

Differential Control of Puff Duration and Interpuff Interval in Cigarette Smokers

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Received 23 November 1981

CHAIT, L. D. AND R. R. GRIFFITHS. *Differential control of puff duration and interpuff interval in cigarette smokers.* PHARMAC. BIOCHEM. BEHAV. 17(1) 155-158, 1982.—While subjects smoked cigarettes under naturalistic conditions, the duration of each puff progressively decreased as the cigarette was consumed, while the time between successive puffs progressively increased. Evidence obtained using modified half-length cigarettes indicates that puff duration, but not interpuff interval, is controlled by the distance from the burning tip (combustion zone) of the cigarette to the smoker's mouth. The results demonstrate that these two fundamental descriptors of cigarette smoking behavior are under differential control, and provide new insights into the pharmacological and behavioral variables that control cigarette smoking.

Cigarette smoking Humans Self-administration Tobacco

CIGARETTE smoking is a widespread, addictive form of human drug self-administration [2,7], with well-documented adverse consequences to society and to the individual smoker. Despite much research, the variables that control cigarette smoking are poorly understood—even the role of nicotine remains unclear [2]. In recent years sophisticated methods for analyzing human and animal drug self-administration have been developed and refined [1]. Yet, until recently, such methods have not been employed in the experimental analysis of cigarette smoking behavior. We have developed a methodology to study cigarette smoking behavior that allows smoking to occur in a naturalistic manner, while permitting the collection of a wide array of topographical measures of smoking behavior [4].

The puff can be considered to be the most fundamental unit of cigarette smoke self-administration [7]. In the present study, we were particularly interested in examining how the duration of individual puffs (puff duration) and the spacing between puffs (interpuff interval) change while a cigarette is smoked. It has been observed that puff duration decreases and interpuff interval increases as cigarettes are smoked (unpublished observations and [8]). However, the mechanism(s) underlying these phenomena remain unknown. It is possible that these within-cigarette changes in smoking topography represent the response of smokers to the cumulative exposure to tobacco smoke that occurs during the smoking of a single cigarette (e.g., a satiation process). Another possibility is that these phenomena may represent the response of smokers to changes in properties of the smoke that occur with the progressive shortening of the cigarette as it is consumed (e.g., changes in the concentration of smoke com-

ponents or smoke temperature). The present study was designed to evaluate such possible mechanisms.

METHOD

Three adult female cigarette smokers (DS, LS, FG) and one male cigarette smoker (CB) served as subjects. They were recruited through newspaper advertisements from the local community, and were paid for their participation on a weekly basis at a rate of approximately \$4.00 per hour. Subjects were not informed of the true nature of the study, and were not given any information as to what type of behavior was "expected" of them. Subjects reported smoking an average of 20 (DS) to 70 (CB) cigarettes per day. Nicotine, tar and carbon monoxide deliveries (FTC values, 1981) of their regular brands ranged from 0.72, 9.2, 12.4 mg/cigarette (FG), respectively, to 1.38, 18.4, 20.5 mg/cigarette (DS). Analysis of expired air carbon monoxide levels indicated that all subjects were inhalers.

The experimental test room and smoking apparatus have been described in detail elsewhere [4,5]. Briefly, subjects sat alone in a small room and smoked all cigarettes through a plastic holder connected via tubing to a pressure transducer. The pressure transducer operated a relay following a decrease in pressure (approximately 5 mm mercury) induced by puffing on a cigarette. The pressure transducer was interfaced with a computer that recorded and controlled experimental events. Subjects could be monitored during sessions through a one-way window.

