**The Role of Sleep Impairment in Associations Between Pain and Nicotine/Tobacco Dependence in Wave 6 of the Population Assessment of Tobacco and Health (PATH) Study**

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**Abstract**

**Objective:** Tobacco use is a significant national health concern that frequently co-occurs with chronic pain. Both pain and use of nicotine/tobacco have been linked to greater sleep impairments (i.e., trouble initiating and maintaining sleep), and there is reason to believe that more severe pain may indirectly contribute to greater nicotine dependence via sleep impairments.

Therefore, the goal of this study was to examine indirect associations between pain severity and nicotine dependence via sleep impairment severity among adults who use cigarettes and electronic nicotine delivery systems (ENDS).

**Methods:** Data were drawn from Wave 6 (March – November 2021) of the Population Assessment of Tobacco and Health Study (PATH), limited to N = 9,682 (54% male; 22% ages 25-24; 77% White) participants who reported regular cigarette smoking and/or ENDS use. Pain severity and sleep impairment were assessed using single items, and nicotine/tobacco dependence was assessed using the Wisconsin Inventory of Smoking Dependence Motives (WISDM).

**Results:** Results indicated positive indirect associations between pain severity and both tobacco and ENDS dependence via sleep impairment severity.

**Conclusions:** Sleep impairment may play an important role in associations between pain severity and nicotine dependence among adults who use cigarettes or ENDS. These findings and future work may warrant the development of interventions that address sleep dysfunction to support nicotine and tobacco cessation, particularly among adults who experience pain.

Keywords*:* pain; sleep; nicotine dependence; tobacco; cigarettes; e-cigarettes

**Introduction**

Combustible cigarette smoking is the leading cause of preventable disease, disability, and death in the United States (Kim et al., 2023). The risks of cigarette smoking are well-documented, including numerous cancers, respiratory diseases, stroke, and cardiovascular disease (Gan et al., 2022; Khoramdad et al., 2020; Pan et al., 2019; Sasco et al., 2004). These known health consequences have contributed, in part, to a surge in the popularity of electronic nicotine delivery systems (ENDS), including electronic cigarettes or e-cigarettes that contain nicotine but not tobacco leaf (Cornelius et al., 2023). Nicotine, the primary psychoactive compound in both combustible cigarettes and ENDS, is a highly addictive substance that reinforces continued use through its effects on neurobiological reward pathways (Corrigall, 1991; Etter & Eissenberg, 2014; Harvey et al., 2004). Nicotine dependence includes symptoms such as difficulty controlling use, craving, tolerance, and withdrawal (Mickens et al., 2010). Greater nicotine dependence has been associated with less motivation to quit smoking and greater difficulties during cessation (i.e., more severe withdrawal symptoms; Han et al., 2023; Hollands et al., 2022; Lin et al., 2021).

There has been increasing focus of the impact/role of chronic pain on tobacco use. The reciprocal model of pain and nicotine/tobacco use posits a bidirectional relationship in which pain increases the likelihood of nicotine use, and nicotine use, in turn, exacerbates pain (Ditre et al., 2011; Ditre et al., 2019; LaRowe & Ditre, 2020). For example, national prevalence estimates indicate that individuals with pain (compared to those without pain) are twice as likely to smoke cigarettes (Shiri et al., 2010; Zvolensky et al., 2010). Cigarette smokers with current pain (compared to those without pain) are more likely to initiate and continue ENDS use and are nearly three times more likely to endorse lifetime polytobacco use (i.e., the use of two or more tobacco products; Powers et al., 2020; Sung et al., 2015). Individuals with pain (compared to those without pain) report lower confidence in their ability to quit smoking (Zale et al., 2014), identify pain as a barrier to cigarette cessation (Ditre et al., 2021; Ditre et al., 2017), and are over two times more likely to meet criteria for nicotine dependence (Zvolensky et al., 2009).

