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Comparison of Three Methods for Measuring Smoking Behavior

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

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List of Abbreviations

a.k.a.	also known as
ANOVA	analysis of variance
ARCI	Addiction Research Center Inventory
CDC	Centers for Disease Control
CO	carbon monoxide
cpd	cigarettes per day
CReSS	Clinical Research Support System
CReSSMicro	Clinical Research Support System Micro
DHβE	dihydro-β-erythroidine hydrobromide
ES	effect size
FR	Fixed Ratio schedule of reinforcement
FTC	Federal Trade Commission
FTND	Fägerstrom Test for Nicotine Dependence
HSD	Honestly Significant Difference
ICC	intraclass correlation
ICI	inter-cigarette-interval
IRB	Institutional Review Board
IPI	inter-puff-interval
kg	kilogram

mg	milligram
ml	milliliters
mm	millimeters
ng	nanograms
NRT	Nicotine Replacement Therapy
ppm	parts per million
PR	Progressive Ratio
SA	self-administration
SC	subcutaneous
SD	standard deviation
SDQ	Single Dose Questionnaire
sec	seconds
SEM	standard error of the mean
TO	time out
TTD	Telemetric Topography Device
QSU	Questionnaire of Smoking Urges
VAS	Visual Analog Scale
μg	microgram

Abstract

COMPARISON OF THREE METHODS FOR MEASURING SMOKING BEHAVIOR

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

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Understanding the factors that influence regular tobacco use often involves detailed assessment of individuals' smoking behavior (i.e., puff topography), including measuring puff number, volume, duration, and inter-puff interval (IPI) via mouthpiece-based, computerized devices. For example, puff topography measurement has been used to study smoking cessation medications, as well as to demonstrate brand-induced changes in smoking behavior. However, some research suggests that the use of a mouthpiece to evaluate puff topography may alter natural smoking behavior. Thus, this study was designed to compare topography measurement using mouthpiece-based methods (i.e.,

desktop and portable computerized devices) to methods that do not use a mouthpiece (i.e., direct observation via video recordings).

Thirty smokers of "full-flavor" or "light" cigarettes (≥15 cigarettes/day) participated in six Latin-square ordered, 2.5-hour experimental sessions. Sessions were separated by at least 48 hours, and were preceded by at least 8 hours of objectively-verified tobacco abstinence (i.e., CO level ≤ 10 ppm). Conditions differed by type of cigarettes smoked (own brand, Merit® Ultra-light) and by type of topography measurement method used (desktop, portable, video observation). All three measurement methods were sensitive to manipulations of cigarette brand (i.e., increased puff duration and volume for own brand relative to ultra-light; $P < .05$) and tobacco abstinence (i.e., increased puff number and volume for bout 1 relative to other bouts, $P < .05$). Measurement of smoking topography differed little between the mouthpiece-based device and direct observation methods. Puff duration, number, and IPI were correlated highly across measurement methods (all r's > 0.68). All methods were also reliable, as demonstrated by high correlations across cigarette bouts within each condition (most r's > 0.78). In contrast, participants perceived the use of either mouthpiece-based device to alter aspects of their smoking behavior (e.g., increased difficulty, reduced enjoyment, altered cigarette taste; $P < .05$) relative to direct observation alone. Although direct observational methods may be optimal for measuring certain smoking characteristics, the many logistical challenges posed by this method likely limit its usefulness in a laboratory setting. Taken together, these results suggest that mouthpiece-based devices offer a convenient and useful tool for researchers examining smoking topography.

Chapter 1

Introduction

Approximately 23% of the American population smokes tobacco cigarettes regularly, exposing themselves daily to at least 4,000 potentially harmful chemical compounds (Centers for Disease Control, 2003; CDC). Specifically, as a cigarette is smoked, chemicals are released during either a particulate phase (e.g., nicotine, benzo[a]pyrene, and nitrosamines; Hecht, 1999) or a gas phase (e.g., nitrogen and carbon monoxide; Zevin, Gourlay, & Benowitz, 1998). Many of these chemicals are known toxins or carcinogens, thus daily exposure to them may lead to a variety of life-threatening diseases (U.S. Department of Health and Human Services [USDHHS], 2004). For example, benzo[a]pyrene and nitrosamines have been associated with cancers of the `lung, bladder, pancreas, and kidney (Wogan, Hecht, Felton, Conney, & Loeb, 2004). Additionally, carbon monoxide (CO) has been implicated in cardiovascular disorder (Lakier, 1992) and respiratory illness (e.g., USDHHS, 2004). Thus, research demonstrates a strong correlation between exposure to tobacco smoke constituents and subsequent health-related problems.

Exposure to these potentially lethal constituents can be reduced greatly when smokers quit, consequently decreasing their risk for smoking-related diseases. In fact, smokers' continued abstinence may engender a level of health that is equivalent to a non-smoker (Fuchs et al., 1996; USDHHS, 2004). Some benefits are immediate: a decrease in heart rate within 20 minutes, a decrease in carbon monoxide level within 12 hours, an improvement in lung function within a few weeks, and a decrease in coughing and

shortness of breath within a few months (Emmons, Weidner, Foster, & Collins, 1992; USDHHS, 2004). Continued abstinence can then lead to substantial decreases in the likelihood of tobacco-related disease. For instance, smoking cessation can reduce the risk of certain cancers (e.g., mouth, esophagus, and bladder) by as much as 50% within several years (e.g., Brennan et al., 2000). The risks associated with coronary heart disease are also cut in half within only 1 year after quitting, and approximates never-smokers' risks within 15 years (USDHHS, 1990). In addition, the risk of a woman delivering a low birthweight baby decreases significantly if she quits smoking either before she becomes pregnant or during her first trimester (Mainous & Hueston, 1994; Secker-Walker, Vacek, Flynn, & Mead, 1998). Thus, quitting smoking increases the likelihood of positive health outcomes.

Despite the health advantages of quitting, few smokers actually achieve long-term cessation. Of the approximately 15 million smokers who make a quit attempt each year, less than 5% are able to maintain abstinence (Cohen et al., 1989; Fiore et al., 1990; USDHHS, 2004). This figure is discouraging, especially given the pharmacologic (e.g., nicotine replacement therapy, bupropion) and/or behavioral (e.g., motivational interviewing, individual counseling) cessation methods that are currently available (Hughes, 2003). Because quit attempts are high, and long-term abstinence rates are low, there is great interest in improving the efficacy of cessation interventions for smokers.

Improving cessation interventions may mean learning more about factors that influence nicotine self-administration. Non-human animals self-administer nicotine (e.g., Corrigall & Coen, 1989; Donny, Caggiula, Knopf, & Brown, 1995), and perhaps more

important, humans also self-administer nicotine (e.g., Harvey, Yasar, Heishman, Panlilio, Henningfield, & Goldberg, 2004). The literature regarding nicotine self-administration in non-human animals and in humans is reviewed below, with particular attention paid to the development of methods to measure self-administration of tobacco-delivered nicotine by humans. As will be described, this dissertation is intended to determine the extent to which these assessment methods influence smoking behavior.

What is Drug Self-Administration?

Drug self-administration refers to a behavior, or a chain of behaviors, in which an organism will engage in order to obtain drug reinforcement (Henningfield, 1983). For example, nicotine self-administration can occur when an individual picks up a pack of tobacco cigarettes, removes one, lights it, brings it to his/her mouth, and inhales tobacco smoke from it, thus obtaining nicotine. Regular smokers execute this chain of behaviors repeatedly; the average pack-a-day smoker takes approximately 10 puffs per cigarette which amounts to more than 70,000 puffs per year (Gritz, 1978). In fact, nicotine is self-administered at a higher rate than many drugs of abuse, including heroin and alcohol (Jarvik, 1978). Thus, understanding nicotine self-administration, and the factors that promote it, is important. As described below, three major learning-based theories have been posited to describe and explain nicotine self-administration: positive reinforcement, negative reinforcement, and cognitive-social learning (Tiffany, Conklin, Shiffman, & Clayton, 2004).

Positive reinforcement can occur when a behavior is associated with rewarding consequences, thus making future occurrences of that behavior more likely (Thompson &

Schuster, 1968). Nicotine is believed to serve as a positive reinforcer by producing rewarding effects which promote the drug's continued use. This idea is supported by the fact that drug-naïve non-human animals will work to self-administer nicotine (Corrigall & Coen, 1989; Donny et al., 1995). In addition, research with human participants demonstrates that nicotine administration increases euphoria and arousal, and enhances performance and memory (Benowitz, 1999; Watkins, Koob, & Markou, 2000). Thus, the rewarding consequences of tobacco-delivered nicotine self-administration may motivate smokers to continue smoking (Glautier, 2004).

Negative reinforcement can occur when a behavior is associated with prevention or removal of aversive consequences, again making future occurrences of that behavior more likely (Thompson & Schuster, 1968). Nicotine has been shown to function as a negative reinforcer in that self-administration of the drug can lead to avoidance or suppression of aversive withdrawal symptoms that appear during tobacco abstinence (e.g., Buchhalter, Schrinel, & Eissenberg, 2001; Hughes & Hatsukami, 1986). Nicotine/tobacco withdrawal symptoms include irritability, anxiety, restlessness, excessive hunger, difficulty concentrating, and sleep disturbance (Gross & Stitzer, 1989; Hughes & Hatsukami, 1986; Shiffman & Jarvik, 1976). Thus, smokers may be motivated to continue using tobacco in order to prevent the emergence of these aversive symptoms (Eissenberg, 2004).

Cognitive-social learning models posit that expectancies about the outcome of a tobacco use episode, as opposed to the outcome itself, are what drive nicotine self-administration behavior (Tiffany et al., 2004). A smoker's belief that smoking will lead

to a positive outcome (e.g., increased euphoria or arousal), or prevent/remove a negative outcome (e.g., decreased withdrawal symptoms), may promote the use of tobacco. According to proponents of these models, whether or not smoking actually produces such outcomes is irrelevant, even if the actual outcome differs from the expectation. Additionally, these models describe other cognitive concepts that may influence smokers' expectancies about tobacco use (Brandon, Herzog, Irvin, & Gwaltney, 2004). Three such concepts, self-efficacy, coping, and craving, can be used to explain a failed quit attempt. Low self-efficacy, or a smokers' belief in their ability to reach a goal (e.g., continued abstinence), has been shown to increase relapse rates (Shiffman et al., 2000). Research also provides evidence for a relationship between a smoker's coping style and successful abstinence outcomes; tobacco smokers with less active coping styles are less likely to remain abstinent (Shiffman, Hickcox, Paty, Gnys, Richards, & Kassel, 1997). Moreover, drug craving or urges may arise due to either environmental (e.g., seeing a cigarette; Siegel, 1999) or cognitive factors (e.g., disruption of thought processes; Tiffany, 1990), and ultimately interfere with a smoker's focus on maintaining abstinence. Together, these constructs represent the primary ideas behind the cognitive-social model of nicotine self-administration (Tiffany et al., 2004)

Although some drug dependence theories emphasize positive reinforcement, negative reinforcement, or cognitive-social factors, they all share common features that are relevant to understanding nicotine self-administration in smokers. Foremost, they emphasize that smoking is a learned behavior (Tiffany et al., 2004). Over time, smokers learn that tobacco use increases positive effects (positive reinforcement model), decreases

negative effects (negative reinforcement model), and/or produces effects that match their expectations (cognitive-social model). Regardless of the underlying process, however, the final outcome is continued nicotine self-administration. The following sections describe nicotine self-administration in non-human animals and humans.

Nicotine Self-Administration in Non-Human Animals

In one of the first studies to demonstrate reliable nicotine self-administration in non-human animals (Corrigall & Coen, 1989), rats (N=15) were initially trained to press a lever for food reinforcement. Following lever training, a chronic intravenous catheter was implanted into the jugular vein of each rat, and this catheter was used to deliver nicotine. An acquisition dose of 0.03 mg/kg/infusion nicotine was then made available, and responding was maintained on a limited-access (access to drug limited to a specified amount of time), fixed-ratio 5 schedule (FR5; 5 lever presses required for drug infusion), with a 1-minute time-out period (TO; responses are recorded, but not reinforced with drug) following each infusion. During this time, responses on the drug-associated lever (i.e., active lever) delivered nicotine, while responses on the other lever (i.e., inactive lever) delivered no consequences. Once responding was stable, saline and nicotine doses in the range of 0.003 – 0.06 mg/kg/infusion were substituted for the acquisition dose of nicotine (i.e., 0.03 mg/kg/infusion). Results revealed that self-administration behavior was dose-dependent: the number of active lever presses increased as the unit dose of nicotine increased, with maximum responding occurring at 0.01 and 0.03 mg/kg/infusion. Increasing the testing dose to 0.06 mg/kg/infusion decreased responding, though the total nicotine intake at this dose was equivalent to that seen with the acquisition dose of 0.03

mg/kg/infusion. Thus, the rats may have altered their response patterns to maintain a certain level of nicotine intake. Extinction was observed following the substitution of saline for nicotine, meaning that responding on the active lever decreased significantly as compared to when nicotine was tested. Moreover, the inactive lever produced minimal responding at all doses tested. Thus, under these conditions, nicotine was able to maintain reliable rates of self-administration (Corrigall & Coen, 1989).

Another study of nicotine intake used a different model of self-administration (Shoaib, Schindler, & Goldberg, 1997). Initially, 14 groups of rats were pretreated with an injection of nicotine (0.015, 0.03, or 0.06 mg/kg/infusion) prior to each training session that included an FR-1 TO 20-second schedule of reinforcement for nicotine (doses same as pretreatment doses). Specifically, rats were trained to poke their noses into a hole to obtain an infusion of nicotine (active hole; a nose-poke produced a feedback tone, thus triggering drug delivery), while nose-pokes into an inactive hole had no consequences. Once responding stabilized, the response requirement was increased up to FR-5, and rats that acquired robust self-administration patterns continued in the study. The testing phase consisted of substituting the acquisition dose of nicotine with either saline or differing doses of nicotine (0.002 – 0.12 mg/kg/infusion). All three nicotine training doses (0.015, 0.03, and 0.06 mg/kg/infusion) were able to produce reliable rates of responding to the active hole without affecting responses to the inactive hole. When the testing doses of nicotine were then administered, response rates changed as a function of dose. The number of responses to the active hole increased as the testing dose of nicotine increased, up to 0.015 mg/kg/infusion nicotine. Similar to results

presented previously (i.e., Corrigall & Coen, 1989), higher testing doses decreased response rates, thus producing an inverted U-shaped curve. Also, saline substitution extinguished nose-poking behavior to the active holes, and responses to the inactive hole were at near-zero levels at all doses tested. Results support the idea that nicotine produces reliable self-administration behavior (Shoaib et al., 1997). Moreover, these findings have been replicated in other studies using rodents (e.g., Donny et al., 1995; Donny et al., 1999), as well as in studies using non-human primates (e.g., Goldberg, Spealman, & Goldberg, 1981; Slifer & Balster, 1985) and dogs (e.g., Risner & Goldberg, 1983). Thus, nicotine's ability to act as a positive reinforcer, as defined by maintaining self-administration in non-human animals, is well-established.

What Factors Influence Nicotine Self-Administration in Non-Human Animals?

Since demonstrating the reinforcing efficacy of nicotine, recent research has focused on examining the factors that modulate nicotine self-administration. A better understanding of these factors may aid the development of effective treatments for smokers. For example, pharmacotherapies for nicotine dependence may be improved by examining the effects of nicotinic agonists (e.g., Corrigall & Coen, 1989) or antagonists (e.g., Watkins, Epping-Jordan, Koob, & Markou, 1999) on subsequent self-administration behavior. These pharmacotherapy medications bind to the nicotinic receptor to either facilitate (agonists; nicotine replacement therapy or NRT) or inhibit (antagonists; mecamylamine) an action at that site (Watkins et al., 2000). The effects of these medications on nicotine self-administration are reviewed below.

One study examined the effects of two nicotinic antagonists on nicotine self-

administration in rats (Watkins et al., 1999). A group of drug-naïve rats (n=13) were trained to self-administer 0.03 mg/kg/infusion nicotine during an acquisition phase under a FR-1 TO 20 second reinforcement schedule. The rats were then allowed access to either 0.03 (n=6) or 0.06 mg/kg/infusion (n=7) nicotine (doses chosen based on a dose-response test prior to the experiment). Once responding stabilized, injections of the noncompetitive antagonist mecamylamine hydrochloride ($\alpha3\beta4$ and $\alpha4\beta2$ nicotinic receptor subtypes; 0, 1, 2, or 4 mg/kg, subcutaneous or SC) were tested on different days. A separate group of drug-naïve rats (n=14) was also trained to self-administer the nicotine dose of 0.03 mg/kg/infusion. These rats then received injections of the competitive antagonist dihydro-β-erythroidine hydrobromide (DHβE; $\alpha4\beta2$ nicotinic receptor subtype; 0, 2, 4, 8, or 16 mg/kg, SC) on different days. Next, a subset of these rats (n=11; plus one additional naïve rat) were given access to the larger nicotine dose of 0.06 mg/kg/infusion to self-administer before being tested with DHβE again (same doses as above). Both nicotine training doses (0.03 and 0.06 mg/kg/infusion) produced reliable rates of responding (i.e., minimum of five injections during each 1-hour period with < 20% variation across days) during acquisition of self-administration. Mecamylamine dose-dependently decreased responding for 0.03 mg/kg/infusion nicotine (2 and 4 mg/kg significantly different from 0 and 1 mg/kg), as well as for 0.06 mg/kg/infusion nicotine (all doses significantly different from 0 mg/kg). Similarly, all doses of the antagonist DHβE significantly decreased responding for 0.03 and 0.06 mg/kg/infusion nicotine as compared to saline. Therefore, mecamylamine and DHβE proved capable of antagonizing nicotine self-administration under these conditions (Watkins et al., 1999).

To the extent that blocking the effects of nicotine might help smokers quit, mecamylamine and DHBE are both potential candidates for tobacco cessation pharmacotherapy medications.

Similar results were reported in a study examining the influence of mecamylamine and erysodine (DHβE analog; α4β2 receptor subtype) on intravenous nicotine self-administration (Mansbach, Chambers, & Rovetti, 2000). Rats (Ns = 4-10; varied for each drug tested, as well as for different doses of the same drug) initially trained under a FR1 schedule of food reinforcement were then given access to cocaine (300 μg/kg/infusion) and the FR requirement gradually increased to 5 lever presses. After responding was stabilized, nicotine (0.03 mg/kg/infusion) was substituted for cocaine. Two separate self-administration procedures were employed in the testing phase: FR5 or progressive ratio (PR; number of lever presses required for drug infusion increases progressively) schedules of reinforcement during which the nicotinic antagonists were tested. Specifically, rats were pretreated with saline, mecamylamine (0.32-3.2 mg/kg), or erysodine (0.32-32 mg/kg) prior to self-administration sessions. Analysis of the baseline rates of self-administration behavior under the FR schedule showed that nicotine produced stable responding, with > 90% of responses occurring on the drug-paired lever. Administration of both nicotinic antagonists decreased self-administration behavior in a dose-dependent manner, as compared to the baseline rates. Analysis of the baseline rates of self-administration behavior under the PR schedule also demonstrated stable responding, with the ordinal number of infusions per session ranging from 10-12 (break points ranging from FR63 to FR158). Again, mecamylamine and

erysodine pretreatment effects on nicotine self-administration were a function of dose; both antagonists decreased significantly break point levels significantly relative to baseline levels. Moreover, saline substitution produced similar decreases in nicotine self-administration under fixed and progressive ratio schedules of reinforcement. Overall, results that demonstrate antagonist blockade of nicotine's reinforcing effects, as defined by decreased self-administration, support the idea that nicotinic antagonists may be useful as pharmacotherapies for nicotine dependence (Mansbach et al., 2000).

This study also examined nicotine self-administration following pre-treatment with nicotine (Mansbach et al., 2000). Again, after training under an FR1 schedule of food reinforcement, rats were given access to cocaine (300 μg/kg/infusion) and the FR requirement gradually increased to 5 lever presses. Nicotine (0.03 mg/kg/infusion) was then substituted for cocaine after responding stabilized. During testing, differing doses of nicotine pretreatment (0, 0.32, 0.56, and 1.0 mg/kg) were administered subcutaneously. Rats were then allowed to self-administer the training nicotine dose (0.03 mg/kg/infusion) under either a FR5 or a PR schedule of reinforcement. Nicotine pretreatment decreased fixed ratio responding significantly, and in a dose-dependent fashion. In contrast, pretreatment with nicotine had no effect on responding under the PR schedule. Thus, nicotine self-administration behavior differed depending on the pretreatment dose and response requirement (Mansbach et al., 2000). Results demonstrated that, at least under some conditions, nicotine preloading can suppress nicotine intake.

The effects of nicotine pretreatment on self-administration behavior were examined in another study using rats (N=8; Corrigall & Coen, 1989). Following training on a FR5 schedule for food reinforcement, rats were given the opportunity to respond for nicotine (0.03 mg/kg/infusion). To assess the effects of nicotine pretreatment on responding, doses of 0, 0.1, 0.3, and 1.0 mg/kg subcutaneous nicotine were given approximately 20 minutes prior to self-administration testing sessions. Results revealed a dose-dependent reduction in the number of self-administered nicotine infusions. Similar to findings reported in other studies, nicotine pretreatment suppressed subsequent nicotine intake in rats under a fixed ratio schedule of reinforcement (Corrigall & Coen, 1989). Taken together, research supports the notion that nicotine preloading may significantly reduce nicotine intake. Consequently, nicotinic agonists (e.g., nicotine gum, patch, nasal spray) have been developed as pharmacotherapies for smoking cessation (Herning, Jones, & Fischman, 1985; Perkins, Grobe, Stiller, Fonte, & Goettler, 1992).

In summary, understanding nicotine self-administration, and the factors that influence it, has been an important and fruitful line of pre-clinical research. Findings generated from this line of research can be used to develop effective pharmacotherapy treatments for smokers. Of course, nicotine self-administration can also be observed in humans, and understanding the behavior in this population is critical to the successful treatment of nicotine dependence.

Nicotine Self-Administration in Humans

As with non-human animals, the reinforcing efficacy of nicotine has been demonstrated in humans using the self-administration paradigm; regular smokers will

self-administer pharmacologically pure nicotine in a laboratory setting (e.g., Harvey et al., 2004). However, outside of the laboratory, smokers self-administer nicotine via tobacco cigarettes. Thus, while a review of the self-administration of pharmacologically pure nicotine is relevant, this introduction also provides a detailed examination of the self-administration of tobacco-delivered nicotine.