Experimental sessions were 100 minutes long and were held five days each week. Each subject was tested individu-

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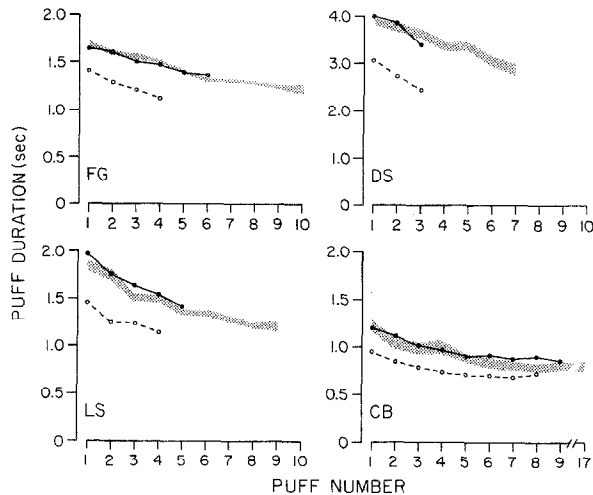


FIG. 1. Puff duration as a function of the ordinal position of the puff within the cigarette (puff number) for full-length (shaded area = \pm one S.E.), half-distal (closed points, solid line) and half-proximal (open points, dashed line) cigarettes, for each subject. Each point represents the mean value from at least 36 cigarettes. The final puff of each cigarette was excluded from analysis. For clarity, the half-proximal-smoked cigarette data are not presented—for each subject the function obtained with these (HPS) cigarettes was identical to that obtained with half-proximal cigarettes. Group mean puff durations for full-length, half-distal, half-proximal and half-proximal-smoked cigarettes were 1.68, 1.83, 1.39 and 1.41 sec, respectively.

ally at the same time each day. While in the room, subjects were allowed to watch television or read the daily newspaper. They were instructed to smoke as much or as little as they desired. Before each session subjects were given cigarettes belonging to one of four types. Subjects were exposed to each type of cigarette from 7 to 15 times, in a mixed order across days. Each type of cigarette was prepared from a subject's regular brand of commercial, filter-tipped 100-mm cigarettes. Subjects were instructed to smoke the cigarettes until they had burned down to a line drawn around the cigarette, at which time they were to extinguish the cigarette.

The four cigarette types were (1) full-length (FL)—these were 100 mm long with the line drawn 60 mm from the distal end (the end away from the filter); (2) half-distal (HD)—these were 100 mm long with the line drawn 30 mm from the distal end. Subjects extinguished HD cigarettes by cutting the tip off with scissors, rather than by crushing them. After sessions the butts were placed in airtight bags and refrigerated for later use (see (4)); (3) half-proximal (HP)—these were prepared by cutting off and discarding the distal 35 mm of 100-mm cigarettes, and drawing the line around these shortened cigarettes 30 mm from the distal end; (4) half-proximal-smoked (HPS)—these were the remains (butts) of HD cigarettes which each subject had smoked during previous sessions; these cigarettes were identical in all other respects to HP cigarettes.

Thus FL cigarettes contained 60 mm of available tobacco, an amount that typically would be consumed during normal smoking. HD and HP cigarettes each contained 30 mm of available tobacco, and differed from each other in the distance of the available tobacco from the subject's mouth (distal vs proximal). HPS cigarettes differed from HP cigarettes

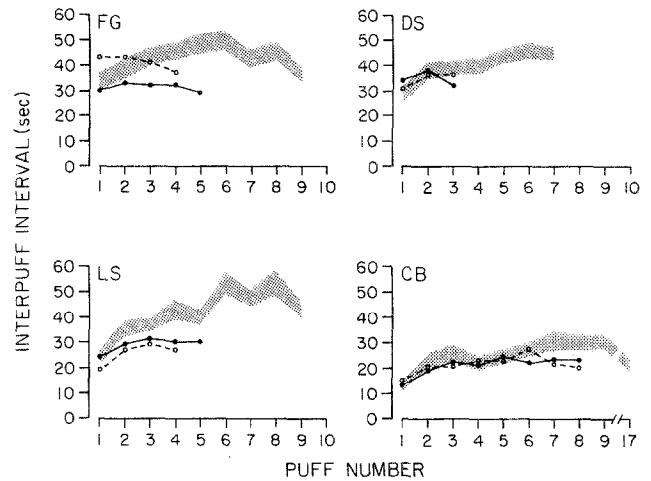


FIG. 2. Interpuff interval as a function of puff number. Details are the same as for Fig. 1. Group mean interpuff intervals for full-length, half-distal, half-proximal and half-proximal-smoked cigarettes were 38.4, 29.1, 31.4 and 30.3 sec, respectively.

only in that HPS cigarettes had been smoked previously by the subject.

