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Determinants of Puff Duration in Cigarette Smokers: II

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NEMETH-COSLETT, R. AND R. R. GRIFFITHS. *Determinants of puff duration in cigarette smokers: II.* PHARMACOL BIOCHEM BEHAV **21**(6) 903–912, 1984.—Studies were conducted to provide information about variables that might account for decreases in puff duration that consistently occur as a whole cigarette is smoked. In two experiments, cigarette smoking was investigated under conditions in which subjects smoked cigarettes which they could not see. Puff duration was shown to covary with manipulations of resistance to draw—increasing tobacco rod length or adding filters proximal or distal to the smoke stream increased puff duration. Filtration of the smoke stream did not influence puff duration when resistance to draw was controlled. Comparison of changes in smoke temperature with changes in puff duration across a whole cigarette, and manipulation of smoke temperature by use of different length cigarette holders suggested that temperature did not appreciably control puff duration. A final experiment with nonhuman simulated puffing of constant puff volume showed that both tobacco rod length and cigarette brand affected puff duration and suggests the possibility that the physics of smoke passing through the cigarette may be a fundamental determinant of changes in puff duration during human smoking.

Cigarettes Smoking Tobacco Self-administration Temperature Cigarette brands Humans

AS a whole cigarette is smoked, the duration of successive puffs decreases. This phenomena has been documented by surreptitious observation of smokers in the natural environment [10], as well as in laboratory studies involving more direct and objective measurement procedures [1,4]. In a recent series of experiments, Nemeth-Coslett and Griffiths [9] explored variables controlling puff duration by studying cigarette smoking under conditions in which subjects smoked cigarettes which they could not see. By manipulating the length of the tobacco rod, the length of the cigarette holder, and the cigarette nicotine delivery, these experiments showed that puff duration covaried with the length of the tobacco rod, and was not appreciably controlled by 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.

The present report represents a direct extension of the Nemeth-Coslett and Griffiths research to provide further information about variables controlling the duration of individual puffs. In the first experiment, the role of smoke temperature was explored by characterizing temperature changes during the smoking of a whole cigarette, and by manipulating smoke temperature. The second experiment investigated the roles of filtration and resistance to draw by manipulating filtration and resistance to draw while holding the length of the tobacco rod constant. The third and final experiment in the series sought to provide information about puff duration independent of changes in smoker's behavior *per se*, by using a standard procedure to simulate puffing.

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 [8] indicated that all subjects were inhalers (mean pre-session CO levels ranged from 18 to 54). The subjects were paid weekly at a mean rate of $8 per session. Subject characteristics and experimental assignment are presented in Table 1.

Experiment 1: Effects of Temperature

In previous studies comparing the smoking of shortened versus full length tobacco rods, the shortened rods were consistently associated with shorter puff durations and higher ratings of subjective heat [9]. Therefore, it is possible that subjects alter the duration of individual puffs in response to changes in smoke temperature. This experiment explored this possibility by characterizing temperature changes during the smoking of a whole cigarette and by manipulating temperature by varying the length of the cigarette holder.

Setting and apparatus. The setting and apparatus have been described in detail previously [1,6]. Briefly, the test room was equipped with a comfortable armchair for the subject, a chair for a research technician, a television set, and a smoking console. The console contained a session light, a depository for cigarette butts and a pressure transducer. During experimental sessions, subjects smoked all cigarettes

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TABLE 1
SUBJECT CHARACTERISTICS

Subject	Age (years)	Years Smoking	Preferred Brand*	Self-Reported Cigarette Consumption (per day)	Experiments
ER	24	13	Kool Menthol (17.0, 1.1)	25	2
TH	34	17	Marlboro 100s (17.0, 1.1)	40	1,2
MR	24	10	Newport 100s (20.0, 1.4)	30	1,2
HH	23	12	Salem Menthol (15.0, 1.0)	30	1
BR	49	33	Kool Super Longs (14.0, 1.0)	50	1
KM	24	10	Kool Menthol (17.0, 1.1)	25	2
SD	29	17	Marlboro 100s (17.0, 1.1)	20	1
JV	30	13	Marlboro Box (17.0, 1.1)	40	1,2
FS	40	20	Raleigh Lights 100s (10.0, 0.8)	40	2

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

through a plastic cigarette holder which was mounted in a funnel-like apparatus. The holder was connected via a 2-m length of tubing (2 mm, o.d.) to a pressure sensitive switch which operated a relay following a decrease in pressure (3.3 mm Hg) induced by puffing on a cigarette. Measures of smoking topography were collected via a remotely located PDP 8/E computer. A fast response temperature microsensor (Bailey Instruments MT-23/3; 63% time constant was 0.15 sec) was mounted in the approximate center of the circular diameter of the cigarette holder and connected via thin shielded cable to a remotely located thermometer (Bailey Instruments, BAT-8) to record peak-temperature changes during puffing. When a cigarette was inserted in the holder, the microsensor was located approximately 7.5 mm from the mouth end of the cigarette holder.

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 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 mounted in a funnel-like apparatus. The funnel-like apparatus allowed the subjects to hold and manipulate 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 had been taken. This series of puffs constituted a trial-block. Fifteen minutes later, the procedure was repeated. Daily sessions consisted of three trial blocks.

Following each trial block, subjects were required to rate: 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 taste of the cigarette (very bad/very good); 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 scale for each of the six questions.

