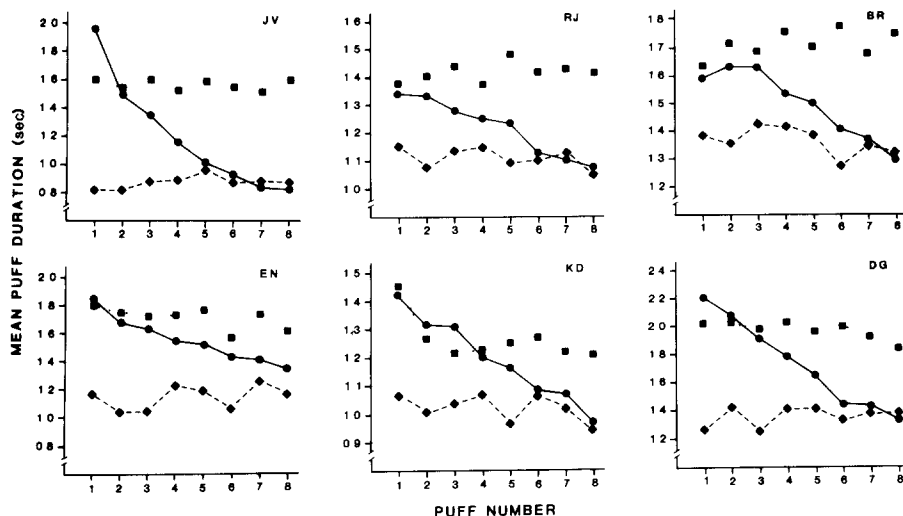


FIG 2 Mean puff duration as a function of sequential puff number for all six subjects in Experiment 1 for the Baseline (Baseline I and II collapsed) (●—●), Full Length (■ - - - ■), and Butt (◆—◆) conditions

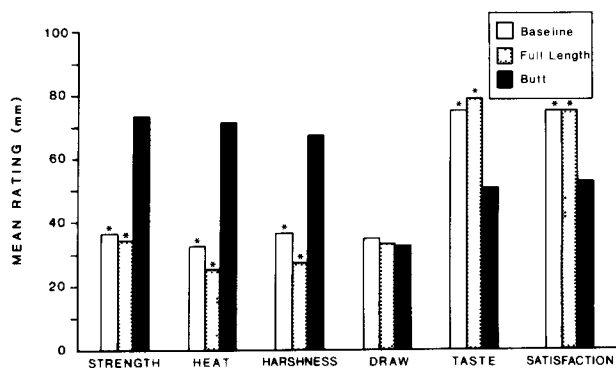


FIG 3. Group mean subjective ratings for the three experimental conditions of Experiment 1. Asterisks indicate that the condition was significantly different ( $p < 0.05$ ) from the Butt condition. There were no significant differences between the Full Length and Baseline (Baseline I and II collapsed) conditions

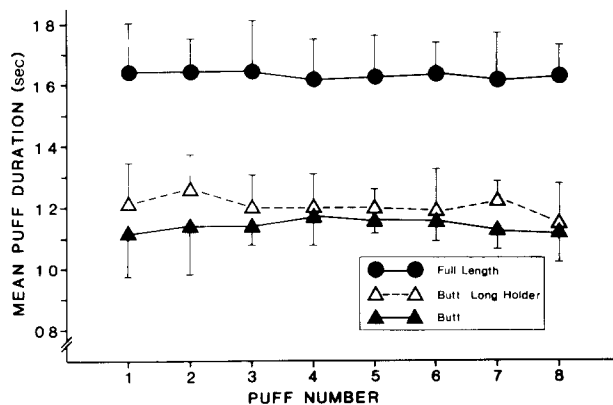


FIG 4 Group mean puff duration as a function of sequential puff number for the Full Length, Butt Long Holder and Butt conditions of Experiment 2. Data points represent means and brackets show 1 S.E.M. for mean data from six subjects ( $n=6$ )

were not significantly different from each other. The only subjective measure which showed no significant effect was draw.

