Associations between cannabis use and availability on prescription opioid use and related outcomes among injured workers

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Abstract

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INTRODUCTION: Work-related injuries are a significant contributor to the high prevalence of acute and chronic, non-cancer pain in the U.S. While opioids are often prescribed for work-related injuries, inappropriate prescribing of opioids for pain management has contributed to the rise in opioid dependence, overdose, and death. Increasing access to medical and nonmedical (also called "recreational") cannabis has been promoted as a strategy to combat the dual crises of pain and opioid-related harms in recent years. However, the health impact of cannabis use for pain and the impact of the increased availability to cannabis remains unclear. In this dissertation, we examined 1) the longitudinal relationships between cannabis use for pain and prescription opioid use, physical function, and psychological outcomes, 2) associations between cannabis

retail outlet availability and cannabis use for pain, and 3) county-level associations between cannabis retail outlet availability and occupational injury rates.

METHODS: We used data from the Washington and Ohio Worker (WOW) study, which aimed to examine the effectiveness of workers' insurance programs in reducing unsafe opioid prescribing among injured workers who received an opioid prescription during the first 6 weeks of occupational injury. Participants completed surveys on pain intensity, pain interference, pain management strategies, and use of prescription opioid medications over a one-year period after injury. In Chapter 2, we assessed longitudinal associations between cannabis use for pain on prescription opioid use, anxiety, depression, pain intensity, and pain interference by using surveys conducted at around 6-weeks (baseline), 6-months, and 12-months after injury. Chapter 3 examined the cross-sectional association between cannabis retail outlet availability and cannabis use for pain. In Chapter 4, we conducted a retrospective, longitudinal county-level analysis examining the association between cannabis outlet retail availability and subsequent occupational injury rates by using workers' compensation claims data for all injured workers covered under state-funded workers' compensation insurance programs from 2014 to 2019.

RESULTS: Approximately 20% of injured workers reported using cannabis for pain at baseline. Self-reported use of prescription opioids in the past week significantly declined over time. There was a significant group by time interaction, such that the reduction in the prevalence of self-reported prescription opioid use over time was slower among participants who used cannabis for pain, compared to those who did not use cannabis for pain (interaction adjusted prevalence ratio [aPR]: 1.31, 95% confidence interval [CI]: 1.02, 1.69). Over time, there were no differences in anxiety symptoms (adjusted count ratio [aCR]: 1.03, 95% CI: 0.97, 1.09), depressive symptoms (aCR = 1.05, 95% CI: 0.98, 0.13), pain intensity [aCR: 1.02, 95% CI: 0.97, 1.06), pain

interference with enjoyment of life (aCR = 1.01, 95% CI: 0.95, 1.07), and pain interference with general activities (aCR = 0.99, 95% CI: 0.93, 1.05) between people who used cannabis for pain and those who did not. In Chapter 3, we found that participants living within a 1.0-mile road network buffer had an elevated likelihood of using cannabis for pain after adjusting for both individual and neighborhood-level covariates; however, this association was not statistically significant (aPR = 1.11; 95% CI: 0.94, 1.30). Sensitivity analyses suggested stronger associations with the larger spatial scales (1.5-mile buffer aPR = 1.17; 95% CI: 1.00, 1.37) compared to the more proximal scale (0.5-mile buffer aPR = 1.04; 95% CI: 0.81, 1.33). Lastly, in Chapter 3, we found little evidence of an association between county-level cannabis retail outlet availability and overall rates of occupational injuries (adjusted incidence rate ratio [aIRR] = 1.00; 95% CI: 0.97, 1.04). Findings suggest county-level associations of cannabis availability with occupational injuries may vary by industry. A within-county increase of 1 retail outlet per 10,000 residents was associated with an 12% increase in injury rates among workers in transportation and warehousing, although results were not statistically significant (aIRR = 1.12; 95% CI: 0.99, 1.27).

CONCLUSIONS: Cannabis use for pain was prevalent among injured workers in WA. Findings from this dissertation suggest a cautionary approach in the recommendation and use of cannabis for pain, as well as the need to consider regulatory approaches that may limit excessive cannabis commercialization. As more states legalize cannabis for use, understanding the health impacts of cannabis use for pain and the increased availability to cannabis is necessary in order to prevent unintended harms.

