

THE EFFECT OF FOOD DEPRIVATION ON CIGARETTE SMOKING IN FEMALES

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Abstract

Studies have shown that food deprivation is associated with increases in the self-administration of nicotine and other substances in laboratory animals. However, little is known about the effects of food deprivation on substance use in humans. The purpose of the present study was to compare smoking rates, expired carbon monoxide levels, and smoking topography in 15 female participants during a state of acute food deprivation and in a non-deprived state. A within-subjects design was utilized to test the primary hypotheses that smoking rate and expired carbon monoxide levels would be greater among the participants in the food-deprived condition than in the non-deprived condition. Analyses indicated that expired carbon monoxide levels were significantly greater in the food-deprived condition than in the non-deprived condition ($p = .05$), although no differences were found in the total number of cigarettes smoked during the laboratory session. Analysis of smoking topography indicated that the time to first puff was significantly greater in the non-deprived condition ($p = .03$), while the sum of the interpuff intervals ($p = .02$) and the time to removal from the last puff were greater in the food-deprived condition ($p = .03$). The total time total smoking was marginally greater in the food-deprived condition ($p = .10$). Findings suggest that females may alter the manner in which they smoke during acute food deprivation.

Introduction

Cigarette smoking continues to be the leading cause of preventable death in the United States, with approximately 438,000 deaths from cancer, cardiovascular disease, and respiratory disease attributed to cigarette smoking annually (CDC, 2005a). Smoking reduces life expectancy by an average of 14 years, and 167 billion dollars are lost each year in health care costs and job productivity (CDC, 2005a). Although the prevalence of smoking has been declining in recent years, nearly 21% of adults in the United States continue to smoke (CDC, 2005b). Prevalence rates remain high despite the societal costs and widespread knowledge of the health consequences of smoking. In order to improve smoking prevention and cessation efforts, researchers must identify and address the specific reasons that individuals initiate and continue to smoke.

Many individuals cite weight control as a reason for continued smoking. Klesges and Klesges (1988) reported that 39% of college females and 25% of males who reported current smoking endorsed the use of smoking as a dieting strategy. Individuals who smoke weigh an average of eight pounds less than those who do not smoke and they tend to gain less weight with age than non-smokers across studies (Klesges, Meyers, Klesges, & La Vasque, 1989). The weight differences between smokers and non-smokers are greater in women than men (Klesges et al., 1989). Smoking cessation has been shown to result in significant weight gain, such that those who remain continuously abstinent for one year may expect to gain an average of thirteen pounds (Klesges et al., 1997). Several studies have indicated that weight concern negatively impacts smoking cessation treatment outcomes (Jeffery, Hennrikus, Lando, Murray, & Liu, 2000; Klesges et al., 1988a; Meyers et al., 1997; Streater, Sargent, & Ward, 1989), and is associated with

treatment attrition and unwillingness to attempt smoking cessation (Copeland, Martin, Geiselman, Rash & Kendzor, 2006; Klesges et al., 1988b; Namenek Brouwer & Pomerleau, 2000). Given the significant weight control properties of smoking, it is not surprising that many individuals smoke for weight control purposes.

There is some evidence that caloric restriction among weight-concerned individuals may be a risk factor for nicotine and other substance use. Dieting and other weight control behaviors often co-occur with smoking (Delnevo, Hrywna, Abatemarco, & Lewis, 2003; Kendzor, Copeland, Stewart, Businelle, & Williamson, 2007; Krahn, Kurth, Demitrack, & Drewnowski, 1992; Lavik, Clausen, & Pederson, 1991; Stewart, Angelopoulos, Baker, & Boland, 2000; Wee, Rigotti, Davis, & Phillips, 2001; Xinaris & Boland, 1990), and dieting has been shown to prospectively predict smoking initiation in females (Austin & Gortmaker, 2001; French, Perry, Leon, & Fulkerson, 1994). Further, those who attempt to quit smoking while dieting may be at greater risk for relapse (Hall, Tunstall, Vila, & Duffy, 1992). Unfortunately, the reasons for the association between dieting and cigarette smoking remain unclear.

Behavioral studies of laboratory animals have indicated that food deprivation and caloric restriction are associated with increases in the self-administration of nicotine and other substances (e.g., Carroll, France, & Meisch, 1979; De La Garza & Johanson, 1987; Lang, Latiff, McQueen, & Singer, 1977). However, the effect of food deprivation on substance use in humans has received less attention. If the impact of food deprivation in humans is similar to the effect found in animals, individuals who engage in dieting or extreme weight control behaviors may be at risk for increased nicotine use and dependence.

Dieting and Substance Use

Correlational studies have suggested that dieting is associated with cigarette smoking and the use of other substances. Results from a large-scale survey indicated that among adults younger than 30 years of age, those who were trying to lose weight were more likely to report current smoking (Wee et al., 2001). Studies have found a positive relationship between dietary restraint scores and weekly alcohol consumption among undergraduate females (Stewart et al., 2000; Xinaris & Boland, 1990). Similarly, dieting and pathological eating behavior are positively associated with level of alcohol consumption and cigarette smoking among children and adolescents (Lavik et al, 1991; Kendzor et al., 2007). Krahn et al. (1992) reported that the prevalence of alcohol, cigarette, and marijuana use was positively associated with dieting severity in college females, and Delnevo et al. (2003) reported that daily smoking was associated with fasting, purging, and the use of diet pills. Studies have shown that females who diet are more likely to initiate and continue to smoke for weight-control purposes (Austin & Gortmaker, 2001; French et al., 1994; Jarry, Coombs, Polivy, & Herman, 1998), and there is some evidence that individuals who begin a weight management intervention while attempting smoking cessation may be a greater risk for relapse (Hall et al., 1992).

Higher rates of cigarette smoking and other substance use have been found among individuals with eating disorders, especially those with Bulimia Nervosa (Anzengruber et al., 2006; Holderness, Brooks-Gunn, & Warren, 1994). Several explanations for the comorbidity between eating disorders and substance use have been hypothesized, including shared personality traits, familial association between the disorders, the use of substances to reduce weight-related anxiety, and increased sensitivity to the rewarding

effects of substances due to food deprivation (Wolfe & Allen, 2000). Smoking prevalence rates between 43% and 57% have been reported in samples of individuals with eating disorders (Anzengruber et al., 2006; Bulik et al., 1992; Haug, Heinburg, & Guarda, 2001; Welch & Fairburn, 1998). Further, the prevalence of cigarette, alcohol, caffeine, amphetamine, and marijuana use are higher among individuals with Bulimia Nervosa than controls and individuals with other eating disorders (Anzengruber et al., 2006; Bulik et al., 1992). Women with symptoms of Bulimia Nervosa are three times as likely to report alcohol dependence and twice as likely to report nicotine dependence as women without symptoms of Bulimia Nervosa (Von Ranson, Iacono, & McGue, 2002). Higher rates of eating disorders have also been found among females with substance use disorders (Holderness et al., 1994; Wilson, 1992).

It is plausible that women who are weight-concerned or have an eating disorder may use nicotine or other stimulants as a means to control weight. Bulik et al. (1992) reported that among female inpatients with Bulimia Nervosa, most endorsed the belief that smoking decreases appetite. Similarly, Welch and Fairburn (1998) reported that most of their study participants with Bulimia Nervosa had smoked to avoid eating or to control weight. More recently, Copeland and Carney (2003) reported that appetite and weight control expectancies for smoking mediated the relationship between dietary restraint and disinhibition and smoking status in college females. Although these findings contribute to our understanding of the relationship between dieting and nicotine use, they do not explain the higher prevalence of non-stimulant drug use among dieting and eating disordered individuals. It is likely that individuals who are dieting may find a variety of substances to be more reinforcing for reasons other than weight control. Cigarettes and

other stimulants may simply offer the added benefit of their weight control and appetite suppressing effects.