Puff duration was defined as the duration for which the pressure sensitive switch was closed. Previous research had shown that some smokers make multiple, closely spaced switch closures during a single "puff" [2]. In the present group of subjects, subject BR intermittently (about 50% of occasions) exhibited "double puffs" (two switch closures separated by a very short interval, usually less than 1 sec). Visual inspection of this subject's smoking behavior suggested that such instances should be treated functionally as one puff; thus, for this subject, the durations of two such switch closures were summed to give a single puff duration.

Experimental conditions. Daily sessions consisted of three trial blocks involving three experimental conditions: (1) Whole Cigarette; (2) Butt Short Holder; (3) Butt Long Holder. The Whole Cigarette condition (trial block) consisted of eight sequential puffs from a whole cigarette which was placed in a 35 mm holder. The other two conditions (trial blocks) consisted of eight puffs from cigarettes which had been pre-cut to produce just 5 mm of smokable tobacco. The conditions differed, however, with regard to the length of the plastic holder: Butt Short Holder (35 mm); Butt Long Holder (100 mm). Peak temperatures were recorded during each puff. The order of trial blocks was quasi-randomized across days, and the study was continued until data from 10 blocks or 80 puffs in each condition had been obtained.

Experiment 2: Effects of Filtration and Resistance to Draw

In the five previous experiments investigating determinants of puff duration, the only consistent correlate of puff duration has been the length of the tobacco rod, with longer puff durations occurring with longer tobacco rods ([1,9]; Experiment 1). It is possible that differences in puff duration are

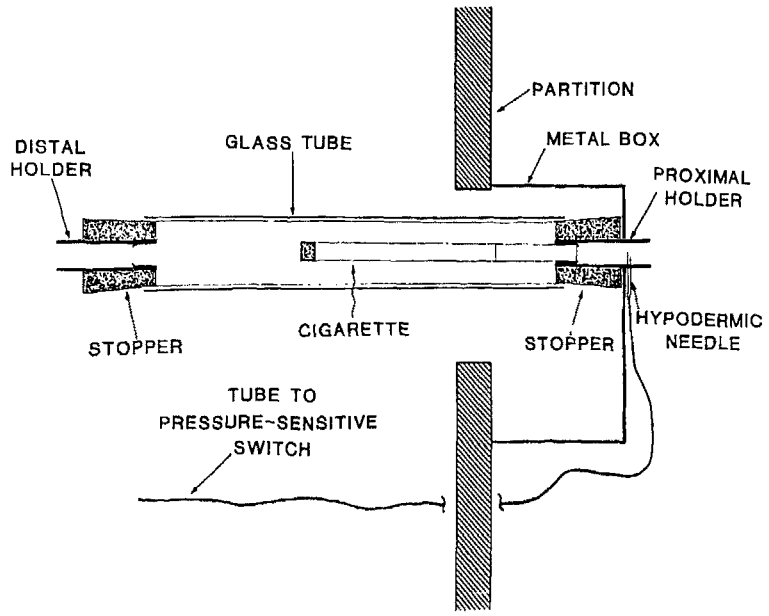

FIG. 1. Schematic cross-section of apparatus used in Experiment 2. Subjects puffed on cigarettes through the proximal holder.

due to differences in filtration and/or resistance to draw produced by different length tobacco rods. In the present study filtration and resistance to draw were manipulated independently while holding the length of the tobacco rod constant by using a special cigarette smoking system that permitted the addition of cigarette filters either proximal or distal to the smoke stream.

Setting and apparatus. A test room was equipped with a comfortable armchair for the subject, a chair for a research technician, a television set, a Grass Model 7 Physiological Recorder System, an Apple IIe computer system and a partition that separated the subject from the research technician. The partition was located on the top of a standard office desk.

The three-sided partition was constructed from ½ inch plywood and measured 40 cm along the front, 40 cm in height and had a depth of 16 cm. Ten cm from the top and 16.25 cm in from each side along the front, a metal box measuring 7.5×10×4 cm was mounted into place (see Fig. 1). In the center of the side of the box facing the subject, a No. 4 rubber stopper was semipermanently fixed. A 35 mm plastic cigarette holder identical to that used in Experiment 1 was inserted in the middle of the stopper so that 12 mm protruded from the widest end, and faced outward toward the subject, while the end of the holder designed to hold the cigarette was flush with the base of the stopper, and facing the technician. This was the proximal holder (Fig. 1). Inserted into the plastic holder was a Becton-Dickinson 18G1-1/2 (28.1 mm) Yale Hypodermic Needle. One end of a 2-m length of tubing (2 mm o.d.) was connected to the needle while the other end was connected to a pressure sensitive switch (Micro Pneumatic Logic, Inc., Ft. Lauderdale, FL) which operated a relay following a decrease in pressure (3.3 mm Hg) induced by puffing on a cigarette. A second rubber stopper and holder (the distal holder), constructed as described above, was permanently fitted into one end of a hollow glass tube which measured 15×2.2 cm (approximately 55 ml capacity). The apparatus was designed such that the glass tube could be easily inserted and removed from the proximal stopper to permit insertion or removal of cigarettes from the proximal holder.

General procedures. Procedures were similar to Experiment 1 except that visual inspection of the cigarette was prevented by the partition instead of the funnel-like apparatus, and trial blocks were spaced at 10 minute rather than 15 minute intervals. Also, since previous studies showed no differences in puff duration across sequential puffs of same-length cigarettes ([9]; Experiment 1) the trial-block size used in this study was reduced from eight puffs to three puffs.