*Experiment 2. Manipulation of Cigarette Length and Distance From the Mouth*

Figure 4 shows the group means for the Full Length, Butt and Butt Long Holder conditions. There was a significant treatment effect  $F(2,12)=27.77$ , and a Newman-Keuls test showed that the Full Length cigarettes were smoked with a significantly longer puff duration than either the Butt or Butt Long Holder conditions. There was no significant difference between the Butt and Butt Long Holder conditions.

As in Experiment 1, although subjects differed in magnitude of effect and absolute puff duration, the effects shown

in the group data are apparent within the individual subjects (Fig. 5).

Although analysis of subjects' ratings of cigarette characteristics showed no significant differences on draw between the three treatment conditions, there were significant differences on all of the other subject rated measures (Fig. 6). As in Experiment 1, the Butt condition was rated significantly stronger, hotter, harsher, worse tasting, and less satisfying than the Full Length condition. The Butt Long Holder condition was identical to the Butt condition, except that it was also rated as being significantly less hot, better tasting, and more satisfying than the Butt condition.

*Experiment 3 Manipulation of Nicotine Delivery*

Puff durations for the Full Length cigarettes were not

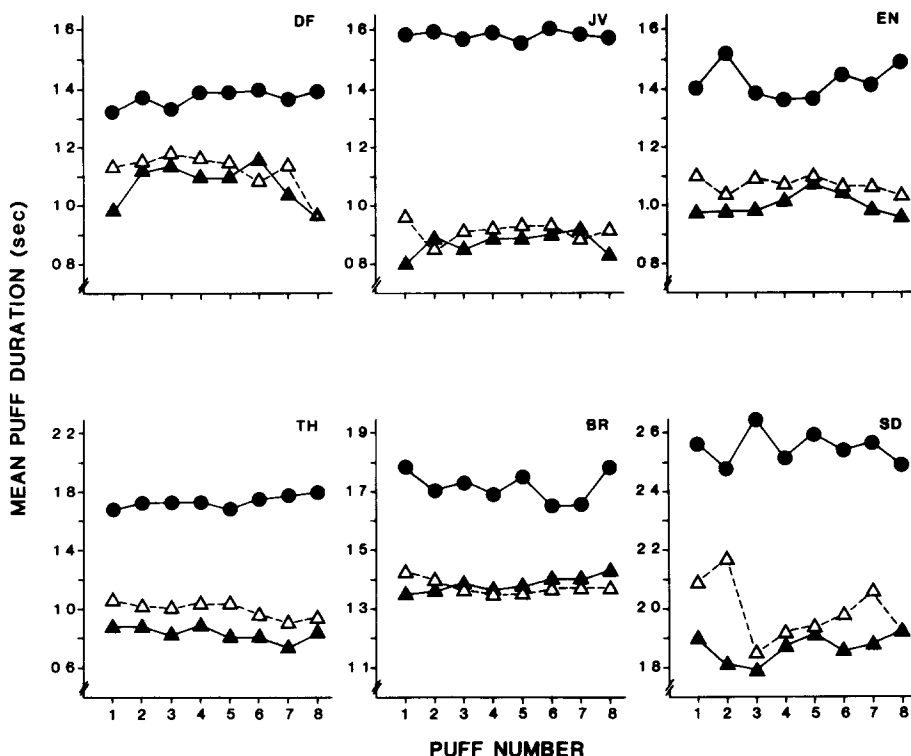


FIG. 5 Mean puff duration as a function of sequential puff number for all six subjects in Experiment 2 for the Full Length (●—●), Butt Long Holder (△—△) and Butt (▲—▲) conditions.

significantly affected by nicotine dose  $F(1,8) < 1$ , or brand of research cigarette  $F(1,4) < 1$  (Fig. 7). However, consistent with results from the previous experiments, half length cigarettes (Middle Nicotine Half-Length) were smoked with a significantly shorter puff duration than the comparable Middle Nicotine Full Length cigarettes. Since block sequencing puts some restrictions on the probability of the exposure of the experimental conditions, a separate analysis was run on data from the first daily exposure of each of the four conditions and compared with the second daily exposure. No significant difference was uncovered with this analysis  $F(1,4) = 1.29, p > 0.05$ .