Food Deprivation and the Self-Administration of Substances in Animals

Etonitazene. A few studies have demonstrated that self-administration of the potent opioid, etonitazene, increases with food deprivation and body weight reduction in rats (Carroll et al., 1979; Carroll & Meisch, 1980a; Carroll & Meisch, 1981). Carroll et al. (1979) found that rats nearly doubled their intake of oral etonitazene solution after they were reduced to 75% of their free-feeding body weights. Increased self-administration of etonitazene was also found to occur when the rats were given access to intravenous infusions (Carroll et al., 1979). The rats self-administered approximately four etonitazene infusions per hour when they were allowed unlimited access to food, but etonitazene infusions reportedly doubled on every third day when food access was restricted (Carroll et al., 1979). The authors observed that increases in the administration of etonitazene began after approximately eight hours of deprivation and continued for the remaining 16 hours of deprivation (Carroll et al., 1979). Carroll and Meisch (1980a) suggested that reductions in body weight, rather than brief periods of food deprivation, might be required to increase the self-administration of etonitazene (Carroll & Meisch, 1980a). However, the authors later reported that oral self-administration of etonitazene was inversely related to percent of free-feeding body weight (Carroll & Meisch, 1981). Specifically, rats reduced to 95% of their free-feeding weight showed smaller increases in oral etonitazene self-administration than rats reduced to 75% or 85% of their free-feeding weights. Findings suggest that brief periods of deprivation and smaller reductions in body weight may simply result in smaller increases in drug self-administration.

d-Amphetamine. Research studies have shown that food deprivation results in the increased self-administration of d-amphetamine in rats and rhesus monkeys. Takahashi, Singer, and Oei (1978) reported that rats self-injected significantly more d-amphetamine when they were reduced to 80% of their free-feeding body weights than rats who were reduced to only 90% or were maintained at 100% of their free-feeding body weights. The authors also found that rats self-injected d-amphetamine at the highest rates when the doses were smallest (Takahashi et al., 1978). Samson (1986) reported that the responding of food-satiated rats for amphetamine decreased as the dose of amphetamine increased, while only very large doses of amphetamine decreased drug-responding in food-deprived rats. Carroll and Stotz (1983) showed that the self-administration of d-amphetamine increased in monkeys when they were reduced to 85% of their free-feeding weight. Similarly, De La Garza and Johanson (1987) reported that intravenous d-amphetamine self-administration increased in monkeys after they were reduced to 75% to 85% of their free-feeding body weights. Interestingly, the authors noted that low doses of d-amphetamine did not maintain drug responding in some of the food-satiated monkeys, although the same doses maintained drug responding in the food-deprived monkeys.

Cocaine. Studies have indicated that food deprivation results in increased cocaine self-administration in rats, rhesus monkeys, and pigeons (De La Garza & Johanson, 1987; Papasava & Singer, 1985; Schaal & Branch, 1992; Schaal, Miller, & Odum, 1995). Papasava and Singer (1985) found that the responding of food-deprived rats for cocaine was inversely related to percentage of free-feeding body weight. Further, it was found that responding for cocaine rapidly decreased when the rats were food satiated (Papasava & Singer, 1985). The results of another study indicated that cocaine self-administration

increased in monkeys after the monkeys were reduced to 75%-85% of their free-feeding body weight (De La Garza & Johanson, 1987). Schaal and Branch (1992) found that significantly larger doses of cocaine were required to decrease the responding of pigeons reduced to 70% of their free-feeding body weight, than pigeons reduced to 90% of their free-feeding weight or pigeons maintained at 100% of their free-feeding weight. Schaal et al. (1995) showed that pigeons maintained at 70% of their free-feeding body weight engaged in more pecking behavior for low doses of cocaine and required higher doses of cocaine to decrease pecking behavior than pigeons maintained at 82.5% to 85% of their free-feeding weight. Using an alternative route of drug administration, Comer, Turner, and Carroll (1995) demonstrated that cocaine base smoking decreased in food-deprived rhesus monkeys as body weight increased.

Alcohol. Although rodents are typically reluctant to consume alcohol, several studies have reported that alcohol consumption increases among rats and mice during periods of food deprivation. McGregor, Saharov, Hunt, and Topple (1999) reported that rats worked harder for beer than a sucrose solution when deprived of food, although consumption of sucrose was greater than beer when the animals were not deprived of food. Further, the rats working for beer worked harder than those working for sucrose when both groups were food-deprived (McGregor et al., 1999). Soderpalm and Hansen (1999) reported that rats consumed nearly 75% more alcohol when reduced to 80% of their free-feeding body weight, and exhibited increases in hedonic taste responses and decreases in aversive taste reactions to the alcohol during food deprivation (Soderpalm & Hansen, 1999).

The findings of Schroff, Cowen, Koch, and Spanagel (2004) suggest that genetics may play a role in the relationship between food deprivation and alcohol consumption. The authors reported that alcohol consumption increased during food deprivation in a strain of mice known to consume greater amounts of alcohol, although the comparison group of mice did not increase their alcohol consumption when deprived of food. The findings suggest that genes may interact with environmental food shortages to produce increases in alcohol consumption. It is important to note that there are methodological difficulties with using alcohol consumption as the outcome variable, given that alcohol contains both calories and water. Depending on the study design, food-deprived animals may simply consume more alcohol in an attempt to reduce a negative energy balance.

Nicotine. Studies have shown that food deprivation results in the increased self-administration of nicotine in rats and rhesus monkeys (De La Garza & Johanson, 1987; Lang et al., 1977). In one study, self-injection of nicotine increased in rats that were reduced to 80% of their free-feeding body weight by seven times that of non-deprived rats (Lang et al., 1977). Oral nicotine administration was also reported to be greater among food-deprived rats than non-deprived rats (Lang et al., 1977). It is important to note that nicotine was administered at the same rate as saline in non-deprived rats (Lang et al., 1977). The authors speculated that nicotine suppressed hunger in the food-deprived rats, and thus self-administration increased with food deprivation. De La Garza and Johanson (1987) reported that intravenous self-administration of nicotine significantly increased in one of three rhesus monkeys after the monkeys were reduced to 75%-85% of their free-feeding body weights, and nicotine responding was found to increase as the dose of nicotine decreased. The authors also noted that low doses of nicotine did not

maintain nicotine responding in some of the monkeys when they were food-satiated, although the same doses maintained responding when the monkeys were food-deprived (De La Garza & Johanson, 1987).

Phencyclidine. Studies have indicated that food deprivation increases phencyclidine self-administration in rhesus monkeys (Carroll, 1982; Carroll & Meisch, 1980b). Carroll and Meisch (1980b) reported that oral self-administration of phencyclidine in rhesus monkeys increased when the monkeys were reduced to 85% of their free-feeding body weight. The authors found that responding for phencyclidine subsequently decreased when the monkeys were food-satiated (Carroll & Meisch, 1980b). Carroll (1982) reported that the responding of rhesus monkeys for oral phencyclidine nearly doubled when the monkeys were switched from a free-feeding diet to a reduced calorie diet designed to maintain them at 85% of their free-feeding body weight. The food-deprived monkeys self-administered phencyclidine at three to seven times the rate of concurrently available water, depending on the fixed ratio delivery schedule.

Other Substances. Studies have provided evidence that food deprivation increases the self-administration of ketamine and pentobarbital in rhesus monkeys (Carroll & Stotz, 1983; Kliner & Meisch, 1982). Carroll and Stotz (1983) showed that self-administration of ketamine increased in monkeys when they were reduced to 85% of their free-feeding weight. Kliner and Meisch (1982) demonstrated that pentobarbital self-administration increased with food deprivation in rhesus monkeys, and abrupt food satiation resulted in decreased pentobarbital self-administration.

Summary. Overall, studies suggest that food deprivation and the resulting reduction in body weight are associated with the increased self-administration of a variety of substances including etonitazene, d-amphetamine, cocaine, alcohol, nicotine, phencyclidine, pentobarbital, and ketamine in rats, mice, rhesus monkeys, and pigeons (e.g., Carroll et al., 1979). Further, the findings of a few studies indicate that greater food deprivation and weight loss are associated with greater self-administration of substances in laboratory animals (Carroll & Meisch, 1981; Comer et al., 1995; Papasava & Singer, 1985). Research suggests that food-deprived animals will work harder for lower doses of substances (Schaal et al., 1995; Takahashi et al., 1978), and larger doses of substances are required to decrease drug responding (Samson, 1986; Schaal & Branch, 1992; Schaal et al., 1995). Finally, studies have indicated that responding for substances decreases rapidly with food satiation (Carroll et al., 1979; Kliner & Meisch, 1982; Papasava & Singer, 1985).

Food Deprivation and Substance Use in Humans

Only a few studies have investigated the effects of food deprivation on substance use in humans. In an early study, increases in coffee, tea, and cigarette consumption were observed in a group of young men during a six-month period of calorie restriction (Franklin, Schiele, Brozek, & Keys, 1948). Participants in the study were placed on a diet of 1570 calories per day, which resulted in a 24% reduction in body weight overall for the entire sample. Increased depression, apathy, and irritability were observed among the men during the period of food deprivation. Unfortunately, statistical techniques were not utilized to evaluate the significance of the observed changes in substance use and mood during food deprivation.

Zacny and de Wit (1990) compared the smoking rates and CO levels of seven male and female participants in four experimental conditions. The conditions varied by feeding condition (24-hour fast vs. normal intake) and cigarette nicotine yields (low vs. high yield). The authors hypothesized that increased cigarette smoking would be more likely to occur during food deprivation and with lower doses of nicotine (i.e., low-yield cigarettes) as found in animals. Participants' CO levels were greater by two parts per million (ppm) in the fasting conditions than in the normal intake conditions. However, the number of cigarettes smoked and the number of puffs taken per cigarette did not differ between the fasting and normal intake conditions. Unfortunately, the ability to draw conclusions from this study is limited by the small sample size and the lack of topography data that might have helped to explain the differences in CO levels between conditions.