For each puff during this study the research technician placed a freshly lit full length cigarette in the proximal holder. The glass tube was then securely fitted over the proximal stopper and the subject immediately instructed to take one puff. The time between tube placement and the puff was purposely kept minimal (approximately 2 seconds) to prevent significant accumulation of side stream smoke in the tube. After each puff, the technician removed the glass tube and extinguished the cigarette. During a trial-block, this procedure was repeated at 45 second intervals.

Experimental conditions. Each trial-block consisted of puffing once from each of three freshly lit full length cigarettes. Daily sessions involved three trial blocks involving three experimental conditions: (1) No Added Filter; (2) Proximal Filter; (3) Distal Filter. The No Added Filter condition involved puffing on cigarettes with no filter placed in the proximal or distal holders. The Proximal Filter condition involved placement of a filter in the proximal holder, while the Distal Filter condition involved placement of a filter in the distal holder (Fig. 1). The filters were Aquafilter® brand (Ft. Lauderdale, FL) and each filter consisted of a 2.5 cm long × 0.8 cm diameter insert made from a special blend of Indian cotton. The size of the insert was appropriate to the size of

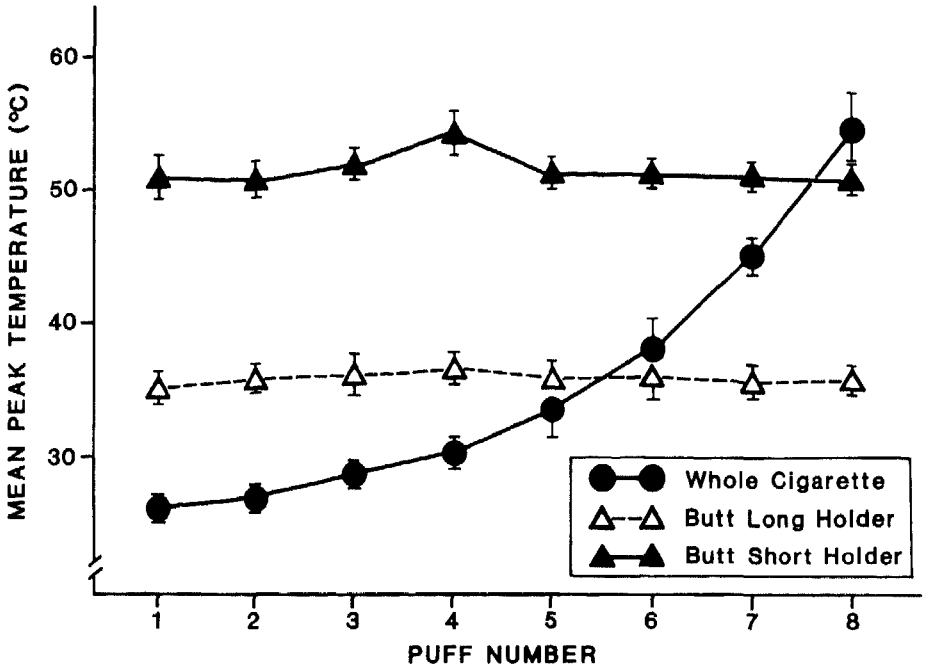

FIG. 2. Group mean peak temperature as a function of sequential puff number for the Whole Cigarette, Butt Short Holder, and Butt Long Holder conditions of Experiment 1. Data points represent means and brackets show 1 S.E.M. for mean data from six subjects (n=6).

the plastic holder because the plastic holder was modified from a commercially available cigarette holder specifically designed to be used with the filter inserts. These inserts were dried by exposing to air for 24 hours prior to use, and fresh inserts were used daily for each condition for each subject. The order of trial blocks was quasi-randomized within and across days, and the study was continued until 10 blocks or 30 puffs in each condition had been obtained.

Experiment 3: Effects of Simulated Puffing

In this final experiment, puff duration and peak puff temperature smoking measures were obtained by using a disposable general purpose 60 cc bulb syringe (The Healthcare Group, Inc., Model 3010) to simulate puffing while holding puff volume constant. In order to achieve objective and replicable puffing, the following procedure was used: The syringe was inserted into a funnel (approximately 6.5 cm in length with 6.5 cm and 1.2 cm end diameters) so that the bulb portion fit snuggly into the tapered portion of the funnel and the nozzle of the syringe (cut approximately 5 cm long) protruded from the spout of the funnel. Cigarettes were placed in one end of a standard 35 mm plastic holder. After the bulb was compressed with the sides of the funnel acting as boundaries, the nozzle of the syringe was inserted to fit snuggly into the open end of the cigarette holder; the bulb was then released. The syringe was removed from the cigarette holder and the funnel after the bulb had been reexpanded. Smoke was evacuated from the syringe into the air with a series of compressions of the bulb. Calibration control studies with full length tobacco rods showed that the syringe procedure mimicked human puffing to the extent that resulting puff durations (1.8 sec approximately) puff volumes (50 cc approximately), and peak pressure amplitudes (25 mm Hg) were in the range of those produced by human smokers. Syringe puffing, however, differed from human puffing in that it produced a characteristic profile of pressure change across the puff (generally increasing), which is unusual for human smokers.

In the first phase of this experiment, ten full length cigarettes from each of six different commercial brands were evaluated (Kool; Kool Super Longs 100s; Marlboro (box); Marlboro 100s; Newport 100s; Tareyton). Each cigarette was premarked so that puffs were obtained from eight evenly spaced sections of the cigarette, thus providing data analogous to human smoking data in the Whole Cigarette condition of Experiment 1. Puff durations and peak puff temperatures were measured with procedures identical to those used in the human smoking experiments.