Human Self-Administration of Pharmacologically Pure Nicotine

Several studies have demonstrated that humans will self-administer pharmacologically pure nicotine under laboratory conditions, though this effect is observed most reliably in individuals who have a history of tobacco cigarette smoking. For example, regular tobacco users have been shown to self-administer intravenous nicotine in a paradigm similar to that reported in animals (Henningfield, Miyasato, & Jasinski, 1983). In this study, smokers participated in three-hour experimental sessions which differed by nicotine dose: 0, 0.75, 1.5, and 3.0 mg/injection (n = 3), or 0 and 1.5 mg/injection (n = 3). Following 1 hour of tobacco abstinence, participants had a catheter inserted into their forearm and, during session were given the opportunity to self-administer saline or nicotine (via the catheter) under a limited-access, FR-10 TO-1 minute schedule of reinforcement. Responses on an active lever delivered nicotine or saline, while responses on an inactive lever had no consequences. At the end of each session, participants were asked to report any drug effects via several subjective questionnaires. Relative to saline, nicotine maintained higher rates of responding in only a few subjects, but analysis of the pattern of responding revealed that nicotine may have maintained self-administration (Henningfield et al., 1983). For instance, the intravenous

route of nicotine intake mimicked regular patterns of cigarette smoking, but saline intake was highly variable. Moreover, within sessions, nicotine was self-administered at a constant rate, while responding for saline decreased significantly by the end of the 3-hour period. Participants also reported that nicotine increased ratings of "drug liking" (Single Dose Questionnaire, or SDQ) and euphoria (Morphine-Benzedrine Group scale of the Addiction Research Center Inventory, or MBG scale of the ARCI), as compared to saline. Taken together, smokers' self-administration behavior and subjective reports suggest that intravenous nicotine may serve as an effective reinforcer in humans under these laboratory conditions (Henningfield et al., 1983).

Another study demonstrated more clearly that intravenous nicotine maintains self-administration behavior in regular tobacco users (Harvey et al., 2004). Eight smokers (mean = 29 cigarettes per day, or cpd) were given concurrent access to saline and nicotine (0.75, 1.5, and 3.0 mg) during each 3-hour experimental session. In contrast to the methods reported previously, responses on one lever resulted in nicotine injections (i.e., as opposed to nicotine and saline injections), and responses on the other lever resulted in saline injections (i.e., as opposed to having no consequences). The FR response requirement (10-1600 lever presses) and the TO period following each injection (1-20 minutes) varied within and across subjects. Response rates (at FR $\geq$ 200) and the number of injections/session (at all FR values except 50 and 1600) were significantly higher for nicotine than for saline. Also, the number of nicotine injections/session was dose-dependent, as this number decreased as the dose/injection increased. Again, nicotine

proved to be reinforcing in these cigarette smokers in a laboratory setting (Harvey et al., 2004).

Other studies have examined nicotine self-administration in humans using other routes of administration. One study compared the self-administration of active versus placebo nicotine gum during a period of tobacco abstinence (Gross & Stitzer, 1989). Forty cigarette smokers ($\geq$ 10 cpd) were randomly assigned to chew either 0 (n = 20; mean = 25.5 cpd) or 2 mg (n = 20; mean = 33.9 cpd) nicotine gum for 10 weeks following smoking cessation. Participants were asked to chew between 5 and 15 pieces of gum per day (supply of 105 pieces/week), and to report to the laboratory twice weekly. During laboratory visits, compliance with all study requirements was verified biochemically via regular recordings of expired air CO (gaseous chemical absorbed into lungs during smoking; used to determine recent smoke exposure), and salivary thiocyanate (metabolite specific to smoke exposure; used to confirm smoking abstinence) and cotinine levels (metabolite specific to nicotine exposure; used to confirm nicotine gum use). Additionally, participants returned unused gum weekly, in order to calculate pieces of gum chewed per day. Participants using active nicotine gum chewed an average of 6.9 pieces per day throughout the duration of the study (no differences across days). In contrast, use of placebo gum decreased significantly from 6.8 to 4.9 pieces per day by the last week. Thus, the average number of pieces of gum chewed per day was significantly different between the two groups. Moreover, self-administration of gum, and abstinence from tobacco, was confirmed with all biochemical measures. Although the methodology employed in this study differs from a typical self-administration model,

results showed that gum containing active nicotine supports self-administration better than placebo gum (Gross & Stitzer, 1989). Other studies using the gum form of nicotine to examine self-administration behavior have confirmed these findings (e.g., Hughes, Gust, Keenan, & Fenwick, 1990).

Similar to research including non-human animals, research including humans has revealed that a variety of factors affect the self-administration of pharmacologically pure nicotine, including nicotinic antagonists (e.g., Rose, Behm, Westman, & Bates, 2003). In this study, the influence of mecamylamine on the self-administration of intravenous nicotine was examined in sixteen men and women. All participants were daily smokers (mean = 24.7 cpd) who abstained from smoking overnight prior to each of four sessions. Two baseline sessions were included to train participants on the self-administration procedures, as well as to determine individual doses for testing sessions. Specifically, in the first session, participants smoked their own brand cigarette *ad libitum* in order to obtain each individual's nicotine dose per puff and per cigarette. The second session consisted of training participants to self-administer nicotine intravenously; the rate of self-administration was equivalent to that recorded in session one (i.e., same number of puffs and nicotine dose/puff). Sessions 3 and 4 were considered testing sessions during which participants' self-administered intravenous nicotine for 4 hours following ingestion of oral mecamylamine (10 mg) or placebo. Although self-administration of nicotine was considered *ad libitum*, participants were not allowed to self-administer a total amount of nicotine/session that exceeded twice their total baseline amount for safety reasons. Salivary nicotine samples were also collected during these sessions. According to the

individualized nicotine measurements taken in the first session, when participants were smoking their own brand of cigarettes, participants self-administered an average of 0.1 mg nicotine per puff (range 0.04-0.15 mg), for an average total nicotine dose per session of 4.7 mg. Results from the testing sessions showed that participants responded significantly more for nicotine in the mecamylamine condition, as compared to the placebo condition. Consequently, the average nicotine dose was 4.3 mg in the mecamylamine session and 3.4 mg in the placebo session. These results are quite the opposite of those reported in the animal literature (i.e., decreased responding for nicotine following mecamylamine administration; Watkins et al., 1999). However, one hypothesis is that smokers initially compensate for mecamylamine-induced blockade of nicotinic stimulation by increasing subsequent intake, and this behavior would extinguish over time (Rose et al., 2003). Nonetheless, nicotinic antagonists significantly influence self-administration of pharmacologically pure nicotine in regular tobacco users.

Another study compared the reinforcing effects of pure nicotine, delivered via a nasal spray, across periods of tobacco/nicotine abstinence or regular use (Perkins, Grobe, Weiss, Fonte, & Caggiula, 1996). Prior to sessions, smokers (N = 24, mean = 19.7 cpd) either abstained from smoking overnight (approximately 12 hours) or engaged in *ad libitum* smoking. Two nasal spray bottles were then presented concurrently to the participants six separate times during each of two trials. One bottle contained placebo spray, while the other contained active nicotine (1.5 μg/kg/spray). Smokers were instructed to self-administer one of the two spray bottles during each of the six presentations per trial. Thus, a maximum of 9 μg/kg could be self-administered during

each trial (i.e., if the bottle corresponding to nicotine was chosen all six times), for a total of 18 μg/kg/session. Results showed that participants self-administered significantly more nicotine following overnight abstinence, as compared to *ad libitum* smoking. Thus, nicotine appears to be more reinforcing in smokers following overnight tobacco abstinence, as compared to when they have not abstained (Perkins et al., 1996).

In conclusion, these data support the non-human animal literature, demonstrating that nicotine serves as an effective reinforcer in humans. Regular smokers will self-administer pure nicotine, for example, in intravenous (e.g., Henningfield et al., 1983) and transmucosal forms (e.g., Gross & Stitzer, 1989; Perkins et al., 1996). Factors such as nicotinic antagonists and tobacco abstinence may alter this behavior, and these findings have contributed to our understanding of smoking cessation treatments. Nonetheless, most regular cigarette smokers do not self-administer pharmacologically pure nicotine routinely. Therefore, an examination of the self-administration of nicotine from tobacco cigarettes is warranted.

Human Self-Administration of Tobacco-Delivered Nicotine

Early research on smoking behavior focused on aspects of cigarette consumption such as packs/year and cigarettes/day. However, assessment of such global measures may not be sufficient for a complete understanding of smoking behavior (see Scherer, 1999 for review). For example, exposure to certain smoke constituents, including nicotine, varies as a function of the way a cigarette is smoked and this variation may not always be captured by counting the number of cigarettes consumed (Benowitz, Jacob, Kozlowski, & Yu, 1986; Bridges, Combs, Humble, Turbek, Rehm, & Haley, 1990; Gust

& Pickens, 1982). Clearly, when specific smoking behaviors change, exposure to smoke constituents also changes; increasing puff volume has been shown to produce subsequent increases in plasma nicotine levels, when other behaviors (e.g., puff number, breathhold duration) are held constant (e.g., Zacny, Stitzer, Brown, Yingling, & Griffiths, 1987). In fact, puff volume varies widely across individuals (e.g., Eissenberg, Adams, Riggins, & Likness, 1999; Gust, Pickens, & Pechacek, 1983). Therefore, knowing that two different individuals smoke a comparable number of cigarettes per day may not indicate an equivalent level of exposure to nicotine, as well as other smoke constituents such as carbon monoxide and carcinogens (Guyatt, Kirkham, Mariner, Baldry, & Cumming, 1989; Moody, 1984).

Given that global measures such as number of cigarettes consumed lack precision, methods that provide more detailed analysis of smoking behavior (i.e., "puff topography") have been developed. Specifically, puff topography provides a quantitative measure of a smokers' nicotine self-administration behavior (Corrigall, Zack, Eissenberg, Belsito, & Scher, 2001; Hatsukami, Morgan, Pickens, & Hughes, 1987; Woodson & Griffiths, 1992; Zacny & Stitzer, 1985). While many potential puff topography variables exist, those commonly reported include puff number (a count of puffs per cigarette), puff duration (measured in seconds), puff volume (measured in milliliters), and inter-puff interval (IPI; time between successive puffs; measured in seconds). Some representative values of these and other variables were provided in a review of 32 studies that included

Table 1

Puff topography data from 32 studies demonstrating individual variability in smoking behavior

Study	Number of Ss	Mouthpiece? Y/N	Puffs/ cigarette	Interpuff interval (sec)	Cigarette duration (sec)	Puff duration (sec)	Puff volume (mL)
Rawbone et al. (1978)	12	N/A	10	41		1.8	
Rawbone et al. (1978)	9	N/A	10	35		2.1	
Woodman et al. (1986)	9	Y	13	18	254	1.9	
Nemeth-Coslett et al. (1986a)	8	Y	8	64	414	1.8	
Nemeth-Coslett et al. (1986b)	8	Y	8	47	362	1.4	
Nil et al. (1986)	132	Y	13	28		2.2	30
Jarvik et al. (1978)	9	Y	10				
Russell et al. (1986)	10	N/A	11	35			
Ashton et al. (1978)	14	N/A		24		1.5	
Schulz & Seehofer (1978)	100	N/A	11	50		1.4	
Schulz & Seehofer (1978)	218	N/A	12	42		1.3	
Henningfield & Griffiths (1981)	8	Y	10	39	351	1.0	
Stepney (1981)	19	Y	13		400		38
Battig, Buzzi, Nil (1982)	110	Y	13	26		2.1	40
Epstein et al. (1982)	63	Y	13			2.4	21
Russell et al. (1982)	12	Y	15	26	324	2.3	40
Gritz et al. (1983)	8	Y	9	47		2.2	66
Ossip-Klein et al. (1983)	9	N/A	8		351	1.4	

Table 1 continued

Puff topography data from 32 studies demonstrating individual variability in smoking behavior

Study	Number of Ss	Mouthpiece? Y/N	Puffs/ cigarette	Interpuff Interval (sec)	Cigarette duration (sec)	Puff duration (sec)	Puff volume (mL)
Ossip-Klein et al. (1983)	9	N/A		12	339	1.9	
Guillerm & Radziszewski (1978)	8	N/A	12	41	390	1.9	39
Gust et al. (1983)	8	Y	9	48	393	1.6	44
Adams et al. (1983)	10	Y		26		1.9	44
Moody (1984)	517	Y	9	26	232	2.1	44
Nil et al. (1984)	20	Y	15	26		1.6	40
McBride et al. (1984)	9	Y	16	25	352	2.1	42
Medici et al. (1985)	17	Y	14	19		2.2	43
Burling et al. (1985)	24	Y	12	28	330	1.7	
Nil et al. (1986)	117	Y	13	22		2.1	42
Hughes et al. (1986)	46	Y	11			1.6	
Bridges et al. (1986)	108	Y	11				56
Puustinen et al. (1986)	11	Y	13	22		2.3	44
Hilding (1956)	27	N	10				
Mean (SD)			11 (2)	34 (12)	346 (53)	1.8 (0.4)	43 (9)
Median			11	28	351	1.9	42.5
Range			8-16	18-64	232-414	1.6-2.4	21-66

Table adapted from USDHHS, 1988
N/A – data not available

puff topography as a primary outcome measure (USDHHS, 1988; see Table 1), and the review makes clear the considerable individual variability in smoking behavior. For example, the average number of puffs taken on a cigarette ranged from 8 to 16 (mean = 11), while average puff duration ranged from 1.6 to 2.4 seconds (mean = 1.8 sec), and average puff volume ranged from 21 to 66 ml (mean = 43 ml). Similarly, average IPI ranged from 18 to 64 seconds (mean = 34 sec). Although study population and methodology varied widely, together these studies demonstrate that smoking behavior can be characterized using detailed puff topography measurement.

How is Puff Topography Related to Nicotine Self-Administration?

Measuring puff topography reliably and accurately is critical because smokers' nicotine intake, as well as their intake of other smoke constituents, is largely defined by the way cigarettes are smoked (e.g., Gust & Pickens, 1982; Herning, Jones, Benowitz, & Mines, 1983). In fact, the link between smoking topography and smoke constituent exposure has originated from several different lines of evidence, as reviewed below.

For instance, research comparing machine- and human-based smoking demonstrates the importance of measuring topography to determine smoke constituent level. Machine-based smoking is used by the Federal Trade Commission (FTC) to measure the level of smoke constituents produced by a burning cigarette (Kozlowski, O'Connor, & Sweeney, 2001). Specifically, cigarettes are machine-smoked according to a standardized procedure; 35-ml, 2-sec puffs are taken once per minute until the butt length is 23 mm (FTC, 2000; Hoffmann, Djordjevic, & Hoffmann, 1997). Smoke constituent content is then analyzed using various biochemical methods, and this

information is used to classify cigarettes (FTC, 2000). Thus, using the FTC method, cigarettes are classified into "full-flavor" (average nicotine = 1.15 mg, tar = 15.63 mg, CO = 15 mg), "light" (average nicotine = 0.73 mg, tar = 9.56 mg, CO = 10.88 mg), and "ultra-light" yields (average nicotine = 0.47 mg, tar = 5.14 mg, CO = 6.71 mg; based on sample of common brands; CDC, 1997).

Although cigarettes are characterized by FTC machine-based yields, evidence suggests that this method of measurement may not be predictive of actual smoke constituent delivery, including nicotine, to the smoker (Djordjevic, Hoffmann, & Hoffmann, 1997; Jarvis, Boreham, Primatesta, Feyerabend, & Bryant, 2001). In fact, post-smoking nicotine blood levels are only modestly correlated with the machine-based yield of cigarettes (e.g., Ashton, Stepney, & Thompson, 1979). This discrepancy is attributed to the high variability in human puffing behavior. For example, FTC puff topography parameters have been compared with data obtained from individuals smoking as desired via a topography measurement device (Djordjevic et al., 1997). Smokers of low- ($\leq$ 0.8 mg nicotine; n = 8; FTC light/ultralight mean = 0.47-0.73 mg nicotine) and medium-yield (0.9 – 1.2 mg nicotine; n = 4; FTC light/full-flavor mean = 0.73-1.15 mg nicotine) cigarettes participated. Compared to the standardized FTC value of 35 ml, puff volumes ranged from 45-63 ml for the low-yield cigarettes and from 43-48 ml for the medium-yield cigarettes. Also, inter-puff-interval values ranged from 18-53 seconds for low-yield and 22-43 seconds for medium-yield cigarettes, clearly lower than the FTC value of 58 seconds. These differences in smoking patterns were reflected in the estimated nicotine and tar yields. Based on their FTC classification, for instance, low-

yield cigarettes have an average yield of 10 mg tar and 0.8 mg nicotine, respectively. However, according to puffing topography data collected from actual smokers, these cigarettes delivered 30 mg tar and 2.1 mg nicotine in this study. Similar results were found for the medium-yield cigarettes. Indeed, these smoking yields are 2-3 times greater than those predicted using the FTC method. Thus, smokers' actual exposure level is a function of individualized smoking patterns, and is not necessarily related to cigarette brand. Study results highlight deficiencies in the way the FTC predicts smoke constituent exposure, while also demonstrating the importance of using puff topography measurement to assess nicotine intake (Djordjevic et al., 1997).

These findings are supported by studies examining the puffing patterns of smokers' when they smoke cigarettes of differing nicotine yields (e.g., Gust & Pickens, 1982). In this study, six daily smokers (mean = 20.8 cpd) experienced a two-day cigarette habituation period (1.2 mg nicotine cigarettes smoked *ad libitum*), followed by three, 1-hour experimental sessions. Within each session, participants smoked two cigarettes of 0.32 (low-yield; FTC ultralight mean = 0.47 mg), 1.25 (medium-yield; FTC full-flavor mean = 1.15 mg), or 2.50 mg (high-yield; FTC full-flavor mean = 1.15 mg) nicotine yields *ad libitum* within each session. Although the cigarettes differed by FTC nicotine yield, they were similar on other characteristics such as tar and CO level. Assessment of topography measures showed that nicotine yield was inversely related to puff volume, duration, and number. Puff volume increased significantly from 36.8 ml when smoking high yield cigarettes, to 44.4 ml with medium yield and to 50.8 ml with low yield cigarettes. Similarly, puff duration was increased with a decrease in nicotine

yield: 1.8 sec (high), 2.2 sec (medium), and 2.4 sec (low). In addition, the number of puffs was significantly greater with low yield cigarettes (8.2 puffs), as compared to high yield cigarettes (7.7 puffs). These results demonstrate that smokers may alter a variety of topography variables when smoking cigarettes with different nicotine yields, presumably in an effort to titrate their nicotine intake (Gust & Pickens, 1982).

A similar study assessing the influence of nicotine yield on smoking topography included analysis of smokers' plasma nicotine levels (Herning et al., 1983). Changes in puff topography and nicotine blood levels were compared when participants (N=11) smoked cigarettes that differed by their nicotine content: low- (0.4 mg; FTC ultralight mean = 0.47 mg), medium- (own brand cigarette; ~1.0 mg; FTC full-flavor mean = 1.15 mg), and high- yield (2.5 mg; FTC full-flavor mean = 1.15 mg). Measures of puff number, duration, volume, and IPI were assessed during the *ad libitum* smoking of each cigarette. Additionally, blood samples were obtained several minutes prior to and following each cigarette. Results revealed characteristic alterations in puff topography as a function of nicotine yield. Although nicotine yield was moderately correlated with plasma nicotine levels, puff topography was a better predictor of nicotine intake. Compared to 25% variability accounted for by nicotine yield, individual differences in smoking behavior (i.e., puffing and inhalation parameters) accounted for over 50% of the variance associated with increased nicotine blood levels. Thus, over half of the differences in nicotine blood levels were due to variations in how cigarettes were smoked. These data highlight the importance of each smoker's personal role in their exposure to nicotine, other than simply the type of cigarette they choose to smoke. In

addition, study results demonstrate the significance of puff topography as a measurement of nicotine intake (Herning et al., 1983). Other studies have corroborated these findings by evaluating the puff topography of smokers when they change cigarette brands (see Kozlowski et al., 2001 for review). For example, smokers take more (number), bigger (volume), and/or longer (duration) puffs per cigarette when they switch from full-flavor to low-yield cigarettes. As a result, increases in exposure to nicotine and other smoke constituents are often observed (e.g., Herning, Jones, Bachman, & Mines, 1981).

Finally, some studies have manipulated individual topography variables to examine the intake of smoke constituents (e.g., Zacny et al., 1987). Seventeen regular smokers (mean = 31.8 cpd) participated in several separate experiments, each of which consisted of several 1.5-hour sessions. During all sessions, participants took a total of 8 puffs, each 60 seconds apart, from cigarettes of their usual brand. Smoking instructions were given such that one topography variable was manipulated while all other variables were held constant. Plasma nicotine and CO levels were determined prior to and at different times following each smoking period. In the first experiment puff volume varied across sessions (15, 30, 45, and 60 ml), while inhalation volume (50% of vital capacity) and breathhold duration (4 seconds) were held constant. Results revealed that smokers' nicotine level increased approximately 4-fold when they changed their puff volume from 15 (4.6 ng/ml) to 60 ml (16.2 ng/ml). Similarly, carbon monoxide increased as puff volume increased; CO boost (i.e., increase in CO from pre- to post-smoking; measured in parts per million or ppm) was 1.0, 4.2, 6.3, and 8.7 ppm for 15, 30, 45, and 60 ml puffs respectively. In another experiment from the same report (Zacny et al.,

1987), breathhold duration was manipulated (0, 4, 8, and 16 seconds) while puff volume (50 ml) and inhalation volume (50 % vital capacity) were held constant. Carbon monoxide boost, but not nicotine boost, increased as breathhold duration increased: from 4.4 (0 sec), to 5.4 (four sec), to 7.3 (8 sec), to 9.3 (16 sec) ppm. Again, study results reveal that individual puffing components are important determinants of smoke constituent exposure (Zacny et al., 1987).

To summarize, the relationship between puff topography and smoke constituent intake (e.g., nicotine, CO) is well-established through several different lines of evidence. Collectively, these data demonstrate the importance of using puff topography measurement to examine the self-administration of tobacco-delivered nicotine, as well as smokers' exposure to other smoke constituents. Importantly, puff topography may also be affected by other external factors, as reviewed below.

What Factors Influence the Puff Topography of Smokers?

A variety of factors influence puff topography, including administration of nicotinic antagonists (e.g., Nemeth-Coslett, Henningfield, O'Keefe, & Griffiths, 1986a) and agonists (e.g., Perkins et al., 1992), as well as cigarette brand (e.g., Guyatt et al., 1989). Together with data from studies examining self-administration of pharmacologically pure nicotine, data from these studies has facilitated a more complete understanding of smoking behavior. In turn, more effective pharmacological and behavioral treatments for smokers have been developed.

Treatment with nicotinic antagonists such as mecamylamine influences cigarette smoking in regular tobacco users (e.g., Nemeth-Coslett et al., 1986a). Eight smokers

(mean = 33 cpd) were administered a dose of oral mecamylamine (0, 2.5, 5.0, 10.0, or 20 mg) prior to the start of each 90-minute session. Each dose was tested three times for a total of 15 sessions. During sessions, participants were instructed to smoke freely their own brand of cigarette, and carbon monoxide levels were recorded before and after each cigarette. Mecamylamine dose-dependently affected several puff topography measures, including number of puffs per cigarette and inter-puff-interval. For example, the average number of puffs per cigarette increased from 8.2 (placebo) to 9.5 (20 mg mecamylamine). Given that total number of cigarettes smoked per session also increased, smokers took an average increase of 9 puffs per session when the high dose of mecamylamine was administered, relative to placebo. These findings were corroborated by the carbon monoxide results: 5.4 ppm (placebo) versus 9.5 ppm (20 mg). Thus, puff topography is influenced by mecamylamine administration, and increases in topography variables are associated with increases in smoke toxicant exposure (Nemeth-Coslett et al., 1986a).