Extensive research has established links between sleep and both pain and tobacco/nicotine use, respectively. For example, there is strong evidence of reciprocal associations between pain and sleep (Campanini et al., 2022; Finan et al., 2013; Koffel et al., 2016), such that increased pain disrupts sleep, which in turn amplifies pain and worsens sleep quality. Research examining the relationship between sleep and nicotine/tobacco use similarly shows that individuals who report cigarette use compared to non-users, are more likely to experience sleep-related difficulties including daytime fatigue, increased sleep disturbance, reduced total sleep time, waking earlier than desired, and insomnia (i.e., problems intiating and maintaining sleep; de Leeuw et al., 2013; Khan et al., 2019; McNamara et al., 2014; Phillips & Danner, 1995). Among adult users of ENDS, poor sleep quality has been associated with greater nicotine dependence and perceived cessation barriers (Zvolensky et al., 2020). Further, dual use of cigarettes and ENDS has been associated with 81% higher odds of insufficient sleep duration (< seven hours) compared to non-users (Poudel et al., 2025). Finally, sleep deprivation has been associated with increased rates of both cigarette and ENDS use (Hamidovic & Wit, 2008; Kianersi et al., 2021).

Taken together, these prior research findings suggest that sleep impairment may serve as a key pathway through which pain influences tobacco and nicotine dependence. Additionally, much of this prior literature has focused on individuals who use cigarettes, thereby limiting generalizability to those who use ENDS or polytobacco users, who represent a large and growing subset of individuals who use nicotine-containing products (Mattingly et al., 2021; McMillen et al., 2015; McNeil et al., 2021). The current study aimed to test indirect associations between pain severity and nicotine dependence via sleep impairment severity among adults who currently use cigarettes and ENDS, respectively. We hypothesized that pain severity would be positively and indirectly associated with both tobacco dependence and ENDS dependence via sleep impairment severity.

**Method**

**Data Source and Sample**

The current analyses employed public-use data from Wave 6 (March 2021–November 2021) of the Population Assessment of Tobacco and Health (PATH) study (United States Department of Health and Human Services et al., 2025), an ongoing, nationally representative longitudinal cohort study of adults and youth in the United States. All participants provided informed consent and data were de-identified. Each Wave of PATH data includes population weights, which allows for representative estimates of the non-institutionalized, civilian U.S. population. Additional details and methodology of the PATH study are described elsewhere (DiGaetano et al., 2024), and data for the current analyses are available at <https://www.icpsr.umich.edu/web/NAHDAP/series/606>. The current sample included N = 9,682 participants who were (1) adults aged 18 years or older at Wave 6, (2) established someday/everyday cigarette or ENDS users, as defined by reporting using cigarettes or ENDS some days/every day, and (3) provided complete data for variables of interest during the assessment.

**Measures**

**Pain Severity**

Pain severity was measured with a single item: “In the past 7 days, how would you rate your pain on average on a scale from 0 to 10 where 0 is no pain and 10 is the worst pain imaginable?” Responses were measured on an 11-point scale, with greater scores indicating more severe pain. Past-week pain ratings have been associated with more robust measures of pain status and severity among adults (Costa et al., 2025; Von Korff et al., 1992), and this single PATH item has been employed in previous work to examine links between pain and nicotine/tobacco use (Powers et al., 2023; Powers et al., 2022).

**Sleep Impairment Severity**

Sleep impairment severity was assessed with a single item: “When was the last time that you had significant problems with sleep trouble, such as bad dreams, sleeping restlessly, or falling asleep during the day?” Participants chose from the following options: Never, over a year ago, two to twelve months ago, or past month. The item was selected from the Internalizing Disorder Screener (IDScr) subscale of the Global Appraisal of Individual Needs- Short Screener (Gain-SS; Dennis et al., 2006), and has been previously used as an indicator of significant sleep concerns (Holtz et al., 2022; Riehm et al., 2019). Consistent with DeAtley et al. (2022), we retained the continuous item design and used item scores as a proxy for symptom severity. This item was recoded as follows: 0: absence of sleep impairment: (combined responses: “never” and “over a year ago”); 1: less severe sleep impairment: (“two to twelve months ago”); 2: significant sleep impairment (“past month”), such that a higher value indicates more severe sleep impairment.

**Nicotine Dependence**

Eleven items from the Wisconsin Inventory of Smoking Dependence Motives Short Form (Brief WISDM; Smith et al., 2010) assessed seven domains related to nicotine dependence and motives for use (Kaplan et al., 2020). Responses ranged from 1 (Not true of me at all) to 5 (Extremely true of me), with higher scores indicating greater dependence (Liu et al., 2017). The 11 items were combined to create a total WISDM score, following Strong et al. (2017), and were written to assess dependence separately for tobacco products and ENDS. In our sample, both the tobacco and ENDS total WISDM scales showed excellent internal consistency (tobacco: *α* = .93; ENDS: *α* = .94).