The second phase of the experiment was a systematic replication of the first phase, under conditions which did not confound length of tobacco rod with previous puffs through the cigarette. As in the first phase, six different commercial brands were examined (Belair 100s; Marlboro 100s; Salem; Tareyton; Vantage 100s (Ultralite); Viceroy 100s). For each brand, 20 puffs from each of 20 cigarettes were obtained. These puffs consisted of single puffs from each of ten fresh full length cigarettes and single puffs from each of ten fresh cigarettes that had been cut to 5 mm of the overwrap. Puff durations were measured with procedures as described previously.

Data Analysis

For each of the three experiments, puff durations, peak temperatures, and when appropriate, subjective ratings were

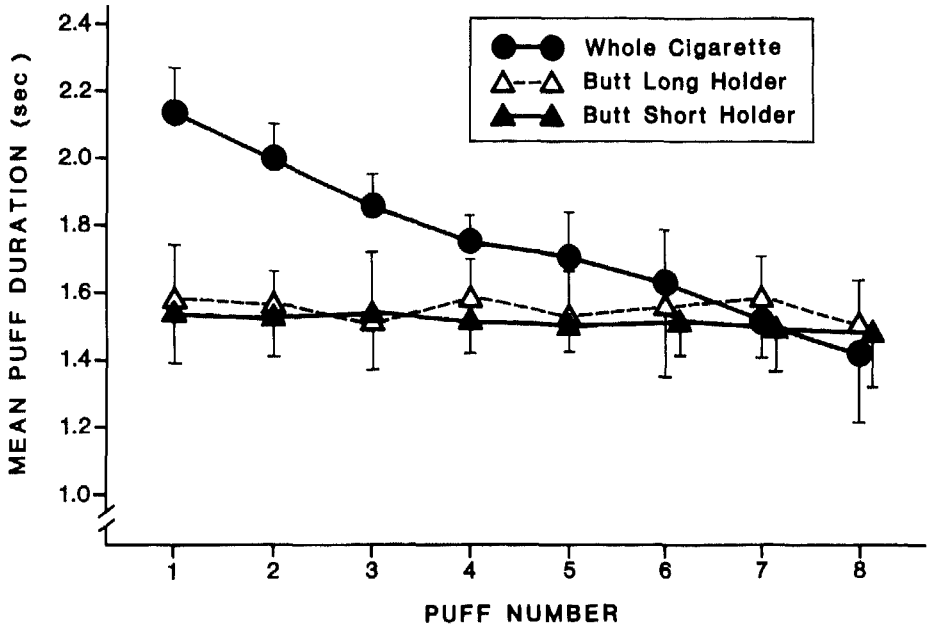

FIG. 3. Group mean puff duration as a function of sequential puff number for the Whole Cigarette, Butt Short Holder, and Butt Long Holder conditions of Experiment 1. Data points represent means and brackets show 1 S.E.M. for mean data from six subjects (n=6).

analyzed separately using a 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: Effects of Temperature

Figure 2 shows peak temperatures across the eight puffs for each of the three conditions. Temperature increased significantly across the eight puffs of the Whole Cigarette condition, $F(14,70)=3.39$, as predicted on the basis of subjective ratings from previous experiments. Temperature was relatively stable across the eight puffs in both butt conditions; however, temperature was substantially and significantly higher in the Butt Short Holder condition than the Butt Long Holder condition $F(1,5)=88.96$. The difference between the two butt conditions shows the success and appropriateness of modifying holder length in order to manipulate puff temperature.

Puff durations across the eight puffs for each of the three conditions are presented in Fig. 3. While puff durations for the Whole Cigarette condition decreased significantly across the eight puffs, $F(14,70)=26.11$, no such decreases occurred in the two butt conditions. Although the butt conditions differed substantially in terms of peak puff temperature (Fig. 2), puff durations were not significantly different between the Butt Short Holder and Butt Long Holder conditions. Figure 4 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 representative of the individual subjects.

Figure 5 shows mean subjective ratings. Subjects rated the Butt Short Holder as significantly hotter than the Butt Long Holder, a result consistent with the measured temperatures presented in Fig. 2. The Butt Short Holder condition was also rated as significantly harsher, tasting worse, and less satisfying than the Butt Long Holder condition. The Whole Cigarette condition was rated as significantly different from both butt conditions on all dimensions except heat and draw. With respect to heat, the Whole Cigarette condition was significantly less hot than the Short Holder, but not than the Long Holder condition. There were no significant differences among conditions on ratings of draw.

Experiment 2: Effects of Filtration and Resistance to Draw

Puff duration across the three puffs in cigarettes with and without added filters are presented in Fig. 6. While there was no significant change across the three puffs, both of the added filter conditions significantly increased puff duration more than 35% $F(2,10)=12.96$. Inspection of individual subject data indicated the treatment effect revealed in the group data was apparent with each of the six subjects.

Subject ratings also differentiated the No Filter Added condition from the two filter conditions. As expected, the Added Filter conditions were rated as having significantly harder draw than the No Filter Added condition (Fig. 7). In addition, the cigarettes with added filters were also judged as significantly less strong, less hot, less harsh, tasting worse, and less satisfying than were the cigarettes without added filters. The Proximal Filter condition was less strong and less harsh than the Distal Filter condition ($p<0.10$, marginally significant). There were no other significant differences between the filter conditions on subjective ratings.

