AN AUTOMATED COMPUTER-BASED SYSTEM FOR THE STUDY OF MARIJUANA SMOKING DYNAMICS

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I. INTRODUCTION

Tobacco cigarette smoking has been widely practiced by humans over the years, and therefore, much research regarding behavioral, pharmacological, and chemical properties of smoking has been conducted by the tobacco industry and various scientific disciplines (1). However, little information is available regarding the characteristics of marijuana cigarette smoking. Our studies involving marijuana cigarettes containing different THC dose levels prompted us to study smoking behavior and profiles of marijuana cigarette smokers (3). A variety of cigarette holders based on a differential pressure-flow technique, have been developed to study smoking behavior where filtertip tobacco cigarettes were used. Rawbone, et al., who studied inhalation and absorption of tobacco smoke used aa specially designed cigarette holder that contained a cellulose filter insert between the differential pressure ports based on the assumption that laminar flow through such a filter would produce a pressure drop that is linearly related to the flow of gas through the holder and cigarette (4). However, their study revealed that the pressure-flow relatioship of the cigarette holder was not truly linear, thereby suggesting that some turbulent flow was present. Filter tobacco cigarettes were used in the Rawbone study as has been the case

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in most of the smoking behavior studies.

Marijuana cigarettes, unlike commercial filter cigarettes, are frequently loosely packed having a non-uniform density. This results in relatively lower draw resistnce and gas flow rates. Marijuana cigarettes also seem to produce considerably more resinous material and heavy particles than do filter cigarettes and would quickly clog a cellulose baffle located between pressure ports. Therefore, to study marijuana cigarette smoking dynamics, it is necessary to use a cigarette holder containing an orifice plate, which is unlikely to become restricted or clogged, and which is constructed of a material that is easy to clean. Such a holder should exhibit very low draw resistance, but the orifice plate will also produce turbulent flow which is no longer linearly related to the differential pressure across the baffel. Instead, the volume flow rate is proportional to the square root of the differential pressure (5,6). Much of the research regarding tobacco smoking dynamics has been conducted without the aid of a fast on-line computer. Most investigators had to rely on discrete electronic hardware to achieve some level of automated data acquisition and processing (2). The square root function associated with the orifice plate technique made this type of analysis more difficult and cumbersome. For real-time acquisition and analysis of marijuana cigarette volume flow rates involving the square root pressure-flow relationship, a fast laboratory computer (e.g., PDP-11/34) is necessary. The use of such a computer for on-line processing of the flow signal to obtain puff volume and related times parameters can easily provide the researcher with immediate smoking status information throughout the course of the experiment.

Research involving tobacco cigarette smoking behavior has demonstrated that an individual's smoking profile affects the level of the dose that is delivered to the smoker, which in turn, relates to how much is absorbed (4). Some investigators have attempted to measure inhalation and absorption of the cigarette smoke, and to analyze the inspired and expired gases (2,4). While these parameters are certainly of interest regarding marijuana smoking,, our primary interest and reason for developing a measurement system is to study puff volume profile and related parameters (i.e., puff duration, interpuff interval, etc.) during smoking, rather than the actual smoke volumes inhaled, and to determine if marijuana cigarettes with increased potencies affect an individual's smoking behavior. A puff volume transducer based on the orifice plate pressure-flow technique was designed for marijuana cigarette studies. Also, a computer program wss developed to acquire and process the signals from the transducer. The entire computerbased system was then calibrated and tested for linearity and accuracy.