Data obtained during the first week of sessions (during which subjects adapted to the apparatus and protocol) were excluded from analysis. For purposes of data analysis, only events detected by the pressure transducer that were separated by at least 5 sec from the previous event were defined as puffs. This criterion successfully excluded from analysis the lighting-up process, which was frequently characterized by a series of puffs in rapid succession. In addition, one subject (DS) regularly exhibited "double puffs" (two events 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 events were summed to give a single puff duration. Group statistical analysis was performed on mean values of puff duration and interpuff interval from each subject using one-way analysis of variance for repeated measures. When significant F values were obtained, Duncan's new multiple range test was used to compare means for the different cigarette conditions.

Several other measures of smoking behavior were collected during the study (such as number of cigarettes smoked and carbon monoxide levels). These data provided information that addresses a separate issue, namely the effect of shortened cigarettes on cigarette consumption and smoke intake. Because this aspect of the study is independent of the present findings, it will be presented elsewhere.

RESULTS

Figure 1 shows that for each subject, puff duration decreased as a function of puff number for FL, HD and HP cigarettes. Results obtained with HPS cigarettes (not shown) were, in every case, identical to results obtained with HP cigarettes. Mean puff durations for HP cigarettes were consistently less than for HD cigarettes for all subjects; this effect was statistically significant ($p \leq 0.05$) for the group. Inspection of Fig. 1 reveals that, for each subject, puff dura-

tions for HD cigarettes (solid points, solid lines) overlap with puff durations obtained when subjects smoked the distal half of FL cigarettes (left half of each shaded area). Similarly, puff durations for HP cigarettes (open points, dashed lines), if shifted to the right, overlap with puff durations obtained when subjects smoked the proximal half of FL cigarettes (right half of each shaded area). These results demonstrate that puff duration is controlled by the distance from the burning end (combustion zone) of the cigarette to the smoker's mouth, and not by puff number itself. (If puff number were the controlling variable, then puff durations for HP and HD cigarettes would be the same at the same puff number, and the dashed and solid lines of Fig. 1 would overlap.)

Interpuff interval as a function of puff number for FL, HD and HP cigarettes is shown for each subject in Fig. 2. For FL cigarettes, interpuff interval increased as a function of puff number for the first six or seven puffs, after which it leveled off or decreased. Changes in interpuff interval with puff number for HD, HP and HPS cigarettes were less consistent across subjects. Except for one subject (FG), interpuff intervals as a function of puff number were the same for HP, HPS and HD cigarettes; for the group, mean interpuff intervals for HP, HPS and HD cigarettes were not significantly different ($p > 0.05$). These results suggest that interpuff interval is controlled by puff number, rather than by the distance from the combustion zone of the cigarette to the smoker's mouth.

DISCUSSION

The present findings show that smoking topography changes in a reliable manner as a full-length cigarette is smoked. Puff duration gradually decreases and interpuff interval gradually increases over the first six or seven puffs. These results confirm observations we have made in other subjects participating in various experiments using the same methodology (unpublished observations). Very similar changes in puff duration and interpuff interval as a function of puff number were reported in a study [8] based on data obtained from surreptitious observation of a large number of smokers in the natural environment. Thus it is unlikely that these within-cigarette changes in smoking topography are artifacts of the experimental environment or procedure.

