WORKPLACE SMOKING BANS AND DAILY SMOKING PATTERNS: IMPLICATIONS FOR NICOTINE MAINTENANCE AND DETERMINANTS OF SMOKING IN RESTRICTED ENVIRONMENTS

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Background: Daily smokers are thought to strive to maintain blood nicotine levels above a certain threshold. Workplace smoking bans pose a substantial barrier to nicotine maintenance. Individuals may compensate for time spent in smoking-restricted environments by smoking more before ("anticipatory") or after work ("make-up" compensation), but this has not been quantitatively examined. **Methods**: 124 smokers documented smoking occasions over 3 weeks using ecological momentary assessment (EMA), and provided information on nicotine dependence and stringency of workplace smoking policy (full, partial, or no bans). Hierarchical linear modeling examined effects of workplace policy, time of day block, and weekday vs weekend on mean cigarettes per hour (CPH) and simulated nicotine levels based upon EMA smoking data. Nicotine levels were assessed relative to two subject-specific standards of comparison: 1) "optimal maintenance," levels achieved through evenly-spaced smoking (ΔEvenNL); and 2) "preferred" nicotine levels achieved at comparable times on weekends (%WeekendNL). Moderating effects of dependence, nicotine clearance rate, and home smoking restrictions were examined. **Results**: Individuals were most likely to change locations to smoke during work hours, regardless of work policy, and frequency of EMA reports of restrictions at work was associated with increased likelihood of changing locations to smoke (OR=1.14, 95% CI 1.08 – 1.21; p=0.0002). Workplace smoking policy, time block, and weekday/weekend interacted to predict CPH ($p<0.01$), and

%WeekendNL (policy*time on weekdays, $p<0.05$), such that individuals with partial work bans – but not those with full bans - smoked more and had higher nicotine levels at Night (9 pm – bed) on weekdays compared to weekends. There was little evidence for interference with nicotine maintenance, although individuals with full or partial bans demonstrated more frequent low-nicotine (<50%WeekendNL) 'trough' events ($p=0.04$). **Conclusion**: Smokers may largely compensate for exposure to workplace smoking bans by escaping restrictions. However, full bans may suppress smoking even after they are lifted, perhaps by extinguishing stimulus associations or denormalization of smoking, whereas partial bans may not have these effects. This may suggest a stronger role for contextual factors in driving temporal variations in smoking. There was little evidence of true compensatory smoking to maintain nicotine levels in the face of smoking restrictions.

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1.0 INTRODUCTION

Daily cigarette consumption is often considered to be a product of “nicotine maintenance,” or the smoker’s attempt to maintain systemic nicotine levels above some point at which aversive symptoms of nicotine withdrawal may appear (Benowitz, 2008). Individuals are thought to smoke consistently throughout the day in order to offset the rapid clearance of nicotine from the body (i.e., terminal half-life of 2-3 hours; Benowitz, 1988; Benowitz, 2008) and prevent nicotine levels from dropping below some “nicotine trough” threshold (“trough avoidance”; Russell, 1971), thereby achieving relatively consistent nicotine levels each day (Benowitz, 1988; U.S.DHHS, 1988; Benowitz, 2001). Such behavior, and the associated difficulty of abstaining from smoking, is considered to be a hallmark of nicotine dependence (Shadel, Shiffman, Niaura, et al., 2000; Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991).

Yet, the majority of today’s smokers regularly confront a direct challenge to this “core” feature of their addiction. Enforced abstinence – in the form of public smoking restrictions – has become a daily occurrence for most smokers in the United States (Collins & Procter, 2011; CDC, 2011). Regulatory measures such as public smoking bans represent a cornerstone of successful tobacco control efforts in the modern era (Jacobsen, Wasserman, & Anderson, 1997; Giovino, 2007). Although smoking restrictions are often framed as a way to protect the non-smoking public from environmental tobacco smoke (or “ETS”: Jacobsen, Wasserman, & Anderson, 1997), these measures explicitly target the behavior of smokers by limiting the contexts in which smoking may occur. Frequent exposure to such regulations may prevent individuals from smoking at regular intervals over the course of the day, which may in turn prevent them from optimally maintaining steady-state nicotine levels. In other words, by imposing external control on the availability of smoking in daily life, environmental smoking restrictions – especially "full" bans, which prohibit smoking in all work areas (McMullen, Brownson, Luke, & Chriqui, 2005) – should serve as a major barrier to the consistent, regularly-spaced, "withdrawal-avoidance" type of smoking thought to be characteristic of daily smokers (Benowitz, 1988; Benowitz, 1992; Eissenberg, 2004; Benowitz, 2008).

Indeed, public bans do appear to change smoking behavior, as evidenced by high compliance rates and significant reductions in ETS in explicitly restricted spaces (Eriksen & Cerak, 2008; Collins & Procter, 2011). However, several reviews have reported that smoke-free policies have little (e.g., reduction of < 2 cigarettes per day; Brownson, Hopkins, & Wakefield, 2002) or no significant effect (Callinan, Clarke, Doherty, & Kelleher, 2010; Bajoga, Lewis, McNeill, & Szatkowski, 2011; Cahill, Maher, & Lancaster, 2008) on total daily cigarette consumption among continuing smokers. Other studies indicate that, although smokers who work in smoke-free environments may smoke less when restrictions are in effect, they increase smoking during periods when smoking is not prohibited (e.g., before and after work: Meade & Wald, 1977; CDC, 1990; Baile, Gilbertini, Ulschak, et al., 1991; Parry, Platt, & Thompson, 2000; on weekends: Kinne, Kristal, White, & Hunt, 1993). Thus, rather than significantly decreasing overall daily consumption when confronted with environmental bans, smokers may compensate for restrictions by shifting temporal patterns of smoking – or, by periodically escaping restrictions throughout the day – in order to maintain “preferred” levels of daily cigarette consumption, and perhaps, to maintain nicotine levels within a preferred range (i.e., above some trough or withdrawal threshold). This would be consistent with other data, suggesting that smokers compensate for other barriers to maintaining nicotine levels (e.g., changes in tar content, introduction of filter vents, etc.; Benowitz, 2001; Scherer, 1999; Evans & Farrelly, 1998).

Assessing the nature of any such temporal shifts in smoking in relation to exposure to restrictions may have important implications for understanding determinants of smoking in less permissive smoking environments (i.e., the modern world). A nicotine maintenance perspective suggests that any compensatory shift in the service of trough avoidance should appear as increased smoking – and a boost in nicotine levels – prior to prolonged exposure to restrictions (e.g., work), which could potentially offset the rapid clearance of nicotine during restricted periods. In contrast, effective trough avoidance cannot be achieved by increasing smoking following a prolonged period of enforced abstinence (e.g., after work), after nicotine levels have already dipped below the withdrawal threshold. Rather, such a pattern may suggest a role for external factors (e.g., availability of smoking, stimulus control) in driving smoking behavior in more restricted environments.

Assuming they are obeyed, as evidence suggests (Eriksen & Cerak, 2008; Collins & Procter, 2011), environmental smoking restrictions are expected to interfere with smokers’ ability to maintain nicotine levels. Greater frequency of exposure to smoke-free environments, particularly during working hours on the workweek (Monday-Friday), may be associated with less smoking, greater interference with nicotine maintenance, and attempts to compensate for this challenge. Alternatively, individuals may be able to escape restricted settings periodically throughout the workday, thus diminishing their potential effects on the regularity of smoking behavior. This has important implications for understanding the ways in which a cornerstone of modern tobacco control does –or does not- affect behavior among continuing smokers.

To date, however, there have been no attempts to assess or quantify nicotine maintenance and compensatory smoking in relation to exposure to smoke-free environments. This study seeks to address this substantial gap in the literature by quantitatively examining the association between exposure to restricted environments, interference with nicotine maintenance, and compensatory shifts in temporal smoking patterns in daily smokers.

1.1 NICOTINE AND DAILY SMOKING PATTERNS

Long established as the primary addictive agent in tobacco (Stolerman & Jarvis, 1995), nicotine is believed to play a crucial role in governing daily patterns of smoking behavior. Symptoms of nicotine withdrawal can emerge following a few hours of deprivation (Benowitz, 2008; Benowitz, 2010), and individuals seek to prevent and/or alleviate such aversive symptoms by regularly smoking (i.e., withdrawal avoidance; Eissenberg, 2004). This has contributed to the dominant perspective that daily smoking patterns of dependent smokers are driven by a need to smoke regularly enough to maintain nicotine levels above some withdrawal threshold or nicotine trough level (Benowitz, 2008; Russell, 1971). Patterns of regular cigarette smoking – both within and across days – are thus often viewed as a direct behavioral reflection of the ebb and flow of nicotine blood levels.

For *ad libitum* daily smokers, a characteristic pattern of nicotine blood levels over the course of a given day can be summarized in the following way. Upon waking, nicotine levels are quite low, the prior day's nicotine having been largely metabolized over the course of a night's sleep. The first cigarette of the day – consumed by many dependent smokers shortly after waking (Baker, Piper, McCarthy, et al., 2007) – produces a rapid increase in nicotine levels (e.g., approximately 10-15 ng/mL nicotine boost per cigarette, Feyerabend, Ings, & Russell, 1985; though see Patterson, Benowitz, Shields, et al., 2003). Additional cigarettes yield intermittent spikes of nicotine, followed by gradual declines as nicotine is continuously broken down by the body. Although nicotine is rapidly metabolized (terminal half-life: 2-3hrs; Feyerabend, Ings, & Russel, 1985), steady smoking leads to gradual accumulation of nicotine in the body over several hours, reaching a relatively stable level, thought to represent an individual's "set point" as a person smokes throughout the waking day.

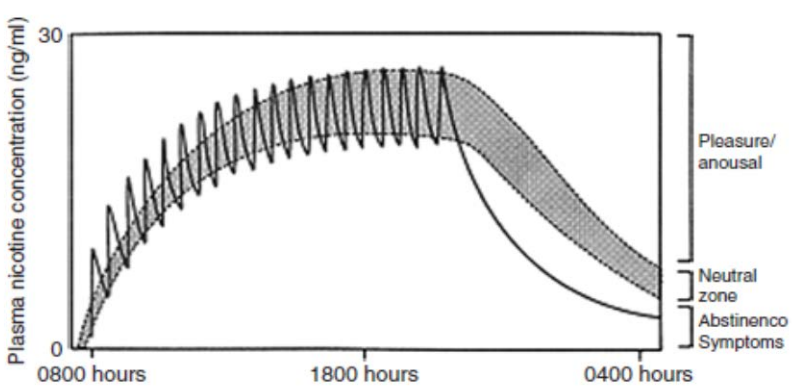

Figure 1. Daily course of smoking and plasma nicotine levels (reproduced from Benowitz, 1992)

Although nicotine levels in a “typical smoker” demonstrate some oscillation from cigarette to cigarette over time (Benowitz, 2008), most daily smokers are believed to distribute cigarettes fairly evenly over the course of the day in order to maintain relatively consistent “steady state” nicotine blood levels (Feyeraband, Ings, & Russell, 1985). Importantly, evenly spacing cigarettes across time may represent the ideal strategy for maintaining nicotine levels (see Figure 1, reproduced from Benowitz, 1992). That is, by evenly distributing cigarettes per day (CPD) over the course of the waking day, one optimizes the ability to maintain nicotine levels within the desired range, and reduces opportunities to hit trough levels and fall into nicotine withdrawal. In addition, daily smokers tend to take in approximately the same amount of nicotine every day (Benowitz, 2008), suggesting a drive to titrate nicotine levels to person-specific ‘typical range’, or set-point described above. Thus, patterns of regular cigarette smoking –both within days and across days- may be viewed in part as a behavioral reflection of the rise and fall of nicotine blood levels within the body across time.

1.2 SMOKE-FREE ENVIRONMENTS AND DAILY SMOKING PATTERNS

Environmental and psychosocial factors – in addition to nicotine blood levels – may also play a significant role in determining patterns of *ad libitum* smoking. For example, individuals are significantly *more* likely to smoke in some real-world situations and *less likely* to smoke in others (e.g., Shiffman et al., 2002; Shiffman & Rathbun, 2011; Shiffman & Paty, 2006). Kozlowski & Herman’s (1984) boundary model of smoking behavior posits that within the broad pharmacodynamic limits of nicotine toxicity (upper boundary) and nicotine withdrawal (lower boundary), smoking behavior may be influenced by a multitude of other factors, such as environmental context.

In today's more stringent tobacco control climate, exposure to environmental smoking restrictions represents an increasingly common *extrinsic* boundary that may constrain a person's daily smoking behavior – and nicotine levels – across time. While often framed as an intervention to protect the *non-smoking* public from the harms of ETS (Jacobsen, Wasserman, & Anderson, 1997), public smoking restrictions directly aim to modify the smoking behavior of continuing smokers. Over the past several decades, smoke-free environments have become increasingly widespread (Eriksen & Cerak, 2008) and are quite effective in suppressing smoking in designated locations (Jacobsen, Wasserman, & Anderson, 1997; Collins & Procter, 2011; Levy & Friend, 2003). The vast majority of US smokers now encounter smoking restrictions on a daily basis (Collins & Procter, 2011; CDC, 2011). By imposing external control on the availability of smoking in certain situations, environmental smoking restrictions may be viewed as a major barrier to the regularly-spaced, withdrawal-avoidance type of smoking behavior thought to be characteristic of daily smokers (Shadel et al., 2000). That is, prolonged exposure to restrictions (e.g., on working days) may be associated with extended intervals between opportunities to smoke cigarettes. For example, the individual who spends the majority of the day confined to a smoke-free building and campus (e.g., a hospital employee) may be unable to smoke for several hours at a time, perhaps long enough for nicotine to be substantially cleared from the body and for withdrawal symptoms to emerge.

High compliance with smoke-free laws (Eriksen & Cerak, 2008; Hopkins et al., 2001) suggests that these interventions have actually changed behavior among continuing smokers (e.g., Collins & Procter, 2011). However, the magnitude of the effect of restrictions on behavior may depend upon several factors. First, the nature or stringency of those policies is an important determinant of their effects (Jacobsen, Wasserman, & Anderson, 1997). For example, smoke-free policies that ban smoking in *all* work areas ("full" bans) are associated with greater reductions in smoking compared to policies that only ban smoking in some areas ("partial" bans) (McMullen et al., 2005; Cahill et al., 2008). Frequent and prolonged exposure to smoke-free environments during work hours – particularly when full smoking bans are in place – may pose a significant barrier to regular smoking and to smokers' ability to maintain levels of nicotine in the body and avoid troughs (e.g., lower levels relative to "accustomed" nicotine levels, or average levels when restrictions are not in effect). In comparison, non-working days may represent times in which the individual encounters much lower levels of restrictions in the environment. Importantly, individuals also differ in the extent to which they are exposed to smoke-free environments in their daily lives outside of work. For example, home smoking restrictions are becoming increasingly common, even among smokers (Levy, Romano, & Mumford, 2004; CDC, 2014), which suggests that it may be important to examine home restrictions as a moderator of workday and non-workday comparisons. Moreover, individuals may differ in the extent to which they encounter smoking restrictions during daily activities. For example, one recent study reported that a public indoor smoking ban in Germany significantly reduced smoking only among those individuals who regularly reported spending time in restricted public areas (e.g., bars; Anger, Kvasnicka, & Siedler, 2011). This suggests that, in addition to severity or type of smoking ban, the frequency with which individuals report exposure to restricted environments in the real world may be an important determinant of overall smoking behavior.

In summary, environmental smoking bans represent a pervasive part of everyday life for most of the population, and evidence suggests that these policies do indeed change smoking behavior. Yet, little is known about how, exactly, smoking bans affect daily smoking patterns among those who continue to smoke. Understanding the ways in which policy affects smoking behavior may provide insight into both the factors that underlay smoking in increasingly restrictive environments, and may also elucidate the ways in which restrictions may -or may not- provoke changes in smoking behavior, which could highlight important targets for interventions to reduce smoking and promote cessation.

1.3 QUANTIFYING INTERFERENCE WITH NICOTINE MAINTENANCE

Though extensively discussed in the literature, the construct of *nicotine maintenance* is seldom examined quantitatively. One possible reason for this is that studying nicotine levels over time is difficult, costly, and often impractical; subjects must be monitored closely and invasively in the confines of the laboratory. The lack of detailed longitudinal information about nicotine blood levels in ad libitum smokers thus makes it difficult to quantitatively assess how and whether individuals might successfully maintain nicotine levels within certain bounds in daily life. Given the association between nicotine blood levels and cigarette consumption across the waking day however (Benowitz, 1992), one potentially useful proxy for assessing nicotine levels over time is the temporal distribution of cigarettes over the course of the day. Although nicotine levels achieved by smoking a single cigarette may vary within and across individuals (Patterson et al., 2003), the rate of cigarette consumption across time offers a rough window into how much nicotine a smoker achieves at various points over the course of a waking day.

Previous work has identified pharmacokinetic parameters that relate nicotine blood levels to amount and intake from cigarettes smoked across time (Feyerabend et al., 1985; Porchet et al., 1988). *Simulated nicotine blood levels* can thus be estimated across time points based upon an equation that takes into account both quantity and temporal spacing of cigarettes along with established pharmacokinetic parameters of nicotine intake and metabolism. Nicotine blood levels at a given point in time are based upon the previous nicotine estimate and the number of smoking events since the last estimate, assuming constant nicotine boost per cigarette (i.e., 14 ng/mL; Porchet et al., 1988) and constant bi-exponential decay of nicotine since the previous estimate (initial half-life = 15 minutes; terminal half-life = 2.12 hours; Feyerabend et al., 1985; Porchet et al., 1988). This method is appealing for assessing nicotine maintenance, as it essentially distills the relevant parameters of smoking patterns – amount and temporal spacing of smoking events – into a single continuous outcome, which is theoretically meaningful for the assessment of nicotine maintenance. Of note, however, this model does not take into account variations in smoking topography –or differences in nicotine content across cigarette brands- that may influence nicotine boost achieved from each cigarette. Smoking intensity can vary considerably both within and across individuals, and may affect the amount of nicotine obtained from each cigarette (Patterson et al., 2003). Thus, while values may not precisely reflect individuals' actual plasma nicotine concentrations, simulated nicotine levels serve as *a single quantitative index of the temporal distribution of smoking* over the course of the waking day.

In this manner, simulated nicotine levels across time will vary as a function of spacing of cigarettes across waking hours. Figure 2 shows simulated nicotine levels across time from two different subjects on individual days, with real-time cigarette events marked at the bottom of each graph. Simulated nicotine levels were based upon real-time smoking data provided by subjects who monitored their ad libitum smoking behavior over a 3-week period, having been instructed to record all cigarettes in real-time on electronic diaries (EDs) as they were smoked. In both cases below, the participants smoke approximately 20 cigarettes over the course of a 15-hour waking day. Both participants begin the day by smoking immediately upon waking; this is shown below as a smoking event immediately prior to reporting waking on the ED. After waking, however, the participant on the left experiences a long interval of abstinence, during which nicotine levels decrease substantially. In contrast, the individual on the right smokes a number of cigarettes in close temporal proximity in the first few hours after waking, resulting in a dramatic increase in levels over the first several hours of the waking day. As the day progresses, the simulated nicotine levels of each subject differ dramatically as a consequence of differential temporal spacing of smoking events. While the subject on the right demonstrates relatively constant cigarette spacing, and achieves relatively steady levels during mid-day and evening hours, the participant on the left shows a dramatic escalation in smoking rate and nicotine levels toward the end of the day, and exhibits considerable variation in trough and peak levels of nicotine achieved on this day.

By analyzing simulated nicotine levels, which take into account spacing and amount of cigarette consumption, along with constant decay of nicotine levels over time, such differences become readily apparent. Moreover, values are meaningful and interpretable within a nicotine maintenance framework of smoking, and thus allow for a quantitative assessment of nicotine maintenance.

a. b.