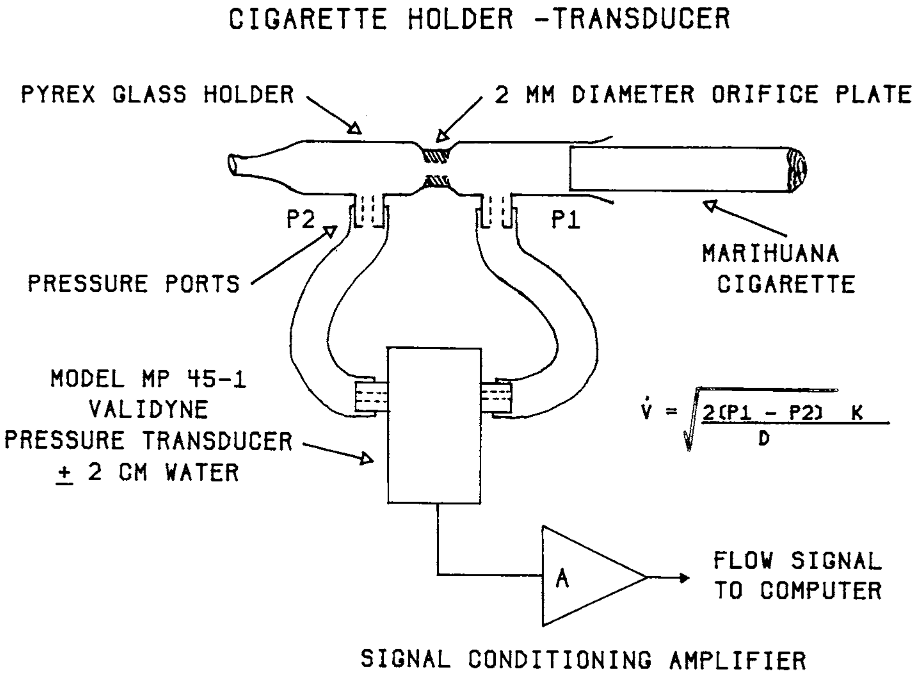

FIGURE 1. Schematic representing the smoking apparatus consisting of the puff volume transducer-holder, Validyne MP45-1 differential pressure transducer, and signal conditioning amplifier.

II. METHODS

A. Puff Volume Transducer

The design of our puff volume transducer, which also serves as the cigarette holder, is based on an application of Bernoulli's law to a simple physics principle - the Venturii flowmeter and is shown in Figure 1. A slight variation of this principle reveals that air, gas, or a fluid flowing through a pipe or tube having a relatively sharp reduction in internal cross sectional area at some point along its length, thereby creating a relatively small orifice, will develop a differential pressure across this constricted section that is proportional to the gas flowiing through the tube (5). Actually, the flow is linearly proportional to the square root of the differential pressure divided by the density of the gas according to the equation:

$$V = \frac{2(P1 - P2)}{D} K$$

where V is gas flow, P1-P2 is differential pressure, D is density of the gas, and K is a constant that takes into account the fixed cross sectional areas of the holder. The integral of this flow signal over time yields total volume through the tube. Therefore, our puff volume transducer is constructed from a pyrex glass tube having an internal diameter (7 mm) slightly less than the outer diameter of a cigarette. This material was selected because it will sustain the intense heat from a marijuana cigarette and also permit easy cleaning. The glass tube is configured to accomodate a cigarette and also permit also cleaning. The glass tube is conigured to accomodate a cigarette at one end and provide a mouth piece for the subject at the other end. An orifice plate located midway along the tube and containing a 2 mm diameter orifice creates the necessary reduction in area. Small pressure sensing ports are constructed in the side of the glass tube, with one located on each side of the baffle. The pressure differential due to flow then appears between these two ports.

The remainder of the smoking dynamics transducer aapparatus then consists of Validyne Model MP45-1 differential pressure transducer, having a sensitivity of +/- 20 mm (water), connected via Tygon tubing to each pressure port of the puff volume transducer. The signal from the pressure transducer is first amplified and low-pass filtered (10 Hz, 12dB per octave), and then routed to a laboratory mini-computer for processing by an on-line program.