In a follow-up study, Zacny and de Wit (1992) compared the cigarette consumption, caffeinated beverage consumption, CO levels, plasma cotinine levels, and self-reported mood of five male smokers who were placed on a restricted calorie diet of 800 calories per day for three days and a normal diet of 3,000 calories per day for three days. No differences in cigarette consumption, caffeinated beverage consumption, CO, or cotinine levels were found between the restricted diet and normal diet conditions. However, subjects endorsed greater fatigue and marginally greater depression in the restricted diet condition. Elation remained stable throughout each day in the restricted diet but decreased in the normal diet condition. The small sample size again limited study conclusions, and smoking topography was not measured.

Lawson, Bulik, Rodefer, Scanlon, and Borger (1997) compared the effects of three feeding conditions lasting three days each, on the coffee and cigarette consumption of four women. The feeding conditions were: 1) three meals per day containing the typical energy intake for each participant, 2) one meal per day containing 50% of the typical daily intake, 3) and three meals per day each containing 50% of the typical intake. The authors hypothesized that individuals would exhibit the greatest increases in cigarette and coffee consumption when they were receiving one meal per day containing 50% of the normal energy intake. No differences in mood, smoking urges, expired CO levels, smoking rate, or coffee consumption were found between the food-deprived and non-deprived conditions. However, the graphical presentation of the data suggested that some of the individuals who participated in the study exhibited increases in cigarette consumption during food deprivation. It is important to note that this study utilized a very small sample size, which limited the ability to detect differences between conditions. Further, the conditions were not counterbalanced, and thus did not control for the possibility of time and order effects.

In a recent study, 17 male and female heavy smokers of normal weight were placed on four diets of varying calorie and carbohydrate levels for six days each in an inpatient hospital setting (Cheskin, Hess, Henningfield, & Gorelick, 2005). The diet conditions were: 1) normal calorie (2,000-2,800 kcals per day), 2) low calorie (700 kcal deficit per day), 3) low carbohydrate/normal calorie ($\leq 20\%$ kcals from carbohydrates), and 4) low carbohydrate/low calorie ($\leq 20\%$ kcals from carbohydrates). Results indicated that participants smoked approximately eight percent more cigarettes (i.e., four cigs over 34 hours) and produced expired CO levels that were 11% higher (i.e., four ppm after 34

hours) in the low calorie diet condition than in the normal calorie diet condition. Interestingly, participants had CO levels that were 15% higher while on the low carbohydrate/low calorie diet than the normal calorie diet, although there were no differences in the number of cigarettes smoked between conditions. Unfortunately, smoking topography was not measured in this study. Differences in smoking topography between conditions may have helped to explain the higher CO levels in the low carbohydrate/low calorie diet, and would have provided additional information about the smoking behavior of participants in each condition. No differences in mood or cigarette craving were found between conditions.

Studies have examined the impact of food deprivation on substance use in women with Bulimia Nervosa, a disorder characterized by dieting and self-imposed food deprivation. Bulik and Brinded (1993) compared the alcohol consumption of five women with Bulimia Nervosa and five healthy controls after a 19-hour fast and in a non-deprived state. No differences in the grams of alcohol consumed or calories consumed from alcohol were found between the food-deprived and non-deprived conditions, and females in the Bulimia Nervosa and control groups consumed equivalent amounts of alcohol (Bulik & Brinded, 1993). Unexpectedly, breath alcohol levels were greater in the non-deprived conditions than in the food-deprived conditions. No differences were found between the food-deprived and non-deprived conditions in mood, although hunger ratings were significantly greater in the food-deprived condition. In another study, the coffee consumption of four women with Bulimia Nervosa and six healthy controls were compared following a 19-hour fast and in a non-deprived state (Bulik, Brinded, & Lawson, 1995). Results indicated that participants consumed significantly more coffee

when food-deprived than when not deprived. This effect was more pronounced in the women with Bulimia Nervosa, who consumed more than twice as much coffee in the food-deprived condition than in the non-deprived condition. No differences in self-reported urges to drink coffee or hunger were found between deprivation conditions or diagnosis (i.e., Bulimia Nervosa vs. healthy controls).

Summary. Although the findings of several studies have suggested that nicotine and caffeine intake may increase in humans during periods of food deprivation (Bulik et al., 1995; Cheskin et al., 2005; Franklin et al., 1948; Zacny & de Wit, 1990), other studies have failed to find increases in substance use (Bulik & Brinded, 1993; Lawson et al., 1997; Zacny & de Wit, 1992). There is initial evidence that both acute and prolonged deprivation may impact cigarette smoking and other substance use (Bulik et al., 1995; Cheskin et al., 2005; Franklin et al., 1948; Zacny & de Wit, 1990). More research is needed to determine whether changes in smoking topography might account for differences in expired CO levels during periods of food deprivation. With one exception (Cheskin et al., 2005), studies have utilized sample sizes of ≤ 10 participants which has limited the statistical power to detect differences between experimental conditions. Unfortunately, inconsistent findings and small sample sizes across studies have limited the ability to draw conclusions about the relationship between food deprivation and substance use in humans.

Food Deprivation and the Reinforcing Value of Substances

Although the findings of several studies have indicated that fasting does not alter the subjective or physiological effects of marijuana, d-amphetamine, or fentanyl in humans (Zacny & de Wit, 1989a; Zacny & de Wit, 1989b; Zacny, Lichtor, Zaragoza, &

de Wit, 1992), behavioral studies have indicated that the reinforcing value of nicotine and caffeine may increase in a fasting state. Bulik et al. (1995) compared the reinforcing value of coffee versus money in females with and without Bulimia Nervosa, following a 19-hour fast and when not deprived of food. The authors found that women made significantly more attempts to obtain coffee on the Apple Picker task (Norman & Jongerius, 1985), a concurrent variable ratio schedule computer game, and earned more points for coffee in the food-deprived condition than in the non-deprived condition. Participants earned five cents for every five points earned on the money schedule, and twenty grams of coffee for every five points earned on the coffee schedule. No differences were found between the Bulimia Nervosa and the control groups. These findings suggest that the reinforcing value of caffeine may increase following a period of food deprivation, regardless of the presence of Bulimia Nervosa.

Bulik and Brinded (1994) compared the reinforcing value of cigarettes versus money in female smokers, with and without Bulimia Nervosa, following an 18-hour fast and in a non-deprived state. Results indicated that the control group spent more time working for cigarettes than money on the Apple Picker task in the food-deprived state than in the non-deprived state (Bulik & Brinded, 1994). Surprisingly, the women with Bulimia Nervosa spent more time working for cigarettes in the non-deprived state than in the food-deprived state (Bulik & Brinded, 1994). There were no main effects of diagnosis or deprivation condition (Bulik & Brinded, 1994). Findings suggest that individuals without Bulimia Nervosa may find cigarettes to be more reinforcing in a food-deprived state than in a non-deprived state, while individuals diagnosed with Bulimia Nervosa may find cigarettes to be more reinforcing in a non-deprived state (Bulik & Brinded, 1994).

There are several possible explanations for the unexpected findings of Bulik and Brinded (1994). Perhaps the individuals with Bulimia Nervosa spent more time working for cigarettes in the non-deprived state than in the food-deprived state because they perceived smoking as a means by which to control appetite and to attenuate the stress associated with eating. Conversely, the women in the control group may have found the food-deprived state to be more stressful than the non-deprived state, thus spending more time working for cigarettes because they believed that cigarettes could be used to alleviate the stress associated with fasting. The authors suggested that the individuals with Bulimia Nervosa might have had greater difficulty adhering to the fasting instructions, which may have affected the study results (Bulik & Brinded, 1994). Further, the authors hypothesized that the participants with Bulimia Nervosa may have been used to brief periods of fasting and were therefore less affected than the control group by the experimental fast (Bulik & Brinded, 1994). Finally, the authors suggested that the participants with Bulimia Nervosa may have been less able to recognize and respond to the sensation of hunger in the fasting condition (Bulik & Brinded, 1994).

Food Deprivation and Stress

Studies have indicated that stress is associated with increases in the desire to smoke as well as increased cigarette smoking (Ng & Jeffery, 2003; Perkins & Grobe, 1992; Rose, Ananda, & Jarvik, 1983; Todd, 2004). Rose et al. (1983) found that individuals smoked more during tasks that were anxiety provoking or which demanded attention than during relaxation. Perkins and Grobe (1992) reported that individuals' desire to smoke was greater during a stressful task than a non-stressful task. Ng and Jeffery (2003) found that high levels of perceived stress were associated with current

smoking and recent increases in smoking. More recently, Todd (2004) reported that individuals smoked more cigarettes and reported more urges to smoke when their perceived level of stress was high and when a greater number of negative events had recently occurred. Some researchers have conceptualized fasting and caloric restriction as a stressor that may be similarly associated with increases in smoking and other substance use (Stone, 1983; Zacny & De Wit, 1990).