**Polytobacco Use**

Polytobacco use was defined using PATH-derived variables, which we used to create two binary variables to indicate whether participants endorsed every day or someday use of cigarettes or ENDS *plus* (1) every day or someday use of any other tobacco product(s), including cigarettes, ENDS, traditional cigars, cigarillos, filtered cigars, pipe, hookah, snus, smokeless tobacco, or IQOS, or (0) no additional tobacco product use.

**Participant Characteristics**

Demographic measures included biological sex (male, female), age (18-24, 25-34, 35-44, 45-54, 55-64, and 65+), race (White, Black, Other), ethnicity (Hispanic, non-Hispanic), household income, and highest level of completed education. Participants also rated their mental health on a six-point Likert scale from 1 (Excellent) to 5 (Poor): “In general, how would you rate your mental health, which includes stress, depression, and problems with emotions.”

**Data Analytic Strategy**

All analyses were conducted in Stata version 18.5 (StataCorp, College Station, TX). Participants were divided into two partially overlapping subgroups using two PATH derived variables: (1) cigarette users (i.e., participants who endorsed lifetime cigarette smoking and currently smoke cigarettes every day or some days) and (2) ENDS users (i.e., participants who endorsed lifetime ENDS use and currently use ENDS every day or some days). Participants who reported polytobacco use (i.e., those who endorsed every day or someday use of cigarettes or ENDS plus the use of additional tobacco products every day or some days) were included in both subgroups. The data were weighted using population and replicate weights adjusting for complex study design characteristics at Wave 6; estimates were calculated with balanced repeated replication methods using a Fay’s adjustment value of 0.3 (Judkins, 1990). Descriptive statistics were calculated for participant sociodemographic variables, pain severity, sleep impairment severity, exclusive and polytobacco product use endorsement, and tobacco and ENDS dependence. Additionally, bivariate correlations were calculated among the main outcome variables and participant characteristics, and covariates were selected based on significant associations with either outcome variable (i.e., tobacco or ENDS WISDM score).

Next, we utilized sgmediation2 (Mize, 2022), a user-written Stata command to test adjusted and unadjusted indirect effect models. All models included past-week pain severity as the predictor, sleep impairment severity as the indirect effect variable, but differed in the dependent variable (i.e., WISDM total score for tobacco users or WISDM total score for ENDS users). Adjusted and unadjusted models measured direct, total effects, and indirect and completely standardized indirect effects (Preacher & Kelley, 2011). The coefficients, standard errors, and percentile bootstrap confidence intervals (PBCI) were generated using 5,000 bootstrap resampling, which were used to manage constraints in statistical power, while reducing the likelihood of Type I errors and biased estimates (Preacher & Hayes, 2004; Tibbe & Montoya, 2022). Indirect effects were deemed significant if the PBCI did not cross zero (Hayes, 2022). Effect sizes (ES) were estimated with the completely standardized indirect effect size, identified as a one-unit change in the standardized predictor (i.e., one standard deviation) on the standardized outcome. ES is interpreted as small (0.01), medium (0.09), and large (0.25; Preacher & Kelley, 2011). We further described the indirect associations by identifying the percentage of the total effect accounted for by the indirect pathway through dividing the product of the indirect effect by the total effect (*ab*/c) in covariate adjusted models.

**Results**

**Participant Characteristics**

Of adult participants who provided data at Wave 6 of the PATH study, approximately 21% (*n* = 6,361) reported someday or everyday cigarette use and 10.89% (*n* = 3,321) reported someday or everyday ENDS use; see Table 1 for participant characteristics by nicotine product endorsement and for the total sample. In the total sample (N = 9,962 participants who reported every day or someday use of cigarettes and/or ENDS), most participants were White (76.69%), more than half (53.98%) were male, and the age category with the greatest proportion of participants was 25-34 years. Participants reported an average past-week pain severity of 3.23 (SD = .048), nearly 34% of the sample endorsed significant sleep impairment, and 32.57% reported current polytobacco use. Participant age, sex, race, total household income, highest level of education completed, perceived mental health symptom severity, and polytobacco use status were significantly correlated (all *p*s < .01) with cigarette and/or ENDS dependence, and were retained in adjusted models as covariates. See Table 2 for bivariate correlations among the subset of cigarette users and Table 3 for ENDS users.