B. System Configuration

A block diagram of the overall computer-based smoking dynamic system is shown in Figure 2. The smoking transducer is located in a shielded subject room, containing an exhaust fan for smoke evacuation, which is remotely located from the computer. The system is controlled by a video terminal located near the smoking apparatus, which also allows the experimenter to monitor calibration results and experiment parameters. An oscilloscope is used to monitor the analog flow signal in order to insure that the signal does not exceed the range of the computer's analog to digital converter. The smoking dynamics program runs on a Digital Equipment Corporation PDP-11/34 minicomputer and under the RT-11 operating system. The PDP-11/34 contains 32K words of memory, a 12-bit A to D converter, a 16-bit parallel 1/0 interface, and a real-

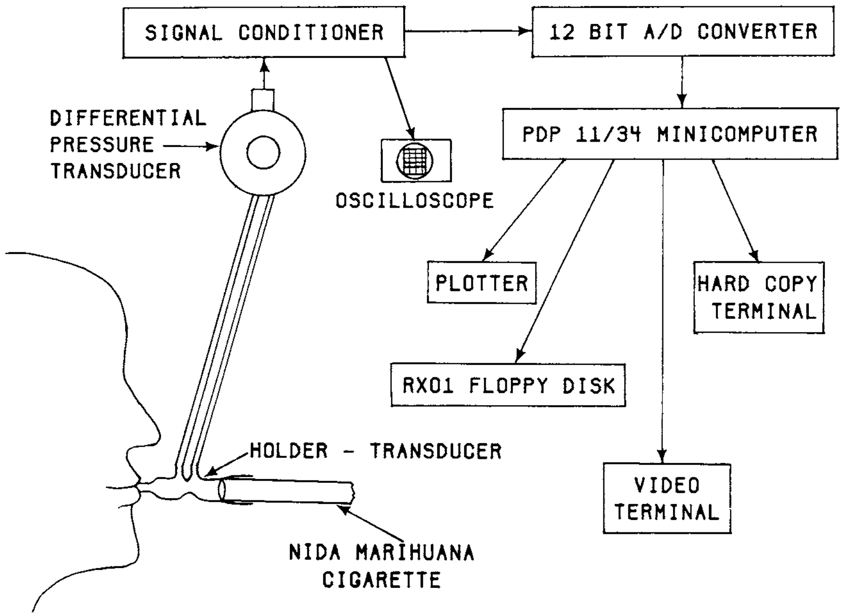

FIGURE 2. Block diagram showing the complete computer-based smoking dynamics system.

time programmable clock. Also, the configuration includes an RX01 floppy disk system for program and data storage, a hard-copy terminal for numerical printouts, and a Hewlett-Packard 7225B X-Y plotter for graphical representation of the data.

The smoking-dynamics on-line program processes the volume flow rate signal from the puff volume transducer in real-time on a puff-by-puff basis. It is written in FORTRAN and calls several assembly language modules that were specifically developed for smoking dynamics acquisition and analysis. A software flow-chart is shown in Figure 3. Basically, the program is arranged in four sections; 1) subject and experiment information entry, 2) calibration, 3) data acquisition and processing, and 4) data output and storage. The information input section of the program permits the experimenter to enter the subject's name, birth date, weight, etc. as well as the experiment information (e.g., type, data, data-set names, comments, etc.).

The calibration section allows the complete system to be calibrated by drawing known volumes of smoke through the cigarette and holder using a 50 ml syringe. A mechanical stop was installed on the syringe at the 50 ml volume mark to insure that each volume is the same. The average of five such volumes is used by the calibration routine to compute the scale factors. We averaged the 5 volumes to compensate for different flow rates. Following calibration, the calibration information is saved on disk for possible future use. Calibration prior to each experiment is important due to ambient