Mecamylamine produced similar effects in another study that included cigarette smokers (~20 cpd; Stolerman, Goldfarb, Fink, & Jarvik, 1973). Participants experienced 5 separate sessions that were preceded by overnight tobacco abstinence. Each session differed by the dose of mecamylamine tested: 0, 7.5, 12.5, 17.5, and 22.5 mg. Following the administration of capsules at the beginning of each session, participants were instructed to smoke their usual cigarette brand *ad libitum* for approximately 2 hours. An increase in the number of puffs and the number of cigarettes was observed following active, but not placebo mecamylamine. For example, smokers took an average of 37.2 puffs/session after active mecamylamine, relative to an average of 29.7 puffs/session

after placebo. There was also a significant difference between the average number of cigarettes smoked for the mecamylamine condition (4.3) as compared to the placebo condition (3.4). Thus, the nicotinic antagonist mecamylamine produced increases in *ad libitum* cigarette smoking in this study (Stolerman et al., 1973).

Puff topography can also be influenced by agonist administration, such as pre-loading with nicotine via replacement medications (e.g., gum, patch, and nasal spray). In one study (Nemeth-Coslett, Henningfield, O'Keefe, & Griffiths, 1987), the effects of nicotine gum (0, 2, 4, or 8 mg) on smoking were examined. Eight smokers (mean = 30.6 cpd) received each dose of nicotine gum a total of four times over 16 sessions. Following gum administration, participants were allowed to smoke their own brand cigarette *ad libitum*. Dose-related decreases in the total number of cigarettes, and thus the total number of puffs, were observed. A similar study also reported decreases in topography variables following pre-loading with nicotine gum (Herning et al., 1985). Six smokers (mean = 30.8 cpd) participated in two independent sessions where nicotine gum (0 or 2 mg) was administered periodically: participants chewed one piece of gum every hour while smoking freely throughout each 4-hour session. Nicotine decreased significantly the total number of puffs (mean = 41.3), as compared to placebo (mean = 45.0). Results from both of these studies demonstrate that nicotine administration can influence puff topography (Herning et al., 1985; Nemeth-Coslett et al., 1987).

Nicotine replacement in the form of nasal spray can also alter puff topography (Perkins et al., 1992). In this study, 8 men and 8 women smokers (mean = 20.8 cpd) were administered differing doses of nicotine (0, 15, or 30 μg/kg) in three separate

sessions. Within each session, participants were presented with the nasal spray every 30 minutes for 2.5 hours (i.e., total of five presentations). During this time, participants were also given unlimited access to their own brand of cigarettes. Total number of puffs and cigarettes/session were decreased significantly by active nicotine (15 and 30 μg/kg) relative to placebo. Thus, nicotine via nasal spray was able to suppress cigarette smoking (Perkins et al., 1992). Similar decreases in topography variables have been reported following pre-loading with high-nicotine cigarettes (Kozlowski, Jarvik, & Gritz, 1975), intravenous nicotine (Henningfield et al., 1983), and oral nicotine tablets (Jarvik, Glick, & Nakamura, 1970). Taken together, results from such studies have been used to predict the efficacy of nicotine replacement medications. That is, medication-induced decreases in puff number or volume in the laboratory may be an indicator of therapeutic efficacy. In fact, this relationship has held for all nicotine replacement medications that have been tested, and may also be true for mecamylamine (Rose et al., 2003). Thus, researchers rely upon measurement of puff topography to help develop and test pharmacotherapies for potential use in smoking cessation interventions.

As mentioned previously, puff topography is also affected by the nicotine/tar yields of tobacco cigarettes when smokers switch brands (e.g., from FTC full-flavor to FTC light cigarettes; Gust & Pickens, 1982; Zacny & Stitzer, 1988). For example, in one laboratory study (Zacny & Stitzer, 1988), 10 full-flavor cigarette smokers (mean = 30.5 cpd) participated in five, 5-day conditions. Each condition differed by the FTC nicotine yield of cigarettes smoked: usual brand (1.0 mg; FTC full-flavor mean = 1.15 mg) or low-yield (0.1, 0.4, and 0.7 mg; FTC light/ultralight mean = 0.47 mg/0.73 mg).

Participants were allowed to smoke the assigned cigarette type *ad libitum* during each condition. Measures of puff topography were assessed twice per week during laboratory visits. Average puff volume increased by 11.3 ml when smoking cigarettes with the lowest yield (0.1 mg; 64.7 ml), relative to own brand (1.0 mg; 53.4 ml). In addition, average inter-puff interval increased significantly with increasing nicotine yields: 22.3 (0.1 mg), 24.7 (0.4 mg), 26.4 (0.7 mg), and 29.7 (1.0 mg). Thus, participants may take larger and more closely spaced puffs when switching from full-flavor, own brand cigarettes to brands with lower FTC yields (Zacny & Stitzer, 1988).

Similar results were observed in another study (Baldinger, Hasenfratz, & Bättig, 1995), in which 12 regular smokers (mean = 24.3 cpd) smoked cigarettes of different nicotine/tar yields: ultra-low nicotine/tar (0.21 mg/1.83 mg; FTC ultralight mean = 0.47 mg), medium nicotine/tar (0.9 mg/11.4 mg; FTC light mean = 0.73 mg), or ultra-low nicotine/medium tar (0.08 mg/9.3 mg; FTC ultralight mean = 0.47 mg). Within each session, participants smoked two of one of the cigarette types *ad libitum*. Participants' total puff volume for ultra-low nicotine/tar cigarettes (mean = 761.3 ml) was increased significantly over the total puff volume for medium nicotine/tar cigarettes (mean = 592.8 ml). Additionally, puff number increased when participants smoked ultra-low nicotine/tar cigarettes (17.5 puffs), as compared to medium nicotine/tar cigarettes (15.3 puffs). Interestingly, there were few significant changes in topography when ultra-low nicotine/medium tar cigarettes were smoked. This finding suggests that tar may play a larger role than nicotine in brand-induced topography changes, and other studies support this idea (Buchhalter et al., 2001; Breland, Evans, Buchhalter, & Eissenberg, 2002b).

A fourteen-month study demonstrated that brand-induced changes in smoking behavior may persist for long periods of time (Guyatt et al., 1989). Puff topography was assessed in 28 regular smokers (mean = 25.1 cpd) during a period when they switched from regular to low yield cigarettes. Participants were monitored for five months while smoking regular cigarettes (tar yield > 10 mg; FTC light/full-flavor mean = 9.56 mg/1.63 mg tar), and then for another nine months while smoking low yield cigarettes (tar yield < 10 mg; FTC ultralight mean = 5.14 mg tar). Mean puff volume increased significantly from 47.2 ml with regular yield cigarettes to 54.7 ml with low yield cigarettes. This 15.9% increase in average puff volume persisted over the 36-week low-yield period. Additionally, the mean number of puffs/cigarette increased after switching to low yield cigarettes: on average, participants took 13.9 puffs from regular yield cigarette and 15.7 puffs from low yield cigarettes, though this effect did not last for the remaining study weeks. Thus, some changes observed in puffing behavior when smokers switch to cigarettes of lower yields may be long-lasting. Results from these and other well-controlled laboratory studies (e.g., Bridges, Humble, Turbek, & Rehm, 1986; Tobin & Sackner, 1982) have provided evidence for brand-induced changes in smoking behavior. Importantly, all studies relied on measurement of puff topography to demonstrate this phenomenon, though the instrumentation used for topography measurement often differed considerably.

How is Puff Topography Measured?

Puff topography measurement has been accomplished using direct observation, desktop computers, and portable devices. Observation of smokers' puff topography

typically occurs in a laboratory, where either a trained observer and/or a video camera records topography variables of interest (e.g., Frederiksen, Miller, & Peterson, 1977). Computerized desktop measurement of topography also takes place in laboratory settings, and variables are recorded and measured by specialized hardware and software (e.g., Henningfield & Griffiths, 1979). Finally, computerized portable devices utilize hardware and software, though measurement of smoking behavior may occur inside or outside of the laboratory (e.g., Evans, Buchhalter, Kleykamp, & Eissenberg, 2003a; Evans & Eissenberg, 2003b). Each of these measurement methods, and their strengths and limitations, are discussed below.

In one of the first studies to examine puff topography via observational measurement, three participants smoked cigarettes according to various smoking instructions (Frederiksen et al., 1977). Smokers were required to 1) smoke as usual, 2) increase IPI (i.e., increase the length of time between each puff), or 3) decrease cigarette duration (i.e., decrease total amount of time smoking) during the smoking of a single cigarette. The puff topography of each cigarette was then examined via video recordings of the sessions. Two outside observers were instructed to measure each of four topography variables using specified operational definitions: cigarette duration (total amount of time cigarette was lit), puff frequency (a.k.a. puff number; number of times smoker brought the cigarette to lips for a puff), puff length (a.k.a. puff duration; amount of time a lit cigarette was in contact with lips during a puff), and inter-puff-interval (amount of time in between successive puffs). Results showed that puff topography could be easily and reliably manipulated, as all participants modified their puffing

behavior according to the instructions. Comparison of ratings between the two independent observers yielded high correlations for all topography variables (r's $\geq$ 0.98; Frederiksen et al., 1977).

Another study included trained observers to record and measure the puff topography of the smoking of two cigarettes (Lichtenstein & Antonuccio, 1981). In each of two, 45-minute sessions, participants (N=24; mean = 20.8 cpd) smoked cigarettes of their usual brand *ad libitum*. Two research assistants recorded a variety of topography variables while observing all smoking behavior. Topography measures, and their operational definitions, were similar to those reported above (i.e., cigarette duration, puff frequency/number, and puff length/duration). Additionally, several other measures included cigarette frequency (number of cigarettes lit during each session), inter-cigarette-interval (ICI; amount of time in between each cigarette), and percentage of tobacco burned (grams of tobacco burned/grams of tobacco in remaining portion of cigarette). Correlation matrix calculations showed that several puff topography variables were highly related between the two cigarettes: puff frequency and duration (r = -0.58), cigarette frequency and ICI (r = -0.58), as well as cigarette duration and % tobacco burned (r = 0.53). Importantly, rater agreement on measurement of all topography variables ranged from 95-100%, demonstrating the reliability of observation as a topography measurement tool (Lichtenstein & Antonuccio, 1981).

Although observation provides a means for analyzing certain aspects of smoking behavior, this methodology is limited because some topography measures (e.g., puff volume) cannot be measured. In addition, evaluation of smoking behavior via direct

observation may decrease measurement accuracy of topography variables such as puff duration. For these and other reasons, researchers have searched for objective and precise methods for measuring puff topography. The result of this search is a wide variety of topography measurement instruments developed in individual laboratories worldwide (e.g., Adams, Lee, Rawbone, & Guz, 1983; Bättig, Buzzi, & Nil, 1982; Henningfield & Griffiths, 1979; Pickens, Gust, Catchings, & Svikis, 1983; Puustinen, Olkkonen, Kolonen, & Tuomisto, 1987; Wiley & Wickham, 1974). In all cases, individuals smoke cigarettes using a specialized mouthpiece into which the cigarette has been placed. Typically, the mouthpiece incorporates a flowmeter that captures pressure differences as smoke is inhaled from the cigarette, and the pressure is converted into flow rate via calibrated software. Subsequently, the software records the chosen puff topography variables using flow onset, rate, and offset measurements. Some of the different versions of these types of topography devices are reviewed below.

One study included the use of a mouthpiece-based flowmeter device to measure smoking behavior (Herning et al., 1981). The design of this type of topography device is fairly common, as it consists of a mouthpiece/flowmeter attached to a pressure transducer via tubing. Again, the transducer relies on desktop computer software to convert pressure changes into flow rate. The use of this desktop device as a puff topography measurement system was evaluated by examining its ability to measure brand-induced changes in smoking behavior. Puff number, volume, duration, and IPI were recorded with the device when participants (N=24) smoked cigarettes with varying nicotine levels: 0.4 mg (low-yield; FTC ultralight mean = 0.47 mg), 1.2 mg (medium-yield; FTC full-flavor

mean = 1.15 mg), and 2.5 mg (high-yield; FTC full-flavor mean = 1.15 mg). Each cigarette type was smoked *ad libitum* on separate days for a total of three sessions. Puff volume was significantly related to nicotine level; on average, participants took bigger puffs from the low-yield cigarettes (47.8 ml), than from the medium- (35.9 ml) and high-yield (36.9 ml) cigarettes. Thus, the flowmeter device used in this study was able to measure brand-induced changes in smoking behavior (Herning et al., 1981).

Puffing patterns of smokers were measured by a similar desktop device with a mouthpiece-based flowmeter design (Bättig et al., 1982). This device included a specialized puffing analyzer which digitized the topography variables puff number, volume, duration, and IPI. Men (n=67) and women (n=43) smoked two of their own brand of cigarette with the device during one experimental session. Comparison of all topography variables across cigarettes yielded high test-retest reliability for men and women smokers. For example, men's average puff volume was 43.7 ml for both cigarettes ($r = 0.89$). The average puff volumes for women were 37.1 ml and 35.4 ml, respectively ($r = 0.86$). Similar results were found for all other topography variables (r's ≥ 0.61), providing evidence for the reliability of this device as a smoking measurement system (Bättig et al., 1982).

Another puff topography instrument was crafted from a pneumotachograph, an apparatus designed to record airflow rate to and from the lungs (Adams et al., 1983). In this study, the smoker was actually seated inside the pneumotachograph apparatus, and connected to a nasal probe and electrocardiogram leads. Positioned in front of the smokers' lips was the mouthpiece, which housed a filter in its center. Pressure changes

across this filter could be detected by a transducer whenever smoke was inhaled from a cigarette that was placed into the mouthpiece. This desktop device allowed for measurement of several topography variables (i.e., number, volume, duration, and IPI) in a study examining patterns of smoking in ten healthy tobacco users (Adams et al., 1983). Subjects smoked a single cigarette of their own brand on four separate occasions via the modified pneumotachograph. Mean puff topography variables across the four cigarettes for each participant were not significantly different. However, between participants there were considerable differences in all topography variables. For instance, across subjects, mean puff volume ranged from 26 to 55.9 ml and mean puff duration from 0.87 to 3.2 seconds. Thus, while there was variability in puffing patterns in different smokers, a consistent puffing pattern was produced using the modified topography instrument (Adams et al., 1983).

A more recent version of the mouthpiece-based flowmeter device is the only one currently available for any researcher to purchase (Plowshare Technologies, Baltimore, MD). This desktop version, called the Clinical Research Support System (CReSS^{TM}), was first marketed in 1998. As shown in Figure 1, CReSS assesses puffing behavior via a differential pressure flow meter contained in a plastic mouthpiece, tethered by vinyl tubing to a measurement interface box that is attached to a desktop computer. Calibrated computer software then captures the topographical information from each cigarette. The accuracy and reliability of CReSS has been demonstrated in laboratory settings (e.g., Buchhalter & Eissenberg, 2000; Eissenberg, Kennedy, Riggins, & Likness, 1998; Lee, Malson, Waters, Moolchan, & Pickworth, 2003). For example, topography variables

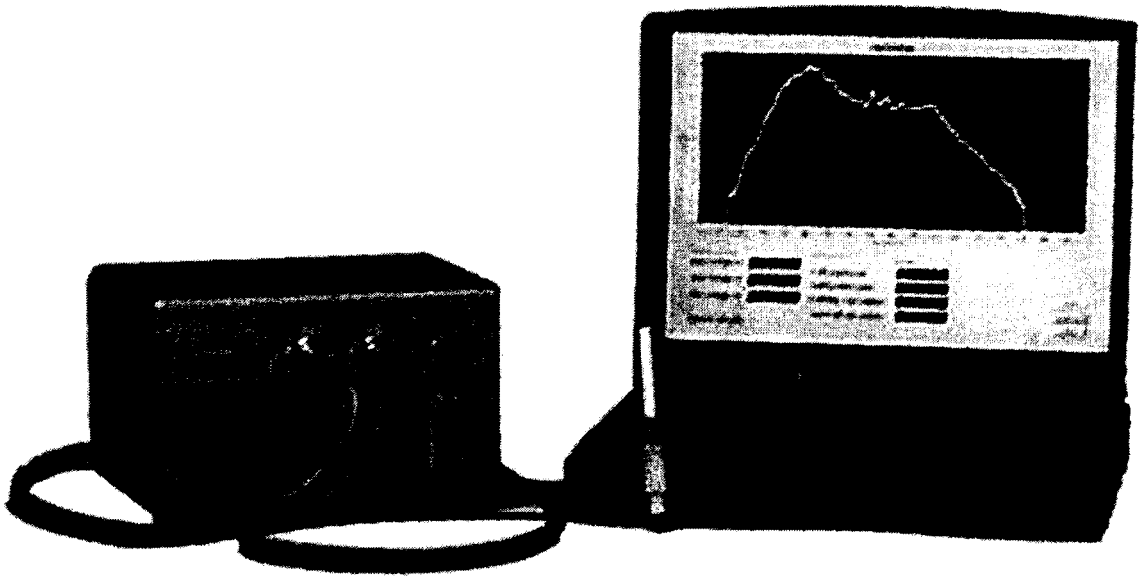

Figure 1: CReSS™ desktop topography system

measured via the desktop system were examined in seven regular smokers (mean = 25 cpd; Lee et al., 2003). In four separate experimental sessions, participants smoked their usual cigarette brand *ad libitum* using CReSS. The device proved to be a reliable measure of smoking topography; high intraclass correlations were observed for puff volume (ICC $\geq$ 0.66) and duration (ICC $\geq$ 0.75), and differences within these variables across study days were non-significant (Lee et al., 2003). In another study (Eissenberg et al., 1998), puff topography measures made by CReSS were compared with those made by direct observation. Eight separate "puffs" were made with a 60 cc syringe on each of 12 lit cigarettes at specified intervals. Puff volume was significantly correlated (r = 0.99) between the two measurement methods (Eissenberg et al., 1998). Thus, CReSS is considered by many to be accurate and reliable in a laboratory setting.

While mouthpiece-based, desktop devices have been an effective tool for providing detailed assessment of puff topography, their use is limited to the laboratory. However, the ability to measure puff topography variables outside of the laboratory is critical; the nature and magnitude of smoking behavior may differ as a function of the environment in which cigarettes are smoked (Hatsukami et al., 1987; Hatsukami, Morgan, Pickens, & Champagne, 1990). For instance, past research has identified a variety of environment-specific factors that may influence smoking behavior: time of day (Morgan, Gust, Pickens, Champagne, & Hughes, 1985), work-place restrictions (Chapman, Haddad, & Doungkamol, 1997), and concurrent drug intake (Henningfield & Griffiths, 1981; Griffiths, Bigelow, & Liebson, 1976). Thus, much effort has also been dedicated to designing a portable system that allows for ambulatory measurement of puff

topography in the smoker's natural environment.

One of the earliest designs included the use of a pocket calculator to record puff number (Henningfield, Yingling, Griffiths, & Pickens, 1980). Specifically, a cigarette mouthpiece attached to vinyl tubing was interfaced to the pocket calculator via a pressure switch. Two electrical terminals from the pressure switch to the calculator provided access to a closed circuit. Each time this circuit closed due to a pressure drop of ≥ 3 mmHg, the calculator would add a "1". Thus, for each change in pressure, the calculator counts one puff. The accuracy and reliability of this calculator device was examined using two different procedures. In the first procedure, over the course of 20 experimental sessions, five participants smoked cigarettes via the portable device or a desktop device (Henningfield et al., 1980). There were no differences in puff number between the different topography devices. Furthermore, the portable device was equally effective as the desktop device at measuring brand-induced changes in smoking behavior across different cigarettes. The second procedure (Henningfield et al., 1980) consisted of participants smoking cigarettes via the calculator device; number of puffs was determined by each participant, but IPI (30 sec), puff duration (5 sec), and bout times (15, 30, 60 and 120 min) were held constant. In addition, puff number was counted manually by the participants using a hand-held recorder. Data generated via the device and manually was significantly positively correlated ($r = 0.99$). Under these circumstances, this modified topography device was accurate and reliable in a laboratory setting (Henningfield et al., 1980). While this mouthpiece-based device was inexpensive and convenient for ambulatory measurement, it was able to record only puff number.

A more advanced mouthpiece-based topography device was later constructed to measure IPI, puff and cigarette duration, and cigarettes per day, in addition to puff number (Pickens et al., 1983). In fact, this device had the capability of recording topography parameters for a total of 10,000 puffs over two consecutive days. All data were measured and recorded via a pressure switch and circuit board housed inside a small metal box, which was approximately the size and weight of a portable radio (~453 grams). Specifically, whenever a puff was detected from the mouthpiece/tubing by the metal box, pulses were generated and counted. The pulses for each individual puff were then stored in separate memory cells for later analysis using compatible software. The accuracy of this device was tested by comparing puff topography data obtained via the device versus an observer. Participants (N=8) smoked a single cigarette twice per day for eight days; one cigarette was smoked using the topography device and one was smoked naturally. An experimental observer was present for all sessions, and manually measured all topography variables with the use of a timer and pushbutton switch. No puff topography variables were significantly different between the two data collection methods, demonstrating the accuracy of this topography device (Pickens et al., 1983). While more advanced than the earlier version, this portable device was unable to measure another important topography variable – puff volume.

Eventually a potentially portable mouthpiece-based device capable of measuring flow rate, and thus puff volume, was developed (Puustinen et al., 1987). The design consisted of a mouthpiece with flow meter that sent information regarding pressure differences to a sensor via plastic tubes. All information was then stored on an interface

box and later converted to a microcomputer for analysis. Similar to previous research (e.g., Herning et al., 1981), the device was tested in a study that examined brand-induced changes in smoking behavior. Low- and medium-tar cigarettes were smoked by regular tobacco users (N=8) over the course of two sessions. Puff number, volume, duration, and IPI were assessed for each cigarette. Participants took significantly more puffs when smoking the low-tar cigarettes (18.4), relative to when smoking the medium-tar cigarettes (13.6). Additionally, the total puff volume was significantly different: 649 ml for low-tar and 345 ml for medium-tar cigarettes. Thus, the microcomputer-based device was able to demonstrate changes in puff topography when smokers switched cigarette brands (Puustinen et al., 1987). Unfortunately, the size (plastic tubes alone are 28 inches long) and weight (~1700 grams) of this device limited its use outside of the laboratory.

In order to improve upon these limitations, another mouthpiece-based device was crafted that was more discreet and significantly lighter in weight than the earlier versions (Kashinsky, Collins, & Brandon, 1995). The Telemetric Topography Device (TTD) conceals all circuitry within a small (~10.8 cm tall x 3.2 cm in diameter), lightweight (90.8 grams) container. Although this design includes a mouthpiece and pressure sensor, it differs from previous models by employing radiotelemetry to measure puff topography. Pressure change measurements from each puff are used to transmit the appropriate sized-tone frequency (individualized based on puff strength) via an FM radio in close proximity to the TTD. Thus, smokers are free to use the device anywhere within range of the radio receiver. Topography measurements obtained from the TTD were compared with those obtained via observation to assess accuracy (Kashinsky et al., 1995). Nineteen

participants smoked their own brand cigarettes via the TTD while simultaneously being video taped. Outside observers later calculated the relevant topography variables manually. All variables between the two measurement methods were highly correlated (r's > 0.84), demonstrating the accuracy of the TTD. Nonetheless, reliance on a nearby radio transmitter for signal delivery significantly limits the use of this device for ambulatory topography measurement.