Neurochemical Changes Due to Food Deprivation

Research has suggested that food deprivation is associated with reduced levels of extracellular dopamine in the nucleus accumbens of laboratory animals, and that substance use during food deprivation may produce both increases in the release and decreases in the uptake of dopamine (Carr, 2002; Pothos, 2001; Pothos, Creese, & Hoebel, 1995a; Pothos, Hernandez, & Hoebel, 1995b; Zhen, Reith, & Carr, 2006). Studies have shown that levels of extracellular dopamine in the nucleus accumbens of rats decrease by as much as 60 percent when rats are reduced to 70 to 80 percent of their free-feeding body weight (Pothos, 2001; Pothos et al., 1995a; Pothos et al., 1995b). In addition, extracellular dopamine has been shown to increase to a greater extent among food-deprived rats than among non-deprived controls after receiving equivalent infusions of amphetamine directly into the nucleus accumbens (Pothos, 2001, Pothos et al., 1995a). Some researchers have speculated that food deprivation may cause an accumulation of dopamine in the presynaptic terminals (Pothos, 2001; Pothos et al., 1995a). The administration of amphetamine or other substances subsequent to food deprivation may displace the accumulated dopamine, resulting in greater than normal concentrations of extracellular dopamine. In addition, other research has indicated that the uptake of

dopamine may be reduced during food deprivation (Carr, 2002; Zhen et al., 2006).

Overall, findings suggest that food deprivation is associated with changes in the release and uptake of dopamine, which persist until energy balance is re-established.

Hormonal changes that occur in response to food deprivation may trigger the dopamine-related physiological changes that are associated with increased substance use. Specifically, insulin and leptin, which are involved in the regulation of feeding and energy balance, and glucocorticoids, such as corticosterone, which are known to rise in response to stress, may impact the release and uptake of dopamine (Carr, 2002; Lu, Shepard, Hall, & Shaham, 2003; Piazza & Le Moal, 1996). Although the exact nature of the impact of changes in hormones levels on dopamine release remains unclear, recent evidence suggests that insulin, leptin, and corticosterone receptors may be present on dopaminergic neurons (Figlewicz, Evans, Murphy, Hoen, & Baskin, 2003; Piazza & Le Moal, 1996). Studies have indicated that these hormones impact the acquisition, maintenance, and reinstatement of substance self-administration in animals (Carr, 2002; Lu et al., 2003; Piazza & Le Moal, 1996; Shalev, Yap, & Shaham, 2001). Hormonal changes resulting from stress and changes in energy balance may impact the release and uptake of dopamine, thus potentially altering the reinforcing properties of substances of abuse.

Effects of Menstrual Cycle Phase on Smoking Behavior

Studies have indicated that menstrual cycle phase may influence smoking rates and cigarette craving. The luteal phase of the cycle occurs following ovulation and prior to the onset of menses, and is associated with increases in progesterone and changes in the ratio of progesterone to estrogen. Studies have indicated that women experience the

greatest premenstrual symptomatology, including negative affect and increased appetite, during the luteal phase (Allen, Hatsukami, Christianson, & Nelson, 1996; Carpenter, Upadhyaya, LaRowe, Saladin, & Brady, 2006; Craig, Parrott, & Coomber, 1992; Marks, Hair, Klock, Ginsburg, & Pomerleau, 1994). Further, the findings of several studies have suggested that cigarette craving and cigarette smoking increase during the luteal phase of the cycle (Allen et al., 1996; DeBon, Klesges, & Klesges, 1995; Franklin et al., 2004; Mello, Mendelson, & Palmieri, 1987; Snively, Ahijevych, Bernhard, & Wewers, 2000). Plausibly, women may increase their smoking rate in an attempt to attenuate negative affect and other symptoms that are commonly experienced during the luteal phase.

It is also possible that sex hormones may alter the reinforcing effects of nicotine. For example, Damaj (2001) reported that progesterone and estradiol blocked the reduction in pain sensitivity that typically results following nicotine administration. Thus, women may smoke more during the luteal phase (when progesterone increases) in an attempt to achieve the positive effects of smoking that are typically experienced in the other phases of the menstrual cycle. Studies that aim to measure the smoking behavior of women over multiple visits must carefully consider the impact of menstrual cycle phase effects.

Hypotheses

The main purpose of the present study was to test the hypotheses that females would smoke a greater number of cigarettes and exhibit greater expired CO levels when food-deprived than when not deprived of food. Further, it was expected that smoking topography would differ between conditions due to hypothesized increases in smoking rates and CO levels during food deprivation. Specifically, it was hypothesized that puff

count, puff volume, average flow, peak flow, puff duration, time of peak, time to removal from the last puff, and total time smoking would be greater when participants were food-deprived than non-deprived. Conversely, the time to first puff and interpuff interval were expected to be greater when participants were not deprived of food. It was anticipated that participants would rate their urges to smoke as stronger, and the cigarettes that they smoked as more pleasurable when they were deprived of food. Finally, it was hypothesized that participants would endorse greater negative mood and less positive mood when they were food-deprived.

Method

Participants

The recruitment goal for the present study was 27 participants based on a medium effect size ($.50\sigma$), power of .80, a significance level of .05 for one-tailed tests, and a within-subjects design. Participants were recruited through fliers posted around the Louisiana State University (LSU) campus, local newspaper advertisements, and the LSU subject pool in which students are able to participate in research for course credit. Individuals were eligible to participate if they were female, within the normal or overweight range of body mass index (BMI; 18.5-29.9), reported smoking at least 10 cigarettes per day, and had CO levels of \geq six ppm. Individuals were excluded from the study if they were within the underweight or obese ranges of BMI (≤ 18.4 or ≥ 30), diabetic or hypoglycemic, or possessed a health condition for which fasting would be contraindicated. One hundred sixty-five individuals attended the initial screening session. Of those who attended, 36 individuals were found to be eligible to participate in the study. Twenty-one of the eligible individuals chose not to participate in the study for a variety of reasons including scheduling conflicts and the fasting requirement. The remaining 15 individuals completed the study. Individuals who participated in the study received either extra course credit ($n = 4$) or a monetary payment for completion of the study ($n = 11$).

Measures

Demographics and Health Questionnaire (DHQ). The DHQ is a self-report questionnaire that inquires about demographic characteristics and health information including sex, race, age, daily smoking rate, preferred brand of cigarette, and health

problems. Height, weight, and expired CO levels were measured by the experimenters and noted on the questionnaire. Weight and height were converted to BMI (kg/m²) for statistical analysis.

Fagerström Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerström, 1991). The FTND is a six-item self-report questionnaire that was administered to assess the degree of nicotine dependence among the participants. Possible scores on the measure range from zero to 10, with higher scores suggesting greater nicotine dependence. The FTND has acceptable internal consistency and there is evidence of construct and predictive validity (Fagerstrom & Schneider, 1989; Heatherton et al., 1991; Kozlowski, Porter, Orleans, Pope, & Heatherton, 1994).

Smoking Rate. The number of cigarettes smoked during each study session was measured by counting the number of remaining cigarettes in the pack at the end of the study session and subtracting from 20 (i.e., a full pack of cigarettes). For further verification, this number was compared with the number of cigarettes butts that were in the ashtray used by each participant.

Expired Carbon Monoxide (Vitalograph Incorporated, Lenexa, KS, USA). A portable Vitalograph ecolozyer was used to measure expired CO levels. According to the SRNT Subcommittee on Biochemical Verification (2002), CO levels of \geq eight parts per million (ppm) suggest recent cigarette smoking with a sensitivity and specificity of approximately 90 percent for heavier smokers. However, it is notable that the half-life of CO may range from one to eight hours depending on a variety of factors including time of day, daily smoking rate, recency of smoking, and physical activity levels (SRNT Subcommittee on Biochemical Verification, 2002). A slightly lower minimum criteria of

\geq six ppm was utilized in the present study, as the target population was expected to include lighter smokers (i.e., \geq 10 cigarettes per day) and CO was measured in the morning during some of the screening sessions.

Smoking Topography (Plowshare Technologies, Baltimore, MD, USA). Smoking topography was measured with a Plowshare CReSSmicro smoking topography device. The topography device has been shown to be a reliable, valid, and detailed measure of smoking behavior (Lee, Malson, Waters, Moolchan, & Pickworth, 2003). Readings from the device provided the following topographical information for each cigarette puff: puff volume (ml), average flow (s), peak flow (ml/s), time of peak flow (s), puff duration (s), and interpuff interval (s). Each variable was averaged across puffs for the entire cigarette. Additionally, the sums of each puff volume, puff duration, and interpuff interval were computed. Total puff count, time to first puff (s), and time to removal from the last puff (s) were also measured with the device. The total time smoking was calculated by summing the time to first puff, all puff durations, all interpuff intervals, and time to removal.

Geiselman Menstrual Cycle Interview (GMCI). Several items from the GMCI were included in order to facilitate the scheduling of the study sessions during the luteal phase of the menstrual cycle for participants who were not taking oral/injectable contraceptives. The specific items utilized in this study included: Normal length of menses, normal length of menstrual cycle, date of onset of last menses, anticipated date of next menses onset, and current day of the menstrual cycle. The luteal phase of the cycle was operationalized as beginning 11 days prior to the onset of menses and continuing until the day before the onset of menses.