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Chapter 1. Introduction

Pain is a common and escalating public health issue with profound implications. Acute and chronic noncancer pain affects more than 50 million adults and can arise from a variety of conditions, including trauma, musculoskeletal injury, or perioperative recovery.[1,2] Work-related injuries are a significant contributor to the high prevalence of acute and chronic pain in the U.S, where over 2 million workers sustain a work-related injury annually.[3] While opioids are often prescribed for workers with occupational injuries,[4] inappropriate prescribing of opioids for acute and chronic pain has contributed to the unprecedented rise in opioid misuse, dependency, and overdose over the past three decades.[5,6] As such, expanding the evidence base for the prevention and management of pain is a critical priority.

Increasing access to medical and nonmedical (also called "recreational") cannabis has been promoted as a strategy to combat the dual crises of pain and opioid-related harms in recent years.[7] While there is some evidence that cannabis can reduce certain types of pain (e.g., neuropathic), evidence for other types of pain is mixed and conclusions remain heavily based on studies examining forms of cannabis that are not commercially available.[8–10] Despite this, pain is a common qualifying condition for which medical cannabis can be obtained, with some states allowing patients with an opioid prescription or a condition in which opioids can be used to purchase cannabis at a registered dispensary.[7,11] Cross-sectional research show that cannabis use is common among people experiencing pain,[12,13] with around one-third of chronic pain patients reporting cannabis as a substitute for prescription opioids.[14,15] Similarly, earlier ecological studies at the state-level have generally reported significant reductions in opioid prescribing,

overdoses, and opioid-related hospitalizations following passage of medical cannabis laws,[16,17] with some speculating that increasing access to cannabis can increase its *medical* use and thereby, allow for better management of pain and the reduction of prescription opioid use and associated harms.[18,19] However, these studies are not able to examine individuals' cannabis or prescription opioids use behaviors.[17,20,21] Prospective studies assessing the associations between cannabis use and prescription opioids and pain intensity have produced mixed results.[22–25] Additionally, despite evidence suggesting that pain can adversely affect affective symptoms and interference in daily functioning, few studies have examined these outcomes. [26]

As more states legalize cannabis, understanding the impact of increased cannabis availability is necessary. Since 1996, 37 states and the District of Columbia have legalized the medical use of cannabis products and 18 of those states, as well as the District of Columbia, have since legalized cannabis for nonmedical use.[27] Research from the tobacco and alcohol literature indicates that physical availability of tobacco and alcohol retailers in neighborhoods can have negative impacts on use of those substances.[28,29] With regard to alcohol, specifically, research has shown associations between alcohol availability and alcohol-related harms, such as traffic accidents.[30,31] There is growing concerns that availability of cannabis retail outlets can affect cannabis use behaviors in a similar manner. State laws and local-level regulations of cannabis can alter people's perceptions about perceived risks and benefits and shape norms regarding acceptability, which can affect use.[32–34] Among people with pain, increased availability of cannabis may influence cannabis use behaviors by increasing access to a wide variety of cannabis products (e.g., edibles, concentrates marketed for pain) and by promoting beliefs that cannabis is safe and effective for pain relief through advertisting.[35–38] Very little is known about the impact of local

availability of cannabis and corresponding cannabis use, especially in the occupational setting where cannabis use has increased among workers in the past decade.[39] Additionally, the acute and chronic effects of cannabis intoxication, such as impairment in attention, memory, and psychomotor function,[40] have raise concerns for workplace safety, especially in safety-sensitive industries, such as construction, warehousing, or transportation, where impairment on the job can affect a worker's own safety and the safety of others.[41]

In 2012, Washington State (WA) became one of the first U.S. states to legalize the production, sales, possession, and use of nonmedical cannabis for those ages 21 and older. The retail cannabis market became operational in July 2014, and as of 2016, WA has a single system which licenses all medical and nonmedical retail sales, regulated by the WA State Liquor and Cannabis Board. As a state that has a more established regulatory framework surrounding the sale of cannabis products, WA provides an important opportunity to examine the implications of cannabis use and availability in a legalized context. This dissertation is built upon the proposed conceptual framework through which cannabis legalization, availability, and use may impact health outcomes, shown in Figure 1 with dashed lines indicating the aims of this dissertation. In Chapter 2, we examine the longitudinal associations between cannabis use for pain on health outcomes, including prescription opioid use, anxiety, depression, and pain intensity and interference, over a one-year period among a sample of recently injured workers. Using the same study sample, we further assess cross-sectional associations between cannabis retail outlet availability on cannabis use for pain (Chapter 3). As the final study of this dissertation project, we examine county-level associations between cannabis retail outlet availability and

occupational injury rates (Chapter 4). We conclude by summarizing our findings and the implications for future research in Chapter 5.