Figure 8 shows the mean subjective ratings of cigarettes for each of the four conditions. Data have been collapsed across cigarette brands which were not significantly different from each other. Among the Full Length conditions, ratings of strength, harshness, and taste showed increasing nicotine dose-related trends which failed to reach statistical significance. Middle Nicotine Half Length cigarettes were significantly stronger than Low and Middle Nicotine Full Length cigarettes, but not stronger than High Nicotine Full Length cigarettes. Middle Nicotine Half Length cigarettes were also significantly hotter than all three Full Length cigarettes. There were no other significant differences.

DISCUSSION

The present series of studies provide new information about variables controlling puff duration. It had been estab-

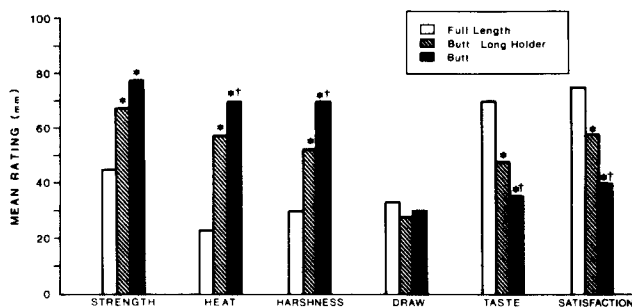


FIG. 6. Group mean subjective ratings for the three experimental conditions of Experiment 2. Asterisks indicate that the condition was a significantly different ( $p < 0.05$ ) from the Full Length condition, daggers indicate that the Butt condition was significantly different ( $p < 0.05$ ) from the Butt Long Holder condition.

lished previously that puff duration decreases as a cigarette is smoked [1,11], and that puff duration was correlated with the distance from the smoker's mouth to the burning ember [1]. Based on the results of Experiment 1, it is concluded that changes in puff duration are not directly under visual stimulus control, since progressive decreases were noted across eight puffs of a whole cigarette, even though the sub-

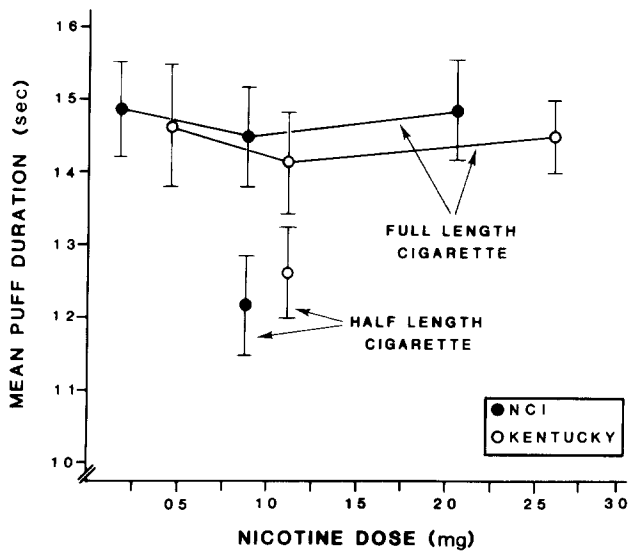


FIG 7. Group mean puff duration as a function of nicotine dose for two different brands of research cigarettes (NCI and Kentucky) for Full Length and Half Length conditions of Experiment 3. Data points represent means and brackets show  $\pm 1$  S.E.M. for mean data from six subjects ( $n=6$ ).

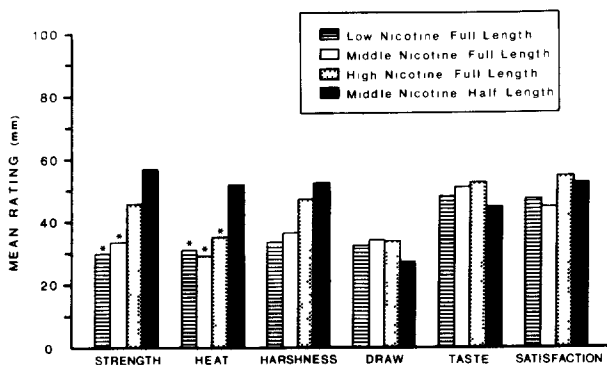


FIG 8. Group mean subjective ratings for the four experimental conditions in Experiment 3, collapsed across the different brands of research cigarettes. Asterisks indicate that condition was significantly different ( $p < 0.05$ ) from the Middle Nicotine Half Length condition.