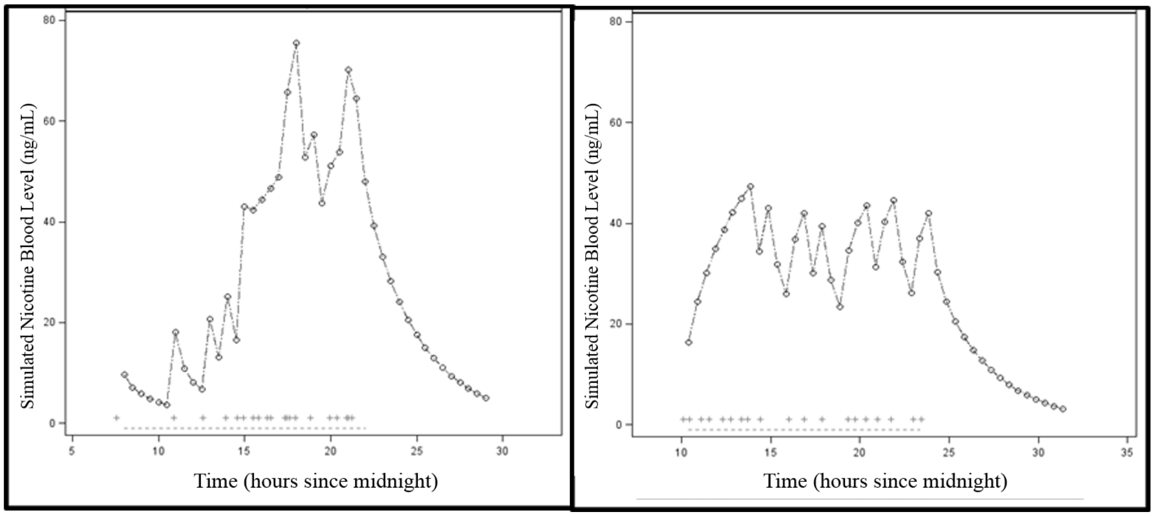

Figure 2. Two participants with similar total cigarettes per day (~20) but different spacing of cigarettes, demonstrate substantial differences in predicted nicotine levels over time.

1.4 STANDARDS OF NICOTINE MAINTENANCE

Although they are useful in quantifying the temporal distribution of smoking, “raw” simulated nicotine levels provide little insight into whether or not individuals are striving to maintain nicotine levels within some person-specific range. As noted above, individuals may differ in typical range of nicotine levels experienced over time, and can differ widely in CPD. Thus, to provide insight into whether nicotine maintenance is efficient or optimal for a given subject on a given day, simulated values must be compared against a conceptually relevant standard or control.

1.4.1 Nicotine Levels Relative to Perfect Spacing of Cigarettes

Optimal nicotine regulation is achieved by spacing cigarettes evenly over the course of the day, minimizing the duration and magnitude of declines in nicotine levels due to metabolism and thus efficiently avoid nicotine troughs (Benowitz, 1992). Deviations from nicotine levels achieved through evenly distributing cigarettes over the course of the day may be viewed as a departure from optimal nicotine maintenance. Thus, comparing nicotine levels achieved via actual temporal smoking patterns to those yielded by evenly-distributed CPD is one way to quantify interference with optimal nicotine maintenance.

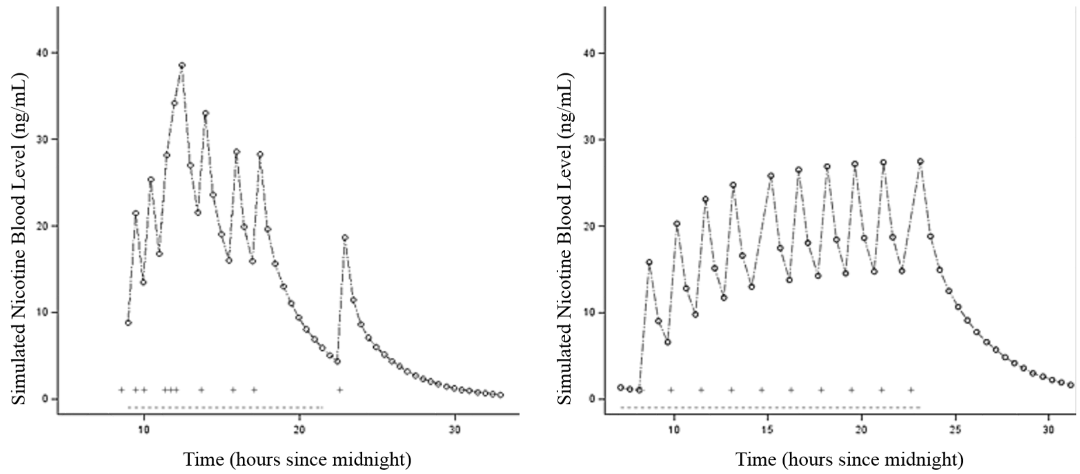

Figure 3. Real-time smoking-predicted nicotine levels compared to evenly-distributed smoking predicted nicotine levels across the waking day (10 CPD).

The set of figures above contrasts estimated nicotine levels from an actual smoker against nicotine levels estimated based upon consuming the same number of cigarettes, but at evenly spaced intervals. As described above, variations in temporal spacing of cigarettes can produce very different simulated nicotine profiles within the waking day, even if daily levels of consumption are held constant. Expressing simulated nicotine levels achieved through real-time smoking in relation to levels achieved through perfect spacing (for given CPD) provides insight into the degree to which an individual's daily temporal smoking pattern differs from an optimal nicotine maintenance smoking pattern and *when* such deviations are most pronounced.

1.4.2 Nicotine Levels on Workweek vs. Weekend Days

Since most individuals encounter the heaviest 'dose' of restrictions in the workplace (CDC, 2011), the effect of exposure to restrictions on nicotine maintenance during working hours on weekdays (i.e., Monday-Friday; or, the *workweek*) is of particular interest. As noted above, weekend or leisure days may represent the conditions in which individuals may engage in truly "ad libitum" smoking, and thus achieve desired nicotine levels throughout the day. Therefore, it may also be useful to quantify 'person-specific' interference with nicotine maintenance by comparing participants' nicotine levels during the workweek to their average nicotine levels achieved during comparable time periods on weekends. In this way, each subject serves as his or her own control, accounting for daily trends in nicotine levels across time of day. This provides a gauge for the degree to which temporal smoking patterns and nicotine levels on workdays differ from those on non-working days.

Since individuals differ with regard to the typical range of nicotine levels that they experience or prefer, this may be a useful index for assessing how and whether individuals breach personal nicotine boundaries on restricted weekdays relative to weekend days. As discussed above, however, individuals also differ in the extent to which weekend days may represent unrestricted days, during which true ad libitum smoking can occur. A growing number of smokers have smoke-free policies at home (Levy, Romano, & Mumford, 2004). For this reason, it may be essential to examine the presence of home restriction policies when assessing effects of workplace restrictions during working hours on workweek nicotine levels compared to weekend nicotine levels.

Substantially lower percentages of simulated nicotine levels during working hours on weekdays compared to weekends, or person-specific 'nicotine troughs', may be viewed as evidence of failure to maintain nicotine. However, as discussed above, no previous work has attempted to quantitatively define the theorized boundaries that differentiate typical nicotine levels from atypical levels. Above 0 ng/mL, it is unclear what may define a "trough" threshold for a given individual. Absent empirical data, it is therefore difficult to identify when and how frequently individuals transgress their lower nicotine boundary, or trough threshold, indicating a failure to maintain. One relatively conservative approach to identifying 'atypical' nicotine levels for a given individual at a certain point in time on workdays may be a 50% deviation from mean nicotine levels during that time period on unrestricted non-workdays. This metric may provide at least some indication of the extent to which exposure to restrictions on workdays interferes with nicotine maintenance relative to non-workdays.

As discussed above, nicotine levels can vary considerably at comparable time points (e.g., midday hours) across days, despite similar total daily CPD. However, expressing the individual's nicotine levels on weekdays relative to levels at comparable times on weekends provides insight into the extent to which smoking patterns during a given time period may differ across days as a function of exposure to workplace restrictions. Figure 4 illustrates nicotine levels over the course of a workday and a non-workday (in this case, a weekend day) for a single subject with full workplace restrictions and no home restrictions. In the panel on the left (Figure 4a.), the individual demonstrates a spike in nicotine levels during the morning hours, followed by a considerable decline in nicotine levels during the midday hours on that day. In contrast, this participant shows consistent smoking over time on a weekend day (Figure 4b.), leading to a more gradual increase in nicotine levels during the morning hours and relatively stable nicotine levels during the remainder of the day. Thus, examining nicotine levels during comparable time blocks across working and non-working days can provide some insight into the extent to which individuals experience interference with nicotine maintenance during restricted working hours during the workweek, relative to comparable times on weekends when individuals may smoke ad libitum.

a. b.

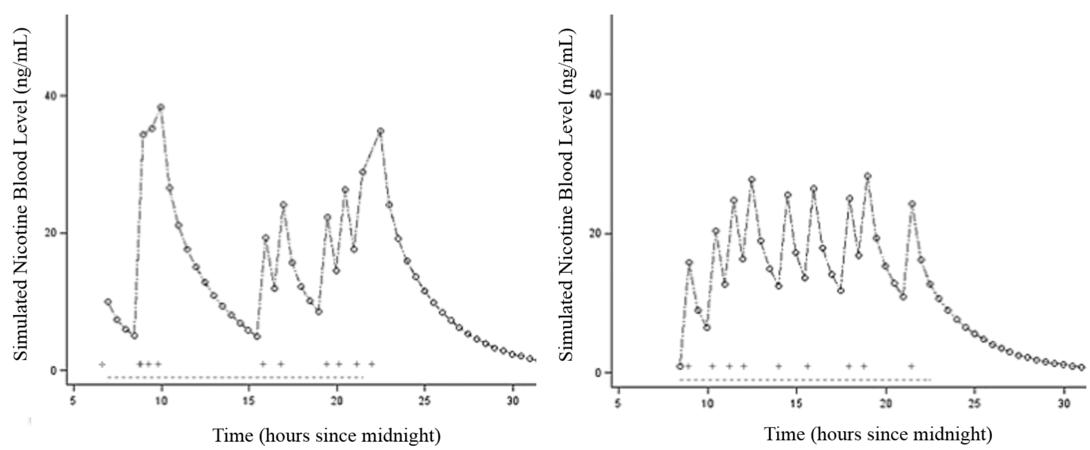

Figure 4. Nicotine levels on a weekday (a.) and weekend (b.) for an individual with full workplace smoking restrictions and no home smoking restrictions.

In summary, simulated nicotine levels can serve as an endpoint for assessing variations in temporal smoking patterns, as they take into account clustering of cigarettes, of cigarettes consumed, and the clearance of nicotine over time. Simulated nicotine levels may be *particularly* useful for assessing nicotine maintenance as expressed in relation to 1) deviation from levels achieved through "ideal" spacing, or optimal "nicotine maintenance", and 2) deviation from levels achieved on workdays compared to non-workdays at comparable times of day (i.e., typical pre-work, mid-workday, and post-work hours). Importantly, this approach incorporates conceptually meaningful controls. That is, interference with maintenance on workdays is defined relative to 1) the subject's total CPD on that day; and 2) the subject's "typical" mean nicotine levels in comparable times of day on non-workdays. Furthermore, this approach also accounts for circadian variations in smoking patterns over the course of the waking day (Chandra et al., 2007), which could potentially confound an analysis of the temporal association between smoking rate and exposure to workplace restrictions.

1.5 RESTRICTIONS AND COMPENSATORY SHIFTS IN SMOKING PATTERNS

Past studies have established that smokers can and do compensate for other barriers to nicotine maintenance (e.g., in response to changes in tar content, filter vents, etc.; Benowitz, 2001; Scherer, 1999; Evans & Farrelly, 1998). Similarly, past research on the effects of restriction policies on cigarette consumption suggest that continuing smokers may partially compensate in the face of environmental restrictions by smoking more cigarettes when restrictions are not in place. With regard to implementation of workplace smoking restrictions, a number of studies have reported decreased smoking at the workplace and/or on workdays, and a corresponding increase in smoking *outside* of work (Borland & Owen, 1995; CDC, 1990; Baile et al., 1991; Borland, Chapman, Owen, & Hill, 1990). Others have reported decreased smoking at the workplace and/or during work hours, but no change outside of work (Brigham et al., 1994; Stave et al., 1991; Olive et al., 1996; Stillman et al., 1990). In line with this, a study by Wakefield et al. (1992) observed that smokers who encountered workplace restrictions smoked less frequently at work compared to outside of work, while individuals with no worksite restrictions showed no difference in self-reported work and leisure cigarette consumption. In another study (Kinne et al., 1993), smokers with strict worksite restrictions reported greater decreases in workday cigarette consumption following implementation of a smoke-free policy relative to individuals with less severe or no policies.

Some previous studies have examined broad variations in temporal smoking patterns in relation to smoking restrictions. Generally, these studies suggest that restrictions selectively suppress smoking during working hours (e.g., 9am-5pm), when they are in effect. For example, a large study (n=3,174) of English smokers reported that smokers who worked at sites with indoor restrictions tended to smoke significantly *more* both before and after the workday (as assessed by global self-report) and less during the workday. In contrast, smokers who worked at a site with no smoking restrictions smoked most during the afternoon (Meade & Wald, 1977). In a more recent study among individuals who reported daily, real-time smoking patterns using electronic diaries, exposure to smoking restrictions was associated with patterns of daily smoking over the course of the day (Chandra et al., 2007). Specifically, exposure to restrictions was negatively associated with rate of cigarette consumption, and this was most pronounced among smokers that demonstrated a characteristic pattern of decreased smoking during the mid-day hours and increased smoking in the evenings (“Daily-Dip Evening Incline” smokers; Chandra et al., 2007). Additionally, Borland et al. (1997) reported that following the implementation of an indoor smoking restriction policy, individuals reported smoking fewer cigarettes and taking fewer smoking breaks during the workday. In addition, Parry et al. (2000) reported that following the implementation of an institutional smoking ban, a majority of university employees reported that their smoking had decreased during the workday. Among these individuals, roughly 22% reported increased smoking before and after working hours, while over 60% reported no change in smoking outside of work hours; the remainder reported reduced smoking outside of work (11%) or cessation.

Thus, some studies suggest that restrictions may correlate with lower smoking during working hours as well as increased smoking before working hours (consistent with a nicotine maintenance perspective); however, there is also evidence in support of increased smoking *following* exposure to restrictions (inconsistent with smoking to avoid nicotine troughs). The exact nature of the relationship between restrictions and elevated smoking rate before and after work is unclear, though, as many studies that report changes do not report on smoking rate during appropriate control settings (e.g., comparable pre-work and post-work time blocks on non-working days). Therefore, past work suggests that individuals may change temporal smoking patterns to compensate for exposure to smoke-free policies. The direction and magnitude of such changes, however, along with the implications for interference with nicotine maintenance during the waking day, remain unclear.

1.6 TEMPORAL COMPENSATION AND NICOTINE MAINTENANCE

The evidence described above suggests that individuals may adjust their temporal smoking patterns in response to smoking restrictions in a number of different ways. These patterns have different implications for understanding motivations to smoke in more restrictive environments. Viewed from a nicotine maintenance perspective, temporal compensation should demonstrate specific features. That is, if the objective of compensation is to maintain nicotine levels above a certain threshold in order to avoid nicotine troughs, continuing to smoke at regular intervals throughout the workday by taking frequent smoking breaks ("ad hoc compensation") is one way in which smokers could successfully maintain nicotine levels. This may manifest as no significant change in temporal smoking patterns in response to restrictions. More specifically, ad hoc compensation may be indicated by instances in which individuals report changing locations to smoke during work hours on weekdays (e.g., went outside of the office building on a "smoke break").

Another approach to compensation, which is consistent with a nicotine maintenance perspective, is increased smoking before exposure to restrictions (e.g., in the morning before work on working days). Such "anticipatory compensation" may help individuals to increase nicotine blood levels to a point, such that they remain above a withdrawal threshold for a few hours, until the next smoking opportunity occurs. In contrast, compensation via "binging" after exposure to restrictions (or "make-up compensation") is at odds with a nicotine maintenance perspective of smoking. That is, after nicotine levels have been sufficiently "restored," and assuming individuals will be able to smoke as desired once restrictions have been lifted, there is no apparent benefit to "overloading" on nicotine after-the-fact. Unlike caloric compensation in the case of eating, excess nicotine cannot be stored and later accessed during “leaner” smoking times – it is continuously, rapidly cleared from the system as time progresses. Make-up compensation is thus inconsistent with a strict nicotine maintenance model of smoking.

As with the construct of nicotine maintenance, no literature has sought to quantitatively define compensatory smoking behavior in the service of nicotine maintenance. Temporal compensation, as discussed above, may be defined as increased smoking rate and nicotine levels prior to or following a period of exposure to restrictions. Similar to the manner in which interference with nicotine maintenance might be indicated by significantly lower smoking rate and nicotine levels (relative to conceptually meaningful standards of comparison), temporal compensation may be defined in terms of increased smoking rate and higher nicotine levels in the time periods before and after exposure to workplace restrictions on weekdays. In addition, just as the appearance of nicotine troughs during typical working hours may be evidence of failure to maintain nicotine levels, compensatory smoking may be also be marked by the appearance of “nicotine spikes” in the hours before and/or after work. No previous work has established quantitative definitions for what constitutes a nicotine trough or a nicotine spike for a given individual. However, substantial deviations of nicotine levels on workdays relative to comparable times on weekends (e.g., ± 50%) may be indicative of a trough (-50%) or a spike (+50%) for that person during that time period (i.e., before typical work hours, during work hours, or after work). With regard to compensatory behaviors described above, anticipatory compensation would thus be associated with greater likelihood of spikes during pre-work hours on weekdays, whereas make up compensation would be associated with greater likelihood of spikes during post-work or evening hours on weekdays.

Evidence for temporal compensation has important implications for evaluating a nicotine maintenance perspective on smoking in restricted environments. If individuals do attempt to compensate by smoking more and achieving higher levels of nicotine before exposure to restrictions, this may suggest a strong role for nicotine maintenance in driving smoking behavior in restricted environments. Alternatively, if individuals fail to compensate prior to workdays, or demonstrate make-up compensation, this may suggest a role for other factors (in addition to nicotine maintenance) in driving daily smoking patterns in restricted settings. Additionally, as noted above, evidence suggests that individuals partially compensate for other barriers to nicotine maintenance by changing smoking topography (e.g., Scherer, 1999). Thus, lack of temporal compensation could also signify that individuals may compensate for restrictions by intensifying smoking intake when restrictions are lifted (Chapman et al., 1997), which could preserve higher systemic nicotine blood levels despite fewer smoking opportunities. This mechanism of compensation could be consistent with a nicotine maintenance perspective as well.

In summary, assessing the nature of temporal compensation in response to restrictions may have important implications for understanding the factors that govern smoking behavior in more restricted settings.

1.7 NICOTINE DEPENDENCE, NICOTINE CLEARANCE, AND COMPENSATION

Exposure to restrictions is expected to interfere with a smoker's ability to maintain nicotine levels relative to two standards: 1) nicotine levels achieved through even temporal spacing of cigarettes, and 2) nicotine levels achieved on restricted working days compared to typical levels achieved at comparable times on unrestricted leisure days. In addition, individuals are expected to demonstrate compensatory increases in smoking during times when restrictions are not in effect (i.e., in pre-work or post-work hours). However, the degree to which restrictions prompt compensatory behavior on workdays may be contingent upon the extent to which individuals are motivated to smoke in order to avoid withdrawal in the first place. That is, the effects of restrictions on nicotine maintenance and smoking patterns – and particularly, evidence for compensation in the face of smoking restrictions – may vary across individuals depending on stringency of nicotine dependence and/or the rate with which nicotine is cleared from the body.

Traditional perspectives of dependent smoking, which emphasize withdrawal avoidance and difficulty abstaining from smoking, imply that more dependent individuals should exhibit greater drive to maintain nicotine levels (e.g., during restricted work hours). Individuals who exhibit greater difficulty tolerating prolonged periods of abstinence may be more likely to demonstrate compensatory behavior compared smokers who are less dependent in this respect. Some past research suggests that this is the case. In one study, only highly dependent smokers demonstrated compensatory increases in smoking when restrictions were not in place following implementation of a smoke-free policy at work (Borland et al., 1990). Similarly, Borland & Owen (1995) reported that only more addicted smokers took more cigarette breaks during working hours following implementation of a ban and were less likely to reduce smoking rate during the work day. In addition, Baile et al. (1991) reported that following implementation of a workplace ban, greater nicotine tolerance was associated with an increase in smoking both before and after work. Thus, more dependent smokers may be more likely to compensate for environmental restrictions in some ways relative to less dependent smokers.