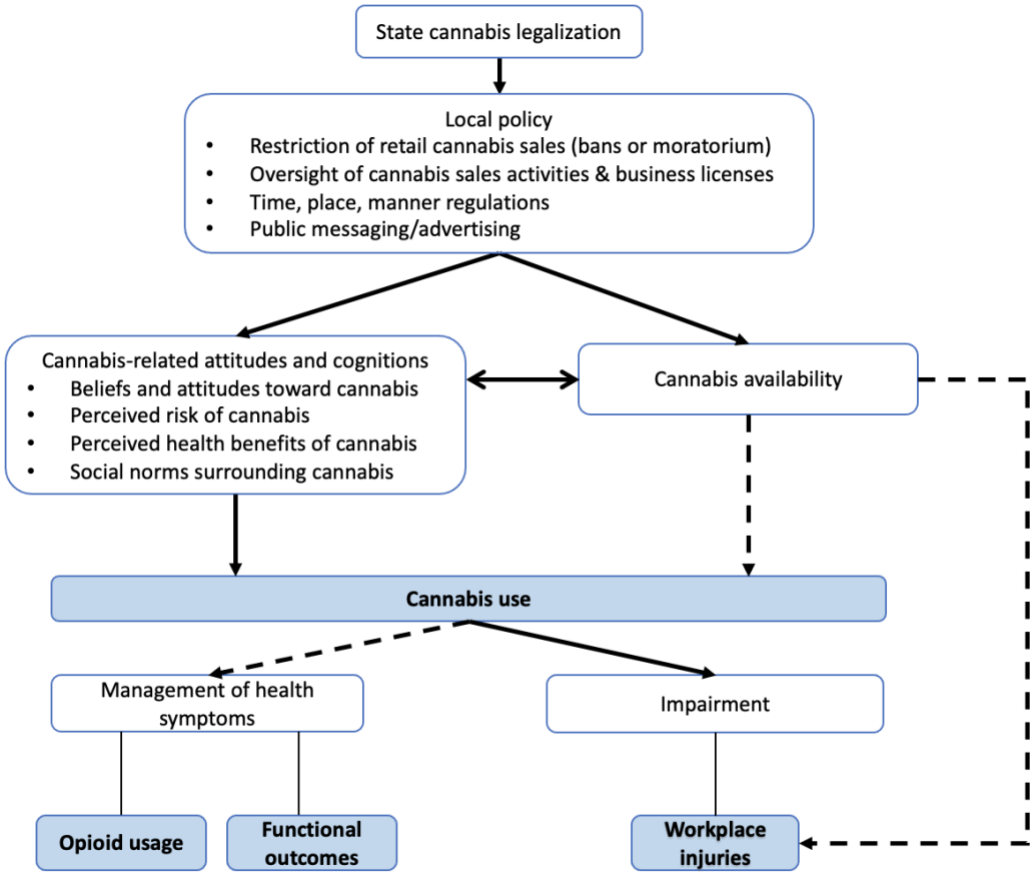


Figure 1.1. Conceptual framework through which cannabis legalization, availability, and use may impact health outcomes. Dashed lines indicate the dissertation aims.

Chapter 2. Associations of cannabis use for pain with prescription opioid use, functional, and psychological outcomes among injured workers

2.1 Introduction

Expanding the evidence base for the prevention, management, and treatment of pain is a critical priority in the U.S., where pain is a highly prevalent and debilitating medical condition.[2,42,43] Acute and chronic, noncancer pain affects more than 50 million adults and is associated with substantial physical, emotional, and societal effects. Chronic pain is a leading cause of disability, contributing to an estimated $630 billion annually in direct healthcare costs and lost productivity.[1,44,45] Work-related injuries contribute significantly to the high prevalence of acute and chronic pain in the U.S, where over 2 million workers sustain a work-related injury annually.[3] Specifically, musculoskeletal disorders, which are common among workers of many occupations, are the leading causes of years lived with disability and account for an increasingly higher fraction of long-term work disability.[46,47] Whiles opioids are often prescribed for work-related injuries, inappropriate prescribing of opioids for pain management has contributed to the rise in opioid dependence, overdose, and death over the past three decades.[6,43,48] Better strategies to treat acute pain stemming from work-related injuries could reduce reliance on prescription opioids in pain management and mitigate the risks of transitioning to chronic pain.[44,49]