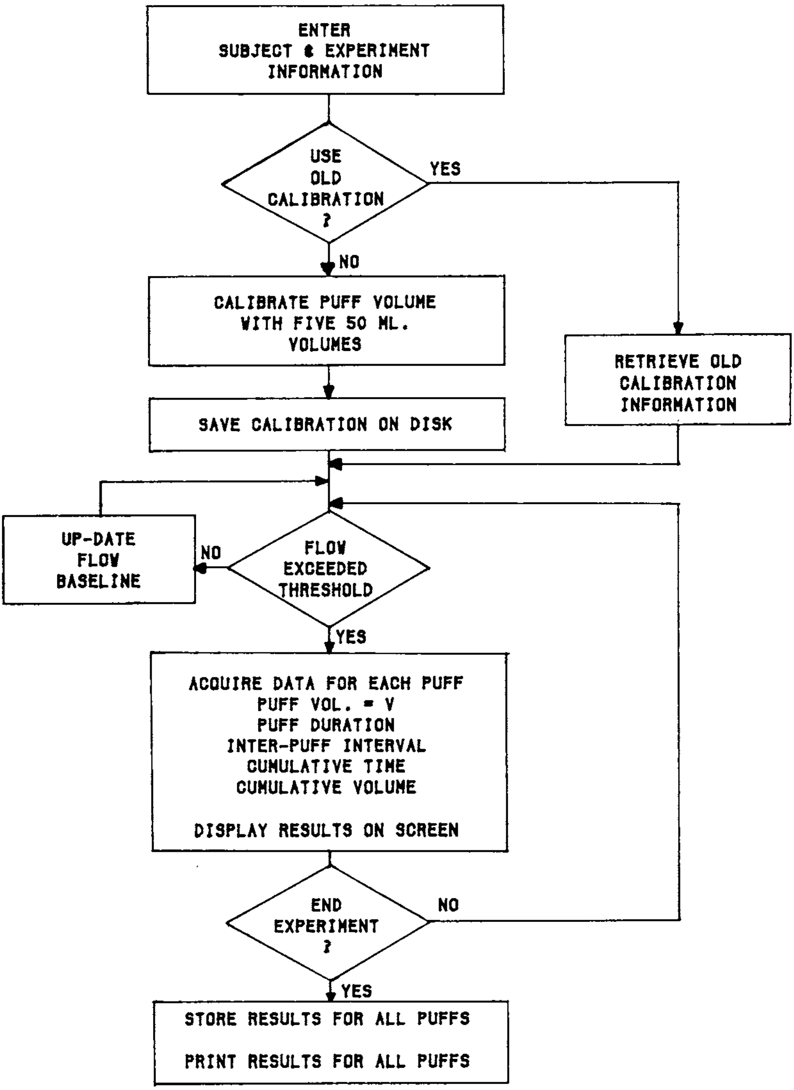

FIGURE 3. Simplified flow chart of the smoking dynamics computer program.

changes in humidity, barometric pressure, and temperature which, in turn, affect the accuracy of the system. Slight differences in calibration values before and after using the cigarette holder with a marijuana cigarette were noted. These differences were attributed to the build-up of residue on the glass holder during smoking. After the puff volume transducer was cleaned, the calibration values returned to those obtained before the cigarette was smoked.

The data acquisition and processing section computes puff volume, puff duration, inter-puff interval, cumulative volume, and cumulative smoking time on a puff-by-puff basis. Immediately following each puff, these parameters are displayed on the screen of a video terminal. An arbitary threshold of 20 A to D converter units was established for the flow signal in order to determine whether or not a puff was in progress. A puff was considered to be in progress if the flow value exceeded this threshold. Also, puff volumes less than 5 ml are considered artifactual and are discarded by the computer. The flow baseline is continuously sampled at 50 samples per second between puffs and averaged over 5 second intervals. Therefore, the flow baseline is automatically up-dated every 5 seconds during inter-puff intervals that exceed 5 seconds. After the last puff of the smoking sequence, which is signaled by the subject depressing a push-button switch connected to the computer's parallel I/O port, the program computes additional parameters regarding smoking dynamics. These include mean puff volume, mean puff duration, total smoking time, total smoke volume, percent of total volume for each puff, percent of total time for each puff, and a linear regression and correlation coefficient of puff volume versus puff duration.

The output and storage section of the program generates a hard-copy printout of smoking dynamic parameters and permits the user to store these data on disk in two different formats. One of the storage formats is compatible with a plotting program that drives the HP 225B X-Y plotter and permits quick and easy analysis of certain smoking parameters (e.g., puff volume versus cumulative time) in graphical form. The other format stores all smoking behavioral data in a large multidimentional array that allows easy editing and further processing (e.g., averaging data across subjects).