Dependence may therefore moderate the relationship between exposure to restrictions and temporal smoking patterns, which may manifest in several ways. First, more dependent individuals may attempt to maintain nicotine levels more adamantly by more frequently escaping restrictions to smoke (Borland & Owen, 1995) and may thus demonstrate greater success at maintaining nicotine levels. In addition, they may be more likely to demonstrate anticipatory compensation in the service of maintaining nicotine levels. In contrast, less dependent individuals may demonstrate less difficulty tolerating periods of abstinence, and may be less likely to compensate beforehand (i.e., anticipatory compensation). By extension, less dependent individuals may be more likely to experience nicotine troughs, to demonstrate greater differences in nicotine levels across work and non-workdays, and to demonstrate greater interference with nicotine maintenance relative to more dependent individuals.

Similarly, individuals differ in the rate at which nicotine is cleared from the body, and past research suggests that faster nicotine clearance rate may be associated with increased smoking behavior (e.g., number of cigarettes per day; Benowitz, Pomerleau, Pomerleau, Jacob, 2003). Smokers who clear nicotine more rapidly may demonstrate greater sensitivity to and/or shorter latencies to nicotine withdrawal symptoms associated with deprivation, which could prompt greater compensatory smoking. In contrast, individuals who metabolize nicotine more slowly may be better able to 'weather' periods of deprivation without experiencing withdrawal, and thus may be less likely to demonstrate compensatory behavior when confronted with periods of enforced deprivation. Fast metabolizers may therefore demonstrate greater interference with nicotine maintenance during work hours, and greater likelihood of anticipatory and ad hoc compensation relative to slower metabolizers.

Therefore, assessing differences in the relationship between exposure to restrictions, interference with nicotine maintenance, and temporal compensation across individuals with different levels of dependence and in relation to individuals' nicotine clearance rate may be important in clarifying how and for whom restrictions affect smoking patterns.

1.8 SUMMARY

Among daily smokers, temporal smoking patterns are thought to reflect the ebb and flow of nicotine levels in the body, such that individuals are expected to smoke regularly enough to maintain nicotine levels above some personal withdrawal threshold or trough level (Benowitz, 2008; Russell, 1971). Exposure to workplace smoking bans may interfere with smokers' ability to maintain nicotine levels during typical work hours on weekdays. However, no studies to date have attempted to assess or quantify interference with nicotine maintenance in relation to exposure to workplace smoking bans, nor has any literature empirically examined evidence for temporal compensation in relation to exposure to smoke-free environments. Clarifying the association between exposure to smoke-free environments, interference with nicotine maintenance, and evidence for temporal compensation may provide insight into the factors that drive smoking and the extent to which a nicotine maintenance model sufficiently accounts for observed daily smoking patterns in the increasingly smoke-free modern world.

The goal of this study is to quantitatively examine interference with nicotine maintenance and evidence for temporal compensation in relation to participants' exposure to environmental smoking restrictions during working hours on weekdays. It is hypothesized that exposure to workplace smoking bans will be associated with reduced smoking rate and greater *interference with nicotine maintenance* during working hours compared to other times on weekdays (vs. weekends), and that exposure to more severe workplace restrictions (i.e., *full* bans) will be associated with *anticipatory* and *ad hoc* temporal compensation – but not *make-up* compensation- on weekdays (vs. weekends). Nicotine dependence is expected to moderate these relationships, such that more dependent individuals will demonstrate less interference with nicotine maintenance and greater likelihood of *anticipatory* and *ad hoc* compensation relative to less dependent individuals. Similarly, nicotine metabolite ratio (NMR), an index of nicotine clearance rate, is expected to moderate relationships, such that those who more rapidly clear nicotine will demonstrate greater interference with nicotine maintenance during work hours and greater likelihood of *anticipatory* and *ad hoc* compensation. Finally, stringency of home restrictions is expected to moderate these relationships, such that individuals with home restrictions will demonstrate smaller differences across weekdays and weekends.

2.0 METHODS

2.1 ANALYTIC APPROACH

This study examines the relationships discussed above through secondary analysis of an existing dataset. The sample, a subset of persons described in Shiffman et al. (2014), includes daily smokers who recorded all ad libitum smoking, in real time via Ecological Momentary Assessment (EMA; Shiffman, Stone, & Hufford, 2008) over a 3-week monitoring period. Exposure to smoking restrictions was not experimentally manipulated in the current study; rather, individuals provided information on presence and stringency of smoke-free policies in their work and home environments. Thus, “natural” variation in restrictions among individuals (i.e., frequency of exposure in the real world, presence and stringency of workplace and home restrictions) is examined in relation to smoking rate and simulated nicotine levels across individuals, and within individuals across days (weekdays vs. weekends) and blocks of time during the day (Pre-work, Work, Post-work, and Night hours).

2.2 TERMINOLOGY

The study takes a multifaceted approach to assessing the relationship between exposure to restrictions, interference with nicotine maintenance, and temporal compensation on weekdays. Below, I define key terms and measures used in the analyses. Terms are also summarized in Table 1.

2.2.1 Predictors

Time

Detailed information on participants' typical work schedules was not available. As such, time at work was assessed as socially conventional business hours (i.e., 9am-5pm). Preliminary analyses using EMA reports (i.e., Location? -- "At work") confirmed that the majority of individuals' work schedules followed expected social workweek patterns. That is, most individuals reported being at work during mid-day hours on weekdays, and not on weekends; in addition, most individuals *did not* report being at work before 9am or after 5pm on weekdays. Students (n=12) and individuals with irregular/unidentifiable work schedules (e.g., no instances of being 'at work'; n=6) were excluded from analyses. 16 participants who were retained in the final sample reported being 'at work' at least 1 time on Saturday or Sunday during EMA observations. [Note: Of these, most reported full work restrictions (n=10).] Post-hoc sensitivity analyses were conducted -with and without these individuals- to assess whether or not results were affected by the inclusion of this group; results were unchanged. In addition, sensitivity analyses were conducted using more stringent definitions for pre-work (4am-8am), work (11am-

3pm), and post-work (8pm-12am) time blocks. The pattern of findings did not change. As such, results are reported for the full sample.

Time of Day Blocks

Time of day was treated as blocks of time corresponding to socially conventional business hours (i.e., 9am-5pm work hours). The following time blocks were used as predictors of continuous outcomes: Pre-work: 4am-8:59am; Work: 9am-4:59pm (the reference condition); Post-work: 5pm-8:59pm; Night: 9pm – bedtime. To account for variable time spans across time blocks for frequency outcomes (i.e., counts of trough and spike events), the Work time block was separated into two 4-hour bins (9am-12:59pm; 1pm-4:59pm).

Weekdays vs. Weekends

Day of week was categorized as either weekdays (i.e., Monday-Friday) or weekends (Saturday and Sunday; the reference group). As discussed above, preliminary analyses suggested that most individuals did not report working on weekends during the EMA monitoring period.

Exposure to Workplace Restrictions

Percent of Restricted Observations at Work

Real-world exposure to work restrictions was quantified as the percent of EMA observations in which smoking was "forbidden," based on all EMA non-smoking observations in which a participant reported being "at work".

Stringency of Workplace Indoor Smoking Policy

Stringency of workplace smoking restrictions was also assessed via individuals' self-report on baseline questionnaires, which included items pertaining to type (e.g., complete indoor ban vs.

smoking allowed in some or all areas) of workplace indoor smoking policies. Workplace indoor smoking policy was examined as a person-level categorical variable, with the following levels: ‘no ban (reference group), ‘partial ban, and ‘full ban’ (Current Population Survey- Tobacco Use Supplement; US Department of Commerce, Census Bureau, 2006).

2.2.2 Moderators

Nicotine Dependence

Nicotine dependence questionnaire measures that purport to assess constructs related to “physical dependence/withdrawal-avoidance,” “compulsion to smoke,” and “regularity of smoking rate” were examined as moderators. The following scales were used: Fagerstrom Test of Nicotine Dependence: FTND total score (Heatherton et al., 1991); Nicotine Dependence Syndrome Scale: drive and continuity subscales (Shiffman et al., 2004).

Rate of Nicotine Clearance

Rate of nicotine clearance was assessed via urinary nicotine metabolite ratio (NMR; 3-hydroxycotinine:cotinine). This measure serves as a reliable proxy for the rate at which individuals metabolize and excrete nicotine from the body (Benowitz et al., 2010).

Home Smoking Policy

Exposure to home smoking restrictions was assessed via individuals’ self-report on baseline questionnaires, with ‘no ban’ (reference group), ‘partial ban, and ‘full ban’ as the response levels (Current Population Survey- Tobacco Use Supplement; US Department of Commerce, Census Bureau, 2006).

2.2.3 Outcomes

A number of outcomes were used to address the two primary hypothesis domains: *Interference with Nicotine Maintenance* and *Temporal Compensation.* These are described in detail below.

Smoking Rate

Smoking rate was calculated as cigarettes per hour (CPH) for each hour of the waking day.

Simulated Nicotine Levels

Cigarette consumption across time was used to simulate nicotine blood levels at half-hour intervals over the entire EMA monitoring period (i.e., continuous time, including nights, from beginning to end of the monitoring period). Estimates at each time point (Nicotine_{t}) were based upon the previous estimated nicotine level (Nicotine_{t-30}), assuming constant bi-exponential decay of nicotine (summarized as the average effect of the influence of initial half-life=15 minutes and terminal half-life=2.12 hours; Feyerabend et al., 1985; Porchet et al., 1988), the number of smoking events in the last half-hour interval, and an average 'boost' of nicotine per cigarette of 14ng/mL (see Equation 1). Instances in which individuals demonstrated multiple smoking events (n > 3) within a 30-minute intervals produced unreasonably high estimates in relation to data from controlled laboratory studies of nicotine pharmacokinetics (Feyerabend et al., 1985; Porchet et al., 1988), and were subsequently adjusted to reflect smaller nicotine boosts

(-2 ng/mL) across subsequent cigarettes (i.e., 4th cigarette boost=12 ng/mL; 5th =10 ng/mL, etc.) [*Note*. Dr. Neal Benowitz assisted in the development and refinement of this algorithm.]

Equation 1. Estimated Blood Nicotine Levels at Time *t*

$$\text{Nicotine}_{t} = (\text{Nicotine}_{t-30} * e^{-1.39} + \text{Nicotine}_{t-30} * e^{-0.16})/2 + (14 \text{ ng/mL} * n_{\text{Cigs}})$$

Nicotine Maintenance Standards of Comparison

Interference with nicotine maintenance and evidence of temporal compensation were assessed in relation to two standards, representing an *optimal nicotine maintenance* smoking pattern and subject-specific *preferred smoking*, respectively:

1) **Simulated Nicotine Levels: Evenly-Spaced Smoking Comparison.** Nicotine levels achieved through evenly-spaced distribution of cigarettes per day served as one standard for assessing interference with nicotine maintenance *across all days*. As anticipated, evenly-spaced smoking (ESS) nicotine levels were lowest in the morning hours, and increased with smoking over the course of the waking day. When the comparison between real-time (RTS) and ESS nicotine was expressed as a percentage, values were biased, such that percentages were artificially inflated in the morning hours relative to later times (i.e., because the denominator was lowest in the morning hours, even small deviations could result in high percentages). 'Raw' difference scores between RTS and ESS at each time point did not show such a bias. Thus, the comparison to *optimal nicotine maintenance* smoking was assessed as the difference score between RTS nicotine levels and ESS nicotine levels (ΔEvenNL).

2) **Simulated Nicotine Levels: Preferred Weekend Smoking Comparison**. Nicotine levels achieved during "ad libitum" smoking periods on weekend days served as a person-specific standard for assessing interference with maintenance in relation to exposure to

workplace restrictions *on weekdays*. This was defined as percent of nicotine levels at each time point on weekdays relative to the participant's mean nicotine levels during the comparable time windows (120 minute blocks) on weekends (%WeekendNL). In this way, each subject serves as his own control, and values are adjusted for approximate time of day. *Trough events* were defined as instances in which % WeekendNL were <50%; *spike events* were defined as instances in which % WeekendNL were >150%.

Table 1. Summary of predictors and outcomes.

Predictor	Measure	Term
Time of Day	**Pre-work** time block (4am-8:59am) **Work** time block (9am-4:49pm) **Post-work** time block (5pm-8:59pm) **Night** time block (9pm-1:59am)	Time Block
Day of Week	**Workweek**: Monday – Friday; **Weekend**: Saturday – Sunday	Workweek/Weekend
Percent of Restricted Observations at Work	**Real-World Observed Percent Exposure to Restrictions.** % of EMA non-smoking assessments at work in which restrictions are reported)	% Observed Work Restrictions
Stringency of Workplace Indoor Smoking Policy	**Global Questionnaire Self-Report.** Stringency of work restrictions: no ban (reference group), partial ban, full ban	Workplace smoking policy
Moderators		
Home Smoking Policy	**Global Questionnaire Self-Report.** Stringency of home restrictions: no ban (reference group), partial ban, full ban	Home smoking policy
Dependence	**Nicotine Dependence Score**. Fagerstrom Test of Nicotine Dependence; Nicotine Dependence Syndrome Scale (Continuity and Drive subscales).	FTND, NDSS Continuity, NDSS Drive
Nicotine Clearance Rate	**Nicotine Metabolite Ratio**. Log-transformed ratio of urinary cotinine (ng/mL) to 3'-hydroxycotinine ng/mL).	NMR

Table 1 (continued)

Outcome Domain	Measure	Term
Smoking Behavior	**Smoking Rate.** Mean cigarettes per hour.	CPH
Interference with Nicotine Maintenance and Temporal Compensation	**Simulated Nicotine Levels: Evenly-Spaced Smoking Comparison.** Mean difference score between real-time smoking predicted nicotine levels relative to even temporal spacing of CPD.	ΔEvenNL
	Simulated Nicotine Levels: Ad Libitum Weekend Smoking Comparison. Mean percent of nicotine levels on workdays relative to mean nicotine levels in comparable time period on non-workdays.	%WeekendNL
Interference with Nicotine Maintenance	**Nicotine Trough Events** (<50% WeekendNL)	
	Likelihood of demonstrating any vs. no trough events	Trough Likelihood
	Number of trough events	Trough Frequency
	Maximum number of contiguous trough events	Max Trough Span
Temporal Compensation	**Nicotine Spike Events** (>150% WeekendNL)	
	Likelihood of any vs. no spike events	Spike Likelihood
	Number of spike events	Spike Frequency
	Maximum number of contiguous spike events	Max Spike Span
Ad Hoc Compensation	EMA-report of changing locations from restricted setting to smoke during work hours on weekdays.	Escaping Restrictions

2.3 HYPOTHESES

The dataset and analyses were structured to assess evidence for interference with nicotine maintenance and temporal compensation in relation to exposure to workplace smoking restrictions. The following primary hypotheses were assessed:

Interference with Nicotine Maintenance

I. Individuals with more frequent exposure to work restrictions will demonstrate greater interference with nicotine maintenance during working hours on weekdays.

II. More stringent workplace smoking policy will be associated with greater interference with nicotine maintenance during working hours on weekdays.

Temporal Compensation

III. Individuals with more frequent exposure to work restrictions will demonstrate greater ad hoc compensation during working hours on weekdays.

IV. More stringent workplace smoking policy will be associated with greater anticipatory compensation and ad hoc compensation –but not make-up compensation- on weekdays.

2.4 DATA ANALYSIS

The dataset was comprised of unbalanced, repeated-measures longitudinal data on smoking events and simulated nicotine levels across time. Individuals varied in terms of the number and timing of data points across the monitoring period, and also varied in the number of missing days (e.g., days on which complete real-time cigarette data was unavailable) over the course of the study. Data were organized hierarchically, with time blocks nested within days, and days nested within subjects. For the purpose of analysis, outcomes were aggregated (e.g., as means, counts, or binary 'present/absent' indicators) within time blocks for each subject-day.

Mixed modeling (SAS ProcMixed) was used to assess the relationships between exposure to restrictions and continuous outcomes of smoking rate and simulated nicotine. Models specified random intercepts across subjects; otherwise, predictors were assessed as fixed effects. Generalized estimating equations (GEE; SAS ProcGenmod specifying log linear link for Poisson data and logit link for Binary data) was used to assess trough and spike counts (Poisson distribution), max trough and spike spans (Poisson distribution), likelihood of demonstrating nicotine spikes and troughs (Binary distribution), and likelihood of changing locations to smoke (Binary distribution). Models were constructed in a hierarchical fashion, sequentially examining effects of time block, weekday/weekend, workplace smoking policy, and their interaction, on outcomes.

2.4.1 Analyses

To evaluate hypotheses I and III, models assessed the relationships between percentage of observed work restrictions and all outcomes during the work time block on weekdays. To address hypotheses II and IV, models examined the interaction between time block, weekday/weekend, and workplace smoking policy for CPH, ΔEvenNL, and likelihood of changing locations to smoke (*ad hoc compensation*). For % WeekendNL and trough and spike events, analyses focused on workplace policy by time block interactions on weekdays. Significant interactions were analyzed via pairwise comparisons to assess the following differences: 1) within workplace smoking policy group, significant differences between time blocks (reference group: *Work* time block); and 2) within time block, significant differences between workplace smoking policy groups (reference group: no ban). For logistic analyses, effects coding was used to assess the contrasts between the Work time block (9am-12:59pm; 1pm-4:59pm) and each of the other time blocks.

All analyses were constrained to time points within the waking day, as defined by participant-reported wake and bedtimes each day. *Interference* was defined as lower CPH, ΔEvenNL and %WeekendNL, and increased trough likelihood, trough frequency, and max trough span during the Work time block. *Anticipatory compensation* was defined as higher CPH, ΔEvenNL and %WeekendNL in the Pre-Work time block; *make-up compensation* was defined by significant *elevations* in the Post-Work and/or Night time block (i.e., *after* work). *Ad hoc compensation* was assessed as increased likelihood of changing locations to smoke during the Work time block on weekdays.

2.4.2 Covariates

Analyses were initially conducted without adjustment for covariates. To assess the influence of various demographic, home, and workplace characteristics on analyses of workplace smoking policy, time block, and weekday/weekend, models were adjusted to control for race, occupation type, number of coworkers who smoke, partner smoking status, and home smoking policy (see

Appendix 4, which shows the results from the policy*weekday*time block interaction analyses on the primary outcomes of CPH, ΔEvenNL and %WeekendNL). There was little substantive difference in adjusted and unadjusted analyses with regard to the hypothesized effects. Unless otherwise noted, results for the unadjusted analyses are presented below.

3.0 RESULTS

3.1 DESCRIPTIVE DATA

3.1.1 Sample Characteristics

The final sample consisted of 124 established daily smokers who reported information on workplace smoking restriction policy and provided at least 5 days of EMA data. On average, participants provided 20.57 (SD=4.00) days of EMA monitoring data. Overall, individuals contributed a total of 1,692 days (1,186 workweek days; 506 weekend days), recorded 25,957 cigarettes, and reported situational data on a total of 14,767 smoking (n=8,039) and non-smoking (n=6,728) occasions.

Smoking and demographic information is summarized in Table 2. Individuals averaged 39.96 (SD=10.69) years old, were 67% Caucasian, and demonstrated moderate levels of nicotine dependence and cigarettes per day.

Table 2. Participant characteristics

	Mean (SD)/%
	n=124
Age	39.96 (10.69)
Gender (Male)	54.84%
Race	
Caucasian	66.94%
African American	29.84%
Other	3.23%
Occupation Type	
White Collar	30.65%
Blue Collar	37.10%
Other	32.26%
Income (<$25,000/year)	40.32%
Workplace Smoking Policy	
Full Ban	51.61%
Partial Ban	30.65%
Smoking Permitted	17.74%
Home Smoking Policy	
Full Ban	17.74%
Partial Ban	22.58%
Smoking Permitted	59.68%
Cigarettes per Day (Real-Time EMA Report)	10.90 (6.38)
Nicotine Dependence	
FTND	5.14 (1.94)
NDSS Drive	-0.29 (1.12)
NDSS Continuity	-0.44 (1.11)

3.1.2 Correlates of Workplace Smoking Policy

Slightly more than half of the sample reported full indoor smoking bans (51.61%) in the workplace; 30.65% reported partial bans, and 17.74% reported no indoor smoking ban in the workplace (i.e., smoking permitted in all areas). In contrast, home smoking policy demonstrated the opposite pattern, such that a majority of individuals (59.68%) reported no indoor smoking ban at home (i.e., smoking permitted); 22.58% reported partial bans, and 17.74% reported full indoor smoking bans in the home. Home smoking policy was unrelated to type of workplace smoking ban (p=0.36). Among individuals with partners, workplace smoking policy was not associated with partner smoking status (p=0.58). In contrast, home smoking policy was significantly associated with partner smoking status (χ^2 = 6.23; p=0.04), such that individuals with full or partial home indoor smoking bans were significantly less likely to report that their partner was a current smoker (36.36% and 46.15%, respectively), compared to individuals with no home smoking bans (72.50%). Individuals with partial or no work bans were also significantly more likely (χ^2 = 17.15; p<0.01) than those with full bans to report that most or all of their co-workers smoked (45.71% and 50.00% vs. 25.42%).