Increasing access to medical and nonmedical (also called “recreational”) cannabis has been promoted as a strategy to combat the dual crises of pain and opioid-related harms in recent years.[7] While there is some evidence that cannabis can reduce certain types of pain (e.g., neuropathic), much of the literature examines forms of cannabis that are not commercially

available and little information exists regarding the risks of medical cannabis use.[8,9,10] Despite this, pain is a common qualifying condition for which medical cannabis can be obtained.[11] Cross-sectional surveys show that 40% to 80% of people using medical cannabis report pain management as their reason for use,[12,13] with 30% of chronic pain patients reporting cannabis as a substitute for prescription opioids.[14,15] Pre-clinical studies have found that cannabis, when co-administered with opioids, can reduce the required opioid dose without reducing analgesic effect, thereby potentially reducing opioid use and harms.[50] Some state-level analyses have reported significant reductions in opioid-related harms following passage of medical and recreational cannabis legalization,[17,20] although a study examining the impact of local retail cannabis availability on opioid overdose deaths found mixed results.[21] However, these studies were not able to examine the extent to which individuals experiencing pain actually use cannabis.[17,20,21]

Prospective studies assessing cannabis use among people experiencing pain are needed. Population-based studies have shown that cannabis use is associated with increased incident prescription opioid use, opioid use disorder, as well as other drug use disorders.[51,52] This corresponds with the competing hypothesis that nonmedical cannabis use could predispose individuals to opioid misuse and harms.[53] Among people experiencing pain, longitudinal studies are limited, and few have examined other physical and psychological outcomes beyond pain intensity, despite evidence suggesting that pain can adversely affect affective symptoms and physical functioning in daily activities.[26] Although many people who use medical cannabis report relief in anxiety and depressive symptoms when using medical cannabis,[54] there is a large literature showing negative psychological consequences, such as depression and anxiety, with prolonged or heavy cannabis use.[55,56] Among people who use cannabis for pain, some

prospective studies have reported significant reductions in opioid use[22,23] and improvements in pain[22,23,57–59] and anxiety[59], while other studies have reported no changes in pain or affective symptoms, such as anxiety and depression,[60,61] or worsening of anxiety.[25] In a four-year follow-up of chronic pain patients prescribed opioids in Australia, cannabis use was associated with *greater* subsequent pain severity, *less* pain self-efficacy, and no reductions in prescription opioid use.[25] However, medical and nonmedical cannabis were not legalized in Australia during the study period; thus, patients were required to use illicitly sourced cannabis. Given that restriction in cannabis access may limit its usage to people with more severe pain, it would be important to conduct prospective studies in settings where nonmedical cannabis is legal and available for use.

In the current study, we used data from a longitudinal study to examine associations of cannabis use for pain with prescription opioid use among recently injured workers in Washington State, where nonmedical cannabis use is legalized. In secondary analyses, we examined associations of cannabis use for pain with anxiety, depression, pain intensity, and pain interference with enjoyment of life and general activities over time. Our study assessed these associations among participants who were recently injured and examined cannabis use during the acute (0-6 weeks) and subacute (6-12 weeks) phases of pain. The management and treatment of pain during these critical stages may prevent the transition to the chronic phase of pain (lasting longer than 3 to 6 months), which could reduce the long-term reliance on prescription opioids and its associated morbidity and mortality.

2.2 METHODS

2.2.1 *Study setting and participants*

This study used data from the Washington and Ohio Worker (WOW) study, which aimed to examine the effectiveness of workers' insurance programs in reducing unsafe opioid prescribing in Washington (WA) and Ohio (OH). Workers were eligible for participation if they were 18 years old or older, filed a new State Fund workers' compensation claim and were covered under workers' compensation insurance programs; received at least one opioid prescription during the first 6 weeks of injury paid for by workers' compensation; and could speak English or Spanish. Between 2019 and 2021, WOW study staff identified eligible workers using the WA and OH state workers' compensation databases. Eligible participants were first contacted by mail, followed by telephone. Using computer-assisted telephone interviews (CATI), trained interviewers obtained verbal consent and administered a baseline survey capturing information on self-reported health status, pain management strategies, use of prescription opioid medications, and sociodemographic characteristics. Interviews for the baseline survey were conducted between August 2019 and September 2021. Of eligible participants from OH and WA, 53% (n=3,374) consented to participate in the study and provided information in the baseline survey. Participants who were recruited in the first year of study recruitment (n=2,738; 86% from WA) were also surveyed at two follow-ups, conducted at 6-month and 12-month after date of injury.