***Indirect association between pain severity and tobacco dependence via sleep impairment severity***

There was a statistically significant indirect association between pain severity and total tobacco WISDM score via sleep impairment severity (*ab*= .0049, SE = .001, 95% PBCI [.002, .008]), such that higher pain severity was associated more severe sleep impairment (*a* path: *b* = .057, SE = .005, *p* < .001), which was in turn, associated with greater total WISDM score (*b* path: *b* = .086, SE = .02, *p* < .001; See Figure 1). The indirect effect accounted for 9.6% of the association between pain severity and total WISDM score, and there remained a significant direct association between pain severity and tobacco WISDM score when accounting for sleep impairment severity (*c’* path: *b* = .05, SE = .007, *p* < .001). The completely standardized indirect association was also significant (β =.011, SE = .003, 95% PBCI [.005, .017]). In addition, when removing covariates there remained a significant indirect association between pain severity and total tobacco WISDM score via sleep impairment severity (*ab* = .009, SE = .002, 95% PBCI [.006, .013]), as well as a significant direct association between pain severity and total tobacco WISDM score when accounting for sleep impairment severity (*c’* path: *b* = .08, SE = .007, *p* < .001).

***Indirect association between pain severity and ENDS dependence via sleep impairment severity***

The indirect association of pain severity on total ENDS WISDM score through sleep impairment severity was statistically significant (*ab*= .003, SE= .002, 95% PBCI [.0002, .008), such that higher pain severity was related to increases in the severity of sleep impairments (*a* path: *b* = .04, SE = 01, *p* < .001), which was associated with greater total WISDM score (*b* path: *b* = .09, SE= .04, *p* = .03; See Figure 2). The indirect effect accounted for 6% of the association between pain severity and total WISDM score, and there remained a significant direct association between pain severity and total WISDM score when accounting for sleep impairment severity (*c’* path: *b* = .04, SE = .02, *p* < .01). The completely standardized indirect association was also significant (β = .008, SE = .005, 95% PBCI [.0007, .019]). In addition, when removing covariates, the indirect association between pain severity and total ENDS WISDM score via sleep impairment severity remained significant (*ab* = .007, SE = .003, 95% PBCI [.0015, .013]), as well as the direct association between pain severity and total WISDM score when accounting for sleep impairment severity (*c’* path: *b* = .033, SE = .016, *p* = .045).

**Discussion**

This is the first study to examine indirect associations between pain severity and nicotine dependence as a function of sleep impairment. Results indicated that pain severity ratings were positively and indirectly associated with both tobacco and ENDS dependence scores via greater level of sleep impairment. These findings contribute to a growing literature linking nicotine/tobacco dependence to both sleep (Boutoua et al., 2008; Hägg et al., 2020; Short et al., 2016) and pain (Campanini et al., 2022; Finan et al., 2013; Koffel et al., 2016), and extends these findings by highlighting sleep impairment as a potential pathway by which pain severity may contribute to greater nicotine/tobacco dependence.

These results may be explained, in part, by the timing and nature of nicotine withdrawal symptoms, which can emerge within hours of last use and frequently coincide with periods of sleep when nicotine intake is interrupted (McLaughlin et al., 2015). The severity of sleep disturbances is related to the amount of nicotine consumed, level of dependence, and duration of abstinence (Jaehne et al., 2009), and may be further compounded by co-occurring pain. Longitudinal studies indicate that individuals who smoke and experience pain report greater fatigue and sleep problems, with insufficient sleep predicting higher pain ratings the following day (Bigatti et al., 2008; Edwards et al., 2008; Wilt et al., 2016). Acute analgesic (Ditre et al., 2016; Ditre et al., 2019) and stimulating (Singh et al., 2023) effects of nicotine may further reinforce ongoing use as individuals attempt to manage both pain and sleep disruption. Together, these findings underscore the importance of investigating the dynamic interplay between pain, sleep impairment, and nicotine dependence.