Experiment 3: Effects of Simulated Puffing

Figure 8 shows the mean puff duration during simulated

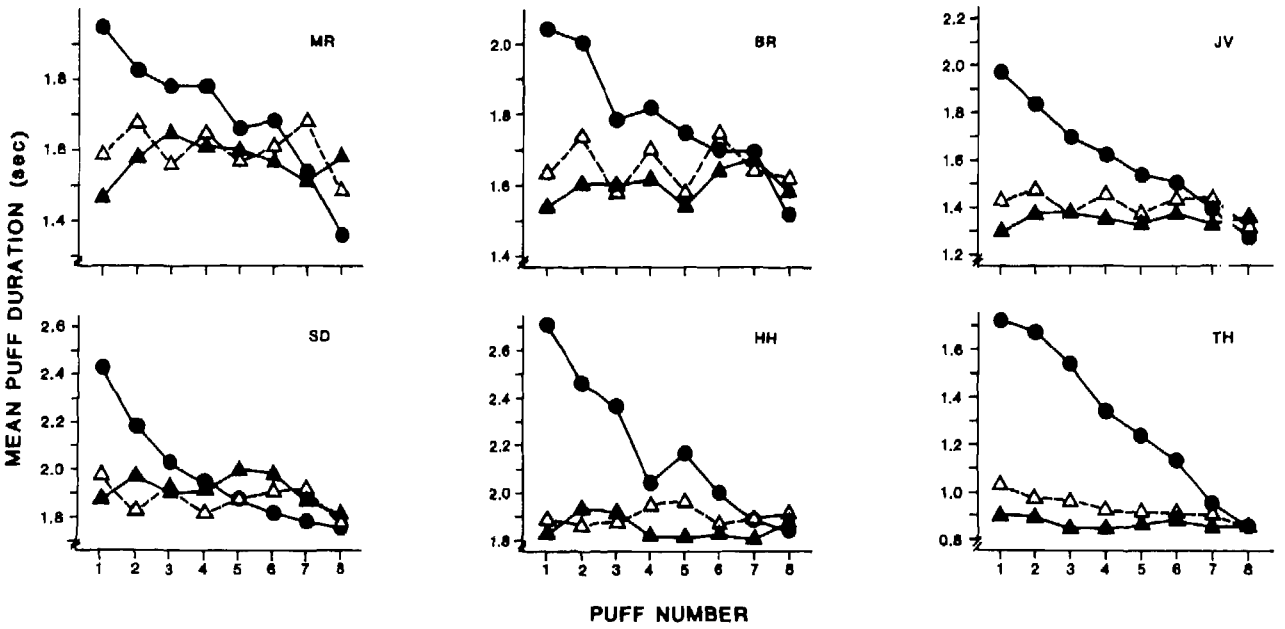

FIG. 4. Mean puff duration as a function of sequential puff number for all six subjects for Experiment 1 for the Whole Cigarette (●——●), Butt Short Holder (▲——▲), and Butt Long Holder (△— — —△) conditions.

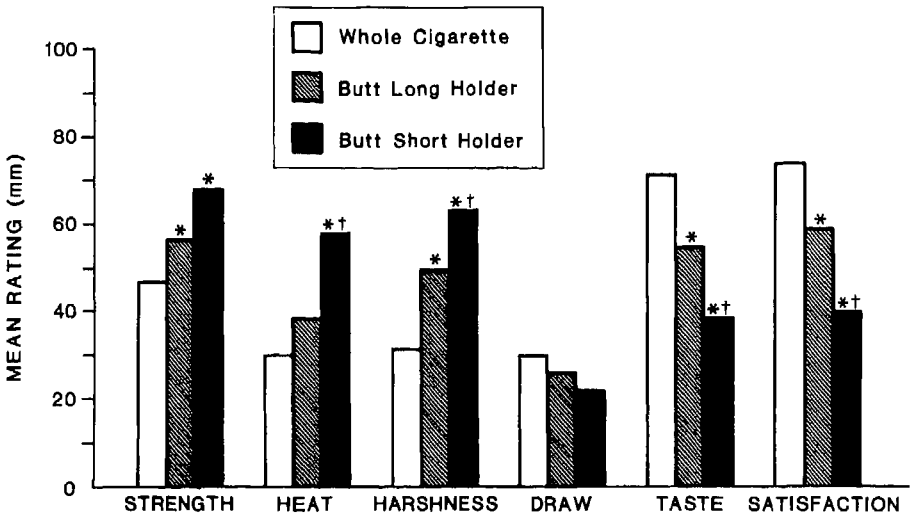

FIG. 5. Group mean subjective ratings for the three experimental conditions of Experiment 1. Asterisks indicate that the condition was significantly different ($p<0.05$) from the Whole Cigarette condition. Daggers indicate that the Butt Short Holder condition was significantly different ($p<0.05$) from the Butt Long Holder condition.

puffing from each of the six different cigarette brands generally decreased monotonically across the eight puffs. Filled circles show analogous, and remarkably similar, data from six human subjects smoking a whole cigarette (replotted from Fig. 3). Analysis of the simulated puffing results revealed significant effects of puff number $F(7,63)=75.59$ and cigarette brand $F(5,45)=27.9$, with a significant puff number × brand interaction $F(35,315)=4.83$.