Eating Inventory (EI; Stunkard & Messick, 1985; Stunkard & Messick, 1988). The EI is a 51-item self-report measure of eating behavior. Three factors of the EI have been derived through factor analysis: Cognitive Restraint of Eating, Disinhibition, and Hunger (Stunkard & Messick, 1985). Studies have indicated that higher scores on the Cognitive Restraint scale of the EI are associated with lower caloric intake, and the scale has been found to more accurately reflect chronic caloric restriction than other commonly used measures of restraint (De Castro, 1995; French, Jeffery, & Wing, 1994; Williamson et al., 2007). Cognitive Restraint scores of 14 or greater, Disinhibition scores of 12 or greater, and Hunger scores of 11 or greater are considered to be within the clinical range (Stunkard & Messick, 1988).

Eating Attitudes Test (EAT-26; Garner, Olmsted, Bohr, & Garfinkel, 1982). The EAT-26 is a 26-item self-report questionnaire, which was used to identify possible eating disorders and to measure eating disorder symptoms. The reliability and validity of the measure have been established, and scores of 20 or greater have been shown to be associated with the presence of an eating disorder (Garner et al., 1982). Individuals who earned scores of 20 or greater were referred for further assessment and possible treatment at the LSU Psychological Services Center (PSC).

Bulimia Test – Revised (BULIT-R; Thelen, Farmer, Wonderlich, & Smith, 1991). The BULIT-R is a 36-item self-report questionnaire that was used to screen for eating disorders and to measure symptoms of Bulimia Nervosa. This measure has been shown to be a valid and reliable measure of the symptoms of Bulimia Nervosa in clinical and non-clinical samples (Brelsford, Hummel, & Barrios, 1992; Thelen et al., 1991; Thelen,

Mintz, & Vander Wal, 1996). Individuals who earned scores of 104 or greater were referred for further assessment and possible treatment.

Body Shape Questionnaire (BSQ; Cooper, Taylor, Cooper, & Fairburn, 1987).

The BSQ is a 34-item self-report measure of concern about body shape. The concurrent and discriminant validity of this measure have been established (Cooper et al., 1987).

BSQ scores of less than 81 suggest little or no worry about body shape, scores of 81-110 suggest slight worry, scores of 111-140 suggest moderate worry, and scores greater than 140 suggest extreme worry about body shape (Cooper & Taylor, 1988).

Visual Analogue Scales (VAS). The VAS is a self-report measure on which participants were asked to indicate their responses to specified questions by drawing a line through a 100 mm line. Each participant was asked to respond to the question “How strong is your urge to smoke right now?” prior to smoking each cigarette, and to the question “How pleasurable was it to smoke this cigarette?” after smoking each cigarette. These ratings were utilized to provide subjective indices of the strength of smoking urges and the pleasure derived from smoking. Additionally, participants were asked to rate their hunger three times during each experimental condition by responding to the question “How hungry are you right now?” Hunger ratings were utilized to provide a subjective index of hunger and to serve as a manipulation check for fasting compliance.

Profile of Mood States (POMS; McNair, Lorr, & Droppleman, 1992). The POMS is a 65-item self-report questionnaire, which lists adjectives that describe an individual’s mood. Individuals were asked to rate, on a five-point scale, the extent to which each adjective described their mood “right now.” Six factors of the POMS have been derived through factor analysis: Tension-Anxiety, Depression-Dejection, Anger-Hostility,

Vigor-Activity, Fatigue-Inertia, and Confusion-Bewilderment. A Total Mood

Disturbance score was calculated by summing the scores of the negative affect subscales and subtracting the Vigor scale. The reliability and validity of the POMS have been established (McNair et al., 1992).

ReliOn Ketone Test Strips (Bayer HealthCare LLC, Mishawaka, IN, USA).

Ketone tests strips were used to measure urinary ketone concentrations. Studies have indicated that ketone levels begin to rise in the first few days of fasting, and plateau within three to five days (Balasse, 1979; Balasse & Fery, 1989). After an overnight fast, the average concentration of ketone bodies has been reported to be approximately one to four mg/dl (Balasse & Fery, 1989). Although measurement of ketone concentrations cannot be used to verify compliance with a short-term fast on an individual level, the presence of ketones in some of the urine samples would provide evidence that the sample as a whole has complied with the fasting instructions.

Hypoglycemic Symptoms Checklist (HSC). The HSC is a 12-item checklist that was developed to identify symptoms of low blood glucose among the participants during the course of the study. Participants were asked to indicate the symptoms that they were experiencing from a list of common symptoms of hypoglycemia. Examples of common symptoms include anxiety, sweating, trembling, irritability, headache, and tachycardia (Carpenito, 1993; Guyton & Hall, 2000; NIH, 2003).

Accu-Chek Aviva Blood Glucose Meter (Roche Diagnostics, Indianapolis, IN, USA). A glucose meter was used to measure blood glucose levels among participants who endorsed three or more symptoms on the HSC. A lancet was used to draw blood from the fingertip. The blood was then applied to a test strip in the glucose meter to

obtain a measurement of blood glucose. Experimental sessions were to be discontinued if blood glucose levels were ≤ 50 mg/dl, as this level of blood glucose is associated with health consequences (Guyton & Hall, 2000). Based on the protocol described by Carpenito (2003), participants with low levels of blood glucose were to be provided with fruit juice in order to increase blood glucose levels to ≥ 70 mg/dl. If blood glucose levels remained < 70 mg/dl after fifteen minutes, the protocol required that the participant be provided with additional fruit juice and escorted to the student health center. There were no known incidents of low blood glucose levels among the participants during the course of the study.

Procedure

Telephone Screening. Individuals who called in response to fliers or newspaper advertisements were briefly screened over the telephone to ensure that they met basic inclusion criteria. Participants were questioned about their age, smoking rate, and health. If callers met the initial inclusion criteria, they were invited to attend an in-person screening session at a psychological health clinic on campus.

In-Person Screening. Women who signed up for the experiment through the LSU subject pool or who met the initial criteria during the telephone screening were scheduled for an in-person screening session. Informed consent was obtained and the DHQ, FTND, EI, EAT-26, BULIT-R, and BSQ were administered. Additionally, CO levels, height, and weight were measured. Women who participated in the screening session were given either a \$20 payment or course credit that could be applied to their Psychology coursework.

Eligible individuals were asked to participate in two additional six and a half hour sessions, one of which required a 24-hour fast. Participants who were not using oral contraceptives were scheduled for both experimental sessions during the luteal phase of their menstrual cycle. Participants who were using oral contraceptives were scheduled for both sessions during the same phase of their birth control pill packs in an attempt to hold hormone levels relatively constant. No menopausal or post-menopausal women participated in the study. The experimental sessions were scheduled at least one day apart, and the order of the deprived and non-deprived conditions was counterbalanced in order to control for potential effects of time and session order. A total of eight participants completed the food-deprived condition first, and the remaining seven participants completed the non-deprived condition first.

Food-Deprived Condition. Participants were instructed to fast for 18 hours prior to their scheduled appointments at 9:00 a.m. Participants were asked not to eat or drink anything containing calories or caffeine after 3:00 p.m. the night before the study, although they were encouraged to consume as much water as desired. Participants were each asked to sign a contract stating that they would adhere to the fasting instructions, and they were informed that a urine sample would be collected during the study session for verification of fasting. At the beginning of the study session, participants were provided with one pack of their preferred brand of cigarettes, a lighter, and an ashtray. Participants were encouraged to go outside to smoke as often as they desired, and they were told that they would be allowed to keep any remaining cigarettes that were left in the pack at the end of the session. Participants were instructed to rate the strength of their urges to smoke prior to smoking each cigarette, and to rate the degree of pleasure

experienced from smoking each cigarette using the VAS. Participants were provided with unlimited access to bottled water throughout the study session. Individuals were asked to complete the POMS, HSC, and VAS hunger ratings at 9:00 a.m., 12:00 p.m., and 3:00 p.m. CO levels, urinary ketone concentrations, and smoking topography were measured between 3:00 p.m. and 3:30 p.m. Participants were provided with a nutritional bar at the end of the study session, and were encouraged to stay and consume more than one nutritional bar if desired.

Non-Deprived Condition. Participants were instructed to eat and drink as usual prior to their scheduled appointments at 9:00 a.m. In order to ensure that participants were not deprived of food, breakfast was provided at 9:00 a.m. and lunch was provided at 12:00 p.m. Breakfast contained approximately 525 calories, and included a cereal bar, yogurt, banana, and orange juice. Participants chose one of several microwaveable frozen meals for their lunch, which was accompanied by water or another non-caloric, non-caffeinated beverage. The lunch food choices ranged from 600 to 680 calories. All other aspects of the session were the same as in the food-deprived condition described above. Upon completion of both of the study sessions, participants received course credit that could be applied to their psychology coursework or a \$130 payment.