In addition to behavioral reinforcement and withdrawal timing, neurobiological mechanisms may underlie the link between pain, sleep impairment, and nicotine dependence. Both pain and sleep disturbance are associated with dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis and alterations in reward-related pathways, including dopamine and acetylcholine systems implicated in nicotine dependence (Koob & Le Moal, 2008; McEwen, 2006). Disruption of the HPA axis may increase allostatic load in individuals with co-occurring pain and sleep impairment, heightening nicotine craving and dependence (Anderson & Platten, 2011; Lovallo, 2006). These biological-behavioral interactions may contribute to a feedback loop in which nicotine is used to manage the compounding effects of pain and poor sleep, while reinforcing dependence, sleep disruption, and pain.

The present cross-sectional findings provide initial support for the potential role of sleep impairment severity in the relationship between pain and nicotine dependence. Both the tobacco and ENDS indirect effect models showed small effect sizes (.01 and .003, respectively), and the indirect effects accounted for nearly 10% of the association between pain and tobacco dependence and 6% of the association between pain and ENDS dependence. Although completely standardized indirect effects were small, they align with prior population-based mediation studies of complex outcomes (Hayes, 2022). Notably, sleep impairment accounted for approximately 10% of the effect of pain severity on tobacco dependence and 6% on ENDS dependence, highlighting sleep as a potentially meaningful, though partial, mechanistic target. Given the high prevalence of chronic pain and nicotine dependence, even modest indirect effects may yield clinically significant benefits. Future intervention studies should assess whether improving sleep leads to clinically relevant reductions in pain and tobacco dependence.

These results suggest that interventions focused on improving sleep could be explored as part of comprehensive strategies to address both pain and nicotine dependence. Cognitive Behavioral Therapy for Insomnia is the first line treatment for insomnia (CBT-I; Walker et al., 2022), which has produced promising improvements in sleep and pain outcomes among adults who experience chronic non-cancer pain (Selvanathan et al., 2021). To our knowledge, only one study has evaluated the effects of CBT-I for smoking cessation (Fucito et al., 2014), which did not identify differences in cessation rates between the treatment and control groups. However, more recent work piloting a smoking cessation intervention which incorporated a CBT-I-based component found significantly greater quit rates among participants in the treatment compared to controls (Patterson et al., 2020). While there is initial promise for supporting smoking cessation through improving sleep, to date, no integrated treatment has been developed to address co-occurring pain, sleep dysfunction, and nicotine dependence to support cessation. If future research supports sleep as a mechanism linking pain and nicotine dependence, Acceptance and Commitment Therapy (ACT), which has shown efficacy in treating each condition individually (Du et al., 2021; McCallion & Zvolensky, 2015; Salari et al., 2020), may hold promise as a comprehensive intervention for individuals with co-occurring pain, sleep disturbance, and nicotine/tobacco use.

Several limitations should be noted. First, the cross-sectional nature of these data prohibits causal inferences. Although this study focused on pain severity as a predictor, it is important to consider other plausible directions of influence. For example, nicotine dependence may increase pain severity indirectly by disrupting sleep, or nicotine use may directly modulate pain perception through neurochemical mechanisms, including short-term analgesia and subsequent hyperalgesia (Ditre et al., 2016, 2018). Conversely, sleep impairment may contribute to greater nicotine dependence via heightened pain severity. Future longitudinal and experimental studies are needed to clarify the temporal ordering and bidirectional pathways between pain, sleep impairment, and nicotine dependence. Such work should also evaluate potential moderators, including pain chronicity, sleep patterns, and mental health status, to identify subgroups most susceptible to these reciprocal effects. Second, although single-item measures are often used in large-scale survey studies to reduce participant burden, they inherently limit construct validity (Clark & Watson, 2016). The PATH study relied on single-item measures of sleep impairment and pain severity, which limited our ability to capture the chronicity or frequency of impairment, factors known to influence both pain experiences (Haack et al., 2019) and smoking-related outcomes (Jaehne et al., 2009; Jaehne et al., 2015; Soreca et al., 2020). In addition, using past-month sleep problems as a proxy for severe impairment may have captured acute, transient disturbances (e.g., due to life events or acute stress; Van Reeth et al., 2000) rather than the severity of chronic sleep dysfunction. Future work would also benefit from employing comprehensive measures of sleep (e.g., sleep quality, insomnia severity, sleep architecture) and pain (e.g., duration, frequency, degree of functional impairment) to clarify how specific dimensions influence dependence. Third, dependence items in PATH may capture global dependence rather than product-specific dependence, warranting further evaluation of measurement invariance. Fourth, given overlap between exclusive and polytobacco use, polytobacco use was included as a covariate to mitigate confounding, though this approach limits attribution solely to exclusive users. Future research should aim to isolate product-specific effects, test whether treating sleep or pain symptoms reduces nicotine dependence, and examine whether effects differ by pain type or sleep disorder.