The most recent model places no boundaries on the location of smoking by including all necessary circuitry within a small (in centimeters, approximately 6.5 width x 5.5 length x 2.0 height), lightweight (87.9 grams with the battery) device. As shown in Figure 2, the Clinical Research Support System-Micro (CReSSMicro™; Plowshare Technologies, Baltimore, MD) is battery-operated and hand-held. It measures all commonly reported topography variables (e.g., volume, duration, number, IPI, and peak flow rate), and also provides the number of cigarettes smoked per hour and per day, cigarette insertion/removal times, and the total cigarette time. In addition, all topography data are time- and date-stamped when recorded.

Two recent studies support the accuracy and reliability of CReSSMicro as a puff topography measurement device, and both used a manipulation that has become a common standard for evaluating puff topography instrumentation: brand-induced changes in topography (Evans et al., 2003a, b). In the first study (Evans et al., 2003a), twenty-two smokers (mean = 20.6 cpd) used desktop or portable topography measurement devices to smoke either own brand (FTC "full flavor" or "light"; mean CO = 12.6 mg, nicotine = 0.9 mg, tar = 12.1 mg) or ultra-light cigarettes (FTC mean CO = 7 mg, nicotine = 0.5 mg, tar

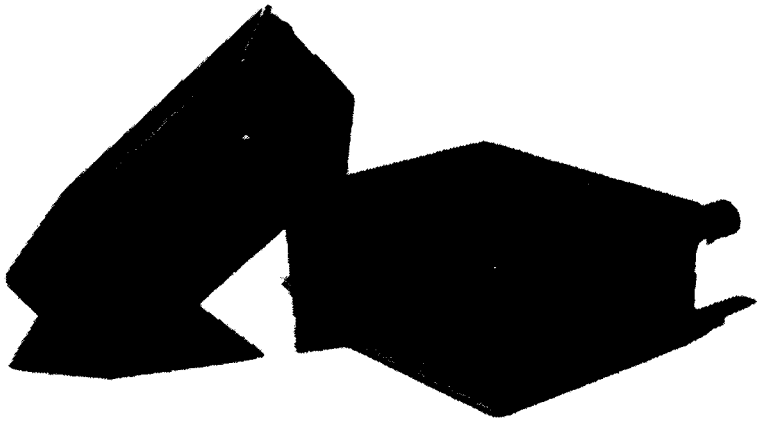

Figure 2: CReSSMicro™ portable topography device

= 5 mg). During each 2.5-hour session, participants smoked one cigarette *ad libitum* every 30 minutes for a total of four cigarette bouts/session. Table 2 shows that both devices measured the oft-reported changes in topography when smokers switch from FTC full-flavor to ultra-light cigarettes. Collapsed across device and cigarette number, average puff volume was significantly greater for ultra-light cigarettes (48 ml), as compared to own brand (42.4 ml). Similarly, average puff duration increased significantly from 1.3 seconds when own-brand cigarettes were smoked to 1.5 seconds when ultra-light cigarettes were smoked. Participants also took 1.6 more puffs when using the ultra-light cigarettes, relative to own brand (Evans et al., 2003a).

The second study (Evans et al., 2003b) involved an examination of topography measurement outside of the laboratory. Thirteen smokers (mean = 18.9 cpd) used CReSSMicro to smoke at least five of their own brand (FTC "full flavor" or "light"; mean CO = 14 mg, nicotine = 1.0 mg, tar = 13.9 mg) or low-yield (FTC mean CO = 7 mg, nicotine = 0.5 mg, tar = 5 mg) cigarettes in the natural environment each day for four consecutive days. Again, brand-induced changes in smoking topography were demonstrated with the portable device. Relative to own brand (mean = 547.5 ml), total puff volume/cigarette increased significantly when subjects smoked ultra-light cigarettes (mean = 653.2 ml) over several days (Evans et al., 2003b). Because the study did not include actual observation of the participants, however, the extent to which the data represented natural smoking behavior is uncertain. Nonetheless, results from these two studies support the notion that topography can be measured reliably using a portable device (Evans et al., 2003a, b).

Table 2

Mean (SD) puff topography values for 22 subjects for own brand and ultra-light cigarettes collapsed across cigarette number and measurement device. Data demonstrate brand-induced changes in smoking behavior.

	Own Brand	Ultra-light	P value
Total volume (ml)	395.6 (114.4)	528.8 (179.6)	<0.001
Average puff volume (ml)	42.4 (14.8)	48.0 (14.9)	<0.05
Puffs/cigarette (number)	10.0 (2.9)	11.6 (4.3)	<0.05
Puff duration (sec)	1.3 (0.7)	1.5 (0.5)	<0.05
IPI (sec)	34.2 (13.5)	32.0 (13.5)	n.s.

Data from Evans et al., 2003a.

Does Measuring Smoking Behavior Influence How People Smoke?

Measurement of puff topography is an important tool in understanding and treating smokers' nicotine/tobacco dependence. This measurement is accomplished using mouthpiece-based desktop or portable topography devices, which have proven reliability and, according to several studies where observers also recorded puff topography, proven accuracy. However, every topography device described requires that a cigarette be smoked through a mouthpiece so that flow can be measured and topography assessed. Given that smoking typically occurs without a mouthpiece, this constraint may limit understanding of how cigarettes are smoked naturally. However, while several studies have included observers, only a few studies have compared mouthpiece and non-mouthpiece based measurement directly (e.g., Höfer, Nil, & Bättig, 1991a, b; Lee et al., 2003; Pickens et al., 1983). An early study compared a portable device and observation as methods for measuring smoking behavior (Pickens et al., 1983). Smokers (N=8) participated in eight sessions that included four days of smoking via the device and four days of smoking as usual. Trained observers recorded puff number and duration for each of two cigarettes during the sessions when participants smoked normally. Results indicated that participants smoked 4.39 fewer cigarettes/day when using the mouthpiece-based device. However, puffs/cigarette and total puff duration increased significantly with the device, as compared to normal smoking. Thus, the mouthpiece may have interfered with natural smoking (as evidenced by fewer cigarettes/day), and participants may have increased their smoke intake/cigarette to compensate for their reduced cigarette intake (Pickens et al., 1983).

Another study included the use of a desktop topography device to examine the influence of a mouthpiece on natural smoking (Höfer et al., 1991a). Men (n=72) and women (n=72) smokers (mean = 23.3 cpd) were divided into four groups based on the nicotine yield of their own brand cigarettes. Specifically, 18 men and 18 women were included in each group: ultra-low nicotine (0.1-0.3 mg; FTC ultralight mean = 0.47 mg), low nicotine (0.4-0.6 mg; FTC ultralight/light mean = 0.47 mg/0.73 mg), medium nicotine (0.7-0.9 mg; FTC light mean = 0.73 mg), and high nicotine (1.0-1.2 mg; FTC full-flavor mean = 1.15 mg). All groups participated in two, 2-hour experimental sessions where they smoked one of their own brand cigarettes *ad libitum* either through a mouthpiece or with direct lip contact. Measures of puff number, duration, volume (mouthpiece only), and inter-puff-interval were recorded. Significant topography differences were observed between the smokers of differing cigarette yields. For example, average puff volume was a function of nicotine yield; from 36.8 ml (high nicotine group) to 44.5 ml (ultra-low nicotine group). Similarly, smokers of ultra-low yield cigarettes took significantly more puffs (12.3) than those smoking high yield cigarettes (10.9). Importantly, differences were also found between the mouthpiece conditions. That is, the use of a mouthpiece increased puff number by 1.5 puffs per cigarette (i.e., 13.1 for mouthpiece and 11.6 for lip contact), as compared to direct lip contact. Also relative to lip contact, the use of a mouthpiece produced increases in total puff duration (26.0 sec versus 22.7 sec) and shorter IPI's (19.8 sec versus 22.7 sec). These findings also suggest that the use of a mouthpiece influences natural smoking behavior (Höfer et al., 1991a).

A similar study (Höfer et al., 1991b) included 36 men and 36 women smokers (mean = 25.5 cpd) of varying filter types. Participants experienced two, 2-hour sessions that differed by measurement method used: mouthpiece or lip contact. Within each session, participants smoked a single cigarette of their usual brand *ad libitum* while puff topography variables were measured. Across filter types, differences were found between mouth-piece versus lip contact for several topography variables. The number of puffs/cigarette was significantly greater when participants used a mouthpiece (15.8), relative to when they used their lips (10.9). Consequently, total puff duration increased by 9.4 sec when a mouthpiece was used to smoke the cigarettes. Also, a mouthpiece shortened the time between successive puffs (IPI; 16.7 sec), as compared to lip contact (21.7 sec). Once again, smoking via a mouthpiece significantly altered natural smoking behavior, as demonstrated by puff topography measurement.

In contrast, a more recent small sample study (Lee et al., 2003) found similar results for smoking with and without a mouthpiece. Ten smokers (mean = 25 cpd) used own brand cigarettes *ad libitum* using either a mouthpiece-based topography system (CReSS) or without a mouthpiece. When the mouthpiece was not used, an observer measured time to smoke and puff number. No differences were observed between mouthpiece and no mouthpiece conditions for these two measures. Thus, the literature contains several reports that suggest that mouthpiece-based topography measurement influences some puff topography variables (Höfer et al., 1991a, b; Pickens et al., 1983), and one report that does not support this idea (Lee et al., 2003).

To complicate matters further, a mouthpiece-based desktop device may alter

topography more than a mouthpiece-based portable device (Evans et al., 2003a). Twenty-two smokers (mean = 20.6 cpd) used desktop or portable topography measurement devices to smoke either own brand or low-yield cigarettes over four separate sessions. Participants smoked a total of four cigarettes *ad libitum* every 30 minutes for a total of four cigarette bouts/session. Both devices measured the oft-reported changes in topography when smokers used the low-yield cigarettes (i.e., increased puff number, duration, and volume). Interestingly, there were differences between some topography variables for the desktop and portable devices (see Table 3). Participants took 10.5 puffs/cigarette when using the desktop device and 11.1 puffs/cigarette when using the portable device. In addition, puff volume was significantly greater for the portable device (480.7 ml) than for the desktop device (443.7 ml). Based on these results, the authors suggested that the portable device allows for more naturalistic smoking behavior, perhaps because desktop devices rely on several feet of tubing to tie the mouthpiece to unwieldy hardware (interface box and computer). However, hypotheses regarding why one device might provide more accurate topography measurement than another were not tested in this study (Evans et al., 2003a).

In conclusion, previous studies suggest that mouthpiece-based devices can influence smoking behavior under some conditions. Moreover, results from one clinical study indicate that a portable topography device may alter normal smoking behavior less than a desktop device. These findings, coupled with the importance of puff topography measurement in understanding self-administration of tobacco-delivered nicotine and developing treatments for tobacco/nicotine dependence, highlight the need for further

Table 3

Mean (SD) puff topography values for 22 subjects for desktop and portable measurement devices collapsed across cigarette number and brand. Data demonstrate differences in smoking behavior as a function of measurement device.

	Desktop	Portable	P value
Total volume (ml)	443.7 (137.8)	480.7 (129.6)	<0.05
Average puff volume (ml)	44.1 (14.4)	46.3 (14.3)	ns
Puffs/cigarette (number)	10.5 (3.3)	11.1 (3.6)	<0.05
Puff duration (sec)	1.4 (0.6)	1.4 (0.6)	ns
IPI (sec)	32.9 (13.5)	33.3 (13.5)	ns

Data from Evans et al., 2003a.

examination of the influence of mouthpiece-based equipment on topography measurement.

Statement of the Problem

Understanding the factors that influence and maintain regular tobacco use requires detailed analysis of individuals' smoking behavior. Also known as puff topography, this type of analysis provides a quantitative measurement of puffing variables such as puff number, volume, duration, and inter-puff interval (IPI). These variables are most often assessed via desktop or portable computerized topography measurement devices. However, all topography devices rely on a mouthpiece, and some research suggests that a mouthpiece may alter natural smoking behavior. In addition, this potential influence may be mitigated with portable systems, relative to desktop systems. More research is needed to determine the extent to which mouthpiece-based devices influence topography measurement and which type of device (desktop or portable) most resembles natural smoking behavior. The goal of this study, therefore, is to compare both desktop and portable devices to direct observation methods on measurement of puff topography.

Statement of Hypotheses

Results for some outcomes can be predicted based on previous work. For instance, all topography measurement methods (i.e., desktop, portable, and video) are expected to accurately measure brand-induced changes in smoking behavior. Participants will take more (number), bigger (volume), and/or longer (duration) puffs when smoking the low-yield cigarettes, as compared to when smoking their own brand (as in Baldinger et al., 1995; Gust & Pickens, 1982; Zacny & Stitzer, 1988). For measurement method,

the portable topography device will likely allow more naturalistic smoking behavior than the desktop device (as in Evans et al., 2003a). Thus, there will be significant differences in puff number and volume between desktop and portable systems, and the desktop system and natural observation, but not between the portable system and natural observation. In addition, all measurement methods will produce reliable measures of smoking behavior. Specifically, puff topography variables will be highly correlated (e.g., $r > 0.80$) across cigarettes within each condition.

Chapter 2

Method

Selection of Participants

A combined total of 30 cigarette-smoking volunteers were needed to complete this within-subject design. This number exceeds the 24 participants required to detect moderate within-subject effect sizes (i.e., $f = .35$), with a moderate correlation between repeated measures ($r \geq 0.50$) with power > 0.80 (Barcikowski & Robey, 1985). In fact, for brand-induced changes and device differences, even larger within-subject effect sizes have been observed in previous studies (i.e., $fs > 0.49$; Buchhalter et al., 2001), as well as moderate to large correlations (i.e., $rs > .64$; Evans et al., 2003a). Thus, with 30 participants, this study had adequate sensitivity to meet all of its objectives.

Volunteers were recruited by word-of-mouth and by Institutional Review Board (IRB) approved advertisements. Interested individuals were excluded if they reported smoking "ultra-light" cigarette brands, as this study was designed to measure brand-induced changes when smokers switch from "full-flavor" or "light" cigarettes to "ultra-light" cigarettes (as in Evans et al., 2003a, b). Smokers currently trying to quit smoking or reduce their cigarette intake were also excluded. Additional exclusion criteria included a history of chronic health problems or psychiatric conditions, and current pregnancy (assessed by urinalysis) or breastfeeding.

A total of 48 individuals met the initial screening criteria via a telephone interview, and thus consented to participate. Of these 48 individuals, four failed their in-person screen (i.e., 1 reported smoking slim-sized cigarettes, 2 reported smoking <15

cpd, and 1 provided a CO reading of <15 ppm), and nine withdrew participation voluntarily prior to their first session. Thus, 35 out of the 48 consented individuals, or or 73%, ran in at least 1 session. Two of these individuals, however, were disqualified due to repeated failures to show for scheduled sessions. A final total of 33 participants completed the entire study (i.e., successfully completed all 6 sessions), though data were discarded for 3 of these individuals (2 used as pilot subjects to test study procedures, and 1 deemed unreliable because post session CO did not reflect topography measurement). The 30 participants included in the final dataset consisted of 14 males (7 non-white) and 16 females (10 non-white).

Completers were between the ages of 18 and 55 (mean = 32.3 years; SD = 11.0) and healthy, as assessed by self-report. They provided a screening CO level $\geq$ 15 ppm (mean = 22.4 ppm; SD = 9.2) to verify current smoking status (CO is an indicator of recent smoke inhalation; e.g., Buchhalter & Eissenberg, 2000), and reported a daily cigarette intake of $\geq$ 15 cigarettes (mean = 19.6 cpd; SD = 4.7) for at least 1 year (mean = 8.0 years; SD = 7.1). These participants were also deemed nicotine dependent by an average score of 6.0 (SD = 2.0) on the Fagerström Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerström, 1991). They were smokers of king-sized (n = 19) or "100's" (n = 11) length, traditional (n = 12) or menthol (n = 18), full-flavored (n = 21) or light (n = 9) cigarettes. This population was appropriate for this study because full-flavor and light smokers are the population most likely to alter their topography (i.e., puff number, duration, IPI) when smoking ultra-light cigarettes (e.g., Evans et al., 2003a, b; Zacny & Stitzer, 1988). In addition, participants were able to

demonstrate approximately 8-12 hours of cigarette abstinence prior to each session (i.e., average pre-session CO = 6.3 ppm; SD = 2.7).

Men and women did not differ on any demographic measure, including number of cigarettes per day [women's mean = 19.0, SD = 4.1; men's mean = 19.7, SD = 5.5; t (28) = 0.4, n.s.], FTND score [women's mean = 6.2, SD = 2.3; men's mean = 5.7, SD = 1.7; t (28) = -0.6, n.s.], and screening CO level [women's mean = 20.6, SD = 8.8; men's mean = 24.4, SD = 9.5; t (28) = 1.2, n.s.].

Telephone Screening Procedure

All interested participants were screened initially via a telephone interview (Appendix A). During this interview, individuals responded to questions pertaining to basic demographic and medical history information, as well as past and current drug use. Information related to participants' drug use included nicotine (FTND; Heatherton, Kozlowski, Frecker, & Fagerström, 1991; CAGE questionnaire for smoking; e.g., Lairson et al., 1992), marijuana (CAGE questionnaire for marijuana use), and alcohol use (CAGE questionnaire for alcoholism; Ewing & Rouse, 1970). Potentially eligible volunteers then visited the laboratory for a detailed in-person screening.

Informed Consent and In-person Screening Procedures

Individuals first reviewed the informed consent form (Appendix B) to ensure that they understood the study, the risks and benefits of their participation, and their rights as research participants. Participants who were willing and able to provide informed consent then completed detailed screening forms (Appendix C) that consisted of questions similar to those asked over the telephone. These forms included the FTND to

determine participants' level of nicotine dependence (Appendix D). The information obtained during the in-person screen intentionally duplicated information collected via the telephone interview to assess reliability in reporting. Individuals who were unable to report screening information reliably were excluded from further study participation. Additional information collected during the screening visit included height, weight, and CO level (breath sample via non-invasive equipment; BreathCO monitor, Vitalograph; Lenexa, KS). Women provided a urine sample to allow for pregnancy testing. Finally, all participants were familiarized with the testing environment, questionnaires, and measurement equipment.

Experimental Cigarettes

Merit® cigarettes (Phillip Morris; Richmond, VA) were chosen as the ultra-light brand to use in this study because they were easy to obtain, and were available in a variety of sizes (e.g., king and 100's) and flavors (e.g., traditional and menthol). Thus, smokers of diverse cigarette types were able to participate in the study. Additionally, this brand of ultra-light cigarette has been administered in past studies that demonstrated brand-induced changes in smoking behavior (e.g., Evans et al., 2003a, b). By the FTC method (FTC, 2000), Merit® ultra-light cigarettes yield 0.5 mg nicotine, 5 mg tar, and 7 mg carbon monoxide. Own brand cigarettes were identified at screening, purchased by the experimenter, and provided to participants during sessions. On average, participants' own brand of cigarettes yielded 1.1 mg (SD = 0.3) nicotine, 14.9 mg (SD = 3.5) tar, and 15.0 mg (SD = 3.0) CO.

Participants were blinded to the low-yield cigarette conditions (i.e., they were not aware either that they were smoking an ultra-light cigarette or that it was Merit® brand), as well as the cigarette type smoked within each session (i.e., own or "other" brand). Blinding was achieved by covering all brand identifiers, such as pictures and/or brand names, with opaque cigarette rolling paper. Rolling paper seemed the most optimal method for blinding given that it is intended to be smoked (i.e., unlike tape or other paper material), and thus would not affect the sensory characteristics of the cigarettes.

Outcome measures

Primary outcome measures included measurement of smoking behavior, or puff topography, and participant acceptability of each measurement method. Secondary outcome measures included subjective measures of nicotine/tobacco withdrawal and physiological response.

Measurement of Smoking Behavior

Puff volume, duration, number, and inter-puff-interval (IPI) were measured whenever participants smoked via desktop and portable computerized puff topography devices; simultaneous video recordings were also made (see below). The mouthpiece-based desktop device used in this study was CReSS™ (Plowshare Technologies, Baltimore, MD), the current gold-standard for puff topography measurement. Past research has demonstrated its accuracy and reliability (Corrigall et al., 2001; Eissenberg et al., 1998; Lee et al., 2003). The portable system used in this study was CReSSmicro™ (Plowshare Technologies, Baltimore, MD), a microcomputer-based version of CReSS™. Preliminary research conducted in this laboratory has provided evidence for the accuracy

and reliability of this hand-held topography measurement system (Evans et al., 2003a, b). The video device used was a mini DV digital camcorder (Canon Elura 80; Canon USA Incorporated; Lake Success, NY). This specific digital recorder was chosen based on features such as size (to minimize the effect on participants' smoking behavior), zoom and color options (for optimal frame quality), and compatibility with laboratory computers. Additionally, the digital video recorder allowed the use of software for frame by frame time analysis (e.g., Adobe Premier Elements 1.0; Adobe Systems Incorporated; San Jose, CA). Topography measures of puff number, duration, and IPI, but not puff volume, were measured using the video recorder. Although it was not feasible to measure puff volume via this method, research shows that duration and volume are highly correlated within and across cigarettes. (e.g., Evans et al., 2003a; Gust et al., 1983; Guyatt et al., 1989). Thus, the ability to measure puff duration, as well as number and IPI, was sufficient for demonstrating brand-induced changes in smoking behavior, and provided data for evaluating the influence of the mouthpiece on topography measurement.

Video data for two pilot volunteers were used to practice scoring and finalize operational definitions for the following smoking topography measures. A puff was counted each time the cigarette/mouthpiece was brought to the smokers' lips, and the cigarette tip glowed red from air being drawn in through the cigarette during an inhalation. Puff number was the total number of puffs for one cigarette > 300 milliseconds. For puff duration and IPI, two different operational definitions were used for each measure and compared. The two definitions for both topography measures

differed by the clip chosen as the onset of a puff: 1) the clip demonstrating initial lip contact with the cigarette/mouthpiece ("lip duration" and "lip IPI"), or 2) the clip demonstrating heat emission by the cigarette tip turning red ("red duration" and "red IPI"). The clip chosen as the offset of a puff was held constant for both definitions, and was the last clip demonstrating that the cigarette/mouthpiece was still enclosed around the lips (i.e., the clip immediately prior to that showing clear removal of the cigarette/mouthpiece). Use of the clip demonstrating the offset of redness/heat emission was not feasible, as the cigarette tip often remained red long after removal of the cigarette/mouthpiece from the smokers' lips.

The decision to use two different operational definitions for duration and IPI was based on initial scoring attempts with pilot data. It was observed that duration scores based on lip contact alone often overestimated, and scores based on redness/lip contact alone often underestimated, actual puff durations. These differences are most likely due to the fact that smokers begin inhaling several clips after lip contact is made, but several clips before the cigarette begins to turn red in color from heat emission (i.e., several clips is equivalent to several milliseconds).

Video data were scored using the above operational definitions by two independent raters: investigator and outside observer. Gross discrepancies (i.e., problems created by problematic recordings or software malfunctions) were resolved prior to data analysis. Final scores between the two raters were then assessed for reliability.