Results

Participant Characteristics

Participants were 60% Caucasian ($n = 9$), 33.3% African American ($n = 5$), and 6.7% Asian ($n = 1$). The mean age of the participants was 27.40 years (± 9.30), and the mean BMI was 23.88 (± 1.97). Participants smoked an average of 18.27 (± 7.26) cigarettes per day for 10.12 (± 8.42) years, and the mean FTND score was 4.73 (± 2.91). The mean CO level of participants at the screening session was 16.13 (± 10.54). See Table 1 for the individual characteristics of each participant. Eligible individuals who participated in the study had marginally higher BMI (23.88 vs. 22.29), $t(34) = 1.99$, $p = .06$, two-tailed, and marginally greater daily smoking rate (18.27 vs. 14.69), $t(34) = 1.80$, $p = .08$, two-tailed, than those who were eligible but chose not to participate. No other differences in demographic, smoking, or eating variables were found between eligible individuals who participated in the study and those who did not participate.

Overall, most participants scored within the normal range on measures of eating behavior and eating disorders. Mean scores on the EI Cognitive Restraint, Disinhibition, and Hunger scales at the screening session were 7.33 (± 4.69), 7.13 (± 2.92), and 6.00 (± 3.14) respectively. The mean score on the EAT-26 was 7.93 (± 8.83). One participant scored above the EAT-26 screening cutoff for eating disorders (i.e., score of ≥ 20). The mean score on the BULIT-R was 55.80 (± 13.34), and none of the participants scored at or above the BULIT-R screening cutoff for Bulimia Nervosa (i.e., score of ≥ 104). The mean score on the BSQ was 84.20 (± 35.92). One participant endorsed extreme worry about weight and shape (i.e., score of > 140) on the BSQ.

Table 1
Individual Participant Characteristics at Screening

	Age	Race	BCPs	BMI	Restraint	CPD	CO	FTND
1 ^a	24	C	None	26.70	15	15	7	6
2	20	AS	Triphasic	23.03	10	11	8	5
3	22	C	Monophasic	24.18	15	11	11	1
4 ^b	22	C	Monophasic	23.79	10	20	11	2
5 ^a	24	C	None	22.98	10	20	6	3
6 ^b	22	C	None	24.27	6	15	18	3
7 ^{a,b}	20	AA	None	21.43	5	17	15	4
8	21	C	Monophasic	19.24	8	12	48	2
9	19	C	None	26.62	6	18.5	11	1
10	44	AA	None	25.39	3	40	14	10
11 ^b	39	AA	None	24.03	1	20	22	9
12 ^{a,b}	22	C	None	24.63	4	12	17	4
13 ^a	34	AA	None	22.32	2	25	22	9
14	47	C	None	23.62	2	17.5	24	6
15	31	AA	None	25.98	13	20	8	6

Note. AA = African American; AS = Asian; C = Caucasian; BCPs = birth control pills; CPD = cigarettes per day. ^aParticipant did not show increase in CO level in food-deprived condition. ^bSmoking topography data not available for participant.

Hunger Ratings

Hunger ratings were compared between conditions to verify that self-reported hunger was greater in the food-deprived than in the non-deprived condition. Hunger ratings were averaged across three time points within each condition. A repeated measures analysis of variance (ANOVA) was conducted to compare average VAS hunger ratings between the food-deprived and non-deprived conditions. As expected, average hunger ratings were significantly greater in the food deprived condition ($M = 76.31$ mm) than in the non-deprived condition ($M = 48.56$ mm), $F(1, 14) = 46.04$, $p = .00$, partial $\eta^2 = .77$, one-tailed. These findings provide evidence that participants complied with the instructions to fast prior to the session.

Urinary Ketone Concentrations

Urinary ketone concentrations were compared between conditions to confirm that a greater percentage of individuals in the food-deprived condition would test positive for ketones than in the non-deprived condition. In the food-deprived condition, 42.9% ($n = 6$) of the participants who provided a urine sample tested positive for urinary ketones, while only 7.1% ($n = 1$) tested positive for urinary ketones in the non-deprived condition. The higher percentage of individuals who tested positive for ketones in the food-deprived condition suggests that overall the sample complied with the fasting instructions.

Nicotine Self-Administration

Repeated measures ANOVAs were conducted to test the hypotheses that the total number of cigarettes smoked during each experimental session and CO levels collected at the conclusion of each session would be significantly greater in the food-deprived condition than in the non-deprived condition. As hypothesized, participants had

significantly greater CO levels in the food-deprived condition than in the non-deprived condition, $F(1, 14) = 3.04, p = .05$, one-tailed. It is notable that 66.67% ($n = 10$) of the participants had greater CO levels in the food-deprived condition, while 20% ($n = 3$) had greater CO levels in the non-deprived condition, and 13.33% ($n = 2$) showed no differences in CO levels between conditions. The participants who did not show increases in CO level in the food-deprived condition are indicated in Table 1. No significant differences were found between conditions in the total number of cigarettes smoked.

Participants were asked to smoke one cigarette at the conclusion of each experimental session in order to measure smoking topography. Topography data were available for 10 of the 15 participants in the study. One individual was excluded from the analyses because she took only one puff from her cigarette, and data were not available for four individuals due to technical difficulties with the topography equipment. Individuals with missing data were excluded from the study given the difficulties associated with data imputation in a small sample. Specifically, imputed topography data might not accurately represent smoking behavior and may have an unduly large influence on study results. This strategy was believed to be the most conservative means of handling the missing data in the analyses. The participants with missing smoking topography data are indicated in Table 1.

Repeated measures ANOVAs were conducted to determine whether smoking topography differed between the food-deprived and non-deprived conditions. Analyses indicated that the time to first puff was significantly greater in the non-deprived condition, $F(1, 9) = 4.57, p = .03$, one-tailed, while the sum of the interpuff intervals, $F(1, 9) = 5.91, p = .02$, one-tailed, and the time to removal from the last puff, $F(1, 9) =$

5.06, $p = .03$, one-tailed, were greater in the food-deprived condition. The total time spent smoking (i.e., time to first puff + puff durations + interpuff intervals + time to removal) was marginally greater in the food deprived condition than in the non-deprived condition, $F(1, 9) = 1.90$, $p = .10$, one-tailed (see Figure 1). No other differences in smoking topography were found between conditions. The means, standard deviations, and effect sizes for CO, smoking rate, and all smoking topography variables by condition are presented in Table 2.

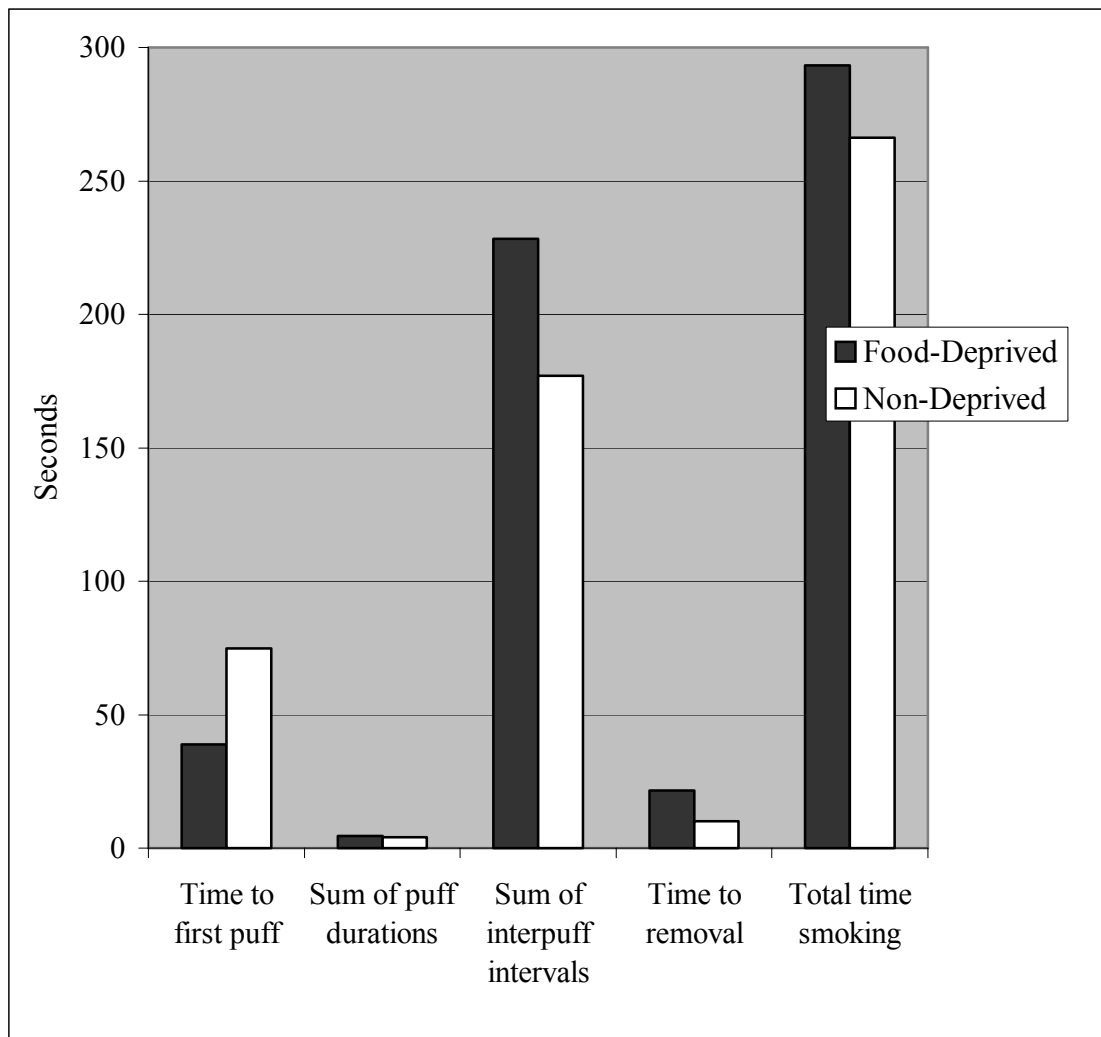


Figure 1. Differences in smoking topography between the food-deprived and non-deprived conditions.