C. Evaluation of System Performance

Following development, the system performance was evaluated by drawiing different known volumes of both tobacco and marijuana through the puff volume transducer. A 200 ml glass syringe was used to draw these test volumes in progressively

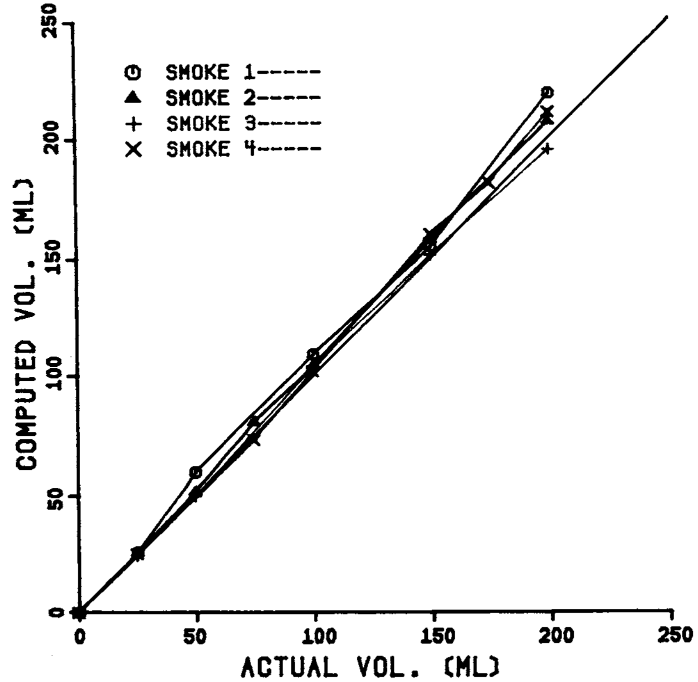

FIGURE 4. The relationship between computed volumes and actual volumes over a 0 to 200 ml range for 2 tobacco and 2 marijuana cigarettes. Known volumes within this range was drawn through the cigarettes using a 200 ml syringe.

increasing or decreasing 25 ml steps over a 200 ml range. The results of this procedure using four different cigarettes (2 unflitered tobacco and 2 marijuana) is shown in Figure 4. Computed volumes were plotted against actual volumes and compared with the line representing a correlation of one. Results indicate that the smoking dynamics system is linear over the range of 0 ml to 150 ml. This proved to be more than adequate siince we have observed most puff volumes fall within the 30 ml to 60 ml range.

A pilot study was conducted, using the smoking dynamics system, to evaluate the smoking characteristics of one marijuana smoker. He smoked on three different days, in a blind cross-over design, marijuana cigarettes of three different potencies (placebo, and 1.5% and 2.9% THC content marijuana). He was instructed to smoke in his customary way and to inhale all of each puff. System calibration using tobacco smoke was performed before testing the subject. A 'stop' button was depressed immediately following the subject's last puff. This caused the computer to store all smoking data on disk. Figure 5 is an example printout of the smoking dynamic parameters that were generated by the smoking of a 1.5% THC content marijuana cigarette.

Figure 6 shows the subject's puff volume smoking profile versus time. It can be seen that differences in THC content of the cigarettes did not significantly alter the puff volume smoking profile or total volume intake.