Subjective measures

During each session, participants responded to computerized subjective questionnaires using a computer keyboard and mouse. Two questionnaires, the Hughes and Hatsukami (1986) questionnaire and the Tiffany-Drobes (1991) Questionnaire of Smoking Urges (QSU), were used to assess nicotine/tobacco withdrawal. The third questionnaire was administered to determine participants' acceptability of the devices used and/or the video equipment present during each session (i.e., Acceptability Questionnaire). All three questionnaires are presented in Appendices E, F, and G, respectively.

Hughes-Hatsukami Questionnaire. The Hughes and Hatsukami (1986) questionnaire consisted of 11 items: "Urges to smoke", "Irritability/frustration/anger", "Anxious", "Difficulty concentrating", Restlessness", "Hunger", Impatient", "Craving a cigarette/nicotine", "Drowsiness", "Depression/feeling blue", and "Desire for sweets". These visual analog scale (VAS) items consisted of a word or phrase centered above a horizontal line (represents 0-100 scale range) anchored on the left with "not at all" (i.e., 0) and on the right with "extremely" (i.e., 100). Subjects responded to these items by moving a mouse-controlled cursor to any point on the line and clicking, thus producing a vertical mark; this mark was able to be further adjusted if necessary. The score for each scale (item) is the distance of the vertical mark from the left anchor, expressed as a percentage of the total length of the horizontal line.

Tiffany-Drobes Questionnaire of Smoking Urges (QSU). The Tiffany-Drobes (1991) QSU consists of 32 items related to smoking urges (e.g., "Smoking would make

me feel very good right now", "I have an urge for a cigarette"). These items were presented as a phrase centered above seven boxes, which are anchored on the left with "strongly disagree" and on the right with "strongly agree". Using a computer mouse, participants responded to each item by moving a cursor to highlight one of the boxes. Participants were able to adjust the placement of the cursor prior to advancing to the next item; scores for each of the seven boxes range from 0 to 6. Items from the QSU were collapsed into two factors that have been defined previously by factor analysis: Factor 1 is related to intention to smoke and Factor 2 is related to anticipation of relief from withdrawal (Tiffany & Drobes, 1991).

Acceptability Questionnaire. The acceptability questionnaire was designed to examine the influence of video and/or topography devices on smoking behavior, and is similar to that used in a previous study examining the use of desktop and portable devices for smoking (Evans et al., 2003a). Specifically, the questionnaire asked to what degree the video/device factors "altered smoking behavior", "made smoking less likely", "reduced smoking enjoyment", "affected the taste of the cigarettes", "made smoking more difficult", and "increased awareness of how much was smoked". Additionally, a final question asked participants if they were interested to know more about their smoking behavior. These seven items were presented in VAS format (question centered above horizontal line representing 0-100 scale range). The score for each scale (item) is the distance of the vertical mark from the left anchor, expressed as a percentage of the total length of the horizontal line.

Physiological Measures

Several physiological measures were collected during each session. Heart rate and blood pressure was monitored continuously via non-invasive computerized equipment (Patient Monitor model 507E, Criticare Systems, Waukesha, WI). Blood pressure was measured every 5 minutes, while heart rate was measured every 20 seconds. In addition, expired air CO levels were collected via a BreathCo monitor (Vitalograph, Lenexa, KS). The CO measurements were taken at screening (to verify current smoking status), at session onset (baseline; to verify overnight tobacco abstinence), and before and after each cigarette was smoked (pre- and post-smoking timepoints).

Experimental Conditions

This laboratory study used a 6-condition, within-subject, Latin square-ordered design to compare topography measurement using mouthpiece-based methods to topography measurement using methods that do not require the use of a mouthpiece (i.e., observation via video recordings). Smokers participated in six, approximately 3-hour experimental sessions. Each session was separated by at least 48 hours to avoid carryover effects, and was preceded by at least 8 hours of objectively-verified tobacco abstinence. Conditions differed by cigarette (own brand, Merit® Ultralight) and topography measurement method (desktop, portable, observation only). In every condition, participants smoked one cigarette *ad libitum* every 30 minutes for two hours; a total of four cigarettes were smoked within each session (e.g., Evans et al., 2003a). The design included four smoking bouts in order to detect effects of cigarette brand (e.g., topography differences between brands as averaged across several cigarettes) and

abstinence (e.g., differences between initial and subsequent cigarette bouts), and to assess reliability of topography measurement (i.e., topography of cigarettes unaffected by factors such as overnight abstinence or the approaching end of session).

Session Procedure

All experimental sessions took place in the Clinical Behavioral Pharmacology Laboratory on Virginia Commonwealth University's medical campus. At the beginning of each session, expired air CO level was measured via a breath sample to ensure compliance with smoking abstinence (i.e., CO levels $\leq$ 10 ppm indicate at least 8 hours of tobacco abstinence). If the pre-session requirement was met, non-invasive, computerized collection of physiologic data began and continued for the duration of the session. Following 30 minutes of baseline physiological assessment, participants responded to a battery of questionnaires to assess baseline tobacco/nicotine withdrawal, and had CO assessed. They then smoked the first of four cigarettes *ad libitum* (either own brand or Merit® Ultralight). In each session, all smoking behavior was video recorded for later analysis. In addition, in two sessions subjects used the desktop device, and in two sessions they used the portable device. After the first cigarette, participants again completed the questionnaires and provided another breath sample. This same pattern (questionnaires, CO measurement, *ad libitum* smoking, questionnaires, CO measurement; see Figure 3) was repeated three more times at 30 minute intervals. The assessment periods were constructed such that subjects smoked a total of four cigarettes in four separate smoking bouts in each of the six sessions. This schedule of events has been used safely, ethically, and successfully in previous studies at VCU (Buchhalter et al., 2001;

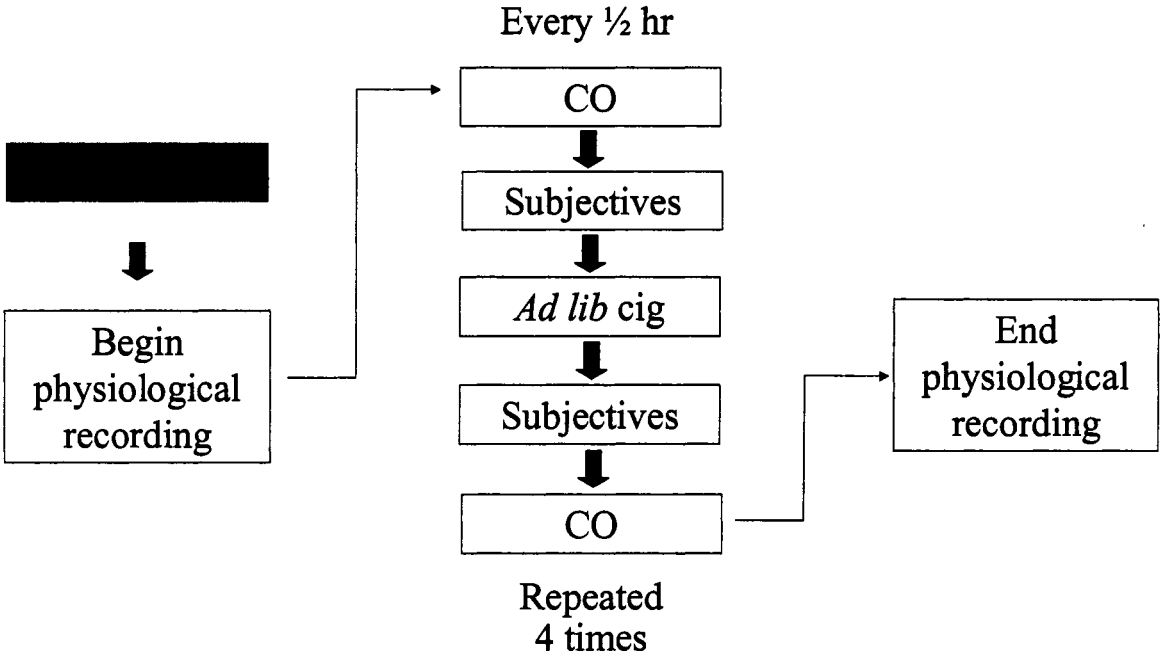

Figure 3: Diagram of session procedure

Evans et al., 2003a). Finally, participants completed an acceptability questionnaire at the end of each session. Participants were paid for their time. Specifically, they received $40 after the second session, $40 after the third session, $60 after the fourth session, $60 after the fifth session, and $100 after the sixth (final) session. Overall, participants earned a total of $300 for successful completion of this study.

Participant Safety and Rights

This protocol used established procedures and involved only minimal risk, other than the risks smokers normally incur when they smoke. Additionally, regular smokers participating in this study were required to undergo a maximum of 12 hours of abstinence from tobacco. Tobacco abstinence can lead to a withdrawal syndrome that includes irritability, anxiety, restlessness, hunger, and difficulty sleeping (Gross & Stitzer, 1989; Hughes & Hatsukami, 1986). Though these effects may be uncomfortable, they are not medically dangerous.

Participants' safety and rights were protected throughout their participation by IRB-approved procedures and highly trained staff. Blood pressure and heart rate, monitored continuously via non-invasive equipment, were required to remain within a pre-determined safety parameter throughout each session: systolic blood pressure between 90 and 150, diastolic blood pressure between 60 and 100, and heart rate between 50 and 110. Individuals who experienced any deviations from these physiological boundaries (as well as any other adverse effects) were assessed immediately by medical staff, who determined their continued participation in the study. Additionally, data were treated with professional standards of confidentiality; data were identified by code

number only (i.e., participants' names were not directly associated with these data) and were stored in locked rooms.

Data Analysis Plan

Prior to data analysis, puff topography values (puff number, duration, and IPI) scored by the two independent raters for the video alone condition were averaged to produce a single value for each puff. These averaged data were used in analyses involving the video condition, as described below.

Puff topography data were analyzed using a 3-factor, within-subject analysis of variance (ANOVA): measurement method (3; desktop, portable, video) x cigarette type (2; own brand, low-yield) x cigarette bout (4; cigarettes 1-4). Of particular interest was each method's ability to demonstrate a known phenomenon, and thus brand-induced changes in smoking topography (i.e., differences in topography variables for own brand versus ultra-light cigarettes) were examined within measurement method. Additionally, Pearson's correlation coefficients [r] were used to explore relationships among all three measurement methods. To determine the relationship between the video and computerized device methods, video scores of smoking with a mouthpiece (i.e., desktop and portable conditions) or without a mouthpiece (i.e., direct observation; video alone condition) were correlated with scores generated by each computerized device (desktop and portable). For each of these methods, puff topography values were averaged across puffs to create a single value for each of the four smoking bouts within both cigarette brands. This calculation resulted in eight scores (4 bouts for each cigarette type) per measurement method for each of the 30 participants. For reliability of measurement for

each method, puff topography data for cigarettes within a session were compared: topography data from cigarettes 2 and 3 were correlated, as scores from other cigarette bouts could have been influenced by abstinence-induced tobacco withdrawal (cigarette 1) or the approaching end of session (cigarette 4). Finally, inter-rater reliability was assessed for video data (duration and IPI) by correlating scores between the two independent raters.

Subjective (withdrawal measures) and physiological responses (heart rate and CO) were also analyzed using ANOVA, though there were 4 factors: measurement method, cigarette type, cigarette bout, and time (pre- and post-smoking for subjective and CO data; pre- and during smoking for heart rate data). Acceptability questionnaire items were analyzed by a 2-factor ANOVA (device and cigarette type). For all analyses, Huynh-Feldt corrections were used to adjust for potential violations of the sphericity assumption. Differences between means were examined using Tukey's Honestly Significant Difference (HSD; $P < .05$).

Chapter 3

Results

Primary Outcome Measures

Primary outcome measures include measurement of smoking behavior, or puff topography. Of particular interest was evaluating each method's ability to measure smoking behavior consistently (reliability) and accurately, and demonstrate brand-induced changes in topography. Also important was participants' acceptability of each device.

Puff Topography Measures

Statistical analysis results for all puff topography variables are displayed in Table 4. Results for device by cigarette brand, cigarette brand by bout, and device by cigarette brand by bout are omitted from this table because on every measure these interaction effects were not statistically significant ($Fs < 3.4$, $Ps > .05$). As is apparent from the table, several topography variables were influenced by cigarette brand (i.e., significant main effect of cigarette brand, $Fs > 6.8$, $Ps < .05$). Specifically, values for these measures were greater for ultra-light than own brand cigarettes. Table 5 shows the means (SD) for all topography measures for both cigarette brands collapsed across device and bout. Compared to own brand, participants took longer puffs when smoking ultra-light cigarettes ('lip' definition of duration; mean difference = 0.24 sec, SD = 0.16; $P < .05$, Tukey's HSD). Similarly, average puff volume (mean difference = 5.9 ml, SD = 9.2) and total puff volume (mean difference = 76.2 ml, SD = 160.6) were greater for ultra-light than own brand cigarettes ($P < .05$, Tukey's HSD).

Table 4

Statistical analysis results for puff topography measures collected during four smoking bouts

	Cigarette Brand[a]		Bout[b]		Device[c, e]		Device x Bout[d]	
	F	P	F	P	F	P	F	P
Topography measures								
Puff volume (ml)	12.2	<.01	3.9	<.05	19.5	<.001	1.7	n.s.
Total puff volume (ml)	6.8	<.05	8.8	<.01	16.7	<.001	0.0	n.s.
Puff duration (sec)								
Red definition	49.8	<.001	2.8	n.s.	3.1	n.s.	2.2	n.s.
Lip definition	73.3	<.001	2.8	n.s.	9.9	<.001	2.2	<.05
Inter-puff-interval (sec)								
Red definition	3.0	n.s.	7.0	<.01	5.4	<.01	2.0	n.s.
Lip definition	3.1	n.s.	6.8	<.01	3.9	<.05	2.0	n.s.
Puff number	3.9	n.s.	13.7	<.001	1.5	n.s.	1.0	n.s.

[1]Statistical results for a) device x cigarette brand, b) cigarette brand x bout, and c) device x cigarette brand x bout were omitted because none were statistically significant for any topography measure (Fs < 3.4, Ps >.05)

[a]df = 1, 29; [b]df = 3, 87; [c]df = 2, 58; [d]df = 6, 174

[e]Device factors: 3 (desktop, portable, video) for duration, IPI, number; 2 (desktop, portable) for average and total volume

Table 5

Means (SD) for puff topography measures for main effects of cigarette brand

	Cigarette Brand [a, b]	
	Own Brand	Ultralight
Topography measures		
Puff volume (ml)	50.7 (18.2)	56.6 (17.1)
Total puff volume (ml)	495.1 (273.6)	571.3 (261.5)
Puff duration (sec)		
Red definition	1.7 (0.7)	1.9 (0.7)
Lip definition	1.8 (0.7)	2.0 (0.7)
Inter-puff-interval (sec)		
Red definition	18.3 (8.0)	16.7 (8.1)
Lip definition	18.2 (8.0)	16.6 (8.0)
Puff number	9.4 (3.2)	10.0 (3.2)

[a] Collapsed across device and bout

[b] Device factors: 3 (desktop, portable, video) for duration, IPI, number; 2 (desktop, portable) for average and total volume

Importantly, these brand-induced changes were demonstrable with all three devices (see Table 6 for means/SD for device by cigarette brand). Puff duration based on the 'lip' definition, for example, was longer for ultra-light relative to own brand for desktop (mean difference = 0.26 sec, SD = 0.5), portable (mean difference = 0.23 sec, SD = 0.3), and video (mean difference = 0.25 sec, SD = 0.4) conditions. This same pattern of results was observed for the 'red' definition of puff duration. Desktop and portable devices also were also sensitive to brand-induced changes in total and average puff volume (puff volume cannot be measured with video method alone). That is, participants took larger puffs on average when smoking ultra-light cigarettes than when smoking own brand cigarettes, whether using the desktop (mean difference = 3.3 ml, SD = 17.1) or portable (mean difference = 8.4 ml, SD = 9.6) device.

Additionally, several smoking topography variables were influenced by bout number (main effect of cigarette bout; $Fs > 3.9$, $Ps < .05$). Mean puff number, for instance, decreased across the four smoking bouts: 10.9 puffs (SD = 3.5) for bout 1, 9.9 puffs (SD = 3.1) for bout 2, 9.3 puffs (SD = 2.9) for bout 3, and 8.9 puffs (SD = 2.9) for bouts 4 (n.s., Tukey's HSD). This gradual decrease in puff number across bouts is revealed by total puff volume as well [i.e., from a mean = 590.9 ml (SD = 280.5) for bout 1 to mean = 498.0 ml (SD = 263.3) for bout 4]. Again, these findings were demonstrable with all three measurement methods. Compared to bout 4, participants took more puffs at bout 1 for desktop (mean difference = 2.1 puffs, SD = 3.3), for portable (mean difference = 2.4 puffs, SD = 3.0), and for video (mean difference = 1.6 puffs, SD = 3.0; $P < .05$, Tukey's HSD).

Table 6

Means (SD) for puff topography measures for device by cigarette brand

	Desktop[a]		Portable[a]		Video[a]	
	Own Brand	Ultralight	Own Brand	Ultralight	Own Brand	Ultralight
Topography measures						
Puff volume (ml)	57.0 (20.1)	60.3 (20.0)	44.4 (13.6)	52.8 (12.6)	n/a	n/a
Total puff volume (ml)	578.7 (327.2)	614.2 (301.1)	411.4 (170.7)	528.5 (207.2)	n/a	n/a
Puff duration (sec)						
Red definition	1.7 (0.7)	2.0 (0.8)	1.7 (0.6)	1.9 (0.6)	1.7 (0.8)	1.8 (0.7)
Lip definition	1.7 (0.7)	2.0 (0.8)	1.7 (0.6)	1.9 (0.6)	1.9 (0.8)	2.1 (0.7)
Inter-puff-interval (sec)						
Red definition	18.1 (8.8)	15.2 (7.2)	18.2 (7.6)	16.7 (7.7)	18.5 (7.6)	18.0 (9.1)
Lip definition	18.1 (8.8)	15.2 (7.2)	18.2 (7.6)	16.7 (7.7)	18.3 (7.5)	17.8 (9.0)
Puff number	9.7 (3.3)	10.2 (3.1)	9.4 (3.0)	10.1 (3.4)	9.2 (3.2)	9.9 (3.1)

[a] Collapsed across bout

Device factors: 3 (desktop, portable, video) for duration, IPI, number; 2 (desktop, portable) for average and total volume

Table 4 also shows a significant main effect of device for several topography variables (Fs > 3.9, Ps < .05), as well as a device by bout interaction for the 'lip' definition of puff duration [F (6, 174) = 2.2, P < .05]. Means (SD) for all topography measures for each device (collapsed across brand and bout) are provided in Table 7. Within each device condition, puff durations ('lip' definition) were shortest at bout 1 relative to the other bouts, and the differences between bouts were least pronounced for video (n.s., Tukey's HSD). Additionally, longer puffs were observed for video than for desktop or portable at all four bouts. The absolute mean difference from video at bout 2, for instance, was 0.2 sec (SD = 0.4) for desktop and 0.2 sec (SD = 0.4) for portable (P < .05, Tukey's HSD). Similarly, significantly longer puffs were observed at bout 3 for video compared to either device: the mean difference was 0.2 sec (SD = 0.4) for desktop and 0.2 (SD = 0.4) for portable (P < .05, Tukey's HSD).

Device also influenced IPI, with both 'red' and 'lip' definitions showing a similar pattern of results. Shorter IPI's were observed with desktop ('red' definition mean = 16.7 sec, SD = 8.1), compared to portable ('red' definition mean = 17.4 sec, SD = 7.7) or video ('red' definition mean = 18.3 sec, SD = 8.3; n.s., Tukey's HSD). For average and total puff volume, participants' took larger puffs when using the desktop device compared to the portable device. Collapsed across cigarette brand and bout, for example, average puff volume was 58.7 ml (SD = 20.1) for desktop and 48.6 ml (SD = 13.7) for portable (P<.05, Tukey's HSD).

To determine the relationship between topography outcomes obtained via direct observation (i.e., video) and computerized mouthpiece-based measurement conditions

Table 7

Means (SD) for puff topography measures for main effects of device

	Device[a, b]		
	Desktop	Portable	Video
Topography measures			
Puff volume (ml)	58.7 (20.1)	48.6 (13.7)	n/a
Total puff volume (ml)	596.4 (314.3)	467.0 (198.3)	n/a
Puff duration (sec)			
Red definition	1.9 (0.8)	1.8 (0.6)	1.8 (0.7)
Lip definition	1.9 (0.8)	1.8 (0.6)	2.0 (0.7)
Inter-puff-interval (sec)			
Red definition	16.7 (8.1)	17.4 (7.7)	18.3 (8.3)
Lip definition	16.7 (8.1)	17.4 (7.7)	18.0 (8.3)
Puff number	10.0 (3.2)	9.7 (3.2)	9.5 (3.1)

[a] Collapsed across cigarette brand and bout

[b] Device factors: 3 (desktop, portable, video) for duration, IPI, number; 2 (desktop, portable) for average and total volume

(i.e., desktop and portable), data from the video-alone condition were correlated with data from the two device conditions. These correlations were significant for all topography variables (r's $\geq$ 0.68, P's < .01), as shown in Table 8. In addition, data from video recordings of participants using each device were correlated with data collected from each computerized mouthpiece-based device. Table 9 displays these data for cigarette brand by bout, and shows high and reliable correlations for all topography variables (r's $\geq$ 0.73, P's < .01).

In order to examine each method's ability to measure smoking behavior reliably, topography data collected from bouts 2 and 3 within each condition were correlated. As evidenced by Table 10, correlations yielded by each method were comparable: video (r's $\geq$ 0.80, P's < .01), portable (most r's $\geq$ 0.78, P's < .01) and desktop (most r's $\geq$ 0.83, P's < .01). Finally, scores between the two independent raters were high for both 'lip' and 'red' definitions of duration and IPI (r's $\geq$ 0.94, P's < .01; see Table 11).