Table 2
Means and Standard Deviations for All Smoking Variables

	Food-Deprived	Non-Deprived	Partial Eta ²	<i>p</i> (1-tailed)
CO Level (ppm) ^a	24.60 (±10.46)	20.20 (±8.00)	.18	.05
Total Cigarettes Smoked ^b	6.27 (±2.09)	6.60 (±1.76)	.05	<i>ns</i>
Total Puff Count ^c	9.10 (±3.78)	8.10 (±3.96)	.09	<i>ns</i>
Avg. Puff Volume (ml)	15.10 (±6.16)	14.27 (±5.45)	.04	<i>ns</i>
Sum of Puff Volumes (ml)	148.12 (±94.50)	129.74 (±95.63)	.10	<i>ns</i>
Avg. Flow (ml/s)	29.83 (±6.43)	28.54 (±4.96)	.08	<i>ns</i>
Avg. Peak Flow (ml/s)	38.56 (±9.80)	36.40 (±8.31)	.11	<i>ns</i>
Avg. Time of Peak (s)	.18 (±.10)	.18 (±.07)	.00	<i>ns</i>
Avg. Puff Duration (s)	.50 (±.16)	.49 (±.15)	.01	<i>ns</i>
Sum of Puff Durations (s)	4.65 (±2.52)	4.19 (±2.70)	.08	<i>ns</i>
Avg. Interpuff Interval (s)	33.68 (±16.06)	33.36 (±27.96)	.00	<i>ns</i>
Sum of Interpuff Intervals (s)	228.19 (±88.17)	177.05 (±96.72)	.40	.02
Time to First Puff (s)	38.91 (±39.83)	74.81 (±75.95)	.34	.03
Time to Removal (s)	21.63 (±24.37)	10.02 (±12.54)	.36	.03
Total Time Smoking (s) ^d	293.37 (±102.21)	266.07 (±109.20)	.17	.10 (<i>ns</i>)

^aExpired CO level was measured at the conclusion of each laboratory session. ^bTotal number of cigarettes includes all cigarettes smoked during each laboratory session.

^cSmoking topography variables were measured while participants smoked one cigarette at the conclusion of each laboratory session. ^dTotal time smoking = time to first puff + sum of puff durations + sum of interpuff intervals + time to removal.

Strength of Urges to Smoke and Pleasure Experienced from Smoking

Repeated measures ANOVAs were conducted to test the hypotheses that participants would rate the strength of their urges to smoke and the subjective pleasure experienced from smoking as greater in the food-deprived condition than in the non-deprived condition. Participants completed VAS urge ratings prior to smoking each cigarette, and then completed VAS pleasure ratings after smoking each cigarette. VAS urge and pleasure ratings were averaged across all cigarettes smoked within each condition. No significant differences were found between the food-deprived and non-deprived conditions on strength of self-reported urges to smoke (58.07 mm vs. 61.88 mm), $F(1, 14) = 2.16, p = .08, \text{partial } \eta^2 = .13$, one-tailed, or pleasure from smoking (65.83 mm vs. 67.25 mm), $F(1, 14) = .27, p = .30, \text{partial } \eta^2 = .02$, one-tailed.

Positive and Negative Mood States

The six subscales of the POMS, Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, and Confusion-Bewilderment, were averaged across three time points within each condition and the Total Mood Disturbance score was computed. Repeated measures ANOVAs were conducted to identify differences between conditions on each of the POMS scales. Analyses indicated that Vigor-Activity scores were significantly lower in the food-deprived condition than in the non-deprived condition, $F(1, 14) = 4.65, p = .02$, one-tailed. Fatigue-Inertia scores, $F(1, 14) = 2.22, p = .08$, one-tailed, and Total Mood Disturbance scores, $F(1, 14) = 2.21, p = .08$, one-tailed, were marginally greater in the food-deprived condition (see Figure 2). No significant differences were found between conditions on the remaining POMS subscales. See Table 3 for POMS subscale means, standard deviations, and effect sizes by condition.

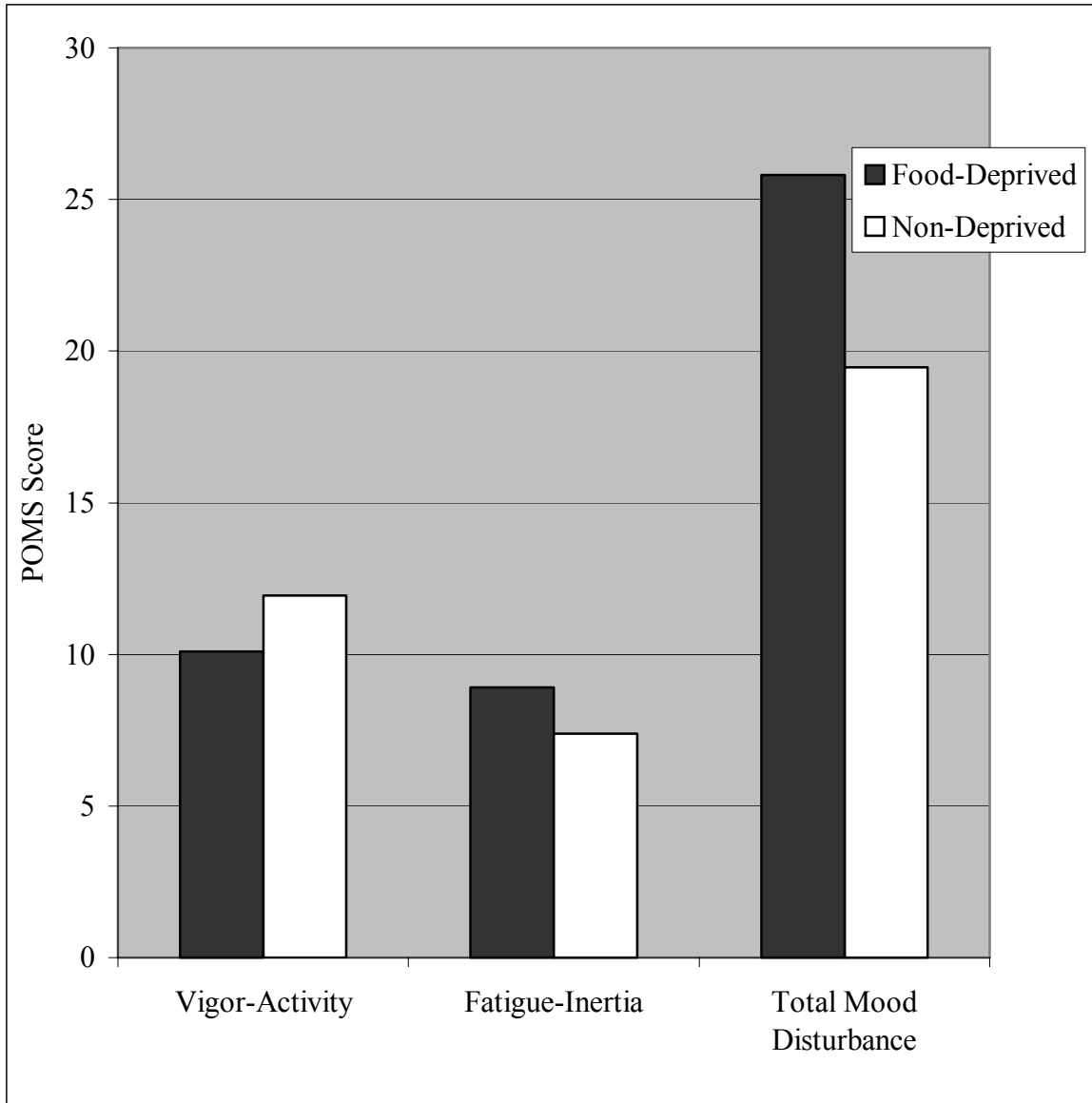


Figure 2. Differences in the POMS subscales between the food-deprived and non-deprived conditions.