The second phase of the experiment (comparing puff duration of single simulated puffs from ten fresh full length cigarettes with that from ten fresh butt length cigarettes, across six brands of cigarettes) systematically replicated the first phase. Puff duration was significantly affected by length of the tobacco rod, $F(1,9)=2811.30$; mean and standard error were 1.74 ± 0.12 and 1.08 ± 0.05 for full length and butt length cigarettes, respectively, and cigarette brand $F(5,45)=10.79$, with a significant length × brand interaction $F(5,45)=5.33$. Taken together, these first and second phase studies show

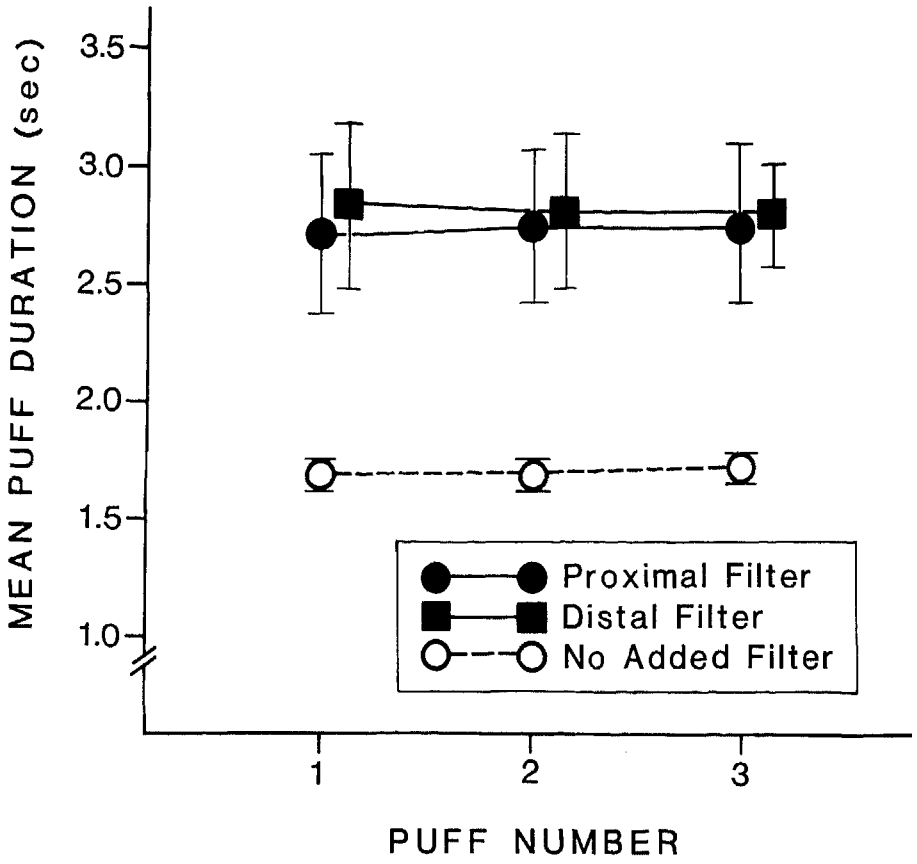

FIG. 6. Group mean puff duration as a function of sequential puff number for the Proximal Filter, Distal Filter and No Filter Added conditions of Experiment 2. Data points represent means and brackets show 1 S.E.M. for mean data from six subjects (n=6).

that although tobacco rod length is a major determinant of puff duration, cigarette brand also affects mean puff duration, as well as the extent of change in puff duration with changes in rod length.

With regard to temperature changes under simulated puffing, mean peak temperatures increased monotonically across the eight puffs, with modest but consistent increases across the first few puffs, and increases of substantially greater magnitude across the last three puffs (Fig. 9). As with the puff duration results, the temperature function was remarkably similar to data from humans smoking a whole cigarette (replotted from Fig. 2), and the analysis revealed significant effects of puff number $F(7,63)=695.57$ and cigarette brand $F(5,45)=5.05$, with a significant puff number × brand interaction $F(35,315)=13.47$.

DISCUSSION

The present research provides new information about variables controlling puff duration. Previous studies had showed that puff duration correlates with length of 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 [1,9]. In previous studies comparing the smoking of shortened versus full length tobacco rods, subjects rated the shortened rods as producing hotter smoke than the full length rods [9]. Therefore, it seemed possible that subjects could be altering the duration of individual puffs in response to changes in smoke temperature. Experiment 1 explored this possibility by characterizing temperature changes during the smoking of a whole cigarette, and by manipulating smoke temperature. The study showed that peak temperature increases monotonically as a cigarette is progressively smoked (this effect was also obtained during simulated puffing in Experiment 3). The results provided two pieces of evidence suggesting that temperature changes are relatively unimportant determinants of puff duration. First, in the first few puffs of a whole length cigarette, changes in temperature are modest relative to changes in puff duration (compare Whole Cigarette condition in Figs. 2 and 3). Second, when temperature was manipulated by varying holder length, puff duration remained unchanged. The effectiveness of the temperature manipulation was revealed both by objective measurement of puff temperature, and by subject ratings of heat. Although the study suggests that heat is a relatively unimportant factor in controlling puff duration, it should be noted that subjective ratings of harshness, taste, and satisfaction were also significantly affected by the experimental manipulation. Whether or not these subjective di-