Acceptability Measures

Statistical analyses (F tests and mean/SD by device) for all acceptability measures are displayed in Table 12. Significant device differences were observed for a variety of items (Fs > 3.7, Ps < .05), though there were no effects of cigarette brand or any interactions between brand and device (Fs < 3.1, Ps > .05). For the majority of items on which there was a main effect of device (i.e., all items except 'make smoking less likely'), higher scores were observed for both computerized devices relative to video alone (P < .05, Tukey's HSD). Based on a 0 (not at all) to 100 (extremely) scale, for example, the item 'increase smoking difficulty' (the item with the largest significant F

Table 8

Correlation coefficients for data collected via computerized device and direct observation methods

	Own Brand				Ultra Light			
	1	2	3	4	1	2	3	4
Desktop vs. Video								
Puff duration (sec)								
Red definition	0.83	0.82	0.85	0.88	0.81	0.75	0.73	0.68
Lip definition	0.79	0.79	0.83	0.87	0.84	0.78	0.75	0.68
Inter-puff-interval (sec)								
Red definition	0.73	0.78	0.75	0.75	0.86	0.87	0.67	0.74
Lip definition	0.72	0.78	0.75	0.74	0.86	0.87	0.67	0.75
Portable vs. Video								
Puff duration (sec)								
Red definition	0.75	0.77	0.72	0.86	0.95	0.83	0.89	0.88
Lip definition	0.71	0.71	0.72	0.84	0.94	0.80	0.85	0.85
Inter-puff-interval (sec)								
Red definition	0.83	0.87	0.73	0.82	0.69	0.75	0.81	0.82
Lip definition	0.82	0.87	0.74	0.82	0.69	0.77	0.81	0.82

All coefficients statistically significant ($P < .01$)

Table 9

Correlation coefficients for data collected via computerized devices and videos of computerized device use

	Own Brand				Ultra Light			
	1	2	3	4	1	2	3	4
Desktop vs. Video of Desktop								
Puff duration (sec)								
Red definition	0.93	0.96	0.97	0.97	0.92	0.87	0.89	0.74
Lip definition	0.95	0.95	0.96	0.98	0.93	0.88	0.95	0.73
Inter-puff-interval (sec)								
Red definition	0.99	0.99	1.00	1.00	0.99	0.99	0.98	0.99
Lip definition	0.99	0.99	1.00	1.00	0.98	0.99	0.98	0.95
Portable vs. Video of Portable								
Puff duration (sec)								
Red definition	0.94	0.97	0.94	0.97	0.97	0.96	0.97	0.97
Lip definition	0.94	0.97	0.95	0.97	0.96	0.96	0.97	0.95
Inter-puff-interval (sec)								
Red definition	1.00	0.98	0.95	0.99	0.99	0.97	1.00	1.00
Lip definition	1.00	0.98	1.00	0.99	0.99	0.95	0.99	1.00

All coefficients statistically significant ($P < .01$)

Table 10

Correlation coefficients for cigarette bouts 2 and 3 within each condition

	Desktop		Portable		Video[a]	
	OB	UL	OB	UL	OB	UL
Topography measures						
Puff volume (ml)	0.95	0.90	0.93	0.90	n/a	n/a
Total puff volume (ml)	0.89	0.85	0.78	0.80	n/a	n/a
Puff duration (sec)						
Red definition	0.95	0.93	0.95	0.95	0.98	0.95
Lip definition	0.95	0.93	0.95	0.95	0.97	0.90
Inter-puff-interval (sec)						
Red definition	0.92	0.83	0.88	0.83	0.91	0.93
Lip definition	0.92	0.83	0.88	0.83	0.92	0.93
Puff number	0.67	0.59	0.48	0.78	0.89	0.80

All coefficients statistically significant ($P < .01$)

[a]Average and total puff volume not able to be measured via video alone

Table 11

Correlation coefficients for rater scores for device by cigarette brand

	Desktop		Portable		Video	
	OB	UL	OB	UL	OB	UL
Topography measures						
Puff duration (sec)						
Red definition	0.999	1.000	0.999	0.997	1.000	0.998
Lip definition	0.999	0.999	0.999	0.998	1.000	0.938
Inter-puff-interval (sec)						
Red definition	1.000	1.000	1.000	0.999	0.999	0.999
Lip definition	1.000	1.000	1.000	0.999	0.999	0.999

All coefficients statistically significant (P <.01)

Table 12

Statistical analysis results for the acceptability questionnaire

Acceptability items	Device[a] F	Device[a] P	Mean (SD) Desktop	Mean (SD) Portable	Mean (SD) Video
Alter smoking behavior	11.9	<.001	51.6 (30.0) *	48.9 (30.1) *	31.9 (26.7) †#
Increase smoking awareness	<1.0	n.s.	54.7 (28.5)	56.2 (26.9)	50.9 (29.5)
Increase smoking difficulty	14.3	<.001	47.3 (33.6) *	40.1 (29.8) *	19.5 (21.0) †#
Reduce smoking enjoyment	13.2	<.001	53.5 (34.5) *	47.6 (30.2) *	29.0 (28.6) †#
Make smoking less likely	3.7	<.05	39.8 (28.8)	38.5 (27.4)	28.8 (28.4)
Affect cigarette taste	10.8	<.001	44.4 (32.9) *	45.6 (31.8) *	25.7 (23.7) †#
Know more about your smoking	2.3	n.s.	73.3 (26.9)	69.9 (24.6)	72.2 (25.8)

[1] Statistical analysis results for main effect of cigarette brand and interaction effect of device x cigarette brand were omitted because neither were statistically significant for any measure (Fs < 3.1, Ps <.05)

[2] Symbols denote significant difference from desktop (†), portable (#), or video (*)

[a] df = 2, 58

value) resulted in an average score of 47.3 (SD = 33.6) for desktop, 40.1 (SD = 29.8) for portable, and 19.5 (SD = 21.0) for video. This same pattern was observed for the items 'alter smoking behavior', 'reduce smoking enjoyment', and 'affect cigarette taste'. In contrast, ratings between desktop and portable devices did not differ for any measure (n.s., Tukey's HSD).

Secondary Outcome Measures

Secondary outcome measures include assessment of nicotine/tobacco withdrawal symptoms, heart rate, and expired air CO level. Table 13 displays statistical analysis results for these measures for selected main (cigarette brand, bout, and time) and interaction (bout by time) effects. All other effects are omitted from this table due to the paucity of significant findings: no main effects of device (i.e., $Fs < 2.8$, $Ps > .05$) and, as described below, only 5 of 75 possible significant two-way interactions (all other $Fs < 3.6$, $Ps > .05$), and only 4 of 75 possible significant three- and four-way interactions (all other $Fs < 2.5$, $Ps > .05$).

Assessment of Nicotine/Tobacco Withdrawal

As Table 13 shows, significant bout by time interactions were observed for 8 of the 11 Hughes-Hatsukami VAS measures ($Fs > 4.5$, $Ps < .05$). For these measures, scores generally decreased from pre- to post-smoking at each bout, and scores at both pre- and post-smoking timepoints decreased as the number of bouts increased. Figure 4 displays 'craving a cigarette/nicotine', the subjective effect measure with the largest F value for the bout by time interaction. As is apparent from this figure, mean craving scores were similar for each device and both cigarette brands at each measurement

Table 13

Statistical analysis results for subjective and physiological measures collected during four smoking bouts

	Cigarette Brand[a]		Bout[b]		Time[a]		Bout*Time[c]	
	F	P	F	P	F	P	F	P
Nicotine/Tobacco Withdrawal								
Hughes Hatsukami VAS								
Urges to smoke	5.2	<.05	102.1	<.001	70.6	<.001	33.0	<.001
Irritability/Frustration/Anger	<1.0	n.s.	6.3	<.05	20.6	<.001	8.8	<.01
Anxious	<1.0	n.s.	12.9	<.001	25.5	<.001	16.8	<.001
Difficulty concentrating	<1.0	n.s.	9.0	<.01	2.5	n.s.	1.8	n.s.
Restlessness	<1.0	n.s.	2.1	n.s.	19.9	<.001	14.2	<.001
Hunger	<1.0	n.s.	2.8	n.s.	4.0	n.s.	8.8	<.001
Impatient	<1.0	n.s.	3.3	n.s.	21.4	<.001	15.9	<.001
Craving a cigarette/Nicotine	7.7	<.01	82.1	<.001	80.8	<.001	42.0	<.001
Drowsiness	<1.0	n.s.	2.8	n.s.	9.0	<.01	1.5	n.s.
Depression/Feeling blue	1.6	n.s.	3.6	<.05	11.3	<.01	4.5	<.05
Desire for sweets	2.3	n.s.	<1.0	n.s.	7.1	<.05	1.3	n.s.
Tiffany Drobes QSU								
Factor 1	10.5	<.01	60.7	<.001	58.1	<.001	13.2	<.001
Factor 2	4.6	<.05	42.9	<.001	25.3	<.001	36.3	<.001
Physiological measures								
Heart rate	8.6	<.01	4.7	<.05	79.5	<.001	68.8	<.001
Carbon monoxide	8.7	<.01	157.9	<.001	196.5	<.001	25.6	<.001

[1]Results for other main and interaction effects are omitted: no significant main effects of device (all F's < 2.8, P's < .05); only 9 significant interactions out of 150 possible interactions (all other F's < 3.6, P's < .05)

[a] df = 1, 28; [b] df = 3, 84; [c] df = 3, 87

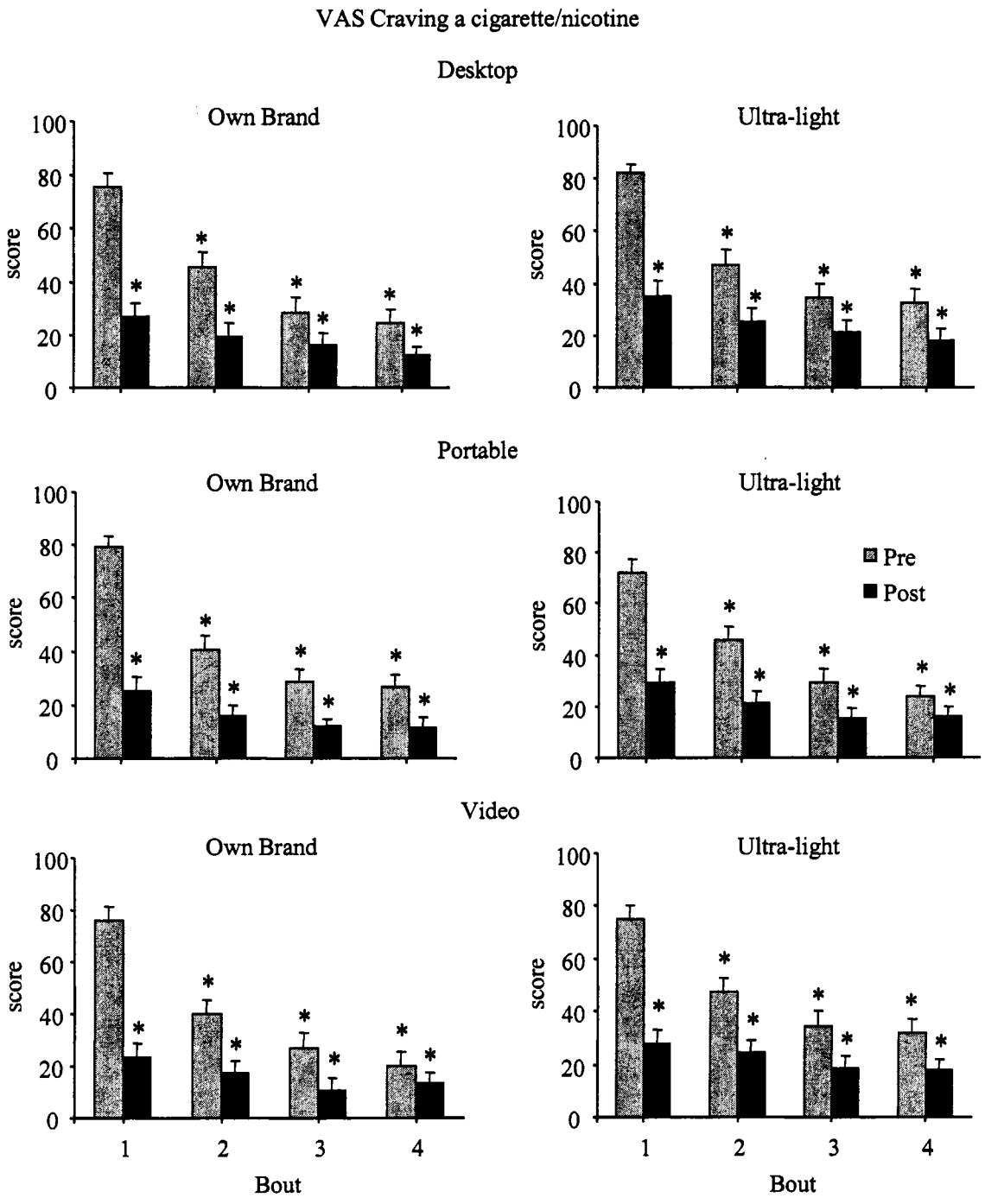

Figure 4: Hughes-Hatsukami VAS Item 'Craving a cigarette/nicotine'. Averaged data (+ 1 SEM) for 30 participants when smoking own brand (left panels) or ultra-light (right panels) cigarettes via desktop (top panels), portable (middle panels), or video (bottom panels) methods. Bars represent pre- (grey) or post-smoking (black) values collected during four *ad libitum* bouts. Symbols indicate a significant difference from baseline (*; i.e., pre-smoking value at bout 1; Ps < .05; Tukey's HSD).

timepoint. However, within each condition scores differed depending on bout and timepoint. Collapsed across device and brand, for example, mean craving decreased from 76.7 (SD = 25.7) to 28.0 (SD = 28.0) for bout 1, from 44.2 (SD = 29.4) to 20.5 (SD = 25.2) for bout 2, from 30.2 (SD = 28.8) to 15.6 (SD = 22.5) for bout 3, and from 26.4 (SD = 26.3) to 14.8 (SD = 22.2) for bout 4 (from pre-smoking at bout 1; $P < .05$, Tukey's HSD). Additionally, the mean difference between pre- and post-smoking values was greater for bout 1 (mean = 48.7, SD = 25.7; $P < .05$, Tukey's HSD) than for bout 4 (mean = 11.6, SD = 14.1). A similar pattern of results was observed for all other VAS items with a significant bout by time interaction.

In addition to the numerous bout by time interactions, several VAS items showed other significant main and interaction effects. For example, there was a significant main effect of cigarette brand for the items 'urges to smoke' and 'craving a cigarette/nicotine' ($Fs > 5.2$, $Ps < .05$). Scores for both of these items were greater for ultra-light (e.g., craving mean = 34.3, SD = 32.4) than for own brand cigarettes (e.g., craving mean = 29.8, SD = 32.0; $P < .05$, Tukey's HSD). Results also showed a main effect of bout for the item 'difficulty concentrating' [$F (3, 84) = 9.0$, $P < .01$], as well as a main effect of time for the item 'drowsiness' [$F (1, 28) = 9.0$, $P < .01$]. Ratings for 'difficulty concentrating' were greatest at bout 1 (mean = 23.1, SD = 26.7), relative to bouts 2 (mean = 18.2, SD = 22.5), 3 (mean = 15.3, SD = 20.3), and 4 (mean = 14.1, SD = 20.3; n.s., Tukey's HSD). For 'drowsiness', scores decreased from pre- (mean = 31.9, SD = 30.9) to post-smoking bout (mean = 27.1, SD = 27.4, $P < .05$, Tukey's HSD).

Also, two-way interactions of brand by bout were observed for the VAS items 'drowsiness' and 'hunger' (Fs > 4.0, Ps < .05). Generally speaking for both measures, scores for own brand were greater than for ultra-light for bouts 1 and 2, but less than ultra-light for bouts 3 and 4. For example, the absolute mean difference between own brand and ultra-light for 'hunger' was 4.6 (SD = 18.3) for bout 1 and 2.3 (SD = 20.8) for bout 4 (n.s., Tukey's HSD). A significant three-way interaction of brand by bout by time was observed for the VAS item 'irritability/frustration/anger' [F (3, 87) = 5.2, P < .01]. Mean scores decreased from pre- to post-smoking for each bout, though the magnitude of these decreases differed for ultra-light and own brand. For instance, the mean difference from pre- to post-smoking for bout 1 was 16.0 (SD = 20.4) for own brand and 7.4 (SD = 15.9) for ultra-light. For bout 4, however, the mean difference was 0.3 (SD = 5.3) for own brand and 2.4 (SD = 5.1) for ultra-light. Nonetheless, these differences were not reliable (n.s., Tukey's HSD). Finally, there was a significant four-way interaction for the VAS item 'desire for sweets' [F (6,174) = 3.4, P < .05], although results showed no clear pattern. Generally, scores decreased minimally pre- to post-smoking at each bout. Collapsed across device and brand, the mean difference between pre- and post-smoking scores was 3.0 (SD = 5.6) for bout 1, 1.4 (SD = 6.1) for bout 2, 1.4 (SD = 4.2) for bout 3, and 1.8 (SD = 4.5) for bout 4. Additionally, scores were greater for own brand versus ultra-light for the two computerized devices but comparable for the video condition: 16.1 (SD = 20.7) versus 13.4 (SD = 18.8) for desktop, 15.6 (SD = 22.7) versus 11.2 (SD = 17.1) for portable and 16.5 (SD = 24.4) versus 16.4 (SD = 24.6) for video (n.s., Tukey's HSD).

For the Tiffany-Drobes QSU, a significant four-way interaction was observed for Factor 1 [$F(6, 174) = 3.0$, $P < .05$], while a significant bout by time interaction [$F(3, 87) = 36.3$, $P < .001$] and a main effect of cigarette brand [$F(1, 28) = 4.6$, $P < .05$] was observed for Factor 2. For Factor 1 ('intention to smoke'; scale from 0 to 90), scores at both pre- and post-smoking timepoints decreased as the number of bouts increased, and the magnitude of difference between these timepoints within each bout also became smaller (see Figure 5). Collapsed across device and brand, for example, mean difference from pre- to post-smoking was 33.6 (SD = 23.2) for bout 1, 26.3 (SD = 21.4) for bout 2, 18.3 (SD = 18.8) for bout 3, and 14.4 (SD = 15.9) for bout 4 ($P < .05$, Tukey's HSD for bouts 1 and 2). Factor 1 scores were also influenced by device and brand, with mean scores greater for ultra-light relative to own brand for each device: 47.8 (SD = 20.4) versus 42.4 (SD = 17.6) for desktop, 44.8 (SD = 18.3) versus 42.3 (SD = 15.1) for portable and 48.2 (SD = 18.3) versus 40.1 (SD = 16.9) for video (n.s., Tukey's HSD).

For Factor 2 ('relief from withdrawal'; scale from 0 to 66) of the QSU, the bout by time interaction was similar to those described for VAS measures. That is, Factor 2 scores decreased from pre- to post-smoking within each bout, and also across pre- and post-smoking time points: mean difference of 17.0 (SD = 13.9) for bout 1, 10.5 (SD = 12.1) for bout 2, 7.2 (SD = 11.0) for bout 3, and 5.9 (SD = 10.0) for bout 4 ($P < .05$, Tukey's HSD). The results for the main effect of cigarette brand for Factor 2 revealed greater ratings for ultra-light (mean = 22.8, SD = 17.2) than for own brand cigarettes (mean = 20.8, SD = 17.3; $P < .05$, Tukey's HSD).

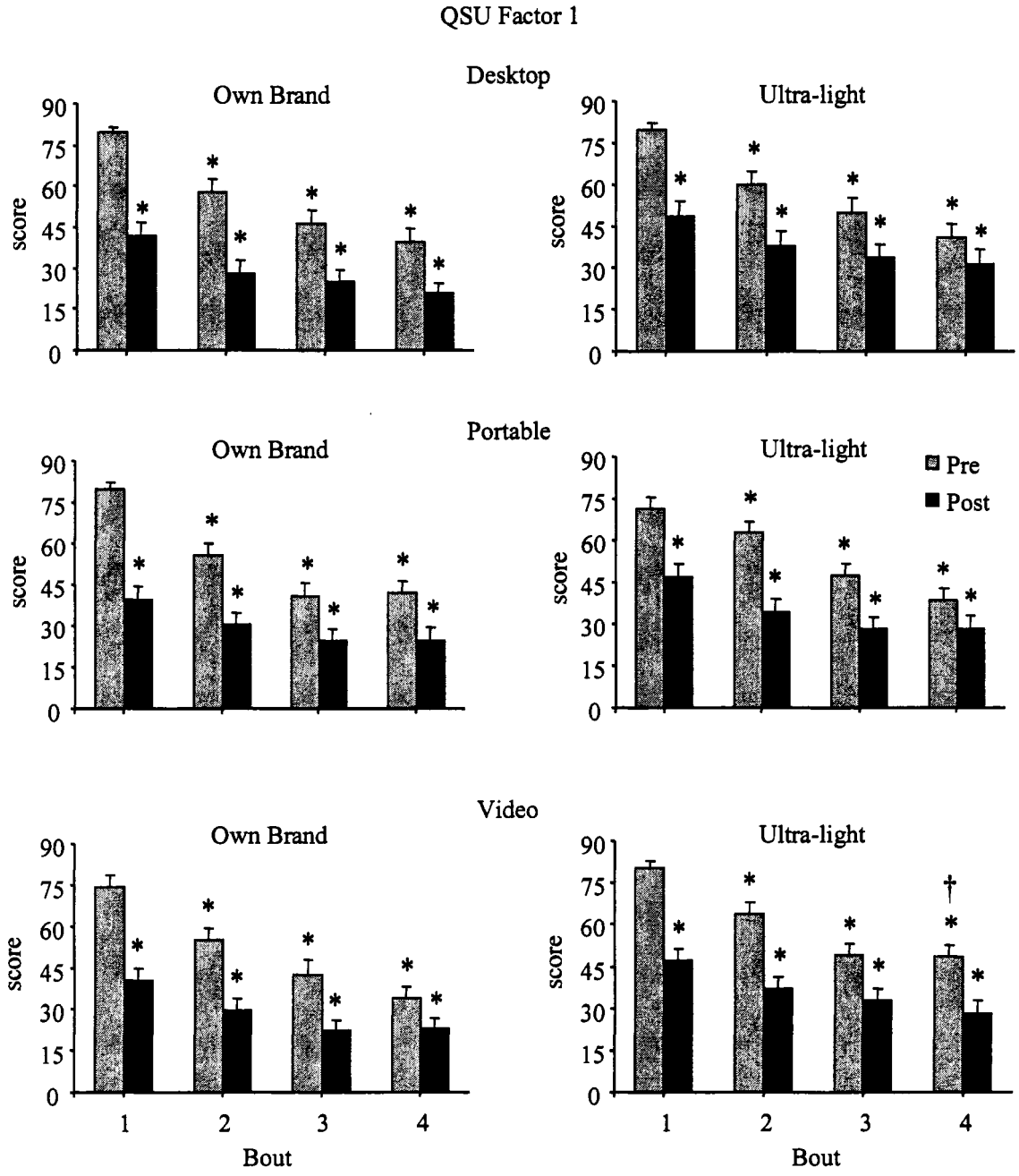

Figure 5: Tiffany-Drobes QSU Factor 1 ('intention to smoke'). Averaged data (+ 1 SEM) for 30 participants when smoking own brand (left panels) or ultra-light (right panels) cigarettes via desktop (top panels), portable (middle panels), or video (bottom panels) methods. Bars represent pre- (grey) or post-smoking (black) values collected during four *ad libitum* bouts. Symbols indicate a significant difference from baseline (*; i.e., pre-smoking value at bout 1) and from own brand at that timepoint within device (†; Ps < .05; Tukey's HSD).

Heart Rate and Carbon Monoxide

A significant brand by bout by time interaction [$F(3, 87) = 7.7$, $P < .01$] was observed for heart rate. As shown in Figure 6 within each condition, significant increases in heart rate were observed during each bout relative to pre-smoking ($P < .05$, Tukey's HSD), and values were consistently greater for own brand relative to ultra-light. Collapsed across time, for example, mean heart rate for bout 1 was 77.4 bpm (SD = 9.0) for own brand and 75.2 bpm (SD = 9.4) for ultra-light. By bout 4, heart rate for own brand (mean = 76.7 bpm, SD = 9.6) remained elevated relative to ultra-light (mean = 74.2 bpm, SD = 10.1). Additionally, own brand produced a greater magnitude of increase from pre- to during smoking as compared to ultra-light, though only for bout 1 (mean difference = 11.9 for own brand, and 9.3 for ultra-light; $P < .05$, Tukey's HSD).