In summary, these findings provide novel insights into the potential influence of sleep impairment in the relation between pain severity and nicotine dependence among a nationally representative sample of U.S. adults. This work extends the reciprocal model of pain and substance use (Ditre et al., 2019; Ferguson et al., 2020) and the reciprocal model of pain and sleep (Finan et al., 2013; Haack et al., 2019) by demonstrating that sleep impairment severity may be a possible mechanistic factor in the relationship between pain and nicotine/tobacco dependence. These results may inform future development of integrated treatments that address sleep disturbance in the context of ENDS and cigarette use, particularly for individuals with co-occurring pain.

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**Disclosure of Interest**

The authors report there are no competing interests to declare.

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**Data Availability**

The dataset associated with this manuscript is publicly available at: <https://www.icpsr.umich.edu/web/NAHDAP/series/606>.

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**Table 1. Sample Characteristics of Adult Cigarette & ENDS Users.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Cigarette Users** | **ENDS Users** | | | **Total Sample** | |
|  | N (%) | N (%) | | | N (%) | |
| **Sex** |  | |  |  | |
| Female | 3,142 (45.62%) | | 1,619 (47.59%) | 4,157 (46.02%) | |
| Male | 2,919 (54,38%) | | 1,538 (52.41%) | 3,911 (53.98%) | |
| **Age** |  | |  |  | |
| 18 – 24 | 807 (6.69%) | | 1,610 (33.09%) | 1,993 (13.10%) | |
| 25 – 34 | 1,449 (20.84%) | | 866 (31.5%) | 1,929 (22.19%) | |
| 35 – 44 | 1,075 (21.08%) | | 308 (16.41%) | 1,237 (20.05%) | |
| 45 – 54 | 961 (18.20%) | | 180 (8.74%) | 1,043 (15.97%) | |
| 55 – 64 | 1,143 (20.48%) | | 142 (6.97%) | 1,206 (17.70%) | |
| 65+ | 630 (12.70%) | | 54 (3.28%) | 666 (10.97%) | |
| **Race** |  | |  |  | |
| White | 4,257 (75.84%) | | 2,318 (79.59%) | 5,734 (76.69%) | |
| Black or African American | 1,103 (16.12%) | | 334 (9.92%) | 1,314 (14.81%) | |
| Other | 571 (8.04%) | | 424 (10.49%) | 854 (8.50%) | |
| **Ethnicity** |  | |  |  | |
| Hispanic | 921 (14.01%) | | 588 (14.17%) | 1,303 (14.02%) | |
| **Income** |  | |  |  | |
| < $10,000 | 1,121 (17.97%) | | 418 (14.41%) | 1,325 (16.50%) | |
| $10,000 - $24,999 | 1,312 (21.59%) | | 507 (15.91%) | 1,601 (20.32%) | |
| $25,000 - $49,999 | 1,514 (26.27%) | | 749 (25.21%) | 1,987 (25.84%) | |
| $50,000 - $99,999 | 1,201 (23.08%) | | 733 (25.87%) | 1,712 (24.15%) | |
| > $100,000 | 611 (11.09%) | | 546 (18.60%) | 1,009 (13.18%) | |
| **Education** |  | |  |  | |
| Less than high school | 1,005 (15.51%) | | 336 (10.12%) | 1,168 (13.95%) | |
| GED | 618 (10.43%) | | 187 (6.95%) | 709 (9.41%) | |
| High school graduate | 1,644 (30.54%) | | 914 (28.62%) | 2,235 (30.17%) | |
| Some college or associates degree | 2,095 (32.33%) | | 1,291 (39.58%) | 2,951 (34.05%) | |
| Bachelor’s or advanced degree | 675 (11.19%) | | 422 (14.73%) | 979 (12.42%) | |
| **Exclusive Tobacco Product Use** | 4,263 (72.98%) | | 1,717 (51.28%) | 5,980 (75.38%) | |
| **Polytobacco Use a** | 1,802 (27.02%) | | 1,443 (48.72%) | 3,254 (32.57%) | |
| **Sleep Impairment Severity** |  | |  |  | |
| Never or over a year ago | 2,989 (51.17%) | | 1,384 (45.89%) | 3,896 (50.40%) | |
| 2 to 12 months ago | 960 (15.52%) | | 549 (16.80%) | 1,309 (15.74%) | |
| Past month | 2,075 (33.31%) | | 1,216 (37.31%) | 2,825 (33.86%) | |
|  | M (SE) | | M (SE) | M (SE) | |
| **Pain Severity** | 3.44 (.051) | | 2.74 (.710) | 3.23 (.048) | |
| **Dependence b** | 2.65 (.018) | | 2.12 (.031) | - | |
| **Mental Health Symptom Severity** | 2.85 (.018) | | 2.84 (.025) | 2.84 (.016) | |