3.1.3 Work and Home Smoking Policy, Smoking, Dependence, and NMR

Workplace smoking policy was unrelated to average real-time cigarettes per day (CPD; $p=0.27$). Similarly, workplace smoking policy was not associated with nicotine dependence (FTND, NDSS Drive, NDSS Continuity) (all $p>0.15$). However, dependence was associated with home smoking policy, such that individuals with full home bans were less dependent on FTND and NDSS Drive (both $p<0.05$) -but not continuity ($p=0.22$)- than individuals with partial bans (FTND: Full Ban: M = 3.33[SD=1.93]; Partial Ban: M = 5.82 [SD=1.61]; No Ban: M = 5.39 [SD=1.77]; Drive: Full Ban: M = -0.44 [SD=1.20]; Partial Ban: M = 0.31 [SD=1.05]; No Ban: M = -0.47 [SD=1.06]). NMR was unrelated to workplace smoking policy, home smoking policy, and nicotine dependence (all $p > 0.10$).

3.1.4 Work and Home Smoking Policy and Occupation Type

Workplace smoking policy was highly correlated with occupational status. Individuals with ‘white collar’ occupations (e.g., accountant, office worker, teacher) were significantly more likely to report full workplace bans (84%) than were those with ‘blue collar’ (e.g., factory worker, custodian, construction worker; 37% full workplace bans) or other occupations (e.g., artist, self-employed; 48% full work bans) (χ^2 =24.92; $p<0.0001$). Home policy was also associated with occupation type (χ^2 =12.29; $p=0.02$), such that individuals with blue collar occupations were significantly more likely to report that smoking was permitted in the home (48% smoking permitted) than individuals with white collar occupations (22%).

3.1.5 Exposure to Smoking Restrictions

Workplace smoking policy was significantly associated with the percent of EMA-reported restrictions (p=0.03), such that individuals with full work restrictions had significantly higher percentages of all EMA events in which smoking was forbidden by law (14%), compared to individuals with partial work restrictions (10%) or no work restrictions (5%). Among individuals who reported work restrictions, those with full workplace bans reported smoking restrictions in a greater percentage of non-smoking events when at work (Generalized Linear Model Least-Square Mean=50% [SE=0.06]) compared to those with partial workplace bans (Least-Square Mean=27% [SE=0.08]) (p=0.02).

People reported that smoking was allowed in 91.09% of all EMA smoking assessments and 83.00% of non-smoking assessments. They reported changing locations to smoke in 31.18% of smoking assessments. When they did not change locations, individuals reported that smoking was allowed in 98.24% (n=5,404) of all smoking events. However, 1.76% (n=97) of smoking events took place when legal restrictions *were* in place, and individuals did not change location. 55 of these instances occurred when participants (n=15) reported being at work. Of the 15 individuals who smoked at work when restrictions were present, 13 reported full workplace bans; the remaining 2 reported partial work bans. That is, individuals did report violating workplace smoking restrictions, but this was quite rare.

3.2 TEMPORAL SMOKING PATTERNS

The following section describes temporal smoking patterns across the entire sample, regardless of workplace policy.

3.2.1 Time of Day

Smoking Rate

Mean CPH varied across time of day. Figure 3 shows the 'raw', unadjusted mean CPH for each hour of the day across all subject-days. Raw mean CPH values indicated a pattern such that smoking rates tended to be lowest between 11am and 6pm, with slightly higher CPH in the early morning and evening hours.

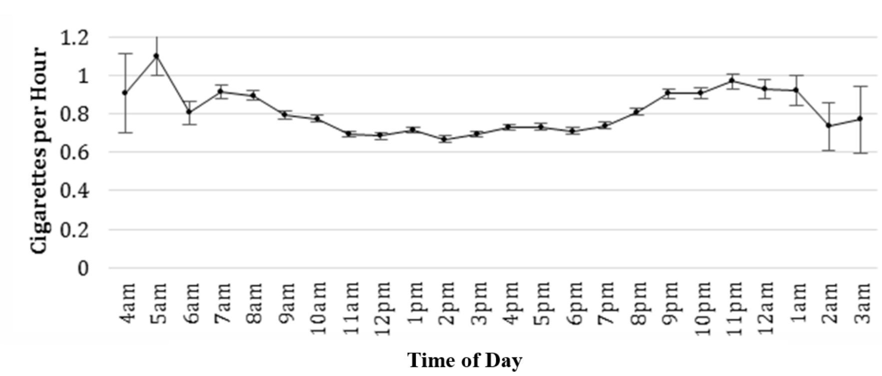

Figure 5. Mean Cigarettes per Hour across Time of Day: All Subject-Days

Hierarchical linear analysis, which accounted for the nested structure of the data, helped to refine this pattern. Figure 6 shows the least square mean values of CPH, aggregated within time blocks, from the unadjusted model of the time block main effect on CPH across all days. As evident in the raw data, the hierarchical analysis revealed a pattern such that CPH decreases slightly from the Pre-Work to Work time block ($p<0.0001$), and subsequently increases during the Post-Work block ($p<0.0001$). In addition, the hierarchical analysis showed a further rise between the post-work and night time block ($p<0.0001$), when mean CPH was highest (1.08 [SE = 0.05]). Unless otherwise noted, all subsequent figures depict model-based least square means.

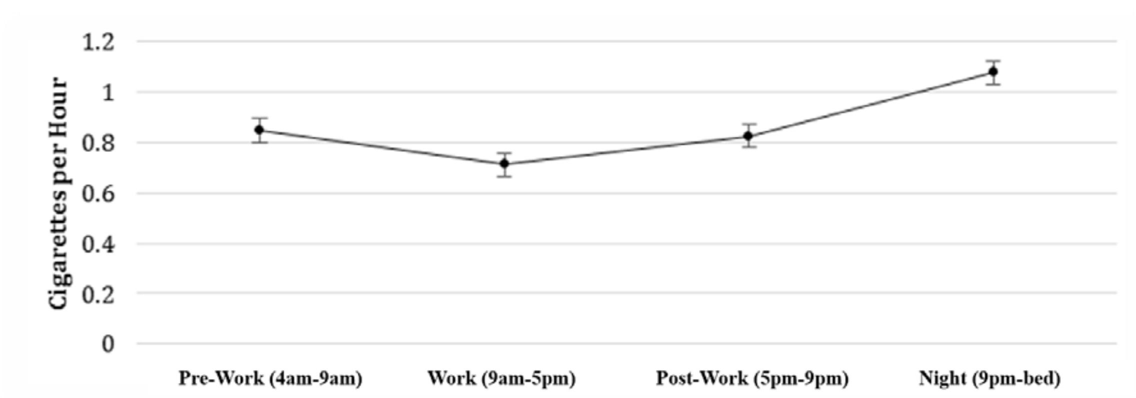

Figure 6. Least-Square Mean Smoking Rate is Highest in the Night Hours: All Days

3.2.1.1 Simulated Nicotine Levels

Simulated nicotine levels demonstrated expected temporal patterns (Benowitz, 1992), such that levels rose relatively quickly after waking, and leveled off toward the evening hours. As anticipated, patterns of raw simulated nicotine blood levels differed across strata of mean daily consumption, with heavier smokers demonstrating steeper increases and higher maximum nicotine levels across waking hours relative to lighter smokers (see Figure 7).

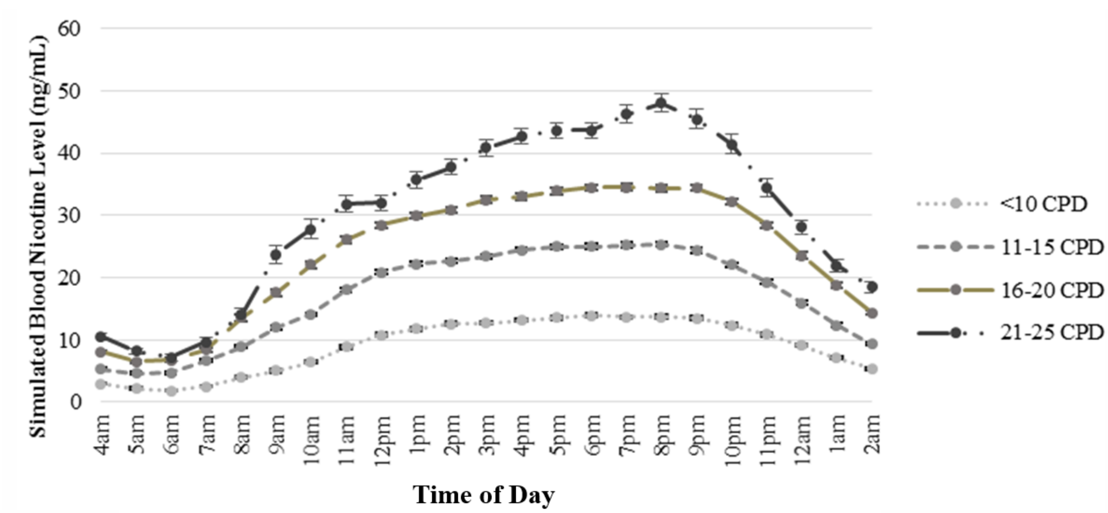

Figure 7. Real-Time Smoking Simulated Nicotine Blood Levels across Time of Day by Strata of Participants' Average CPD

Patterns of real-time smoking (RTS) nicotine levels were similar to those generated from evenly-spaced CPD (Figure 8). However, among the heaviest smokers (20-25 CPD; n=4), RTS nicotine levels initially increased more rapidly (until roughly 10am), but took longer to reach a maximum level of approximately 48 ng/mL around 9pm; in contrast, evenly-spaced smoking (ESS) nicotine levels reached a similar maximum by 5pm, at which point levels plateaued.

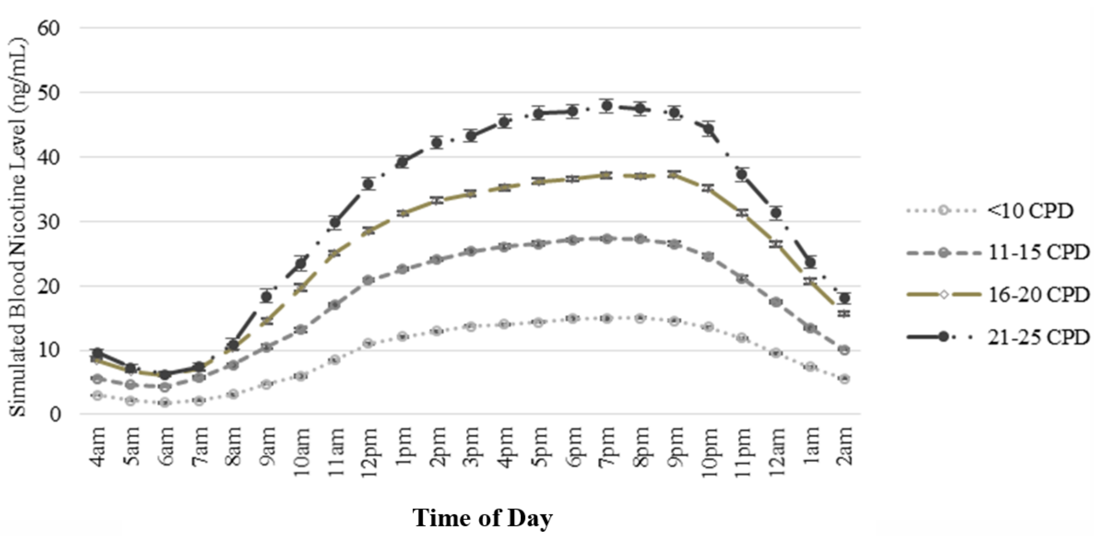

Figure 8. Evenly-Spaced Smoking Simulated Nicotine Blood Levels across Time of Day by Strata of Participants' Average CPD

3.2.1.2 *Evenly-Spaced Smoking Comparison*

Mixed analyses revealed differences between RTS and ESS nicotine levels across time blocks (main effect of time block on ΔEvenNL: $p<0.001$), such that RTS nicotine levels were higher than ESS levels in the Pre-Work time block (see Figure 9; Figure 10), but fell below evenly-spaced smoking nicotine levels toward the end of the day.

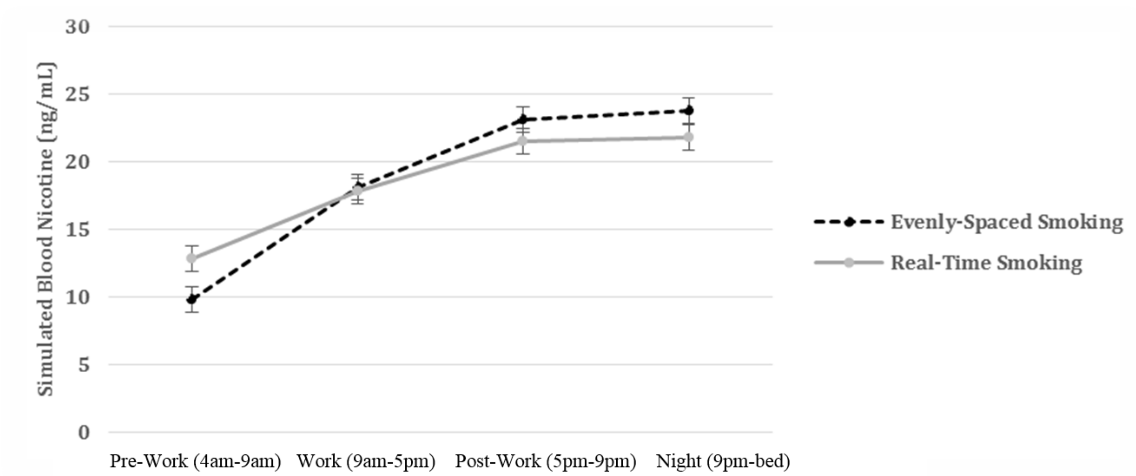

Figure 9. Real-Time vs. Evenly-Spaced Smoking Nicotine Levels across Time of Day (LS Means from separate models)

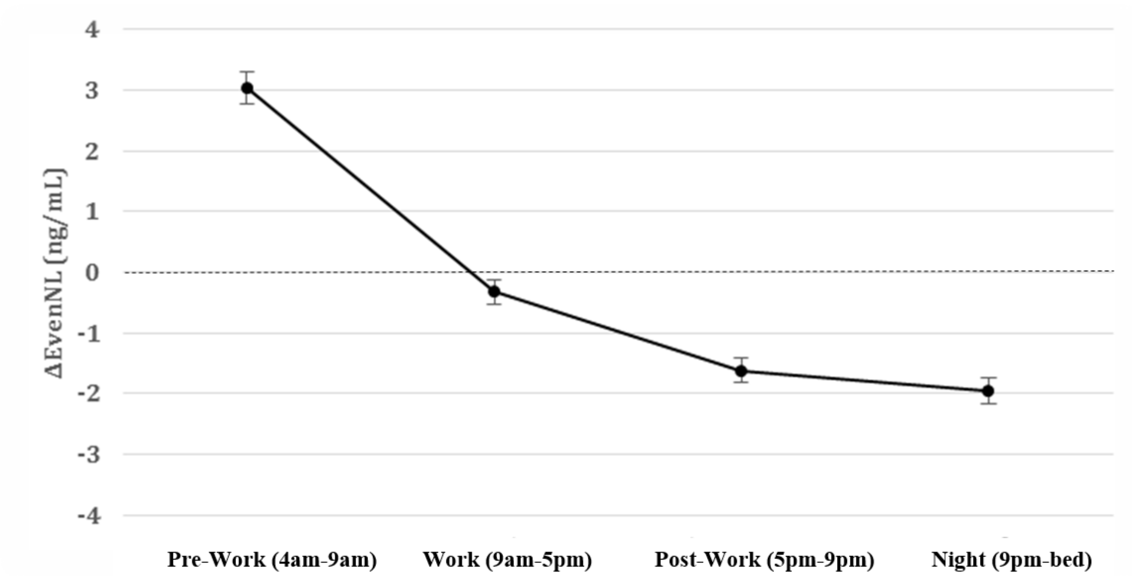

Figure 10. Difference between Real-Time vs. Evenly-Spaced Smoking Nicotine Levels across Time of Day (all days)

3.2.1.3 *Likelihood of Changing Locations to Smoke*

Figure 11 shows participants' average number of reports of changing location to smoke across time blocks. There was a significant main effect of time block on likelihood of changing location to smoke, such that individuals were significantly more likely to report changing locations during the work time block relative to the pre-work (OR=1.70 [1.33 – 2.16]; $p < 0.0001$), post-work (OR=1.20 [1.02 – 1.41]; $p=0.03$), or night (OR=1.43 [1.12 – 1.81]; $p < 0.01$) time blocks.

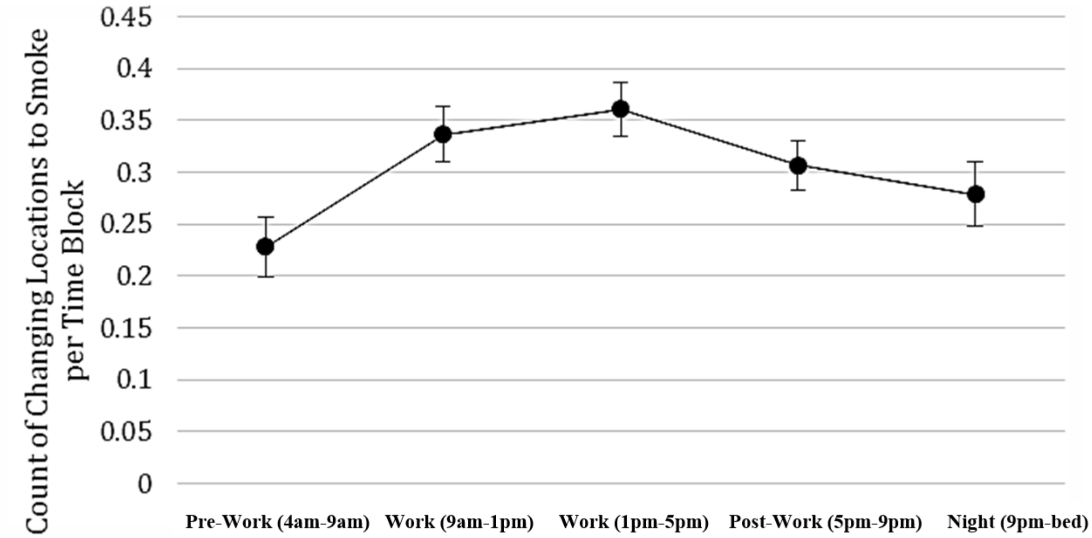

Figure 11. Counts of Changing Locations to Smoke per Time Block

3.2.2 Time of Day across Weekdays and Weekends

3.2.2.1 Smoking Rate

Mixed analyses showed main effects of weekday/weekend on smoking patterns. On average, individuals smoked 0.77 more total cigarettes per day on weekdays compared to weekends (11.15 [SE=0.53] vs. 10.38 [SE=0.54]; p<0.0001), and there was a significant main effect of weekday/weekend on CPH across all time blocks, such that individuals demonstrated slightly higher mean CPH on weekdays compared to weekends (0.85 [SE=0.04] vs. 0.81 [SE = 0.04]; p=0.04). However, patterns of CPH across time blocks were similar on both workweek days and weekend days; there was no significant time block by workweek/weekend interaction (p=0.26) across the full sample (Figure 12).