jects could not see the cigarette, and that appropriate adjustments in puff duration occurred in response to manipulation of the length of unseen cigarettes. The results of Experiment 1 also suggest that satiation does not appear to be an important factor controlling puff duration, since no decreases were noted when eight puffs were taken in the Full Length or Butt conditions. Also of interest is the observation that differences in puff duration appropriate to the length of the unobservable cigarette (i.e., Full Length versus Butt) were apparent even at the first puff.

With regard to the subjective rating measures in Experiment 1, cigarettes in the Butt condition were significantly stronger, harsher, hotter, worse tasting and less satisfying

than either the Full Length or the whole cigarettes. Contrary to our expectations was the fact that measures for the Baseline conditions did not fall as an average between the two extreme lengths, but consistently matched the measures obtained in the Full Length condition.

The second experiment was designed to provide information about tobacco rod length versus distance from the burning ember to the smoker's mouth as controlling variables for puff duration. In all of the previous studies, the length of the tobacco rod had been confounded with the ember-to-mouth distance. These factors were dissociated in the second experiment by varying both the length of the tobacco rod (i.e., Full Length versus Butt and Butt Long Holder conditions), and the distance that the smoke must travel to reach the mouth (i.e., Butt versus Full Length and Butt Long Holder conditions). Since puff durations for the two Butt conditions were not significantly different from each other, it appears that length of tobacco rod and not distance from mouth to burning ember, per se, is an important determinant of puff duration.

Because it is believed that nicotine delivery varies inversely with the length of the tobacco rod [6,14], it is possible that the control of puff duration in response to length of the tobacco rod represents a puff-by-puff titration phenomenon in which subjects are adjusting their smoke exposure in face of changing nicotine levels. The possibility was explored by manipulating nicotine concentration while holding all other factors constant. There were no significant differences obtained by this manipulation.

It is sometimes assumed that particulate/smoke components are deposited, due to a rod filtration effect, along the tobacco rod of a cigarette as it is smoked, and that these deposits result in increased pharmacological delivery (i.e., increased tar and nicotine) on successive puffs as a cigarette is smoked. The present study provides no evidence that this alleged increased pharmacological delivery due to particulate build-up affects puff duration. Experiment 1 showed that puff durations were virtually identical under conditions that subjects puffed on either a not-previously smoked 5 mm tobacco rod or a tobacco rod that had been previously smoked down to the last 5 mm. (Figures 1 and 2, compare puff 8 in Baseline and Butt conditions.) This result is also compatible with other research [1] which showed no topographical differences (i.e., puff duration, interpuff interval) under analogous experimental conditions involving half-length cigarettes. It appears that whatever role nicotine plays in the maintenance of cigarette smoking behavior, it does not exert a puff-by-puff control over puff duration.

The present results also suggest that puff duration is not controlled by changes in subjective acceptability of cigarette smoke. In the first experiment, the Butt condition was rated as significantly stronger, hotter, harsher, worse tasting and less satisfying than the Full Length condition. Thus it seems plausible that subjects took shorter puffs from the short cigarettes because the cigarettes were less subjectively acceptable. This hypothesis is refuted by the results of the second experiment which showed that although the Butt and Butt Long Holder conditions differed in subjective ratings of heat, harshness, taste, and satisfaction, these conditions did not differ in puff duration.

In conclusion, the present study was undertaken to provide information about variables that might account for the decreases in puff duration that consistently occur as a whole cigarette is smoked. The study showed that puff duration correlates with length of tobacco rod, while visual stimulus

control, satiation, distance from the smoker's mouth, nicotine concentration, particulate build-up, and subjective acceptability of cigarette smoke do not contribute significantly to the control of puff duration. Further experiments using this same methodology are currently in progress to assess the effects of other variables (e.g., temperature, filtration) that may influence puff duration.

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