*Note.* Groups were not mutually exclusive; N = weighted count; % = weighted proportion; Means and standard errors are weighted; a endorsement of some day or every day polytobacco product use; b average WISDM score.

**Table 2. Bivarate Correlations Among Cigarette Users**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variables** | **1** | **2** | **3** | **4** | | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
| **Sex** | 1 |  |  | |  |  |  |  |  |  |  |  |
| **Age** | -.074\*\* | 1 |  | |  |  |  |  |  |  |  |  |
| **Black a** | .040\*\* | .090\*\* | 1 | |  |  |  |  |  |  |  |  |
| **Other b** | .018 | -.099\*\* | -.154\*\* | | 1 |  |  |  |  |  |  |  |
| **Income** | .084\*\* | -.047\*\* | -.199\*\* | | -.004 | 1 |  |  |  |  |  |  |
| **Education** | -.068\*\* | -.004 | -.093\*\* | | .018 | .386\*\* | 1 |  |  |  |  |  |
| **Sleep c** | -.132\*\* | -.070\*\* | -.093\*\* | | .013 | -.029\* | .032\*\* | 1 |  |  |  |  |
| **Pain d** | -.099\*\* | .236\*\* | -.004 | | .016 | -.180\*\* | -.103\*\* | .230\*\* | 1 |  |  |  |
| **Dependence e** | -.115\*\* | .166\*\* | -.065\*\* | | -.038\*\* | -.130\*\* | -.132\*\* | .168\*\* | .236\*\* | 1 |  |  |
| **Mental Health f** | -.159\*\* | -.040\*\* | -.070\*\* | | .033\*\* | -.141\*\* | -.059\*\* | .379\*\* | .263\*\* | .209\*\* | 1 |  |
| **Polytobacco Use** | .102\*\* | -.335\*\* | -.022 | | .060\*\* | .017 | .016 | .069\*\* | -.036\*\* | -.080\*\* | .042\*\* | 1 |

*Note*. Sex: female= 0, male= 1; Polytobacco use: no= 0, yes=1; a race: white & other= 0, black= 1; b race: white & black= 0, other= 1; c sleep impairment severity; d pain severity; e WISDM total score; f perceived mental health symptom severity; \*= *p* < .05; \*\*= *p* < .01.