Figure 7 shows data for expired air CO, for which significant device by brand [$F(2, 58) = 4.1$, $P < .05$], brand by bout [$F(3, 87) = 250.3$, $P < .001$], brand by time [$F(1, 29) = 13.5$, $P < .01$], and bout by time [$F(3, 87) = 25.6$, $P < .001$] interactions were observed. Within every condition, CO increased significantly at each time point relative to the pre-session value (i.e., bout 1 pre-cigarette value; $P<.05$, Tukey's HSD), and scores at both pre- and post-smoking timepoints increased with successive bouts. The figure also shows that CO was significantly greater when participants smoked own brand cigarettes (mean = 16.5 ppm, SD = 8.7) relative to ultra-light cigarettes (mean = 14.8 ppm, SD = 6.9; $P < .05$, Tukey's HSD). These brand-induced changes were demonstrated with each device, though the differences were more pronounced for

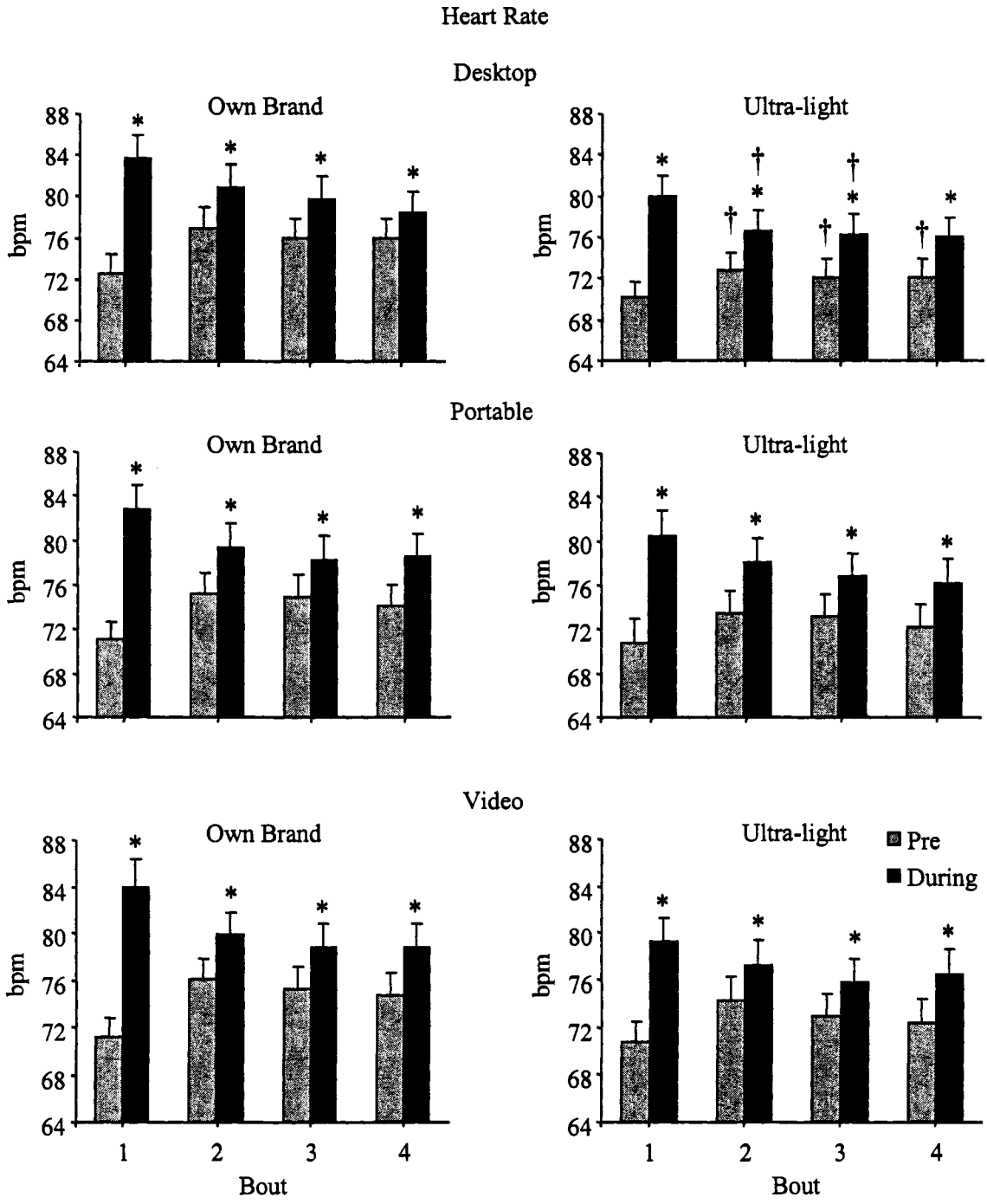

Figure 6: Heart Rate. Averaged data (+ 1 SEM) for 30 participants when smoking own brand (left panels) or ultra-light (right panels) cigarettes via desktop (top panels), portable (middle panels), or video (bottom panels) methods. Bars represent pre- (grey) or during-smoking (black) values collected during four *ad libitum* bouts. Symbols indicate a significant difference from pre-smoking at that bout (*), and from own brand at that timepoint within device (†; Ps < .05; Tukey's HSD).

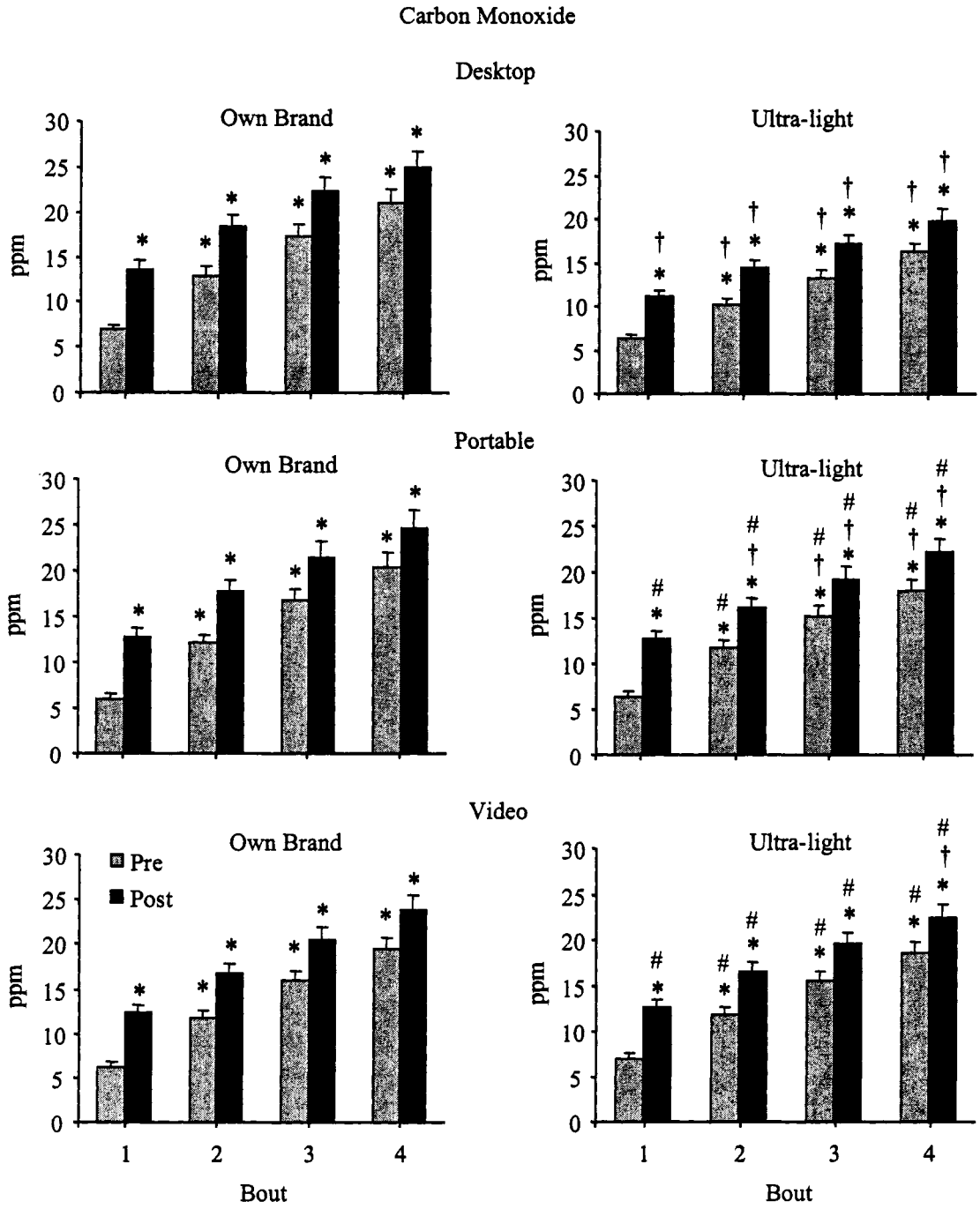

Figure 7: Carbon Monoxide. Averaged data (+ 1 SEM) for 30 participants when smoking own brand (left panels) or ultra-light (right panels) cigarettes via desktop (top panels), portable (middle panels), or video (bottom panels) methods. Bars represent pre- (grey) or post-smoking (black) values collected during four *ad libitum* bouts. Symbols indicate significant difference from baseline (*; i.e., pre-smoking value at bout 1), from own brand at that timepoint within device (†), and from desktop at that timepoint within cigarette brand (#; Ps < .05; Tukey's HSD).

desktop (mean difference = 3.2 ppm, SD = 5.5) than for portable (mean difference = 1.0 ppm, SD = 5.3) and video (mean difference = 0.2 ppm, SD = 4.6; n.s., Tukey's HSD).

Chapter 4

Discussion

Puff topography is an important measurement tool for researchers investigating the various factors influencing smoking behavior, including nicotinic antagonists (e.g., Nemeth-Coslett et al., 1986a) and agonists (e.g., Perkins et al., 1992), as well as cigarette brand (i.e., ultra-light versus full-flavor or light; e.g., Guyatt et al., 1989). The ability to measure puff topography is facilitated by the use of computerized, mouthpiece-based devices. However, given that cigarette smoking typically occurs without a mouthpiece, these computerized devices may influence smoking behavior and thus confound measurement. In order to address this issue, this study compared topography measurement using two mouthpiece-based devices (i.e., desktop and portable) to direct observation via video recording (i.e., with no mouthpiece). In particular, devices were compared on their ability to demonstrate oft-reported changes in topography (e.g., cigarette brand-induced and abstinence-induced effects; Baldinger et al., 1995; Gust & Pickens, 1982; Guyatt et al., 1989; Zacny & Stitzer, 1988), and to measure topography across cigarettes reliably (e.g., Evans et al, 2003a). Overall, study results showed that measurement of smoking topography differed little between the mouthpiece-based device and direct observation methods. All three methods demonstrated brand- and abstinence-induced changes effectively, measured smoking topography reliably, and were correlated highly across all topography measures.

Measurement of Brand-induced Changes and Tobacco-Abstinence Effects

Consistent with past work (e.g., Gust & Pickens, 1982; Zacny & Stitzer, 1988), characteristic brand-induced changes in smoking behavior were observed in this study. Specifically, smokers altered aspects of their puff topography when they switched from their own brand of cigarette (full-flavor or light) to an ultra-light. These brand-induced changes included significantly longer puff durations, and larger average and total puff volumes for ultra-light than for own brand cigarettes. Importantly, this finding was demonstrable with all three measurement methods. The magnitude of topography differences (e.g., puff duration) between cigarette brands did not differ significantly between the computerized and video methods, and was within the range of values reported elsewhere (e.g., Guyatt et al., 1989; Zacny & Stitzer, 1988). Thus, the mouthpiece-based devices were sensitive to differences in cigarette brand, as was the direct observational method.

Also of interest was whether abstinence-induced effects of smoking could be detected with each measurement method. That is, following a period of cigarette abstinence, smokers' may increase the number of cigarettes smoked, the number of puffs taken per cigarette, or take larger puffs (e.g., Zacny & Stitzer, 1985). In this study, the effects of 8 to 12 hours of tobacco abstinence on puff topography were revealed by all three measurement methods. Participants took significantly more puffs from the first cigarette relative to subsequent cigarettes as assessed by both desktop (mean = 11.1 versus 9.0 puffs) and portable (mean = 11.1 versus 8.7 puffs), as well as the video methods (mean = 10.5 versus 8.8 puffs; $P < .05$, Tukey's HSD). Consequently, total puff

volumes decreased as cigarette bout increased for both computerized devices ($P < .05$, Tukey's HSD). These results show that previously reported abstinence-induced changes in topography were measured with each measurement method, and the magnitude of these changes did not differ across methods (n.s., Tukey's HSD).

Taken together, the fact that all three measurement methods were equally sensitive to manipulations known to influence topography (i.e., cigarette brand and tobacco abstinence) suggests that each may be effective for use in studies investigating factors that influence smoking behavior.

Comparison of Mouthpiece-Based Devices with Video Recordings

In addition to assessing each method's ability to measure brand- and abstinence-induced changes in smoking behavior, correlations were used to examine the relationships among measurement methods. Thus, topography data collected via video recordings (smoking without a mouthpiece) were compared with topography data collected via desktop or portable devices (smoking with a mouthpiece). Results showed high and reliable correlations across cigarette brands and smoking bouts for data collected with video and mouthpiece-based methods (all $r's \geq 0.69$, $P < .01$). Significant correlations were also observed for data collected from video recordings of participants using each device (video recordings of smoking with a mouthpiece) and data collected from each computerized device (all $r's \geq 0.73$, $P < .01$). That is, the computerized devices measure smoking topography precisely as is observed via direct observational methods. Furthermore, the reliability of each method was supported by high correlations for data collected across smoking bouts: all correlations between cigarette bouts 2 and 3

were high and reliable for all topography measures (most r's $\geq$ 0.67, P < .01). Past work (Evans et al., 2003a) used a similar analytic method to demonstrate reliability of the desktop (r's $\geq$ 0.75) and portable (r's $\geq$ 0.64) devices, and this study confirms these findings. Collectively, these data support the notion that topography measurement via direct observation or mouthpiece-based devices does not differ.

Despite the fact that all three methods were sensitive to brand- and abstinence-induced changes and highly reliable, a few differences were observed across methods. Some research shows that relative to smoking conventionally (i.e., with direct cigarette to lip contact), smoking through a mouthpiece results in more (greater number), longer (greater duration), and/or more closely spaced (shorter IPI) puffs per cigarette (e.g., Höfer et al., 1991a, b; Pickens et al., 1983). However, at least one study did not observe any differences in smoking with or without a mouthpiece (Lee et al., 2003). In contrast to these earlier reports, participants in this study took significantly shorter puffs when smoking with desktop or portable devices, compared to when observed smoking without a mouthpiece (P < .05, Tukey's HSD). Additionally, puff volumes were differentially affected by the two mouthpiece-based devices; larger average and total puff volumes were observed for desktop than for portable (P < .05, Tukey's HSD). This finding also deviates from previous laboratory-based work, where use of the portable device resulted in significantly larger total volumes than use of the desktop device (Evans et al., 2003a). Thus, across studies, mouthpiece-based devices have been shown to produce differences in one direction (e.g., longer puffs; Höfer et al., 1991a, b; Pickens et al., 1983), the other direction (e.g., shorter puffs, as in the current study), or no differences at all (e.g., Lee et

al., 2003). This pattern may be reflective of chance variation rather than actual differences caused by a mouthpiece-based measurement system. However, another possible explanation is that the video method is an accurate representation of natural smoking, and observed differences across studies are due to the manner in which the computerized devices measure topography as compared to previous device designs (e.g., Henningfield et al., 1980). Specifically, desktop and portable devices used in this study measure topography variables via a sensor which detects changes in pressure that cross a pre-determined threshold, whereas previous designs have relied on a pressure sensitive on/off switch (e.g., Henningfield et al., 1980; Pickens et al., 1983).

Acceptability of Measurement via Mouthpiece-Based Devices and Video Recordings

Though all three measurement methods demonstrated oft-reported changes in smoking behavior, participants perceived that the mouthpiece-based devices influenced their smoking relative to video alone ($P < .05$, Tukey's HSD). For example, participants reported that use of either computerized device increased the difficulty of their smoking: mean difference from video alone was 27.8 (SD = 31.5) for desktop and 20.7 (SD = 28.9) for portable. Self-report data also indicated that, relative to video alone, both devices reduced participants' smoking enjoyment and affected cigarette taste. Participants reported that the devices made smoking less likely than video alone [e.g., mean difference = 10.9 (SD = 27.1) for desktop, and 9.6 (SD = 20.1) for portable]. Ratings between the two computerized devices, however, did not differ on any acceptability item (n.s., Tukey's HSD). Interestingly, these self-report data are in contrast to behavioral data (i.e., smoking topography), with which few differences were observed across

measurement methods. Similar dissociations between behavioral (e.g., bar pressing, driving, choice) versus subjective (e.g., self-reports of drug liking, high, impairment) data have been reported in past research examining a wide variety of drugs (nicotine and caffeine; e.g., Jones & Griffiths, 2003, opioids; e.g., Lamb et al., 1991, and alcohol; e.g., Liguori, D'Agostino, Sworkin, Edwards, and Robinson, 1999).

Feasibility of Measurement via Mouthpiece-Based Devices and Video Recordings

Based on the acceptability results, topography measurement in the laboratory might best be accomplished using video recordings that minimize influence on smoking characteristics (cigarette taste and enjoyment). However, there are several important limitations to using video recordings as a topography measurement tool. Certain topography variables such as puff volume cannot be measured via video, and these variables may be particularly useful for examining factors such as smoke constituent intake (e.g., CO and plasma nicotine; Herning et al., 1981; Zacny et al., 1987). The video method is also labor-intensive and time-consuming, compared to either computerized device method. Video recordings of each of the four smoking bouts in a session required approximately 45 minutes to score; therefore, scoring the six sessions required at least 4 hours per participant for each of the two raters. Ultimately, approximately 240 total hours were necessary for scoring data for the 30 participants. In contrast, data from the computerized devices are transferred during smoking directly to the computer, where software calculates and records the topography values instantaneously.

Another challenge with the video method involved instructing participants on their position within the camera frame. For instance, gross movements often resulted in

images out of frame, and thus missing data. Consequently, participants were required to limit their movements during smoking bouts (e.g., maintaining straightforward pose, keeping ashtray within arm's length, etc). Equally important for capturing video data was the placement of participants' fingers on their cigarettes while smoking. Some smokers naturally hold their cigarettes at the proximal end of the butt, so that their fingers and lips make contact with each puff. Holding the cigarette in this manner, however, made it difficult to detect the onset of a puff (i.e., choosing the clip clearly demonstrating enclosure of smokers' lips around cigarette). Thus, while smoking instructions may have influenced study results (topography and/or acceptability ratings), they were necessary for maximizing the quality of video recordings. The use of the video method, therefore, places significant constraints on topography measurement which may be remedied by the use of either computerized device method.

Influence of Method on Nicotine/Tobacco Withdrawal and Physiological Response

Symptoms of nicotine/tobacco withdrawal, produced by overnight tobacco abstinence (8 to 12 hours), were reliably suppressed by smoking. These abstinence effects were largely independent of measurement method. Ratings for VAS measures such as 'craving a cigarette/nicotine', 'urges to smoke', and 'irritability/frustration/anger' were high at pre-smoking timepoints for the first bout of each session. Significant decreases in ratings for such measures were then observed at post-smoking timepoints at all bouts. Similar smoking-induced suppression of withdrawal has been reported elsewhere (e.g., Breland, Buchhalter, Evans, & Eissenberg, 2002a; Evans et al., 2003a; Hatsukami, Dahlgren, Zimmerman, & Hughes, 1988).

Although withdrawal-suppression was observed for both own brand and ultra-light cigarettes (i.e., significant decreases from pre- to post-smoking), the magnitude of these differences was affected by cigarette brand on some measures. For the VAS items 'craving a cigarette/nicotine' and 'urges to smoke', and QSU Factors 1 ('intention to smoke') and 2 ('anticipation of relief from withdrawal'), scores for ultra-light decreased to a lesser degree than scores for own brand cigarettes. Similar findings have been reported elsewhere (e.g., Zacny & Stitzer, 1988, but see Breland et al., 2002a). On measures where measurement method influenced subjective measures of abstinence effects (i.e., Factor 1 of the QSU, VAS item "desire for sweets"), there was no clear pattern to the results and differences between means were not reliable (n.s., Tukey's HSD). These observations, therefore, may reflect Type I error.

As expected, heart rate was not differentially affected by topography measurement method. Within each method, however, heart rate increased significantly from pre- to during-smoking at all bouts. Elevations in heart rate immediately following smoking are often reported (e.g., Buchhalter & Eissenberg, 2000), and this study confirms these findings. Additionally, heart rate was generally greater for own brand (mean = 77.3 bpm, SD = 11.4) cigarettes, as compared to ultra-light (mean = 74.8 bpm, SD = 11.2). This effect was most pronounced at bout 1, as the pre- to post-smoking difference in heart rate was larger at this bout for own brand than for ultra-light. Post-smoking increases in heart rate for the other bouts, however, were similar for both cigarette brands.

Unlike previous work (e.g., Evans et al., 2003a; Höfer et al., 1991a; Lee et al., 2003), expired air CO levels were influenced by measurement method. The source of this effect was the larger magnitude of difference between own brand and ultra-light cigarettes for the desktop condition, relative to either portable or video conditions. This finding is possibly explained by the significantly larger puff volumes observed with use of the desktop device (collapsed across brand and bout; mean = 58.7, SD = 20.1), as compared to the portable device (collapsed across brand and bout; mean = 48.6, SD = 13.7). Past research supports this idea, as larger puff volumes result in greater CO boosts (i.e., increase from pre- to post-smoking) than smaller volumes (i.e., 73.8 versus 50.4 ml; e.g., Zacny & Stitzer, 1986). Another potential explanation is the variable degrees of cigarette vent blocking (i.e., mouthpiece or fingers/lips covering the vent holes located on the cigarette butt) imposed by each method. The desktop mouthpiece typically results in no vent blocking, whereas the portable mouthpiece blocks vents on many cigarette brands. The degree of blocking via conventional smoking is less predictable; the number of blocked holes may differ across puffs within the same cigarette and also across smokers. Thus, smoking cigarettes via a mouthpiece that does not cover any vent holes (i.e., desktop device) may allow for a greater volume of air to be drawn in through ventilated cigarettes (i.e., ultra-light brand). In turn, use of the desktop device may have produced a larger difference in CO levels between own brand and ultra-light cigarettes, as compared to either the portable device or smoking conventionally. Nonetheless, average CO for measurement method (i.e., collapsed across bout and brand) did not differ significantly: 15.4 (SD = 7.9) for desktop, 15.9 (SD = 8.2) for portable, and 15.7 (SD =

7.6) for video. Additionally, all three measurement methods demonstrated increases in CO from pre- to post-smoking at each bout ($P<.05$, Tukey's HSD).