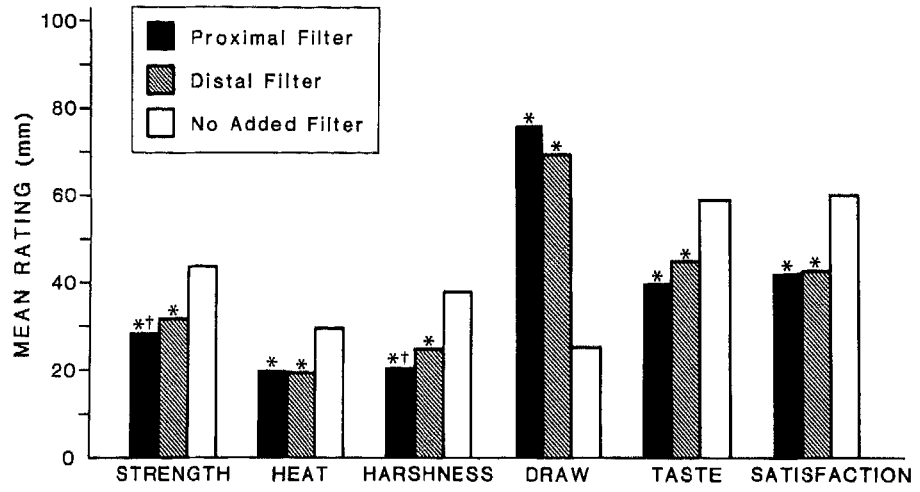

FIG. 7. Group mean subjective ratings for the three experimental conditions of Experiment 2. Asterisks indicate that the condition was significantly different ($p<0.05$) from the No Added Filter condition. Daggers indicate that the Proximal Filter condition was significantly different ($p<0.10$) from the Distal Filter condition.

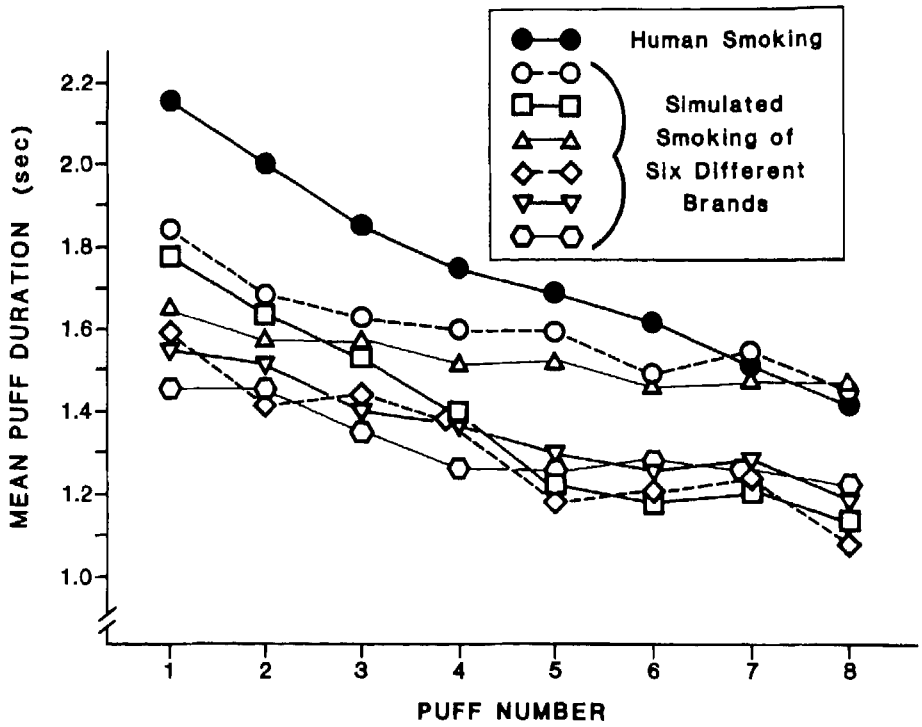

FIG. 8. Mean puff duration as a function of sequential puff number for each of six different commercially available cigarette brands (Experiment 3). Open symbols show data obtained during simulated puffing with a bulb syringe; closed symbols show analogous data from a group (n=6) of human cigarette smokers (replotted from Experiment 1).

mensions are inseparable correlates of heat cannot be determined from the present study.

Since in previous studies, the only consistent correlate of puff duration was the length of the tobacco rod ([1,9]; Experiment 1), it was possible that differences in puff duration are due to differences in filtration and/or resistance to draw produced by different length tobacco rods. This possibility was explored in Experiment 2 by independently manipulating filtration and resistance to draw while holding the length of the tobacco rod constant by using a special cigarette smoking system that permitted the addition of cigarette filters either proximal or distal to the smoke stream. Thus,