Table 3
Means and Standard Deviations for the POMS Subscales

POMS Subscales	Food-Deprived	Non-Deprived	Partial Eta ²	<i>p</i> (1-tailed)
Tension-Anxiety	9.03 (±5.45)	7.86 (±6.37)	.10	<i>ns</i>
Depression-Dejection	6.87 (±8.81)	6.15 (±9.58)	.02	<i>ns</i>
Anger-Hostility	5.14 (±6.21)	3.96 (±6.11)	.10	<i>ns</i>
Vigor-Activity	10.09 (±4.17)	11.93 (±4.32)	.25	.02
Fatigue-Inertia	8.90 (±5.79)	7.38 (±5.84)	.14	.08 (<i>ns</i>)
Confusion-Bewilderment	5.97 (±4.69)	6.04 (±5.41)	.00	<i>ns</i>
Total Mood Disturbance	25.81 (±29.19)	19.46 (±33.36)	.14	.08 (<i>ns</i>)

Discussion

The results of the present study indicated that expired CO levels were greater among women after a 24-hour fasting period than when they were not deprived of food. However, no differences in the total number of cigarettes smoked were found between the conditions. Smoking topography data indicated that participants in the food-deprived condition took their first puff sooner, had longer intervals between puffs, and took longer to remove the cigarette from the machine following their last puff. Although the total time spent smoking was marginally greater in the food-deprived condition, this was due primarily to greater interpuff intervals and greater time to removal among the participants in the food-deprived condition. Results indicate that individuals may smoke differently when they are deprived of food than when they are not deprived of food. The results of this study add to the initial evidence that nicotine administration increases during periods of food deprivation in humans (Cheskin et al., 2005; Franklin et al., 1948; Zacny & de Wit, 1990).

Unexpectedly, many of the smoking topography variables including puff volume, puff duration, and average flow were not significantly different between conditions. It is important to note that the topography analyses included only 10 participants, thus the power to detect differences was limited. It is possible that differences between conditions would become apparent with a larger sample size. For example, total puff count (9.10 vs. 8.10) and total puff volume (148.12 vs. 129.74) were greater in the food-deprived condition than in the non-deprived condition, although differences did not fall within the range of statistical significance. Non-significant differences in topography variables

including puff volume, puff count, and peak flow likely contributed to the observed differences in CO levels between conditions.

Participants in the food-deprived condition scored lower on the POMS Vigor-Activity scale, and marginally greater on the POMS Fatigue-Inertia and POMS Total Mood Disturbance scales. It appears that participants experienced significantly reduced positive mood (i.e., Vigor-Activity) during food deprivation. Significant differences in negative mood states between conditions may have become apparent in a larger sample. It is possible the participants may have altered their smoking topography and increased their nicotine consumption in the food-deprived condition in an attempt to attenuate decreases in positive mood or increases in negative mood.

Surprisingly, no differences between conditions were found in the strength of participants' self-reported urges to smoke or the subjective pleasure experienced from smoking. These findings fail to support the hypothesis that smoking is more reinforcing among food-deprived participants, or that food-deprived participants are more sensitive to the positive effects of nicotine. Perhaps smoking serves another function, such as the attenuation of hunger, negative affect, stress, or decreased positive affect. It is also possible that the VAS is not a valid means by which to measure self-reported urges or pleasure experienced from smoking. Alternative measures of smoking urges and pleasure should be utilized in future studies to confirm these findings.

The findings of present study are similar to the findings of Zacny and de Wit (1990), who reported that expired CO levels were greater among individuals following a 24-hour fasting period than when the individuals were not deprived of food. However, it is notable that the differences in expired CO levels between conditions were greater in the

current study. This may be due to the exclusion of males from the study, the efforts to control for hormonal variation among the female participants, and the larger sample size. Smoking topography was also measured in the current study, which allowed for the examination of variables that might account for the observed differences in expired CO levels.

Cheskin et al. (2005) reported that individuals smoked a greater number of cigarettes and had higher CO levels while on a low calorie diet than on a normal calorie diet. The reported effects of food deprivation on the number of cigarettes smoked may have reflected the longer duration of the diet conditions (i.e., six days each). It is possible that acute food deprivation is associated with smaller increases in nicotine intake than the increases associated with prolonged periods of food deprivation. This hypothesis is consistent with the findings of previous studies indicating that substance administration is inversely related to reductions in body weight (Carroll & Meisch, 1981; Papasava & Singer, 1985). Thus, the total number of cigarettes smoked may be a less sensitive means by which to measure increased nicotine intake during acute periods of food deprivation. Increases in cigarette consumption may only become apparent with prolonged periods of food deprivation and significant weight loss.

The findings of the present study have implications for individuals with eating disorders, chronic dieters, and those who suffer from inadequate caloric consumption due to impoverishment. Such individuals may be at greater risk for smoking initiation, increased smoking rates, nicotine dependence, and relapse following cessation. Eliminating extreme dieting practices and improving body image may be an effective means by which to prevent smoking among adolescents and to facilitate smoking

cessation among adults. The development of smoking cessation interventions, which encourage moderate lifestyle changes rather than strict dieting early in the quit attempt, may improve cessation outcomes among weight-concerned individuals. Recent evidence suggests that sequential interventions in which the weight management component follows the smoking cessation component may be beneficial at reducing post-cessation weight gain (Spring et al., 2004). It is possible that weight management interventions may be successfully initiated among those who are overweight or have weight-related concerns after a period of stable smoking abstinence.

This study has several strengths and limitations. The strengths of this study include the use of a within-subjects design and the recruitment of a larger sample than has been utilized in most of the previous studies in this area. Moreover, the sample was limited to women and an attempt was made to control for hormonal variation across conditions. Smoking topography provided a more sensitive measure of nicotine intake that has not been measured in similar studies. Finally, several strategies were utilized to encourage and verify participant compliance with the fasting instructions. Participants were informed in advance that they would be asked to provide a urine sample to verify that they had complied with the fast. Further, hunger ratings, ketone concentrations, and mood ratings were compared between conditions to provide evidence of fasting. Nearly 43% of food-deprived individuals tested positive for ketones in the present study, which is similar to previous findings indicating that a 24-hour hour fasting period was associated with the presence of urinary ketone bodies in approximately 38-50% of urine samples (Zacny & de Wit, 1989b; Zacny & de Wit, 1990; Zacny et al., 1992). Limitations include the small sample size (although larger than most previous studies) and the

laboratory setting. Due to the demanding nature of the study and the provision of a monetary payment for participation, it is unclear whether the sample utilized in this study actually reflects the population of females who smoke. Although efforts were made to encourage compliance with fasting, a more accurate and reliable method of verifying compliance was not available.

Future studies should examine the relative impact of chronic versus acute food deprivation on nicotine consumption. Although dietary restraint was measured in the present study, the sample size was not large enough to examine the impact of the interaction between dietary restraint and acute food deprivation on cigarette smoking. Individuals who exhibit elevated dietary restraint may smoke at higher rates than those with lower restraint because they are in chronic state of self-imposed food deprivation. Weight is also likely to be an important factor, given that body weight reflects dietary restraint and food deprivation. Individuals who engage in extreme caloric restriction, thus maintaining a reduced body weight, may be at particular risk for increased substance use.

It is possible that individuals with eating disorders may be more likely to exhibit increases in substance use during food deprivation than individuals without eating disorders. Individuals with eating disorders, such as Bulimia Nervosa, regularly engage in fasting and caloric restriction. As a result, the body weight of such individuals is likely to be below normal or below free-feeding weight. The findings of one study have indicated that women with Bulimia Nervosa may exhibit greater increases in caffeine consumption during food deprivation than individuals without eating disorders (Bulik et al., 1995). More research is needed to determine whether there is an association between food deprivation and increased substance use among those with eating disorders. Such

research may help to explain the high comorbidity between eating and substance use disorders.

Smoking outcome expectancies may also play a role in the relationship between food deprivation and increased nicotine intake. Individuals who possess the belief that smoking can be used to reduce hunger and control appetite may be more likely to increase their smoking rate during periods of increased hunger and food deprivation. Future studies should compare individuals with weak and strong beliefs in the weight-control properties of smoking, in order to determine whether such beliefs impact smoking behavior during food deprivation. Such individuals may be at risk for increased cigarette smoking or relapse when dieting or engaging in more extreme weight control methods.

It is currently unclear whether the use of substances other than nicotine increases in humans during periods of food deprivation. Although there is limited evidence that caffeine intake may increase during food deprivation (Bulik et al., 1995), other studies have found no increases in alcohol and caffeine consumption during food deprivation (Bulik & Brinded, 1993; Lawson et al., 1997). More research is needed to determine whether the use of caffeine, alcohol, and other substances of abuse increase with caloric restriction. Further, it is unclear whether increases in substance use during food deprivation might be limited to stimulant drugs with appetite suppressant and weight control properties, or whether the use of substances increases for reasons other than appetite control.

Finally, little is known about the physiological mechanisms by which food deprivation may produce increases in substance use in humans. Studies of animals have suggested that changes in hormones levels during food deprivation may influence the

release and uptake of dopamine. Future studies must identify the relationship between the hormonal changes that occur in humans during food deprivation and increased substance use. It would be interesting to compare the activity of dopamine in the nucleus accumbens following substance administration between food-deprived and non-deprived participants using positron emission tomography scans (PET) or other technology. It is important for researchers to apply the knowledge gained from animal studies to studies of humans, in order to gain a better understanding of the comorbidity between eating disorders, dieting, and substance use.

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Vita

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