Study Limitations

This study has several limitations which may influence the generalizability of results. First, aspects of the laboratory setting may have influenced natural smoking behavior. During the course of each 2.5-hour session, participants were required to remain seated, not allowed to consume foods or beverages other than water, asked to limit their activities (e.g., only reading and listening to headphones permitted), and connected to equipment for physiological monitoring (i.e., blood pressure cuff and heart rate probe). The start time for each session was scheduled as convenient for each participant's schedule, but held constant across sessions; therefore, the time chosen may not have coincided with their normal smoking periods. The ability to control these factors allowed for a direct evaluation of device, abstinence period, and cigarette brand influence on topography. Nonetheless, research suggests that smoking behavior varies according to factors outside of the laboratory environment (time of day, work-place restrictions, and concurrent drug intake; Chapman et al., 1997; Henningfield & Griffiths, 1981; Griffiths et al., 1976; Morgan et al., 1985). Thus, study results may not generalize to smoking in a more naturalistic environment.

Second, Type I and Type II error may have influenced the effects reported here. Type I (α) error refers to the rejection of the null hypothesis when, in fact, it is true (i.e., reporting a spurious effect; Cohen, 1988). The probability of this type of error may have increased due to the many comparisons conducted (referred to as experiment-wise error

rate; Keppel, 1991). Differences between means, however, were examined using a conservative post-hoc test, Tukey's HSD. This test controls for Type I error rate by maintaining the alpha level (α) at a chosen value ($p < .05$ for this study) across all comparisons. While some of the findings reported as statistically significant may be due to chance (i.e., Type I error), most effects observed in this study have been reported elsewhere (e.g., brand- and abstinence-induced changes in topography, smoking-induced withdrawal suppression). Thus, these effects are more likely to reflect reliability in measurement than a Type I error.

Conversely, Type II (β) error refers to a failure to reject the null hypothesis when, in fact, it is false (i.e., Cohen, 1988). The probability of this type of error varies inversely with Type I error, effect size, sample size, and power. In this study, the lack of many significant main and interaction effects involving the device factor may reflect Type II error. Given that Type I error was controlled tightly (via Tukey's HSD), any real differences may have gone undetected. More likely, however, is that this failure to reject the null hypothesis reflects the true state of the world. This study was designed to examine the effects of cigarette brand, abstinence, and method on measures of smoking topography, nicotine/tobacco withdrawal, and physiological response. The observed effect sizes (ES; partial η^2) for effects of brand, bout and time factors were large (most partial $\eta^2 > 0.7$), relative to those for effects of measurement method (most partial $\eta^2 < 0.2$). The ability to detect brand- and abstinence-induced effects on a variety of measures, therefore, suggests that this study's sample size provided adequate statistical power for detecting real differences. The fact that few differences between measurement

methods were observed on any measure may indicate negligible effect sizes or the true state of the world.

Conclusions and Future Directions

Overall, the results of this study provide support for the continued use of mouthpiece-based devices to measure puff topography in the laboratory. As with direct observation via video recording, desktop and portable mouthpiece-based methods detected brand- and abstinence-induced changes in a variety of smoking topography measures. Data collected using all three methods were also highly correlated across cigarette brand and bout. In contrast, participants perceived both mouthpiece-based devices to influence their smoking (i.e., difficulty, enjoyment, cigarette taste) relative to direction observation. Participants also reported that they would be less likely to smoke with a mouthpiece-based device, despite the fact that no overall differences in smoking behavior were observed between methods under these laboratory conditions.

Nonetheless, future work might examine the influence of measurement method on smoking behavior and user acceptability outside of the laboratory. Thus, the portable mouthpiece-based device could be compared with direct observational methods in a real world setting (e.g., smokers' home). Such a study could involve participants' smoking a minimum number of cigarettes under each condition, as they engage in their normal activities (i.e., eating, watching television, etc) in a chosen environment.

Taken together, study results suggest that mouthpiece-based devices offer a useful and convenient tool for evaluating the factors that influence smoking topography. Although direct observational methods may be optimal for measuring certain aspects of

smoking (e.g., enjoyment, cigarette taste), any logistical challenges posed by this method likely limit its usefulness in a laboratory setting.

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Appendix A

Telephone Screening Form

Date _____
Interviewer _____

Interviewer: "I would like to ask you some questions about yourself and your health status as well as your use of nicotine, alcohol, and other drugs. The purpose of these questions is to determine whether or not you are eligible to participate in either the study/studies I just described or in any of the other studies being conducted in the lab. All of your responses are confidential. You are not required to answer any question and you may stop this interview at any time. May I begin the questions?"

Document caller's response by circling either: *Yes or No*

If Yes: begin form. If No: thank caller for calling.

How did you hear about us/our studies? _____

Personal Information:

1. "What is your first name?" _____
2. "What is a phone number at which you can be contacted?" _____
3. "What time/day is best to call you?" _____
4. "If we call and you are not available, may we leave a message?" *Circle Yes or No*
5. "What is your date of birth?" _____
6. "What is your height?" _____ (feet/inches)
7. "What is your weight?" _____ (pounds)
8. "Did you graduate high school or obtain a GED?" *Circle Yes or No*

[Note to interviewer: If yes, please note which one] _____

9. "How many years of education have you completed?" _____ (years)
   (e.g., 12 yrs = high school diploma; 16 yrs = college degree)

General health status:

10. "Are you under a doctor's care for a medical condition?" *Circle Yes or No*

    If Yes: "Please describe the condition":

11. "Are you taking any prescription or over-the-counter medications?" *Circle Yes or No*

    If Yes: "Please identify the medication":

12. "Do you have any chronic health concerns or problems?" *Circle Yes or No*

    If Yes: "Please describe the concern or problem":

13. Do you have any heart conditions? *Circle Yes or No*

    If Yes: "Please describe the condition":

14. Do you have any psychiatric conditions like depression or anxiety? *Circle Yes or No*

    If Yes: "Please describe the condition":

15. "Have you ever been diagnosed with high or low blood pressure?" *Circle Yes or No*

    If Yes: "Please indicate whether it is high or low":

16. "Do you have fainting spells?" *Circle Yes or No*

17. "Do you have seizures?" *Circle Yes or No*

18. "Do you have any kidney problems?" *Circle Yes or No*

Cigarette use:

19. "Do you smoke tobacco cigarettes?" *Circle Yes or No*

If No: Skip the remainder of this section.

20. "What brand of cigarettes do you smoke?" _____

    Circle:
    Regular/Light/Ultra light

    Non-menthol/Menthol

21. "Hard pack or soft pack?" _____

22. "Regular or 100s?" _____

23. "Have you ever felt a need to cut down or control your smoking, but had difficulty doing so?" *Circle Yes or No*

24. "Do you ever get annoyed or angry with people who criticize your smoking or tell you that you ought to quit smoking?" *Circle Yes or No*

25. "Have you ever felt guilty about your smoking or about something you did while smoking?" *Circle Yes or No*

26. "Do you ever smoke within half an hour of waking up (eye-opener)?" *Circle Yes or No*

27. "How many cigarettes/day do you smoke?" _____ *(num of cigs)*

[Note to interviewer: Please note the exact number of cigarettes/day smoked, and ALSO circle the appropriate group →

10 or less
11-20
21-30
31 or more

28. "For how long have you smoked this number?" _____ *(mnths/ years)*

29. "How soon after you wake up do you smoke your first cigarette?" *Circle: Within 30 min. After 30 min.*

30. "Do you find it difficult to refrain from smoking in places where it is forbidden (e.g., at the library, at the movies)?" *Circle Yes or No*

31. "Which cigarette would you hate to give up the most?" *Circle: 1st in the morning Any other*

32. "Do you smoke more frequently during the first hours after awakening than during the rest of the day?" *Circle Yes or No*

33. "Do you smoke if you are so ill that you are in bed most of the day?" *Circle Yes or No*

Smokeless Tobacco Use:

34. "Do you use smokeless tobacco (i.e., snuff, dip, or chew)?" *Circle Yes or No*

If No: Skip the remainder of this section.

35. "What brand of smokeless tobacco do you use?" _____

36. "How many times/day do you use smokeless tobacco?" _____

37. "For how long have you used smokeless tobacco?" _____ *(mnths or yrs)*

Interviewer: "I'd like to ask you some additional questions about your use of alcohol and other drugs."

Alcohol use:

38. "Have you ever been treated for alcohol abuse/dependence?" *Circle Yes or No*

39. "Do you use (drink) alcoholic beverages?" *Circle Yes or No*

If Question #39 is No: Skip the remainder of this section.

40. "Have you ever felt you ought to cut down on your drinking?" *Circle Yes or No*

41. "Have people annoyed you by criticizing your drinking?" *Circle Yes or No*

42. "Have you ever felt bad or guilty about your drinking?" *Circle Yes or No*

43. "Have you ever had a drink first thing in the morning to steady your nerves or get rid of a hangover (eye-opener)?" *Circle Yes or No*

44. "How many alcoholic drinks (by alcohol I mean beer, wine, or liquor) do you have on a typical day? _____ *(num of drinks)*

45. "How many days out of the last 30 have you used alcohol?" _____ *(num of days)*

Marijuana use:

46. Have you ever, in your lifetime, smoked marijuana or hashish? *Circle Yes or No*

If No: Skip the remainder of this section.

47. "Have you smoked marijuana within the past month?" *Circle Yes or No*

If No: Skip to question 54.

48. "Have you ever felt a need to cut down or control your smoking of marijuana, but had difficulty doing so?" *Circle Yes or No*

49. "Do you ever get annoyed or angry with people who criticize your marijuana smoking or tell you that you ought to quit smoking?" *Circle Yes or No*

50. "Have you ever felt guilty about your marijuana smoking or about something you did while smoking?" *Circle Yes or No*

51. "Do you ever smoke marijuana within half an hour of waking up (eye-opener)?" *Circle Yes or No*

52. "How many days out of the last 30 have you smoked marijuana?"_____ *(number of days)*

53. "Can you estimate how much money you spend each month on marijuana?"_____ *(dollars)*

54. "Have you ever received medical treatment related to your marijuana use? *Circle Yes or No*

Other drug use:

55. "Have you used any other illicit drugs within the past month?" *Circle Yes or No*

If Yes: "Please identify which drug or drugs."

For women only:

56. "Are you currently pregnant?" *Circle Yes or No*

57. "Are you currently breast-feeding a child?" *Circle Yes or No*

58. "Which contraceptive method(s) are you currently using (including abstinence)?" _____

59. "What was the first day of the onset of your last period?" _____

Interviewer: "Thank you for responding to these questions. I need to pass on your responses to the principal investigator who will then determine whether or not you are eligible to participate in a study; someone will contact you within approximately two working days if you are eligible. If you are not eligible for any of our current studies, then you will *not* be contacted."
[if respondent does not have a phone, they can call us back in a few days]

Additional studies
60. "Even if you are not eligible for one of our current studies, may we call you sometime in the future if there are additional studies for which you are qualified?"

Document caller's response by circling either: *Yes* *or* *No*

Appendix B

Informed Consent Form

Title: Measuring smoking behavior

VCU IRB Number: 3813

Sponsor: National Institute on Drug Abuse

Purpose: The purpose of this research study is to find the best way to measure smoking behavior.

Description of the study and your involvement: If you agree to join the study, you will participate in six, approximately 3- hour sessions at the Clinical Behavioral Pharmacology Laboratory located on VCU's medical campus. Each session will begin at approximately the same time each day, and will be separated by at least 48 hours. Before each session, we will ask you to not drink any caffeine-containing beverages, or eat any foods, for 1 hour. We will also ask you to not smoke any cigarettes or other material for 8 to 12 hours before the session; we will use a simple breath test to make sure that this requirement is met. Our breath test is not perfect, but will be the only measure that we can accept to make certain that no smoking has occurred for 8-12 hours before the session.

In three sessions, you will be smoking your own brand of cigarette. In the other three sessions you will be smoking another, normally marketed cigarette brand. We will provide you with all cigarettes that you will smoke during these sessions, though you may not know which brand you are smoking.

Within each session, you will be smoking one cigarette every 30 minutes for a total of four cigarettes. In four sessions you will smoke each cigarette through a mouthpiece that is either connected to a laptop computer or directly attached to a handheld computer. In the other two sessions, you will smoke the cigarettes without a mouthpiece. In all sessions we will videotape you smoking. We will also ask you to participate in other data collection procedures that include monitoring your heart rate, blood pressure, and skin temperature, measuring the amount of carbon monoxide that is in your breath, and using several questionnaires to measure how you feel before and after smoking each cigarette. You will have an opportunity to experience all of the questionnaires and equipment before your first session.

Risks and Discomforts: You may experience some discomfort during sessions when you are not using your usual brand of cigarettes or when you are not smoking. Side effects from not smoking can include bad mood, nervousness, restlessness, excessive hunger, difficulty concentrating, and sleep problems. Though uncomfortable, these

feelings are not medically dangerous. If you find any effects or data collection procedures unacceptable, you may stop your participation at any time.

Benefits. You will derive no personal benefit from this study other than the money that we pay you for the time that you spend in the laboratory. However, your participation will help us in the future as we try to measure smoking behavior accurately.

Costs of Participation. There is no cost to you for participation except for your time. Participating in this study will take about 18 hours.

Payment for Participation. You will be paid for the time that you are in the laboratory. Specifically, you will receive $40 after the second session, $40 after the third session, $60 after the fourth session, $60 after the fifth session, and $100 after the sixth/final session. In all, you can earn $300 for successful completion of this study.

Alternatives. This is not a therapeutic study. You have the alternative not to participate.

Confidentiality of Records. We will not tell anyone the answers that you give us; however, information from the study and the consent form signed by you may be looked at or copied for research or legal purposes by the sponsor of the research (the National Institute on Drug Abuse) or by Virginia Commonwealth University.

Confidentiality of your records will be maintained by keeping all data in a locked file and in a coded database. Release of this information will be withheld, consistent with the law, unless you give permission to release information. What we find from this study may be presented at meetings or published in papers, but your name will not ever be used in these presentations or papers.

The smoking sessions will be videotaped using a camera that is sensitive to heat. The resulting tapes and/or computer files will always be stored in a locked room within a locked laboratory or in a locked cabinet within a locked office. The tapes/computer files will be used to measure smoking behavior, and will be destroyed once this measurement is complete.

If an Injury Happens. Virginia Commonwealth University and the VCU Health System (formerly known as the Medical College of Virginia Hospitals) have no plan for providing long-term care or compensation in the event that you suffer injury as a result of your participation in this research study. If you are injured or if you become ill as a result of your participation in this study, contact your study doctor immediately. Your study doctor will arrange for short term emergency care or referral if it is needed. Fees for such treatment may be billed to you or to appropriate third party insurance. Your health insurance company may or may not pay for treatment of injuries as a result of your participation in this study.

Pregnancy. Every effort will be made to have women enter this study on an equal basis with men. Smoking may be harmful to a fetus, and pregnant women may not participate in this study. If you suspect that you are pregnant, or if you are currently breast-feeding a baby, please inform the investigator now and do not participate. We will conduct a urine pregnancy test during the screening evaluation visit to ensure that pregnant women do not participate.

Voluntary Participation and Withdrawal. You do not have to participate in this study. If you choose to participate you may stop at any time without any penalty. You may also choose not to answer particular questions that are asked in this study. The investigators will answer any questions that you may have. If you choose not to participate or to discontinue your participation, this choice will in no way affect any medical care you receive now or in the future at this institution. Your participation may be stopped by Dr. Eissenberg at any time without your consent and for any reason, including if you experience adverse effects or if you do not comply with the study restrictions. Any significant new findings which develop during the course of the research study that may affect your willingness to continue to participate will be provided to you.

Questions. You can call Dr. Eissenberg at 827-3562 for information about the research or about research-related injury.

Participants' Rights Information. If you have questions about your rights as a research participant, you may contact:

Office for Research Subjects Protection
Virginia Commonwealth University
Virginia Biotechnology Research Park, BioTech One
800 East Leigh Street, Suite 115
P.O. Box 980219
Richmond, VA 23298-0219
Telephone: 804-828-0868

If you agree to join this study, please print and sign your name below. You will receive a copy of this consent form.

Consent. I have read this consent form. I understand the information about this study. All my questions about the study and my participation in it have been answered. I freely consent to participate in this research study.

By signing this consent form I have not waived any of the legal rights which I otherwise would have as a participant in a research study.

_____

Participant's Printed Name

Signature of Participant	Date
Signature of Person Performing Consent	Date
Witness's Printed Name	
Signature of Witness	Date
Signature of Investigator	Date

Appendix C

In-person Screening Forms

Personal Information

Name _____

Address _____

_____

Home phone _____

What time/day is best to call you? _____

Height _____ (feet and inches) Weight _____ (pounds)

General health status:
Are you under a doctor's care for a medical condition?_____ (If yes, please describe below)

Are you taking any prescription medications?_____ (If yes, please identify below)

Do you have any chronic health concerns or problems?_____ (If yes, please describe below)

Do you have any heart conditions?_____ (If yes, please describe below)

Do you have any psychiatric conditions?_____ (If yes, please describe below)

Have you ever been diagnosed with high or low blood pressure?_____ (If yes, please specify high or low)

Smoking Behavior:
Do you smoke cigarettes?_____ (yes or no)

What brand of cigarettes do you smoke?_____

Regular, light, or ultra-light? _____

Hard pack or soft pack? _____

King size or 100s? _____

How many cigarettes/day do you smoke? _____ (number of cigarettes)

For how long have you smoked this number? _____ (months or years)

Have you ever felt a need to cut down or control your smoking, but had difficulty doing so?_____ (yes or no)

Do you ever get annoyed or angry with people who criticize your smoking or tell you that you ought to quit
smoking?_____ (yes or no)

Have you ever felt guilty about your smoking or about something you did while smoking?_____ (yes or no)

Do you ever smoke within half an hour of waking up (eye-opener) ?_____ (yes or no)

Do you use any medications which contain nicotine (such as the nicotine patch or gum)?_____ (yes or no)

For women only:
Are you currently pregnant?_____

Are you currently breast-feeding a child?_____

Which contraceptive method(s) are you currently using (including abstinence)?_____

What was the first day of the onset of your last period?_____

<u>Additional research</u>
May we call you if there are additional studies for which you are qualified? _____
(yes or no)

By signing this form below, you indicate that you have answered the above questions truthfully.

Participant's Signature	Today's Date
Investigator's Signature	Today's Date

Appendix D

Fägerstrom Test for Nicotine Dependence

Please answer the following questions (mark an X in one box only):

1. How soon after you wake up do you smoke your first cigarette?

Within 5 minutes	Within 6-30 minutes	Within 31-60 minutes	After 60 minutes
☐	☐	☐	☐

2. Do you find it difficult to refrain from smoking in places where it is forbidden (e.g., in church, at the library, at the movies)?

Yes	No
☐	☐

3. Which cigarette would you hate to give up the most?

The first one in the morning	All others
☐	☐

4. How many cigarettes a day do you smoke?

10 or less	11-20	21-30	31 or more
☐	☐	☐	☐

5. Do you smoke more frequently during the first hours after waking than during the rest of the day?

Yes	No
☐	☐

6. Do you smoke if you are so ill that you are in bed most of the day?

Yes	No
☐	☐

Appendix E

Hughes & Hatsukami (1986)

These phrases may or may not describe how you feel right now. Please respond to each word or phrase with how you feel right now by drawing a vertical mark anywhere along the horizontal line.

	Not at all	**Extremely**
1. URGES to smoke		
2. Irritability/frustration/anger		
3. Anxious		
4. Difficulty concentrating		
5. Restlessness		
6. Hunger		
7. Impatient		
8. CRAVING a cigarette/nicotine		
9. Drowsiness		
10. Depression/feeling blue		
11. Desire for sweets		

Appendix F

Questionnaire of Smoking Urges (Tiffany & Drobes, 1991)

For each item please indicate how you feel RIGHT NOW by placing an X in the appropriate bubble.

1. Smoking would make me feel very good right now.

Strongly disagree — Strongly agree

2. I would be less irritable now if I could smoke.

Strongly disagree — Strongly agree

3. Nothing would be better than smoking a cigarette right now.

Strongly disagree — Strongly agree

4. I am not missing smoking right now.

Strongly disagree — Strongly agree

5. I will smoke as soon as I get the chance.

Strongly disagree — Strongly agree

6. I don't want to smoke right now.

Strongly disagree — Strongly agree

7. Smoking would make me less depressed.

Strongly disagree — Strongly agree

8. Smoking would not help me calm down right now.

Strongly disagree — Strongly agree

9. If I were offered a cigarette, I would smoke it immediately.

Strongly disagree — Strongly agree

10. Starting now, I could go without smoking for a long time.

Strongly disagree — Strongly agree

11. Smoking a cigarette would not be pleasant.

Strongly disagree — Strongly agree

12. If I were smoking this minute, I would feel less bored.

Strongly disagree — Strongly agree

13. All I want right now is a cigarette.

Strongly disagree — Strongly agree

14. Smoking right now would make me feel less tired.

Strongly disagree — Strongly agree

15. Smoking right now would make me feel happier now.

Strongly disagree — Strongly agree

16. Even if it were possible, I probably wouldn't smoke right now.

Strongly disagree — Strongly agree

17. I have no desire for a cigarette right now.

Strongly disagree — Strongly agree

18. My desire to smoke seems overwhelming.

Strongly disagree — Strongly agree

19. Smoking right now would make things seem just perfect.

Strongly disagree — Strongly agree

20. I crave a cigarette right now.

Strongly disagree — Strongly agree

21. I would not enjoy a cigarette right now.

Strongly disagree — Strongly agree

22. A cigarette would not taste good right now.

Strongly disagree — Strongly agree

23. I have an urge for a cigarette.

Strongly disagree — Strongly agree

24. I could control things better right now if I could smoke.

Strongly disagree — Strongly agree

25. I am going to smoke as soon as possible.

Strongly disagree — Strongly agree

26. I would not feel better physically if I were smoking.

Strongly disagree — Strongly agree

27. A cigarette would not be very satisfying right now.

Strongly disagree — Strongly agree

28. If I had a lit cigarette in my hand I probably would not smoke it.

Strongly disagree — Strongly agree

29. If I were smoking right now I could think more clearly.

Strongly disagree — Strongly agree

30. I would do almost anything for a cigarette now.

Strongly disagree — Strongly agree

31. I need to smoke now.

Strongly disagree — Strongly agree

32. Right now, I am not making plans to smoke.

Strongly disagree — Strongly agree

Appendix G

Acceptability Questionnaire

Please respond to each question by making a vertical mark anywhere along the horizontal line.

Did the laboratory environment and/or the computerized equipment:

	Not at all	**Extremely**
1. Alter your smoking behavior today?		
2. Make you less likely to want to smoke today?		
3. Reduce your smoking enjoyment today?		
4. Affect the taste of the cigarettes you smoked today?		
5. Make smoking more difficult today?		
6. Increase your awareness of how much you smoked today?		
7. How much would you like to know more about the way you smoke?		

Vita

Melissa Danielle Blank was born in Baltimore, MD on June 25, 1977. She received her high school diploma from Fort Hill High School in Cumberland, MD in 1995, and her B.A. in Psychology from the University of Maryland, Baltimore County in 1999. She began the Biopsychology Program at Virginia Commonwealth University in August, 2002, and obtained her M.S. degree from this program in May, 2004.