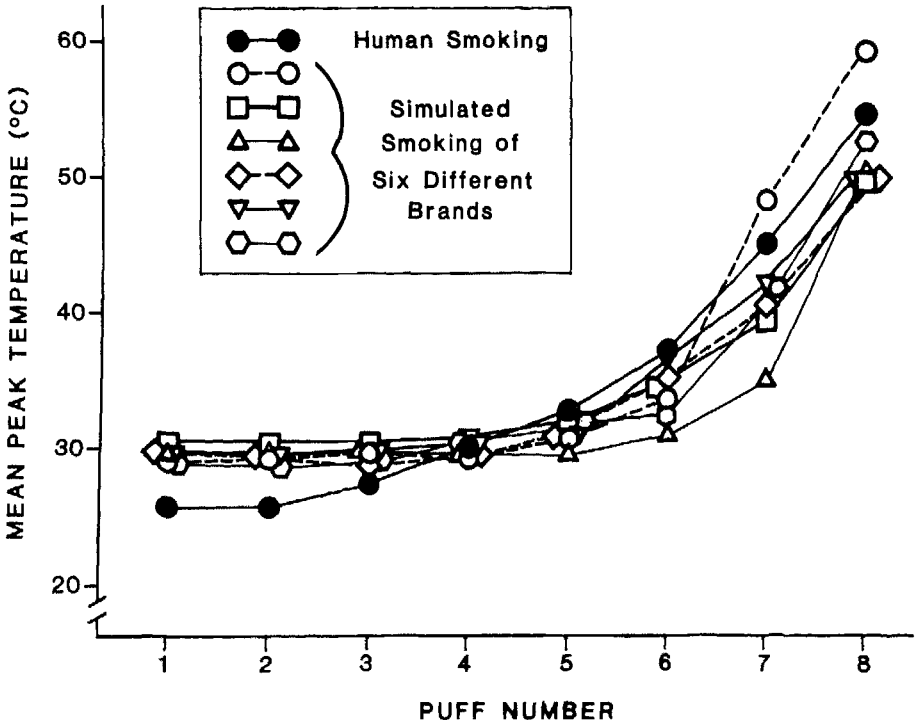

FIG. 9. Mean peak temperature as a function of sequential puff number for each of six different commercially available cigarette brands (Experiment 3). Open symbols show data obtained during simulated puffing with a bulb syringe; closed symbols show analogous data from a group (n=6) of human cigarette smokers (replotted from Experiment 1).

compared to a No Added Filter condition, the distal filter (through which the smoke stream did not pass) could be expected to increase resistance to draw without changing filtration, while the proximal filter (through which the smoke stream passed) could be expected to increase resistance to draw *and* filter particulate material from the smoke stream. The study showed that resistance to draw was a determinant of puff duration (both filter conditions increased puff duration), while filtration of the smoke stream did not influence puff duration (there was no difference in puff duration between proximal and distal conditions). The effectiveness of the manipulation of resistance to draw was demonstrated by the significantly increased ratings of draw under both filter conditions. The effectiveness of the manipulation of filtration of smoke stream was suggested by the marginally significant difference in ratings of strength and harshness between the proximal and distal filter conditions.

While Experiment 2 suggested that resistance to draw is a determinant of puff duration, it is not clear whether resistance to draw is a major determinant of the changes in puff duration which occur as a whole cigarette is smoked. The resistance to draw manipulations in Experiment 2 significantly influenced ratings of strength, heat, harshness, draw, taste, and satisfaction. Previous experiments comparing tobacco rods of different lengths showed analogous significant changes in subjective ratings, but no effect on ratings of draw (Experiment 1; [9]). Thus, because the resistance to draw manipulation produced increases in ratings of draw while manipulating cigarette rod length did not, it is unclear whether the effects of the added filtration manipulation on puff duration was functionally related to changes in puff duration which occur as a whole cigarette is smoked.

Although Experiment 2 implicated resistance to draw in the control of puff duration, it remained unclear the extent to which changes in puff duration during the smoking of a cigarette depended on behavioral changes made by the smoker. It was possible that changes in puff duration are primarily a function of the physics of smoke passing through a cigarette. Experiment 3 was undertaken to provide more information about this possibility by eliminating the human smoker by simulating puffing using a bulb syringe to provide objective, replicable puffing of constant volume. Also, information about the effects of differences in cigarette construction was provided by evaluating a variety of different commercially available cigarette brands. The close similarity of results between bulb and human puffing (Figs. 8 and 9) suggested that length of the tobacco rod *per se* is a fundamental determinant in puff duration. The fact that cigarette brand also significantly determined mean puff duration, as well as extent of change in puff duration across different tobacco rod lengths, demonstrated the importance of differences in cigarette construction across brands. This latter finding also emphasises the methodological consideration that cigarette brands should not be interchangeable in smoking research.

It should be noted that in Experiment 3, the simulated puff procedure purposely held puff volume constant across the different tobacco rod lengths. Two human smoking studies suggest that puff volume may decrease as a cigarette

is smoked [5,7]. If this is true, and if puff duration does covary with puff volume as has been suggested by some studies [3,5], then the predicted magnitude of change in puff duration for human smokers should be greater than that obtained under the simulated smoking conditions.

In a recent paper, Gust *et al.* [5] reported data at variance with some of the results of the present report. Specifically, they found that as a cigarette is smoked, puff duration is relatively constant across ordinal puff number. This finding is inconsistent with results from a series of observational and laboratory studies showing that puff duration decreases across the cigarette ([1, 4, 9, 10], the present report). It is possible that the anomalous results of Gust *et al.* [5] reflect artifacts introduced by their measurement procedures, or alternatively, artifacts introduced by averaging data from cigarettes containing different numbers of puffs.

The present report extends the understanding of the determinants of puff duration. In combination with results from previous studies [1,9], human smoking studies have shown that puff duration covaries with manipulations of resistance to draw (i.e., tobacco rod length and added proximal or distal filters). Puff duration does not appear to be appreciably controlled by visual stimulus control, satiation, distance from the burning ember to the smoker's mouth, nicotine delivery, particulate build-up during smoking, subjective acceptability of cigarette smoke, smoke temperature and filtration of the smoke stream. Studies with simulated puffing also indicate that resistance to draw (i.e., tobacco rod length) influences puff duration, and suggest the possibility that the physics of smoke passing through a cigarette may be a fundamental determinant of changes in puff duration during human smoking. The ultimate biological significance of puff duration as a measure of human cigarette smoking behavior must await future parametric studies exploring the relationship between puff duration and such measures as carbon monoxide and nicotine blood levels.

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