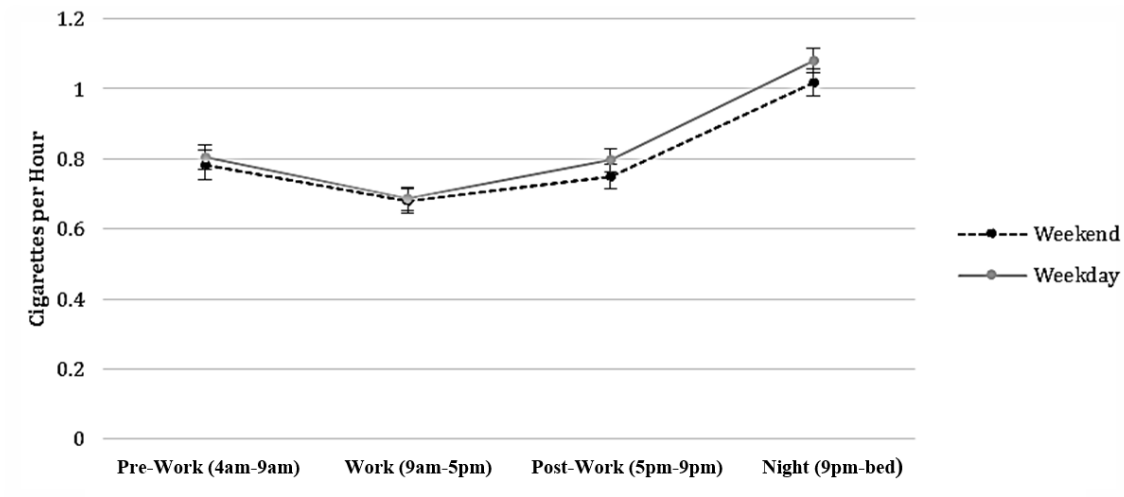

Figure 12. Least Square Mean Smoking Rate across Time Blocks on Weekdays vs. Weekends

3.2.2.2 *Simulated Nicotine Levels*

As reflected in analyses of CPH, real-time simulated nicotine levels were similar on workweek days compared to weekend days (19.26 ng/mL [SE =0.90] vs. 18.50 ng/mL [SE = 0.91]), and as shown in Figure 13, the pattern across time blocks did not differ by workweek/weekend (i.e., no significant time block x workweek/weekend interaction; p=0.19).

However, examining the pairwise comparison of LS means within the Night time block, simulated nicotine levels were slightly higher in the workweek days compared to weekend days (22.38 [SE=0.95] vs. 20.49 [SE = 1.00]; p=0.05) (see Figure 13).

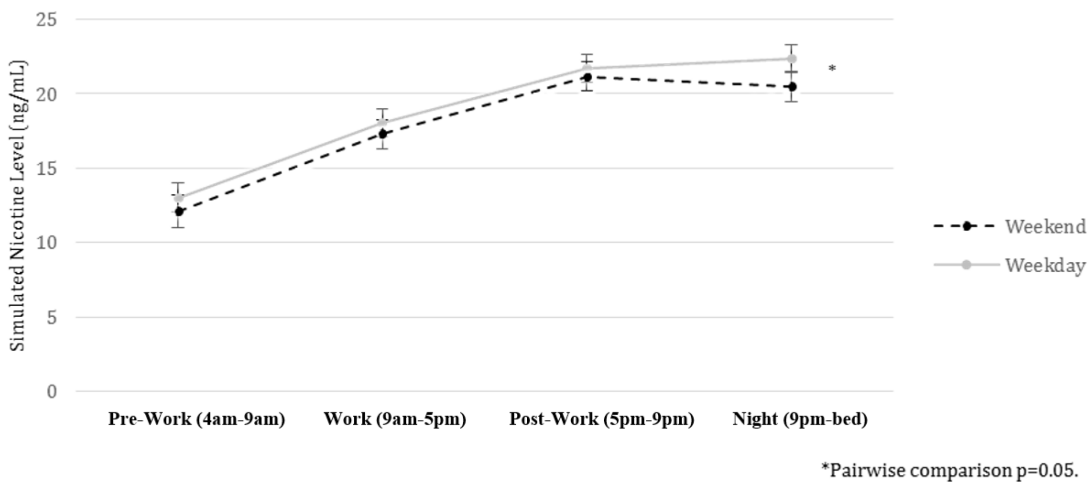

Figure 13. Least Square Mean Simulated Nicotine Levels by Time Block on Weekdays and Weekends

There was a significant interaction between time block and weekday/weekend ($p < 0.008$), such that ΔEvenNL was significantly higher (i.e., closer to optimal spacing) in the Night time block on weekdays compared to weekends ($p=0.004$) (see Figure 14).

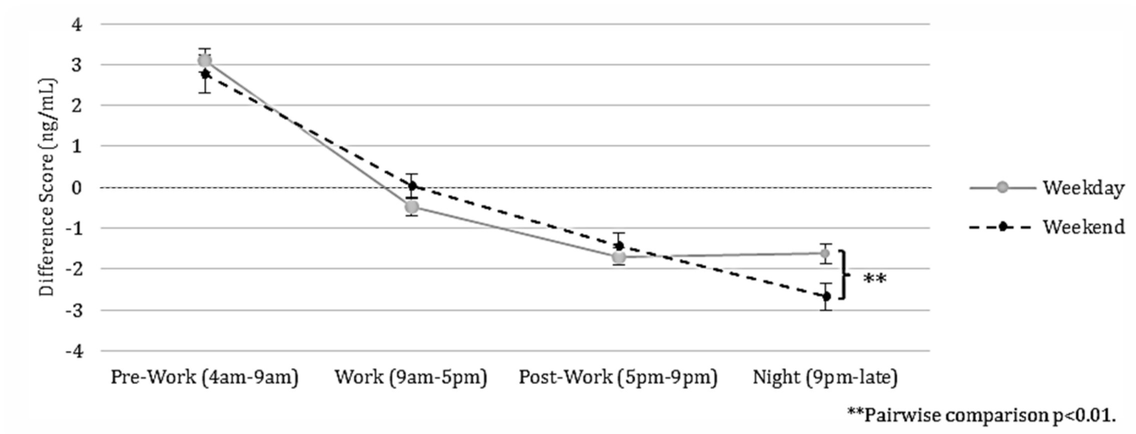

Figure 14. Time Block by Weekday/Weekend Interaction on Least Square Mean Difference between Real-Time and Evenly-Spaced Smoking Simulated Nicotine Levels

There was also a significant main effect of time block on %WeekendNL on weekdays (see Figure 15). Relative to the weekend standard of comparison, participants showed a decrease in nicotine levels from the Pre-Work to Work time blocks (-15% [SE = 3.80]; $p<0.0001$). Levels demonstrated a non-significant decline from the Work to Post-Work time blocks (-6% [SE =

3.30]; p=0.052), and then rose again between the Post-Work and Night time blocks (+14% [SE = 3.40]; p<0.0001). %WeekendNL was highest in the Pre-Work and Night time blocks, and did not significantly differ across those periods.

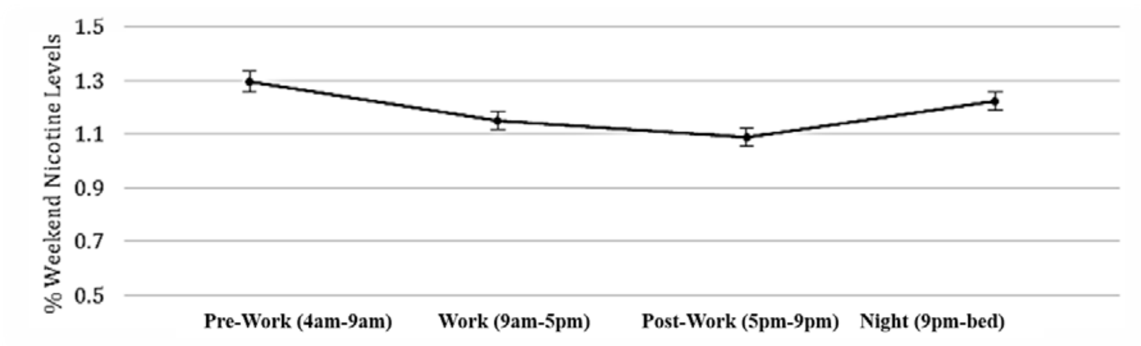

Figure 15. Main Effect of Time Block on Mean % Weekend Nicotine Levels

3.2.2.3 *Likelihood of Changing Locations to Smoke*

Individuals reported changing location to smoke more frequently on average during Work hours on weekdays compared to weekends (M=0.37 [SE=0.03] changes location/time block vs. M=0.29 [SE= 0.03]). Individuals were significantly more likely to report changing locations to smoke during the Work time block on weekdays compared to weekends (OR=1.37 [1.11 – 1.70]; p=0.004).

3.2.3 *Summary of Temporal Smoking Patterns*

In summary, when examined without regard to workplace smoking policy, smoking and nicotine levels decreased between Pre-Work and Work hours, and peaked in the Night hours. Individuals demonstrated consistently higher nicotine levels on weekdays relative to comparable times on weekends, and weekday nicotine levels were highest in the Pre-Work and Night time blocks. Individuals were also more likely to escape restrictions in order to smoke during work hours on weekdays compared to weekends. Moreover, simulated nicotine levels were higher in the Night hours on weekdays compared to weekends, and individuals showed higher nicotine levels relative to an *optimal spacing* strategy in the Night time block on weekdays compared to weekend.

3.3 WORKPLACE SMOKING POLICY EFFECTS ON TEMPORAL SMOKING PATTERNS

Results for analyses of workplace smoking policy effects on interference with nicotine maintenance and temporal compensation are first summarized by hypothesis domain to present broad patterns of evidence across outcomes. Results are subsequently presented by outcome to describe effects in greater detail.

3.3.1 *Results Summary by Hypothesis Domain*

Summary of Evidence for Interference with Nicotine Maintenance (Hypotheses I & II)

There was little evidence of a relationship between workplace smoking policy and interference with nicotine maintenance during the Work time block on weekdays. That is, workplace smoking policy was not associated with lower CPH, ΔEvenNL, %WeekendNL, or increased trough likelihood or max trough span during the Work time block on weekdays. The exception to this was that individuals with either full or partial bans demonstrated higher trough counts (both p=0.04) during Work hours on weekdays relative to individuals with no workplace restrictions. Table 3 provides a summary of evidence for interference with nicotine maintenance across analyses.

Table 3. Summary of evidence for interference with nicotine maintenance during working hours on weekdays.

	Evidence for Interference with Maintenance					
	CPH	**ΔEvenNL**	**%Weekend NL**	***Trough Likelihood***	***Trough Frequency***	***Max Trough Span***
% Observed Work Restrictions	--	--	--	--	--	--
Workplace Smoking Policy						
Full Ban	--	--	--	--	$p < 0.05^{\dagger}$	--
Partial Ban	--	--	--	--	$p < 0.05^{\dagger}$	--

Note. † Models for %WeekendNL, trough likelihood, trough count and max trough span based on time*policy interaction on weekdays.

Summary of Evidence for Temporal Compensation (Hypotheses III & IV)

Evidence for temporal compensation varied depending upon outcome and type of work ban, but there was little data in support of temporal compensation (see Table 4). Results suggested that the trends toward higher evening smoking on weekdays observed across the full sample were driven by those individuals with partial work bans. Smokers did not demonstrate anticipatory compensation in relation to stringency of work restrictions. Analyses of smoking rate suggested that individuals with partial work bans –but not those with full bans-engaged in make-up compensation in the Night time block on weekdays relative to individuals with no work bans. In addition, analyses of nicotine levels in relation to weekend smoking (%WeekendNL) showed a similar pattern, such that that individuals with partial bans showed a markedly different temporal smoking pattern relative to those with full or no work restrictions, such that smokers with full work bans demonstrated significantly lower %WeekendNL in the Night time block on weekdays (vs. weekends) compared to those with partial or no work bans. Smokers also demonstrated ad hoc compensation, such greater frequency of EMA reports in restricted work environments was associated with greater likelihood of changing locations to smoke during Work hours.

Table 4. Summary of evidence for temporal compensation during the workweek.

	Anticipatory Compensation			*AdHoc Compensation*	*Make-Up Compensation*		
	CPH	**ΔEvenNL**	**%Weekend NL**	**Likelihood of Changing Location**	**CPH**	**ΔEvenNL**	**%Weekend NL**
% Observed Work Restrictions	--	--	--	$p < 0.001$	--	--	--
Workplace Smoking Policy							
Full Ban	--	--	--	--	--	--	--
Partial Ban	--	--	--	--	$p < 0.01$	--	$p < 0.05$

3.3.2 Results by Outcome

Results are described in detail by predictor and outcome below.

3.3.2.1 Percent of Restricted Observations at Work

Smoking Rate

Individuals' frequency of exposure to restrictions was unrelated to smoking rate during work hours. Smokers who more frequently reported being in restricted work environments did not differ from individuals with less frequent EMA reports of work restrictions on CPH during the Work time block on weekdays (p=0.31).

Simulated Nicotine Levels: Evenly-Spaced Smoking Comparison

Similarly, frequency of exposure to restrictions was unrelated to mean ΔEvenNL during the Work time block on weekdays (p=0.15).

Simulated Nicotine Levels: Ad Libitum Weekend Smoking Comparison

Frequency of exposure to restricted environments at work was also unrelated to mean %Weekend NL during the Work time block on weekdays (p= 0.22).

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home smoking policy, dependence, and NMR did not moderate these relationships.

Likelihood of Changing Locations to Smoke

Smokers who reported greater frequency of exposure to restricted environments at work were more likely to report changing locations to smoke during Work hours. As shown in Figure 16, a 10% increase in percent observed work restrictions was associated with a 1.4% increase in likelihood of changing locations to smoke during the Work time block on weekdays (OR=1.14, CI 1.08 – 1.21; p=0.0002).

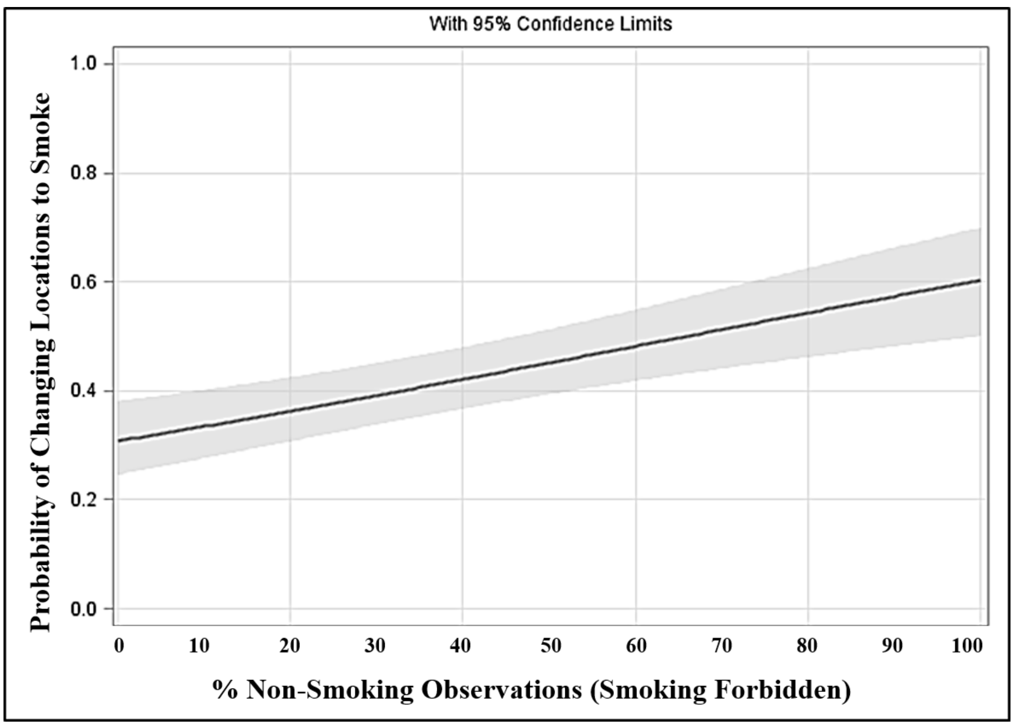

Figure 16. Probability of Changing Locations to Smoke is Associated with Frequency of Reporting Restrictions at Work

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home smoking policy, dependence, and NMR did not moderate this relationship.

3.3.2.2 Stringency of Workplace Indoor Smoking Policy

Smoking Rate

There was a significant workplace smoking policy- by time block- by-workweek/weekend interaction on CPH (p=0.007), such that individuals with partial work bans demonstrated increased smoking in the Night time block on weekdays relative to individuals with no ban (Figure 17). Due to concerns that effects may have been driven by increased smoking on Friday evenings, analyses were conducted in which CPH on Mon-Thurs was compared to weekend smoking. The pattern of results was unchanged (p=0.002).

CPH during the Work time block did not significantly differ across workweek/weekend for any policy group (within the Work time block, weekday/weekend x workplace smoking policy interaction was non-significant, p=0.72; see Figure 17a-c). That is, there was no evidence of workplace smoking policy effects on interference with nicotine maintenance during Work hours. Rather, the 3-way interaction effect was driven by differences in the Night time block, specifically among those with partial bans (see Figure 17b).

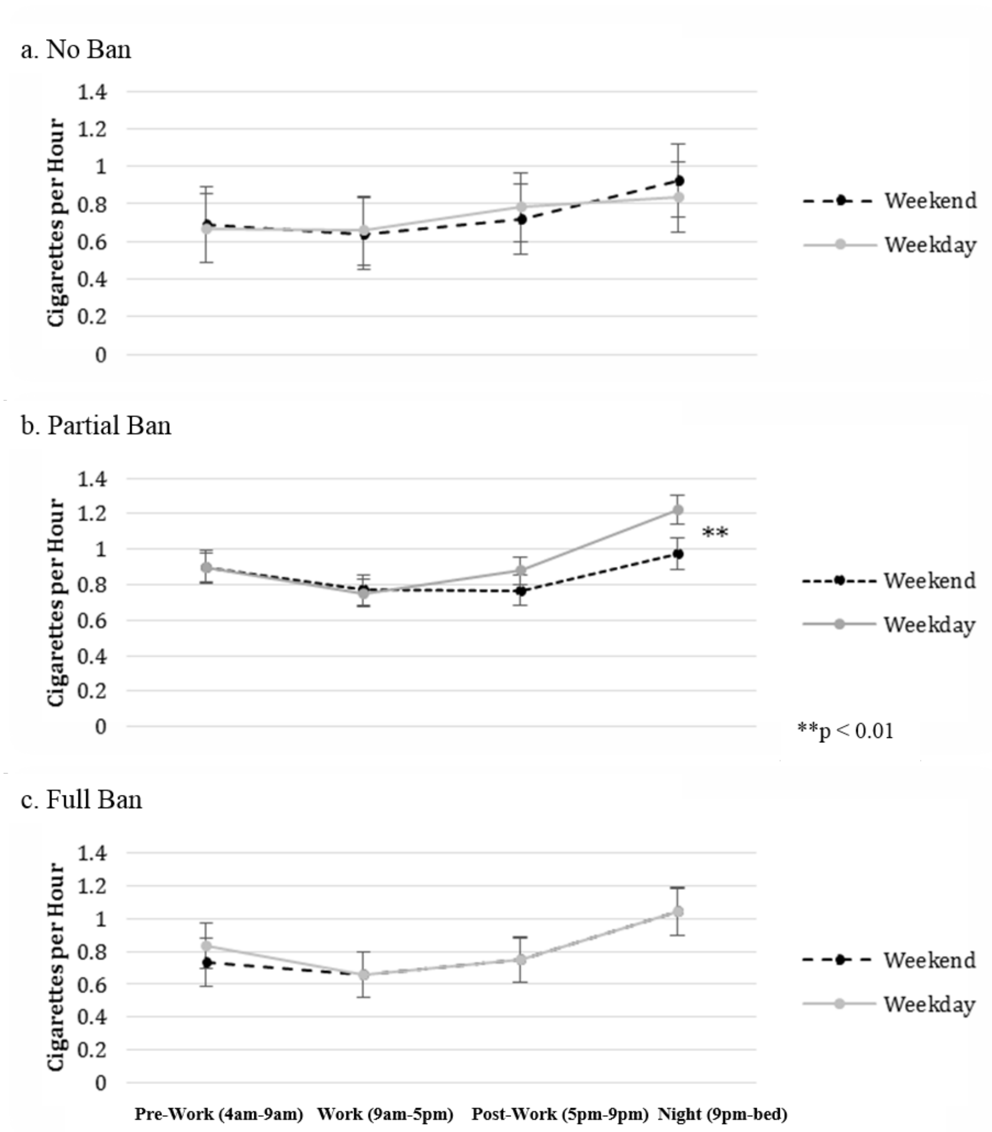

Figure 17. Workplace Smoking Policy x Time Block x Weekday/Weekend Interaction on CPH

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home smoking policy, dependence, and NMR did not moderate this relationship.