**Table 3. Bivariate Correlations Among ENDS Users**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Variables** | **1** | **2** | **3** | **4** | | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
| **Sex** | 1 |  |  | |  |  |  |  |  |  |  |  |
| **Age** | -.098\*\* | 1 |  | |  |  |  |  |  |  |  |  |
| **Black a** | -.041\* | .035\* | 1 | |  |  |  |  |  |  |  |  |
| **Other b** | .020 | -.083\*\* | -.139\*\* | | 1 |  |  |  |  |  |  |  |
| **Income** | .169\*\* | -.026 | -.149\*\* | | -.021 | 1 |  |  |  |  |  |  |
| **Education** | -.005 | .017 | -.038\* | | .016 | .320\*\* | 1 |  |  |  |  |  |
| **Sleep c** | -.185\*\* | -.032 | -.061\*\* | | -.009 | -.073\*\* | .009 | 1 |  |  |  |  |
| **Pain d** | -.105\*\* | .275\*\* | .001 | | -.015 | -.176\*\* | -.119\*\* | .231\*\* | 1 |  |  |  |
| **Dependence e** | -.045\* | -.039\* | -.094\*\* | | -.003 | -.007 | -.046\* | .152\*\* | .100\*\* | 1 |  |  |
| **Mental Health f** | -.204\*\* | -.050\*\* | -.051\*\* | | -.015 | -.144\*\* | -.069\*\* | .416\*\* | .265\*\* | .135\*\* | 1 |  |
| **Polytobacco Use** | .036\* | .132\*\* | .073\*\* | | -.019 | -.141\*\* | -.120\*\* | <.001 | .136\*\* | -.118\*\* | .020 | 1 |

*Note.* Sex: female= 0, male= 1; Polytobacco use: no= 0, yes=1; a race: white & other= 0, black= 1; b race: white & black=0, other= 1; c sleep impairment severity; d pain severity; e WISDM total score; f perceived mental health symptom severity;\*= *p* < .05; \*\*= *p* < .01.

**Figure 1. Conceptual Model of the Indirect Association of Pain Severity on Tobacco Dependence Via Sleep Impairment Severity**

WISDM

Pain Severity

**Total Effects *(c* path)**

*b* = .052 (.09), *SE* = .007 (.006), *p* < .001

Sleep Impairment Severity

***b* path**

***a* path**

**Direct Effects (*c’ path*)**

*b* = .05 (.08), *SE* = .007, *p* < .001

WISDM

**Figure 1**. Conceptual model of the indirect association of pain severity on tobacco dependence through sleep impairment severity. *Note*: *N* = 6,361 cigarette users; unadjusted values on each pathway are listed after (if disparate from) adjusted result; *a* path = association of X & M; *b* path = association of M on Y; *c’* path = direct association between X on Y, controlling for M; *c* path = total association of X on Y. Covariates included: age, sex, race, income, education, polytobacco use, and perceived mental health symptom severity.

**Indirect Effects: *ab* products**

*Adjusted: ab* = .005, SE = .001, PBCI95% = .002, .008

*Unadjusted: ab* = .009, SE = .002, PBCI95% = .006, .013

**Completely Standardized Indirect Effects: *ab* products**

*Adjusted:* *β* = .011, SE = .003, PBCI95% = .005, .017

*Unadjusted: β* = .021, SE = .004, PBCI95% = .013, .029

*b* = .06 (.08), *SE* = .007 (.005), *p* < .001

Pain Severity

*b* = .09 (.12), *SE* = .02, *p* < .001

**Figure 2. Conceptual Model of the Indirection Association of Pain Severity on ENDS Dependence Via Sleep Impairment Severity**

**Total Effects *(c* path)**

*b* = .05 (.04), *SE* = .016 (.01), *p* < .01

WISDM

Pain Severity

Sleep Impairment Severity

***b* path**

***a* path**

*b* = .04 (.07), *SE* = .01, *p* < .001

*b* = .09 (.10), *SE* = .04, *p* < .05 (*p* < .01)

**Direct Effects (*c’ path*)**

*b* = .044 (.03), *SE* = .016, *p* <.01 (*p* = .045)

WISDM

Pain Severity

**Indirect Effects: *ab* products**

*Adjusted: ab* = .003, SE = .002, PBCI95% = .0002, .008

*Unadjusted: ab* = .007, SE= .003, PBCI95% = .0015, .013

**Completely Standardized Indirect Effects: *ab* products**

*Adjusted: β* = .008, SE = .005, PBCI95% = .0007, .019

*Unadjusted: β* = .018, SE = .008, PBCI95% = .004, .035

**Figure 2**. Conceptual model of the indirect association of pain severity on ENDS dependence through sleep impairment severity. *Note*: *N* = 3,321 ENDS users; unadjusted values on each pathway are listed after (if disparate from) adjusted result; *a* path = association of X & M; *b* path = association of M on Y; *c’* path = direct association between X on Y, controlling for M; *c* path = total association of X on Y. Covariates included: age, sex, race, income, education, polytobacco use, and perceived mental health symptom severity.