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ENTER FILE NAME FOR DATA:*SUBJ31.DAT
DISK READING COMPLETE!
DO YOU WANT TO PRINT DATA ARRAY?Y
SMOKING DYNAMICS RESULTS:
NAME:
COMMENT:
VOL. CALIBRATION=  15.795    PUFFS=  17
BIRTHDAY . 4-10-54     WT=  185.000   HT=  187.960
TOTAL TIME= 460.600           TOTAL VOL.=     0.664
PUFFPUFF VOL  PUFF DUR   INT PUF I % VOLUME   % TIME
 1     48.914     1.400      0.000       7.365      0.000
 2     48.932     2.100     18.100       7.368      3.930
 3     60.684     1.900     18.400       9.137      3.995
 4     61.470     2.000     22.500       9.256      4.885
 5     59.998     1.900     29.600       9.034      6.426
 6     46.617     1.500     27.200       7.019      5.905
 7     50.882     1.500     27.200       7.661      5.905
 8     40.842     1.600     28.700       6.150      6.231
 9     40.461     1.300     21.500       6.092      4.668
10     35.509     1.300     25.200       5.347      5.471
11     34.350     1.700     25.400       5.172      5.515
12     26.087     1.200     27.500       3.928      5.970
13     28.072     1.100     34.500       4.227      7.490
14     17.323     1.000     25.700       2.608      5.580
15     18.365     0.800     30.100       2.765      6.535
16     26.268     0.800     30.600       3.955      6.644
17     19.355     0.800     32.900       2.914      7.143
AVG PUFF VOL=    39.066   AVG PUFF DUR=      1.406
SLOPE=    30.883  INTERCEPT=    -4.352  CORR COEF=      0.877
END OF DATA OUTPUT !
DO YOU WANT TO PRINT ANOTHER FILE? N

BYE!
STOP --
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FIGURE 5. Example printout of smoking dynamics parameters for one marijuana (1.5% THC) cigarette smoker.

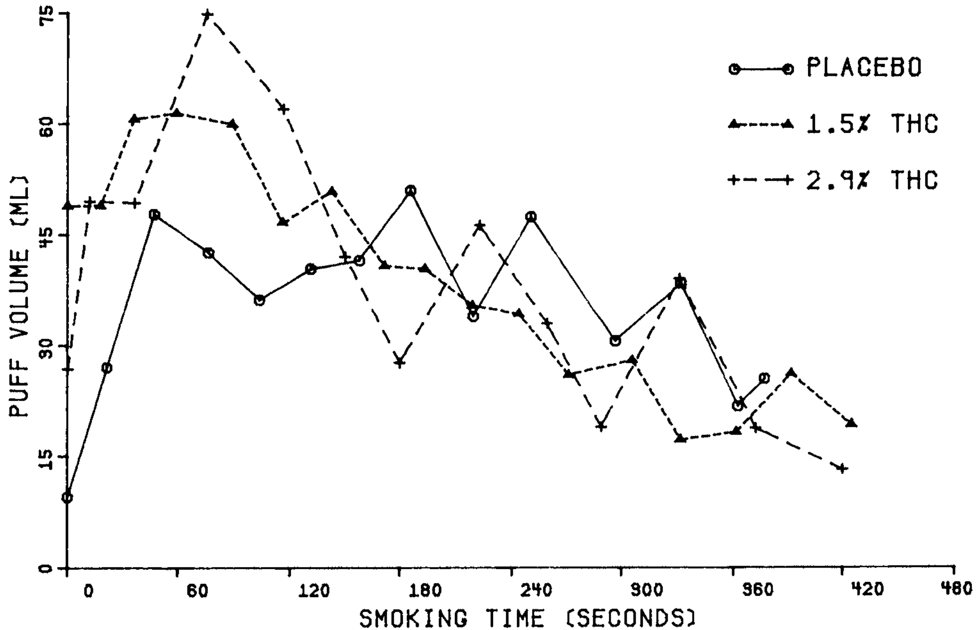

FIGURE 6. Graph showing one subject's puff volume smoking profile versus total smoking time for a placebo (circle), 1.5% THC (triangle), and 2.9% THC (+) dose levels.

III. CONCLUSIONS

A computer-based smoking dynamics system has been developed that allows us to evaluate the smoking behavior of marijuana cigarette smokers by measuring puff volume, puff duration, and inter-puff intervals. Performance evaluation indicates that puff volumes through an ignited marijuana cigarette can be measured accurately over a 0 to 150 ml range, and that system linearity is maintained over this range. Using this system to evaluate the smoking behavior of one subject smoking marijuana cigarettes of 0%, 1.5%, and 2.9% THC content, we found that there is little or no difference in this subject's puff volume profile between the three THC dose levels. Test results from this pilot experiment also indicates that the smoking dynamics system is easy to use, and that it performs well on a repeatable basis under actual smoking conditions.

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