Currently, deliveries of tar, nicotine, carbon monoxide and other smoke components are determined for different brands of cigarettes by smoking machines that are programmed to smoke cigarettes at a fixed puff duration and interpuff interval. Delivery values thus obtained are being used in the design and interpretation of epidemiologic and toxicologic studies of cigarette smoking. The present results suggest that the parameters currently used to program smoking machines might not reflect the manner in which most people smoke cigarettes. It is likely that modification of these parameters in a way that would more accurately reproduce human smoking patterns would yield more accurate (and thus more useful) estimates of delivery of tobacco smoke components [8].

There are several possible explanations for the control of puff duration by the distance from the combustion zone of the cigarette to the smoker's mouth. One simple explanation is that, the greater the distance from the burning end of the cigarette to the mouth, the more time it takes for the smoke to reach the mouth, simply because the leading edge of the smoke stream must travel a longer distance. Thus the decreasing puff durations observed as cigarettes burn down

may reflect a response of the smoker to a progressively decreasing smoke transit distance. Related to this explanation is the fact that, the greater the distance from the combustion zone to the mouth, the greater the resistance to draw (due to a greater amount of tobacco through which the smoke must pass). Thus the within-cigarette decrease in puff duration may reflect the smoker's response to a progressively decreasing resistance to draw. Other possible explanations are distinct from, but not completely independent of, the above two factors. Tar and nicotine delivery per puff have been reported to increase as a cigarette is smoked [9]. Therefore, smokers may take progressively shorter puffs to maintain a uniform puff-by-puff exposure to some tobacco constituent(s). Smoke temperature may also play a role, since one would expect the temperature of inhaled smoke to increase as the distance from the combustion zone to the mouth decreases. In this case smokers may take progressively shorter puffs to avoid exposing themselves to aversive smoke temperatures. Further studies would be required to evaluate to what extent each of these possible factors was responsible for the present results.

Compared to puff duration, the changes observed in interpuff interval as a function of puff number were more variable across subjects and more complex. In general, however, the data are consistent with the concept that interpuff interval is controlled by puff number. If this is the case, the increase in interpuff interval observed during the smoking of a cigarette may reflect a within-cigarette satiation process. A study in which puff number is specifically manipulated as an independent variable would more directly address this issue.

One result of the present study that warrants comment is the fact that all subjects smoked half-proximal-smoked (HPS) cigarettes and half-proximal (HP) cigarettes in an identical fashion. It was assumed that HPS cigarettes would contain more nicotine (and other particulate smoke components) than HP cigarettes, due to a filtration effect as smoke from the previously-smoked distal half of HPS cigarettes passed through the proximal half [3]. We thought that smokers might alter their smoking behavior in a manner to compensate for this presumed increased nicotine delivery of HPS cigarettes relative to HP cigarettes. The fact that this did not occur suggests either that HPS cigarettes did not in fact deliver significantly more nicotine than HP cigarettes, or that the measures of smoking behavior used here were not sensitive to changes in smoke nicotine concentration.

In the past behavioral scientists have often emphasized the role of psychosocial factors in the smoking process [7]. In general, this approach has not proved useful in elucidating the controlling variables that underlie the establishment and maintenance of cigarette smoking. We believe a more fruitful approach may lie in the detailed analysis of the discrete behaviors of which smoking is composed, and correlation of the behavioral measures with puff-by-puff deliveries of the pharmacologically-active constituents of tobacco smoke (nicotine, tar, carbon monoxide and possibly others). Understanding the pharmacological and behavioral variables that control cigarette smoking should provide a more rational basis for the design of smoking prevention and cessation programs [6], as well as for the design of safer cigarettes. The discovery in the present study that two fundamental descriptors of cigarette smoking (puff duration and interpuff interval) are under differential control demonstrates the usefulness of this approach.

ACKNOWLEDGMENTS

This research was supported by USPHS grant DA-01935. The authors wish to thank David O'Leary for preparation of the figures and those who provided useful comments on the manuscript.

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