Simulated Nicotine Levels: Evenly-Spaced Smoking Comparison

Smokers' mean real-time and evenly-spaced smoking nicotine levels did not differ during the Work time block on weekdays and weekends (i.e., ΔEvenNL=0). In addition, people did not differ across policy groups in patterns of ΔEvenNL across time block and day of week (i.e., there was no significant interaction between workplace smoking policy, time block, and workweek/weekend on mean ΔEvenNL (p=0.06)). Examining differences between the full and partial bans groups and the no ban policy group revealed no significant effect of workplace policy groups on weekdays in any time block (i.e., no evidence of temporal compensation; see Figure 18a, b).

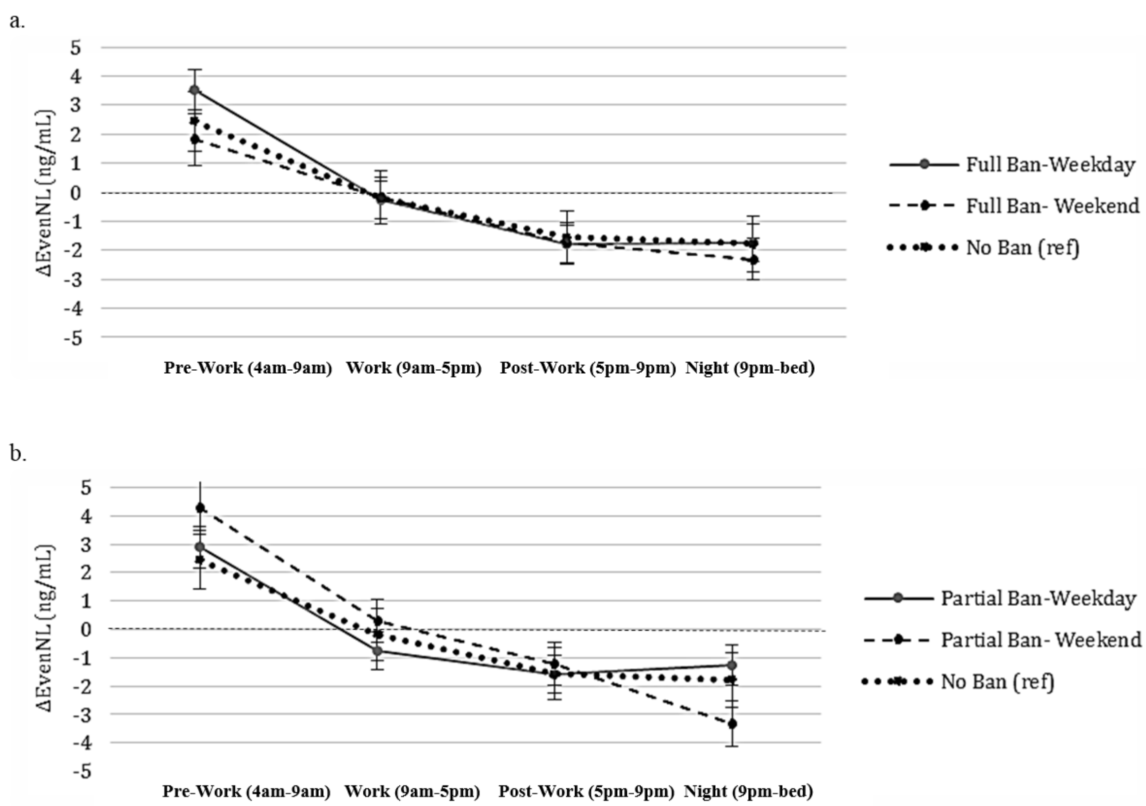

Figure 18. Workplace Smoking Policy x Time Block x Weekday/Weekend Interaction on ΔEvenNL

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home smoking policy, dependence, and NMR did not moderate these relationships.

Simulated Nicotine Levels: Ad Libitum Weekend Smoking Comparison

There was a significant workplace smoking policy by time block by workweek/weekend interaction on %WeekendNL (p=0.02). Figure 19 shows %WeekendNL across time blocks on weekdays by workplace smoking policy group. There were no differences in mean %WeekendNL during the Work time block (9am-5pm) across policy groups (i.e., no simple effect of workplace smoking policy within work time block: p=0.91). Moreover, %WeekendNL exceeded 100% across all time blocks and policy groups. In other words, nicotine levels were higher during work hours on weekdays than on weekends, regardless of policy group.

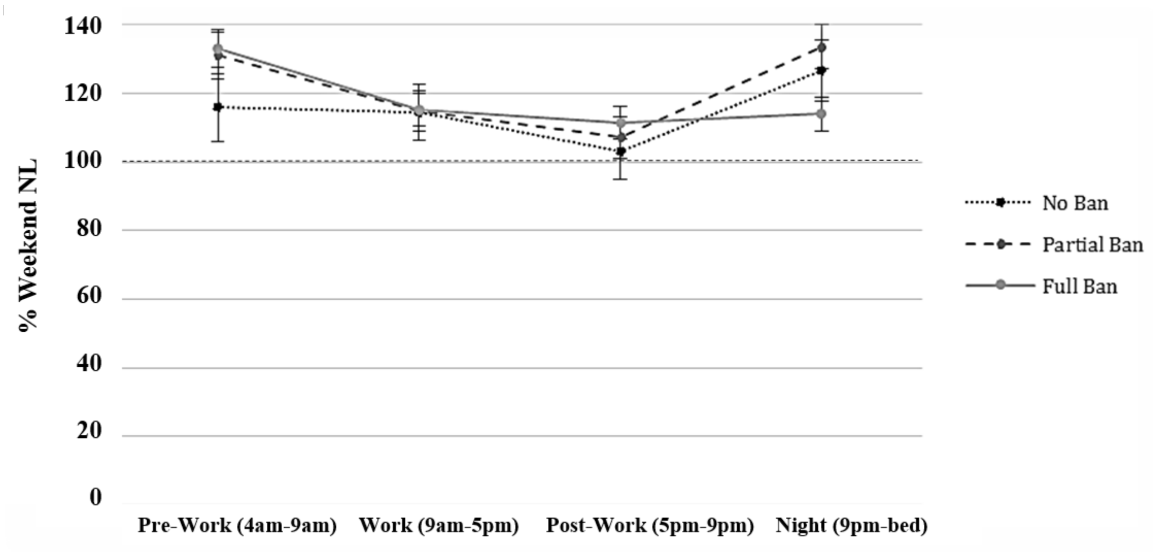

Figure 19. Workplace smoking policy by time block interaction on %WeekendNL

The interaction between workplace smoking policy and time block on weekdays ($p=0.02$) was such that individuals with partial bans demonstrated significantly different temporal patterns of %WeekendNL relative to individuals with full bans (see Figure 20). Individuals with full workplace bans demonstrated a temporal pattern such that %WeekendNL was highest in the Pre-Work time block, then decreased significantly during the Work time block (-17.74% [SE = 5.22]; $p < 0.001$), and remained stagnant across subsequent time blocks (all $p > 0.38$) (see Figure 20a).

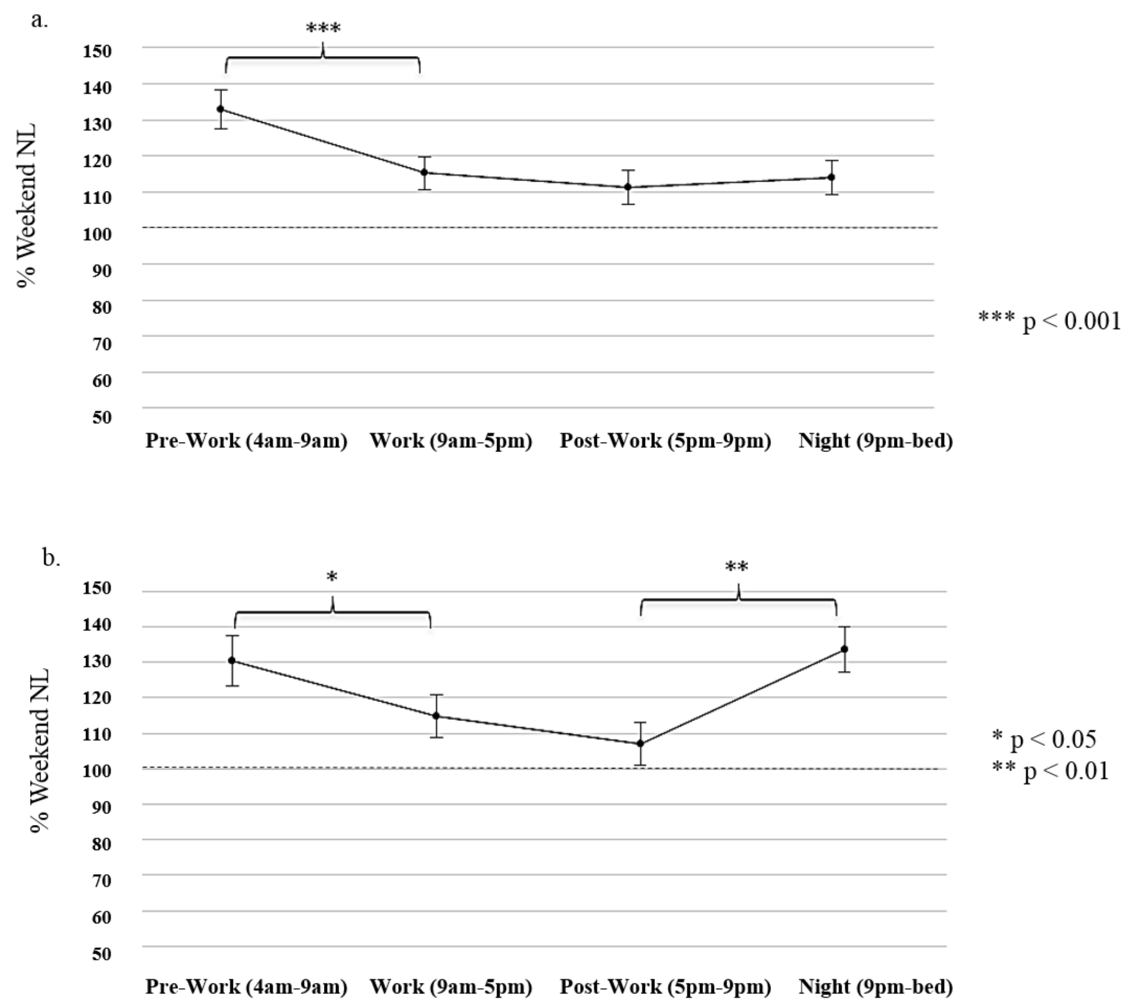

Figure 20. % WeekendNL across Time Blocks: Individuals with Full and Partial Bans

In contrast, individuals with partial work bans demonstrated a distinctly different pattern, such that %WeekendNL decreased from the Pre-Work to Work time blocks (-15.60% [SE = 7.06]; p=0.03), remained unchanged between the Work and Post-Work time block (p=0.21), and –as reflected in other analyses- rose significantly between the Post-Work and Night time blocks (+18.89% [SE = 6.45]; p=0.004) (see Figure 20b).

Importantly, however, examining differences in %WeekendNL across workplace smoking policy groups separately, within each time block, revealed no differences between full or partial workplace policy groups in comparison to the reference category (i.e., individuals with no ban; see Figure 19).

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home policy was a significant moderator of the relationship between workplace smoking policy and time block for % WeekendNL (3-way interaction p<0.0001). For individuals with full home restrictions, partial work bans were associated with anticipatory compensation as well as make-up compensation on weekdays; in contrast, full work restrictions were not associated with compensation. [N.B. Cell sizes were small for this analysis (n<10); as such, data should be interpreted with caution.] For individuals with partial or no home bans, there was no evidence of temporal compensation: %WeekendNL was similar across all time blocks.

Dependence did not moderate the relationship between workplace policy and time block on % WeekendNL. NMR did not moderate the relationship between workplace policy and time block on % WeekendNL (3-way interaction p=0.06).

Nicotine Troughs (<50% WeekendNL)

Trough Likelihood

There was a significant main effect of time block on likelihood of demonstrating any vs. no nicotine troughs ($p<0.0001$), such that smokers were significantly more likely to demonstrate troughs during typical work hours compared to post-work (OR=1.48 CI 1.26 – 1.75; $p<0.0001$) and night hours (OR=2.39 CI 1.90 – 2.95; $p<0.0001$). However, this was unrelated to workplace policy (i.e., no significant time by policy interaction; $p=0.17$).

Trough Frequency

As reflected in analyses of trough likelihood, there was a significant main effect of time of day on trough counts ($p<0.0001$), such that individuals showed significantly higher trough counts during weekday work hours compared to pre-work ($p<0.0001$), post-work ($p=0.005$) and night ($p<0.0001$) hours (see Figure 21).

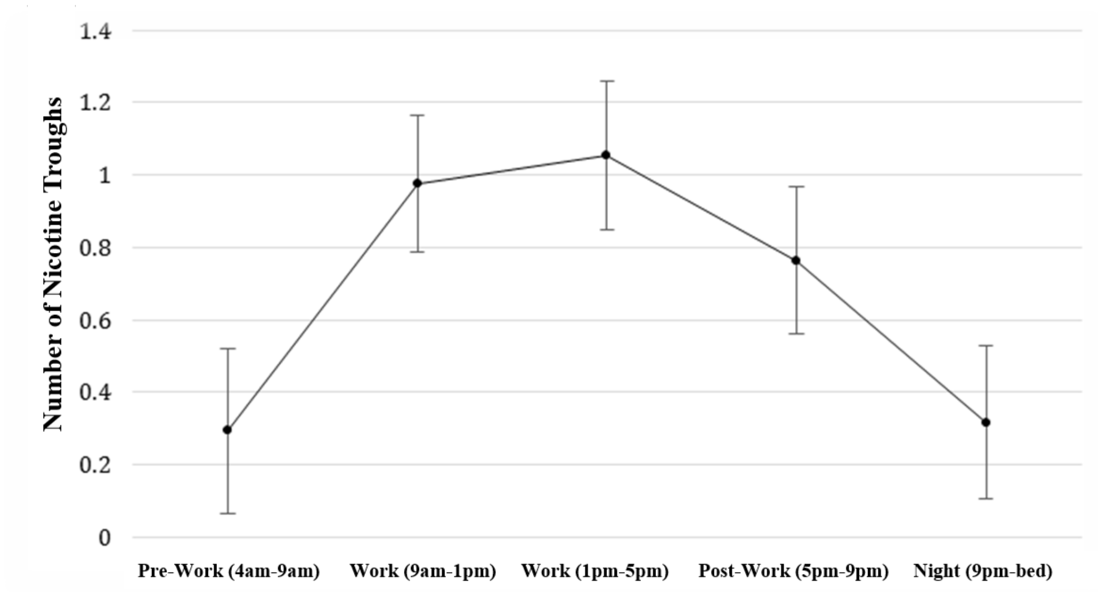

Figure 21. Trough Count across Time of Day on Weekdays

In addition, there was a significant time by policy interaction on trough counts (p=0.037), such that individuals with full or partial bans demonstrated significantly higher trough frequencies during work hours compared to other times (i.e., interference with maintenance among individuals with any type of work ban). In contrast, individuals with no work restrictions showed no significant main effect of time.

Max Trough Span

There was a significant main effect of time on maximum trough span ($p<0.0001$), such that individuals demonstrated significantly longer trough episodes during the midday time blocks relative to the pre-work ($p<0.0001$), post-work ($p=0.005$), and night ($p<0.0001$) time blocks However, this was unrelated to workplace policy ($p=0.07$).

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home smoking policy, dependence, and NMR did not moderate these relationships.

Nicotine Spikes (>150%WeekendNL)

Spike Likelihood

There was a significant main effect of time block ($p<0.0001$) on likelihood of demonstrating *any versus no* nicotine spikes, such that individuals were significantly more likely to demonstrate spikes during typical working hours compared to pre-work (OR=1.69, CI 1.25 – 2.29; $p<0.001$) and night hours (OR=1.53, CI 1.20 – 1.96; $p<0.001$). However, this was unrelated to workplace policy (i.e., no significant interaction between time and policy; $p=0.73$).

Spike Frequency

Similarly, as observed in analyses of trough likelihood, there was a significant main effect of time block on % WeekendNL spike counts ($p<0.0001$). Individuals demonstrated significantly higher spike counts during work hours compared to either pre-work ($p<0.0001$) or night ($p<0.0001$) hours. However, there was no significant time block by workplace smoking policy interaction on nicotine spike counts ($p=0.17$).

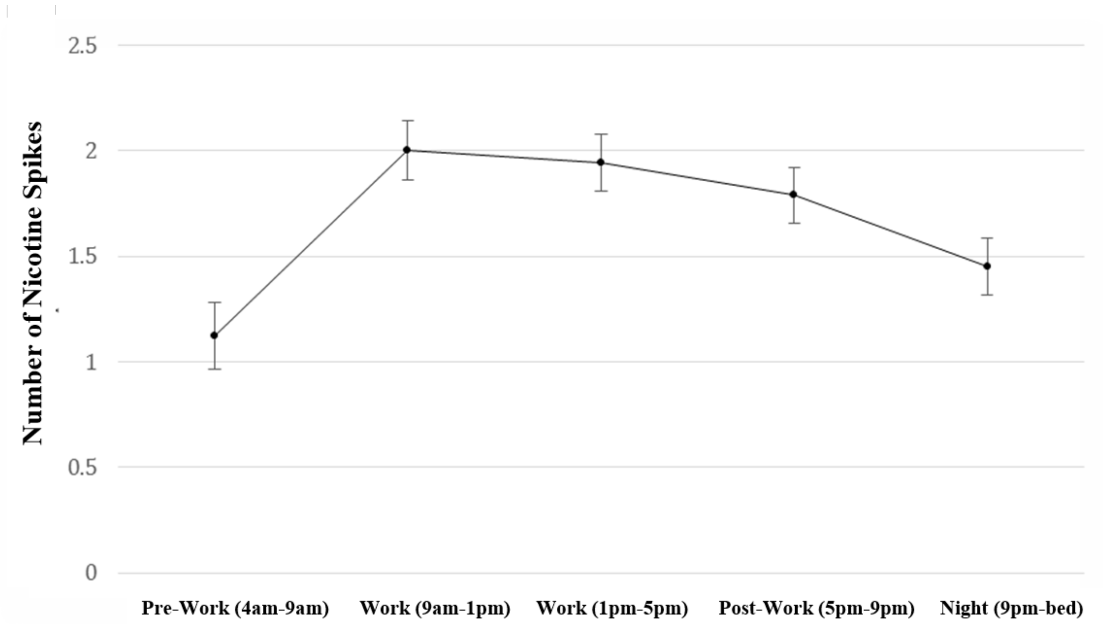

Figure 22. Nicotine Spike Patterns across Time on Weekdays

Max Spike Span

There was no significant time block by workplace smoking policy interaction on maximum nicotine spike span (p=0.68).

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Nicotine dependence, NMR, and home policy did not moderate the relationship between workplace smoking policy and time block for spike likelihood, frequency, or duration.

Likelihood of Changing Locations to Smoke

Individuals' workplace smoking policy was not associated with their likelihood of changing locations to smoke during the work time block across weekdays and weekends (OR=1.00 [95%CI 0.89-1.01]; p=0.12).

Moderating Effects of Home Bans, Nicotine Dependence, and NMR

Home smoking policy, nicotine dependence, and NMR did not moderate this relationship.

4.0 DISCUSSION

This is the first study to quantitatively assess the relationship between exposure to workplace smoking bans, interference with nicotine maintenance and compensatory smoking. Simulated nicotine levels, based upon subjects' real-time reports of smoking, were compared to two different standards (even spacing of daily cigarettes, and subjects' preferred levels of smoking on weekends) in order to assess the relationship between restrictions and changes in smoking patterns across time.

Surprisingly, smokers' exposure to workplace smoking bans was largely unrelated to interference with nicotine maintenance. People were most likely to change location to smoke during typical work hours on weekdays, and individuals who reported greater frequency of exposure to restrictions while at work were more likely to change locations. This suggests that individuals may largely compensate for exposure to bans by escaping smoke-free settings throughout the workday to smoke as 'needed'. Yet, despite little evidence for interference with smoking patterns during work hours, individuals with partial workplace smoking bans also smoked more after work hours on weekdays compared to weekends. Findings are generally consistent with a Boundary Model of smoking behavior (Kozlowki & Herman, 1984), which accounts for both internal and external determinants of smoking patterns. These data suggest that individuals strive to maintain nicotine levels within certain rough parameters (i.e., by readily escaping restrictions to smoke throughout work hours on weekdays), and thus avoiding broad deviations in smoking rate or nicotine levels. However, increased smoking in the evening on weekdays among those with partial restrictions cannot be explained purely through a drive to maintain nicotine levels *following* exposure to restrictions, and may instead be driven by contextual factors (e.g., transition from work to home, cigarette availability, or other factors) in this group.

4.1 TEMPORAL SMOKING PATTERNS

The finding that smoking rates tended to be lowest during the Work time block and highest in the Night time block in this sample is consistent with previous studies that have examined temporal variations in smoking patterns in relation to workplace bans. Many studies have reported decreased smoking during work hours, relative to other times of day, among individuals who work in restricted settings (e.g., Meade &Wald, 1977; Chandra et al., 2007; Borland et al., 1990). In addition, several studies have observed increased smoking in the evening hours after work among individuals with workplace smoking bans. Meade & Wald (1977) reported that, compared to factory workers with no workplace ban, workers with indoor smoking restrictions reported lower smoking rates during work hours, and smoked more heavily before and after work. Similarly, Chandra et al. (2007) reported a significant association between exposure to smoking restrictions and lower smoking rates during the midday hours among a group of smokers, who demonstrated escalated smoking in the morning and evening hours ("Daily-Dip Evening Incline" group). In addition, Parry et al. (2000) found that a subset of smokers (22%) reported increased smoking *after* work hours following the implementation of a university smoking ban. Thus, multiple previous studies have documented similar temporal smoking patterns among some groups of smokers who encounter workplace restrictions, such that that smoking rates decrease from early morning to work hours, and subsequently increase in the night hours.

In some ways, however, the observed smoking patterns in this sample were unexpected. The participants in this study represent a subset of individuals from a larger study on ad libitum smoking patterns. Previous analyses on the full sample (Shiffman et al., 2014) suggested a slightly different pattern of smoking rate across time, such that rates tended to be higher in the early morning hours and decreased over time. There are a number of reasons that may account for these differences. First, although they overlap, the samples are different. Only individuals who provided information on workplace smoking policy, and did *not* demonstrate evidence of irregular work schedules, contributed data to the current analyses (n=124). This excluded over a third of the sample used in Shiffman et al. (2014) (n=194). Second, the data were analyzed in very different ways. In this study, smoking data were aggregated within conceptually meaningful time blocks, corresponding to socially conventional work and non-work hours, and the mixed regression analyses accounted for subject clustering effects (i.e., mean CPH within time block, nested within days, nested within subjects). In contrast, Shiffman et al. (2014) analyzed CPH across 6 time blocks, and found that smoking rate was highest during the early morning time block (4am-6am in Shiffman et al., 2014). However, only 0.3% of smoking data fell within the hours of 4am and 6am in the current study, which suggests that the pattern of higher CPH in the “morning hours” reported for the full sample in Shiffman et al. (2014) may be unrepresentative of average smoking rates during morning or Pre-Work hour across the sample. By comparison, the use of aggregated values within the Pre-Work time block (4am-8:59am) in this study may have reduced skew attributable to rare instance of very early morning (4am-6am) smoking, and may thus represent a more appropriate estimate of average morning or Pre-Work smoking rates in this sample.

4.2 REAL TIME SMOKING VERSUS EVENLY-SPACED SMOKING

Across all days, individuals demonstrated the highest nicotine levels (relative to evenly-spaced smoking) in the Pre-Work time block, and levels subsequently declined over the course of the day. That is, individuals appeared to smoke the first cigarette of the day sooner after waking than would be predicted by even spacing of cigarettes. This is consistent with the tendency for dependent smokers to smoke shortly after waking (Baker et al., 2007), which may be a reflection of the drive to replenish nicotine levels after a night’s sleep (e.g., Benowitz, 1992). However, this finding may also be attributable to statistical handling of time blocks. Average wake time across all subject days was close to the beginning of the working time block (8:30am vs. 9am), and individuals reported being awake for slightly more than 14 hours each day (see Appendix 3). So, for an individual who smoked 10 CPD, the time between evenly spaced cigarettes would be slightly more than 1 hour. Using this approach, the average participant thus did not wake early enough to demonstrate *any* ‘evenly-spaced’ cigarettes in the pre-work (4am –

9am) time block. Consequently, evidence of escalated nicotine levels in the morning hours relative to evenly spaced smoking may have been inflated due to average participant wake times falling toward the end of the morning time block.

4.3 WEEKDAY VERSUS WEEKEND SMOKING

Contrary to expectations, individuals demonstrated modestly heavier smoking on weekdays compared to weekends. This has significant implications for interpreting the simulated nicotine data in relation to the "ad libitum weekend smoking" standard of comparison. In addition, it suggests that different factors may play a role in driving smoking on weekdays compared to weekends. The majority of the sample (82%) reported that they were able to smoke in at least some areas of their home. Since individuals report spending the majority of their non-work hours at home (e.g., Shiffman et al., 2014), it follows that smoking should be more "accessible" across waking hours on weekend days than on weekdays. What, then, may account for reduced smoking on weekend days? One potential explanation is that individuals simply *report* fewer cigarettes on weekends. Although smoking rate was higher on weekdays compared to weekends when examining real-time smoking reports, retrospective *timeline follow-back (TLFB)* reports of CPD suggested no difference in cigarette consumption across weekdays and weekends (14.11 vs. 14.25 CPD, respectively; p=0.23). There are well-established biases associated with retrospective recall of cigarette consumption, including a tendency toward digit bias (e.g., greater likelihood of reporting 10 or 20 CPD; Shiffman et al., 2009), so it is unclear whether or not TLFB represents a more accurate assessment of smoking patterns across days compared to real-time reports (see Shiffman, 2009a). Alternatively, it is possible that other situational factors that may be specific to weekday or workplace, such as work stress or the transition period between work and home (see Shiffman et al., 2002), may account for increased smoking on weekdays compared to weekends. More research is needed in order to assess the factors that may promote increased smoking (or, reported smoking) on weekdays compared to weekends.

4.4 WORKPLACE SMOKING BANS, INTERFERENCE WITH NICOTINE MAINTENANCE, AND TEMPORAL COMPENSATION

4.4.1 Interference with Nicotine Maintenance

Despite the fact that smoking rates were lowest during Work hours, there was little evidence in support of interference with nicotine maintenance during Work hours on weekdays vs. weekends. Work restriction policy was not associated with reduced smoking rate or lower simulated nicotine levels relative to either evenly spaced smoking or ‘ad libitum’ weekend smoking during Work hours. This is largely consistent with research suggesting that the implementation of smoking bans has surprisingly modest effects on rates of cigarette consumption among those who continue to smoke following the implementation of bans (Callinan et al., 2010; Bajoga et al., 2011; Cahill et al., 2008; Hopkins et al., 2011). However, consistent with hypotheses, workplace smoking bans (full, partial) were associated with greater frequency of nicotine trough events during Work hours. In addition, regardless of workplace smoking policy, individuals were more likely to demonstrate nicotine spikes during work hours compared to other times of day. This suggests that individuals may experience longer periods of abstinence, punctuated by 'bunching' of cigarettes within small temporal windows (i.e., smoke breaks) to a greater extent during Work hours on weekdays compared to weekend days. Thus, despite maintaining similar or higher *mean* nicotine levels relative to evenly-spaced smoking or weekend smoking patterns, individuals appear to demonstrate more irregular or clustered temporal patterns of smoking during the day on weekdays. This is consistent with the perspective that exposure to workplace restrictions on weekdays may contribute to more uneven or sporadic temporal distributions of smoking, which could make smoking during the workday more uncomfortable and/or less desirable among those with workplace bans. Future studies could help to clarify the relationship between explicitly modeling the relationships between exposure to restrictions, variance in smoking rate and nicotine levels, and subjective effects of smoking (e.g., cigarette satisfaction, hedonics).

4.4.2 Escaping Restrictions during Work Hours

Individuals were more likely to change locations to smoke during work hours on weekdays, regardless of workplace smoking policy. This, in conjunction with the finding that restrictions were generally not associated with metrics of interference with nicotine maintenance, suggests that, overall, individuals may effectively compensate for prolonged exposure to restrictions by escaping restrictions during the workday. Apart from other findings, this appears to be consistent with a nicotine maintenance perspective of smoking. That is, despite exposure to smoking bans during the workday, individuals generally smoke *consistently enough* during Work hours to maintain 'typical' nicotine levels. In other words, just as individuals appear to compensate (albeit, imperfectly) for other barriers to nicotine maintenance, such as increasing puff volume in response to smoking "lights" or lower-nicotine cigarettes (Scherer, 1999; Benowitz, 2001), smokers may compensate for a "switch" to restricted environments by periodically escaping that context to smoke.

A related interpretation of these results is that, although environmental smoking bans may pose a barrier to consistent smoking *in theory*, this barrier is far from insurmountable. By design, most indoor smoking bans only forbid smoking in a particular location, and the vast majority of evidence suggests high compliance with smoke-free laws. However, even within broad categories (e.g., "full" indoor bans), workplace policies may differ considerably in terms of strength, degree of enforcement, and ease with which they can be circumvented or escaped (McMullen et al., 2005; Jacobsen & Wasserman, 1999). Importantly, individuals in the current study had likely already adapted to the presence of smoking-restrictions at work. Some data suggests that, following implementation of bans, individuals may acclimate to the presence of restrictions over time. For example, in one study (Owen & Borland, 1997), individuals showed an initial drop in response to the implementation of a workplace smoking ban; however, over the course of a 2 year follow up, their cigarette consumption increased toward pre-ban levels. Thus, smokers may have learned to ways to effectively "get around" smoking bans during Work hours.

Alternatively, it is also possible that informal norms related to smoking at work –or, simply smoking around others- may affect smoking behavior during typical Work hours regardless of explicit policy, thus masking any relationship between stringency of bans and interference with nicotine maintenance. Indeed, smoking tended to be lowest during daytime hours across all policy groups. This may suggest that suppression of smoking observed during the daytime may be associated with factors other than exposure to smoke-free settings, such as social norms or daytime activity (e.g., individuals may smoke less when they are busy during waking hours). Other studies have shown a relationship between circadian patterns of substance use and typical business hours. For example, one recent study demonstrate that cocaine use tends to be suppressed during typical business (9am-5pm) hours and increases in the evening hours among polydrug abusers, even those who do not work (Phillips, Epstein, & Preston, 2013). This could suggest that, apart from explicit environmental restrictions, internalized norms –beliefs that substance use is socially unacceptable- may shape smoking patterns (Poland et al., 2006), such that individuals may escape work areas to smoke, regardless of explicit workplace smoking policy.

Although frequency of escaping restrictions during work hours was unrelated to stringency of workplace bans, the frequency with which people reported exposure to work restrictions on EMA was associated with increased frequency of changing locations to smoke during work hours. This may be a reflection of heterogeneity in the stringency and enforcement of restriction policies within a broad category (i.e., “full” indoor bans vs. “partial” indoor bans). That is, it is possible that EMA-reported frequency of encountering restricted settings at work captures some aspect of the ease with which individuals may escape or avoid indoor bans (or, choose unrestricted areas) during the workday, which is not captured in the global report of “severity” of workplace smoking policy (i.e., full vs. partial).

Smoking regulations such as workplace bans represent a key branch of tobacco control (Jacobsen, Wasserman, & Anderson, 1997; Warner & Mendez, 2010). As reported in other studies (see Collins & Procter, 2011), individuals in this study largely adhered to smoking regulations and, with very few exceptions, avoided smoking in areas where smoking was forbidden. Thus, workplace bans appeared to be effective in achieving their explicit goal of reducing ETS in restricted settings. However, stringency and presence of smoking bans at work did *not* seem to significantly interfere with people’s drive –and ability- to maintain smoking patterns during the workday. The results of the current study suggest that while smoke-free policies may constrain the *environments* in which smoking occurs, they have little effect on how often or how much people smoke, particularly if individuals can escape or avoid these measures. This has important implications for tobacco control policy. For example, full site bans may need to be combined with another policy element (e.g., limiting number or duration of smoking breaks; enforcement of fines for smoking during the workday and/or on work premises) in order to reduce the actual and/or perceived availability of smoking during the workday, and thus reduce smoking behavior. Future studies may help to clarify this by identifying the parameters that may influence the extent to which work restriction policies affect smoking patterns during work hours (e.g., building size, frequency of enforcement, stringency of enforcement, proximity of off-site smoking areas, etc.).

4.4.3 Compensation at Night after Work

Although workplace smoking bans did not interfere with nicotine maintenance, results consistently indicated a relationship between work bans and increased smoking during the night hours on weekdays. However, results were contrary to the hypothesized relationships: individuals with partial work bans –*not* full work bans- demonstrated *make-up* compensation on weekdays. Increased smoking in the evening or nighttime hours on weekdays is notably inconsistent with a nicotine maintenance perspective of smoking behavior. That is, increasing smoking rate and "overloading" on nicotine -after levels have returned to "normal" following exposure to workday restrictions- cannot be explained by negative reinforcement or avoidance of withdrawal symptoms/nicotine troughs. This is particularly curious when viewed from a nicotine maintenance perspective, considering that individuals showed little evidence of interference with maintenance during the day on weekdays.

Increased smoking in the evenings after work among some smokers may have important implications for conceptualizing the factors that maintain smoking behavior in more restricted settings. The conventional model of daily smoking behavior posits that individuals smoke largely to avoid nicotine troughs associated with withdrawal symptoms (i.e., "trough avoidance"; Russell, 1971). It is possible that smokers with partial workplace bans increase smoking during the Night time block in order to stave off troughs over the course of a night's sleep. In other words, they may demonstrate another manner of anticipatory compensation for an extensive period of abstinence: nightly sleep. This would be consistent with a nicotine maintenance –or, trough avoidance- perspective of smoking. There was also some other evidence of increased smoking in the Pre-Work time block (anticipatory compensation) among the subset of individuals with partial restrictions who reported full home smoking bans (n=6). Thus, some individuals may be driven to smoke more in both the morning and evening hours in an attempt to avoid nicotine troughs when smoking is unavailable overnight (i.e., during sleep) and during (partially) restricted daytime hours. However, it is unclear as to why those with partial bans –and not those with full or no bans- might be more likely to smoke in order to avoid night-time withdrawal. It seems unlikely that exposure to partial restrictions during Work hours would confer an increased drive to smoke before bedtime to avoid troughs during the night. Differences in dependence or NMR across work policy groups may have suggested increased drive to avoid nightly withdrawal symptoms among those with partial bans. However, no such group differences were observed. As such, it is difficult to explain the relationship between partial work bans and increased smoking at night on weekdays from a strict nicotine maintenance perspective of smoking.

Alternatively, rather than smoking to avoid withdrawal associated with nicotine troughs, the observed increases in smoking in the evening hours may reflect nicotine “peak-seeking”, or smoking for the positive reinforcing effects of nicotine. Russell (1971) argued that some smoking –specifically, among individuals who smoke less than 1 cigarette per hour- may be driven by a desire to obtain the acute reinforcing effects of nicotine (i.e., “peak seeking”). Analyses of mean smoking rate suggest that a majority of the sample smoked less than 1 cigarette per hour, and as such could be viewed as “peak-seekers,” using Russell’s description. In other words, individuals in the current sample may smoke not only to avoid or counteract symptoms of nicotine withdrawal, but also to achieve some other desired effects of nicotine.

Such peak seeking may account for the observed increases in smoking rate at Night on weekdays. Post-hoc analyses were conducted in order to assess whether or not cigarettes smoked in the Night time block may have been uniquely associated with features of mood (e.g., positive affect, negative affect, arousal, attention). This assessment revealed no differences in mood reported during smoking events in the evening hours for individuals with or without work restrictions (or partial bans, compared to those with full bans), which suggests that differences in affective state on weekdays do not account for escalated smoking among those with partial restrictions.

In addition, past research also suggests that cigarettes smoked following periods of deprivation may be associated with increased satisfaction, or pleasurable or reinforcing effects of smoking. Fant et al. (1995) reported that individuals who were subjected to longer periods of deprivation (30 minutes, up to 6 hours) perceived stronger effects and greater pleasure from test cigarettes, relative to less-deprived individuals. Thus, consistent exposure to restrictions may be associated with increased perceived pleasure of cigarettes smoked at the end of the day, when restrictions are not present. Post-hoc analyses of perceived satisfaction of cigarettes -reported in EMA in the subsequent non-smoking assessment- revealed no differences across time blocks, nor in relation to workplace policy. However, assessment data for cigarettes smoked during the Night time block were sparse, as cigarettes smoked in this period often were not followed by a non-smoking assessment before the participant went to bed. Thus, the relationship between prolonged exposure to restrictions and satisfaction of cigarettes smoked *after* restrictions are lifted (e.g., on weekday nights) remains unclear.

If exposure to restrictions does result in more salient, acute pleasurable effects of smoking and decreases the extent to which nicotine levels influence smoking patterns, it is possible that peak-seeking smoking behavior may become increasingly characteristic of smoking patterns in restricted environments. Shiffman (2009b) posited that increasingly stringent tobacco control policy may be a driving force behind the substantial increase in the prevalence of non-daily smokers, who by virtue of their smoking patterns, *cannot* be said to smoke in order to avoid withdrawal/nicotine troughs. However, if nicotine peak-seeking has become an increasingly important determinant of smoking, it remains unclear what specific effects of nicotine individuals are seeking (e.g., cognitive effects, mood effects, etc.), and whether or not profiles of peak-seeking may differ across individuals (see Shiffman, Ferguson, Dunbar, & Scholl, 2012). Future studies should assess the relationship between exposure to restrictions, smoking patterns, and perceived pleasurable effects of cigarettes, as this may be important for understanding the factors that help to maintain smoking in restricted environments.

Similarly, it is unclear how exposure to smoking restrictions may affect cigarette *craving*. Past work suggests that exposure to restrictions may also be associated with smokers' experience of cigarette cravings, often viewed as the subjective "drive" to smoke (Drummond, 2001; West & Schneider, 1987). A wealth of data supports an inverse relationship between duration of abstinence and craving for cigarettes (Jarvik et al., 2000), and past studies suggest that some cigarettes (particularly those smoked in restricted settings) are craved more so than others (Dunbar, Scharf, Kirchner, & Shiffman, 2010). In addition, studies of other drugs suggest that drug (cocaine) craving is highest during daytime hours, even though drug use is suppressed (Phillips et al., 2013). Thus, regular exposure to work bans may correlate with increased exposure to cigarette craving during work hours. However, other data suggest that perceived cigarette *availability* may be inversely associated with cigarette craving (Wertz & Sayette, 2001). Therefore, exposure to restricted settings may actually *reduce* craving experienced during prolonged periods of enforced abstinence; cigarette craving may then spike in situations where smoking is once again available. Thus, the relationship between exposure to smoke-free environments and craving remains unclear. Craving is associated with cessation failure (Killen & Fortman, 1997; Shiffman et al., 1996; Shiffman et al., 1997), and as such, it is a common treatment target for tobacco cessation interventions (Marlatt & Gordon, 1985). Consequently, understanding the relationship between exposure to restrictions and cigarette craving may have important implications for treating tobacco dependence in more restricted settings. Although this was beyond the scope of the current study, future studies should examine the relationship between exposure to smoke-free environments and patterns of cigarette *cravings.*

4.5 MAKE-UP COMPENSATION AND PARTIAL WORK BANS

Heavier evening smoking on weekdays observed among those with partial work restrictions, but not among individuals with full bans, was unexpected. Previous studies suggest that full work bans have a greater impact on smoking behavior than partial bans (e.g., Farrelly, Evans, & Sfekas, 1999). It was hypothesized that, since individuals with partial bans are –by definition- able to smoke in some work areas, any relationship between work restrictions and smoking patterns would be attenuated, relative to the full bans group. However, full restrictions may also be more effective than partial bans at constraining how much people smoke –even after restrictions are lifted. Individuals who are exposed to partial workplace bans may experience a smaller 'dose' of restrictions (e.g., Farrelly, Evans, & Sfekas, 1999; McMullen et al., 2005), which could be insufficient to produce the degree of behavioral change that might lead to a more global reduction in their smoking compared to individuals with full restrictions. One possibility is that full restrictions may produce greater reductions in smoking, which could correspond to lower nicotine “set points” and diminished drive or need to smoke once smoking *is* available compared to individuals with partial restrictions. However, this is difficult to infer from the current data, as there were no there were no differences in smoking rate during work hours across policy groups in this sample. Alternatively, over time, exposure to full restrictions during the workday may more effectively weaken associations between smoking and various environmental cues (e.g., being indoors, presence of others). In this way, exposure to full restrictions may more effectively facilitate extinction to distal smoking cues (Conklin, Robin, Perkins, Salkeld, & McClernon, 2008) compared to partial bans. This could result in lower smoking –or, reduced reactivity- in the context of such distal cues, even after restrictions are lifted. In contrast, partial restrictions may function to maintain some common associations between smoking and environmental contexts (e.g., being around other smokers), which may then continue to function as triggers for smoking once restrictions are lifted. This could account for the observed pattern of results, such that those with partial restrictions –but not full restrictions- demonstrated greater smoking after work hours on weekdays.

Some authors have described smoking in terms of a “social trend”, which is governed in part by the degree to which smoking is perceived as socially normative or stigmatized (Poland et al., 2006; Pampel, 2005). This view of smoking suggests that the effect of smoking restrictions on behavior may be mediated in part by their ability to foster greater perceived stigma, or denormalization, of smoking (Poland et al., 2006; Pampel, 2005; Hammond, Fong, Zanna, Thrasher, & Borland, 2006; Collins & Procter, 2011). If exposure to environmental smoking bans does indeed result in a reduction in the perceived social acceptance of one's smoking, rather than simply communicating the momentary availability of smoking in a particular setting, regular exposure to strict restrictions may convey the message of smoking denormalization. The perception that smoking is not socially condoned may predict more generalized reductions in smoking, beyond explicitly restricted settings; thus, this perspective may suggest *no increase* in smoking even when formal restrictions are not in effect (e.g., outside of the workplace). Indeed, previous research suggests that exposure to more comprehensive environmental tobacco restrictions –at the population level- is associated with greater social denormalization of smoking, which is in turn associated with greater intention to quit and increased likelihood of non-daily vs. daily smoking (Hammond et al., 2006). Thus, individuals who experience greater exposure to more stringent environmental smoke-free regulations (e.g., full workplace bans) may perceive greater denormalization of smoking behavior, which may suppress smoking even when environmental restrictions are not in place (e.g., after work hours). This is consistent with the observed pattern of results. Individuals with partial bans demonstrated increased smoking after work hours on weekdays, whereas those with full smoking restrictions demonstrated no such increase.

It is also possible that other group characteristics, rather than type of work policy, might account for the observed differences in make-up compensation across workplace smoking policy groups. Those with partial work restrictions *did not* differ from those with full work restrictions in terms of a number of important individual characteristics which might have been expected to facilitate increased smoking, including partner smoking status, home smoking policy, number of household smokers, or nicotine dependence. In addition, adjusting for various demographic factors (see Appendix 4) did not affect the pattern of results (i.e., make-up compensation in the Night time block among smokers with partial restrictions). However, workplace policy was significantly associated with occupational status ($p<0.001$), such that individuals with partial bans were significantly more likely than those with full restrictions to have blue collar occupations (e.g., service workers, factory workers, cashiers, etc.). This is consistent with national survey data, suggesting that higher SES individuals are more likely to encounter more severe workplace smoking bans, compared to lower SES workers (CDC, 2011).

Given these differences in occupational status, another possible explanation for the "make up" compensation observed among individuals with partial bans is that these individuals are more likely than those with full workplace restrictions to report certain external environmental factors or triggers (e.g., others' smoking, stress) that may be associated with increased smoking in the evenings on weekdays. Socioeconomic status is significantly correlated with smoking behavior; the myriad cultural, occupational, and psychosocial factors associated with "blue collar" occupations may contribute to differences in smoking patterns (Sorenson et al., 2004). For example, Graham (1998) posited that certain aspects associated with low-income status, such as increased child-care responsibilities at home and fewer coping resources, were particularly important determinants of increased smoking among low-income compared to higher-income women. Post-hoc analyses suggested that individuals with full and partial bans did *not* differ in the likelihood of reporting various situational factors in the evening hours that were posited to be associated with increased smoking (e.g., Shiffman et al., 2002), including mood, being at bar, drinking alcohol, being with others, engaging in housework or leisure activities, being around other smokers, availability of cigarettes, or reporting that smoking was allowed or forbidden by law or personal rules.

However, individuals with partial bans *were* significantly *less* likely than those with full bans to report that smoking was discouraged or forbidden due to other's rules in the evening time block (OR= 0.27, 95% CI 0.08 - 0.90, p=0.03). Thus, one possibility is that these individuals smoke more after work because their smoking is less discouraged by others' rules. Put another way, blue collar individuals with partial bans may perceive less stigma associated with their smoking outside of the workplace. This is consistent with findings that lower SES individuals are less likely to be exposed to environmental restrictions (Taurus, 2007; Cokkinides et al., 2009) and perceive less stigma associated with their smoking (Pampel, 2005; Morris et al., 1999; Hammond et al., 2006).

A related interpretation of these findings is that individuals with partial bans may smoke more after work simply because they perceive that they are able to do so. That is, Night hours on weekdays may be associated with a salient signal for the opportunity to smoke ad libitum. Since individuals with partial work restrictions are ostensibly more capable of smoking ad libitum during work hours, it was hypothesized that any effect of partial bans on smoking patterns would be muted or even absent among this group. However, the assumption that those with partial bans are *more capable* of smoking *ad libitum* at work compared to those with full bans may be incorrect. Blue collar occupations tend to be associated with higher job strain (Siegrist et al., 1990; Johnson & Hall, 1988), less control over work tasks (e.g., Bosma et al., 1997), and less control over daily work schedules (Ala-Mursula et al., 2004). Even though restrictions do not appear to significantly interfere with nicotine maintenance during Work hours, smokers with 'blue collar' occupations may therefore perceive less autonomy or control over when they smoke during the workday (i.e., when they take their smoke breaks), as compared to white collar workers. Consequently, although they may ostensibly be subject to less rigorous environmental smoking restrictions, the nature of blue collar work that is associated with partial bans may have very different implications for perceived availability of cigarettes during work hours. That is, despite being able to smoke in some areas, blue collar individuals with partial bans may have relatively little access to cigarettes during Work hours. As such, the transition from work to home at Night may serve as a very clear signal that smoking is available, which may be sufficient to prompt escalated smoking on weekday Nights in this group. Understanding the extent to which different types of restrictions influence smoking patterns during the day across different subgroups may have important implications for appreciating the factors that function to suppress or promote smoking for different individuals. This, in turn, may have important implications for understanding variations in tobacco control policy effects, and tobacco-related health disparities, across the socioeconomic gradient. More research on the relationship between daily smoking patterns, cigarette availability, perceived control over smoking, and exposure to different types of workplace smoking restrictions may help clarify these relationships.

4.6 FUTURE DIRECTIONS

Comprehensive tobacco control measures have been immensely effective at reducing overall prevalence and consumption of smoking in the United States since the first Surgeon General's report in the 1960's (Giovino, 2007; Warner & Mendez, 2010). However, decades of successful policy initiatives have also shaped a dramatically different landscape for smoking in today's world. For example, the past several years have witnessed a dramatic rise in the number of non-daily smokers (up to a third of current smokers; Substance Abuse and Mental Health Services Administration, 2013), whose patterns of consumption cannot be explained by conventional perspectives of nicotine dependence. Although past work has suggested that non-daily smoking is associated with more stringent policy climates (Shiffman, 2009b), it is unclear how temporal smoking patterns among non-daily smokers may –or may not- be correlated with exposure to smoke-free settings.

In addition, new evidence suggests that home smoking bans are continuing to increase in popularity among U.S. households (CDC, 2014). Whereas a small percentage of individuals (18%) in the current study reported full indoor bans at home, data suggest that homes are becoming increasingly smoke-free (nearly 40% of Pennsylvania households with at least 1 smoker had full indoor bans as of 2011; CDC, 2014). This signifies a continued decline in availability of smoking *outside* of the workplace, which may further impede efforts to maintain 'preferred' levels of cigarette consumption in the face of public smoke-free policies. This may have significant implications for understanding potential effects of social stigma and perceived availability of smoking outside of the workplace on smoking patterns among individuals who continue to smoke.

Finally, the past several years have witnessed a meteoric rise in the popularity of "alternative" nicotine products, such as electronic nicotine delivery systems (ENDS; e.g., "e-cigarettes") and non-combustible tobacco products, in recent years (Zhu et al., 2013; Chapman & Wu, 2014). Some studies have suggested that light or non-daily smokers may be more likely to use alternative nicotine products (i.e., electronic cigarettes) than moderate daily smokers (Adkison et al., 2013; Zhu et al., 2013). This may suggest an important relationship between continued and/or reduced smoking in restricted settings and *increased* use of alternative nicotine products. The growing popularity of “alternative” nicotine products also evokes myriad questions related to how we conceptualize and treat nicotine dependence in the increasingly less permissive policy climate. For example, individuals could potentially weather extended periods of abstinence –and avoid nicotine troughs and withdrawal symptoms more easily- by supplementing smoking with alternative nicotine products during restricted work hours. Indeed, although some individuals appear to use ENDS to assist with reducing smoking and supporting quit attempts (e.g., Adkison et al., 2013), there is little evidence supporting their utility as a smoking cessation or reduction aid. Rather, recent data suggest that individuals may use ENDS as a *substitute* for cigarette smoking, when smoking is otherwise not available or allowed (Chapman & Wu, 2014). Much more research is needed in order to fully assess the extent to which use of alternative nicotine products –and the evolving regulatory climate surrounding their use- may affect patterns of cigarette consumption and nicotine intake, and what implications this may have for understanding and treating nicotine dependence.

4.7 LIMITATIONS

This study was subject to a number of limitations. Participants did not provide precise data on their physical location (e.g., at work vs. at home) or activity (job vs. other) at every moment over the course of the study – only when they were sampled at random and at a subset of smoking occasions. In addition, since the initial study was not designed to monitor exposure to restricted environments, the data reflect an incomplete picture of exposure to restrictions in the world, in real time. As such, the data allowed for ‘best-estimates’, rather than precise measurements of participants’ environmental context– and consequently, the presence or absence of restrictions – at a given time. In addition, as discussed above, although participants reported whether work restrictions were full or partial, the relative ease with which individuals could escape restricted settings to smoke was unknown. Future studies may benefit from examining real time exposure to smoke-free policies on an event-based sampling scheme, in order to more fully capture the individual’s experience and reactivity to tobacco policy exposure in real time. In addition, assessing perceived acceptability and attitudes toward smoking, as well as perceived availability of smoking, may be useful in understanding the extent to which explicit regulations versus perceived norms may influence smoking behavior across time and contexts.

Restrictions were also not randomly assigned or experimentally manipulated in this study. Thus, individuals may have demonstrated some degree of self-selection with regard to exposure to restricted settings at work and home; individuals who are able to tolerate restrictions may be more likely to voluntarily spend their time in restricted settings. Therefore, the effects of restrictions on nicotine levels and maintenance across individuals may be biased. In addition, most individuals have had considerable time to adjust to restriction policies in the workplace; as of September 11, 2008, non-hospitality workplaces in Pennsylvania were required to be smoke-free, and many sites implemented voluntary bans much sooner. It is thus unclear how smoking patterns – and compensatory behavior – may have changed as a result of the *introduction* of restriction policies, since the current study is merely a cross-sectional examination of ‘steady state’ restrictions.

In addition, simulated nicotine blood levels were estimates, intended to quantify the distribution of cigarettes across time- true nicotine blood levels were unknown. Changes in nicotine topography when individuals are able to escape restrictions may presumably allow individuals to maintain higher systemic nicotine blood levels despite fewer smoking opportunities (Chapman et al., 1997), and would be consistent with the notion that individuals compensate via changing topography when presented with an obstacle to maintaining nicotine (e.g., Scherer, 1999). However, more detailed and controlled information on nicotine boost – or even the topography – of cigarettes smoked immediately before or after to exposure to restricted environments is needed in order to assess this issue.

Finally, as noted previously, no previous studies have attempted to quantitatively assess interference with nicotine maintenance in the natural world, nor have any studies quantitatively examined evidence for temporal compensation in relationship to smoke-free environments. Consequently, the methodological approach, while grounded in theory, has not been previously established in the literature. This aspect, however, also represents a considerable strength of the current study. The approach utilizes detailed, longitudinal behavioral data to help quantify theorized constructs such as nicotine maintenance and nicotine troughs, which are inherently quantitative in nature, yet rarely defined in quantitative terms. More broadly, this approach addresses a fundamental gap in the tobacco control literature, by attempting to bridge smokers' exposure to tobacco control policy with their actual behavior –and estimated exposure to nicotine- in the real world.

4.8 CONCLUSION

This is the first study to use a multi-faceted quantitative approach to assess interference with nicotine maintenance and temporal compensation among daily smokers with varying degrees of exposure to restricted work environments. There was little evidence for interference with nicotine maintenance during work hours on weekdays. Participants largely compensated for exposure to workplace bans by periodically escaping restrictions to smoke. This suggests that bans achieve their intended effect of reducing ETS in restricted settings, thus benefitting the health of the non-smoking public. However, they do *not* appear to significantly impede regular smoking during work hours among those who continue to smoke. This is consistent with the position that environmental restrictions alone are insufficient to significantly reduce smoking.

In addition, different types of bans may have differential effects on smoking outside of the workplace. Individuals with partial workplace bans –but not full bans- showed escalated smoking in the evening on weekdays, which is inconsistent with a strict nicotine maintenance perspective of smoking. This may suggest that less stringent (i.e., partial) bans may only suppress smoking where and when bans are in effect. In contrast, more stringent (i.e., full) workplace bans may affect smoking behavior even after restrictions have been lifted, perhaps because they more effectively denormalize smoking and/or extinguish associations between smoking and certain environmental triggers (e.g., being indoors, socializing, etc.). Thus, not all smoking bans are equivalent, and this heterogeneity may be important for understanding their effects on smoking patterns in the real world. Individual differences (e.g., in socioeconomic status), additional policy measures (e.g., penalties associated with “smoke breaks”), and features of restricted environments (e.g., ease of escaping restrictions) may be important considerations in assessing and augmenting effects of smoke-free policies on behavior, even when smoking is not explicitly forbidden.

As environmental smoking restrictions become more ubiquitous and the availability of smoking becomes more constrained, situational factors may play an increasingly important role in driving continued smoking behavior. Better understanding the environmental factors that both constrain and facilitate smoking across different segments of the population may be instrumental in shaping more effective interventions to help further reduce the public health burden of smoking and move toward a legitimately smoke-free world.

APPENDIX A

Table 5. Selected electronic diary assessment items.

Cigarettes available?	1= Yes, easily 2= Yes, with difficulty 3= No
Smoking allowed?	1= Forbidden 2= Discouraged 3= Allowed
Smoking forbidden or discouraged?	1= By law 2= Your own rules 3= Other's rules
About this cigarette: Did you change location to smoke?	1=Yes 2=No

APPENDIX B

Workplace and Home Smoking Restriction Self-Report Items

Source: Current Population Survey-Tobacco Use Supplement

Citation: US Department of Commerce, Census Bureau (2006). National Cancer Institute and Centers for Disease Control and Prevention Co-sponsored Tobacco Use Special Cessation Supplement to the Current Population Survey (2003): http://riskfactor.cancer.gov/studies/tus-cps/

Items used:

Which best describes your place of work's smoking policy for INDOOR, PUBLIC OR COMMON AREAS, such as lobbies, rest rooms, and lunch rooms?

Not allowed in ANY public areas……………………… ☐

Allowed in SOME public areas………………………. ☐

Allowed in ALL public areas…………………………… ☐

Which statement best describes the rules about smoking INSIDE YOUR HOME?

No one is allowed to smoke anywhere INSIDE YOUR HOME…………………………………………………… ☐

Smoking is allowed in some places or at some times INSIDE YOUR HOME………………………………… ☐

Smoking is permitted anywhere INSIDE YOUR HOME ☐

APPENDIX C

Effects of Participant Wake Time on Temporal Smoking Patterns and ΔEvenNL

Mean wake time on weekdays was approximately 8:30 am and mean bed time was approximately 11 pm; on weekends, mean wake time was approximately 9:20 am and mean bed time was approximately 11 pm. Time awake on weekdays was approximately 40 minutes longer than time awake on weekends (14 hours 17minutes [SE=7.18 min] vs. 13 hours 38 minutes [SE=8.00 min]; $p < .0001$). However, this was not associated with workplace smoking policy (weekday x policy interaction for time awake: $p=0.84$). In addition, type of workplace smoking policy was unrelated to average wake time ($F(2,121)=1.05$, $p=0.35$) and bed time ($F(2,121)=0.18$; $p=0.84$). Workplace smoking policy was also unrelated to earliest or latest times that participants reported being at work in EMA monitoring (Earliest Work: $F(2,88)=2.43$; $p=0.09$; Latest Work: $F(2,88)=0.07$; $p=0.93$).

Since the average participant wake time was close to the end of the Pre-Work time block, and timing of evenly-spaced cigarettes was a function of wake time, it was hypothesized that patterns of ΔEvenNL would vary as a function of wake time. Indeed, the main effect of time block on ΔEvenNL was significantly moderated by participants' wake time ($p=0.003$), such that individuals who reported waking after 8:30 am (mean wake time across all subject days) demonstrated no difference between real-time and evenly-spaced smoking nicotine levels in the

Pre-Work time block, negative ΔEvenNL in the Work and Post-Work time blocks, and positive ΔEvenNL (i.e., higher real-time smoking nicotine levels) in the Night time block.

APPENDIX D

Table 6. Output from adjusted models for work policy x day x time block effects on primary outcomes

1. Smoking Rate: Adjusted Model

Effect	Num DF	Den DF	F Value	Pr > F
race	2	80	0.43	0.6493
gender	1	80	5.87	0.0177
occupation_code	6	80	1.29	0.2704
partner_smk	4	80	3.75	0.0076
no_household_sm	2	80	1.8	0.1715
work_smk	4	80	0.26	0.9023
home_smk	1	80	6.51	0.0127
weekend	1	100	5.03	0.0272
t_work	3	289	38.49	<.0001
t_work*weekend	3	253	1.19	0.3129
indoor_policy	2	80	3.52	0.0344
weekend*indoor_policy	2	100	4.33	0.0157
t_work* indoor_policy	6	289	1.21	0.3026
t_work*weekend*indoor_	6	253	3.01	0.0073

2. ΔEvenNL: Adjusted Model

Effect	Num DF	Den DF	F Value	Pr > F
race	2	80	3.49	0.0352
gender	1	80	0.85	0.3581
occupation_code	6	80	1.78	0.1128
partner_smk	4	80	1.85	0.1282
no_household_sm	2	80	2.07	0.1334
work_smk	4	80	1.96	0.1083
home_smk	1	80	0.08	0.7725

weekend	1	100	0.05	0.819
t_work	3	291	62.1	<.0001
t_work*weekend	3	263	3.46	0.017
indoor_policy	2	80	0.36	0.7015
weekend*indoor_policy	2	100	1.91	0.1527
t_work* indoor_policy	6	291	0.78	0.5826
t_work*weekend*indoor_	6	263	2.04	0.0606

3. %WeekendNL: Adjusted Model

Effect	Num DF	Den DF	F Value	Pr > F
race	2	80	0.07	0.9348
gender	1	80	7.83	0.0064
occupation_code	6	80	0.94	0.4719
partner_smk	4	80	1.43	0.2315
no_household_sm	2	80	1.29	0.2805
work_smk	4	80	1.28	0.2866
home_smk	1	80	8.47	0.0047
t_work	3	286	10.21	<.0001
indoor_policy	2	80	0.57	0.57
t_work*indoor_policy	6	286	2.65	0.0163

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