The present analysis was limited to data from participants in WA who were recruited in the first year of recruitment since 6-month and 12-month surveys were available. Among WA participants (n=2,362), follow-up rates were high at 6-month (85%) and 12-month surveys

(83%). We excluded participants from OH due to differences in regulatory policies surrounding cannabis legalization and access, which can affect cannabis use.[32–34] Specifically, nonmedical cannabis is not legalized in OH, and while medical cannabis was legalized in 2016, the first medical cannabis dispensary did not open in OH until 2019. In contrast, WA was one of the first U.S. states to legalize the production and sale of nonmedical cannabis use in 2012, with the retail cannabis market opening in July 2014. In WA, workers' compensation provides no-fault industrial insurance coverage for most employers and workers. The Department of Labor and Industries (L&I) is the sole regulator of workers' compensation, which administers medical services and wage replacement benefit for injured workers through either a public State Fund, which covers 70% of WA's workforce, or through self-insured employers, which covers the remaining 30%.[62] We excluded 40 participants who reported they had cancer, and a total of 2,322 participants remained in the analyses. Data on cannabis use for pain and covariates were obtained from the baseline survey, while self-reported outcome data were obtained from baseline, 6-month and 12-month surveys. Study procedures were approved by the University of Washington institutional review board and the Washington State institutional review board.

2.2.2 *Exposure*

The main exposure of interest was cannabis use for pain management, which was assessed in the baseline survey. Participants were asked, "I am going to read a list of things you may have done to treat the pain from your injury on [INJDATE]. Please tell me which you have used", with "Cannabis (CBD, medical cannabis)" listed as a possible response option. Baseline surveys occurred around 4 to 8 weeks after date of injury (mean: 6 weeks). We characterized cannabis use for pain as a binary indicator, indicating any or non-use of cannabis for pain.

2.2.3 *Outcome*

Self-reported outcomes were assessed at baseline, 6-months, and 12-months after injury. The primary outcome was self-reported prescription opioid use. At each survey, participants were asked about opioid medications and were provided "some examples of opioid pain medicines [such as]: Hydrocodone, Vicodin, Codeine, Oxycodone, Percocet, Oxycontin, Percodan, Methadone, Morphine, MS Contin, Tramadol, and Fentanyl." Participants were then asked: "Have you taken opioid medications in the past week?". For this analysis, we created a binary variable indicating current or noncurrent prescription opioid use.

To corroborate self-reported prescription opioid use, we used pharmacy dispensing records up to one year after injury in order to assess prescription opioid discontinuation as a sensitivity analysis. Pharmacy data were obtained from WA's L&I workers' compensation system and WA's Prescription Monitoring Program (PMP) and include records of prescription medications dispensed, including medication name, days supplied, and date dispensed. WA's L&I workers' compensation pharmacy data include information on opioids dispensed that are related to the workers' compensation injury or illness; however, data do not include opioids dispensed that are billed to participants' primary health insurance, paid out-of-pocket, or were not covered by workers' compensation. In contrast, the WA PMP has prescription records for Schedule II to V drugs for prescriptions dispensed within WA beginning in 2011; however, data do not provide information on whether opioids dispensed were due to work-related injuries. Linkage of workers to PMP data is completed by an outside vendor (Appriss) using their internal algorithms/fuzzy logic. Briefly, L&I provides a list of direct identifiers (e.g., first name, last name, and date of birth) to the PMP vendor, the vendor links the personal identifiers provided to PMP records, and

then provides L&I with the full history of PMP records linked to workers' compensation claimants. PMP records were provided for 83% of workers in our study.

Secondary outcomes included self-reported pain intensity, interference, and depression and anxiety symptoms. The Pain, Enjoyment, General Activity (PEG-3) scale is a 3-item validated scale that measures pain intensity and interference. Participants were asked to describe their average pain intensity, pain interference with enjoyment of life, and pain interference with general activity during the past week.[63] Each item was scored from 0 (no pain or no interference) to 10 ("pain as bad as you can imagine" or "completely interferes"). We assessed each of the three items separately in order to assess multiple dimensions of pain. As a supplemental analysis, we also examined whether participants experienced clinically important changes, defined as 30% or more improvement from baseline for each of the three items.[43] Symptoms of depression and anxiety were assessed using the four-item Patient Health Questionnaire for Depression and Anxiety (PHQ-4), a validated screening tool for detecting potential anxiety and depressive disorders.[64] The PHQ-4 consists of two items from the PHQ-2 for depression and two items from the GAD-2 (Generalized Anxiety Disorder-2) for anxiety. For each item, participants were asked to rate how often they have been bothered by anxiety and depressive symptoms over the last 2 weeks from 0 (not at all) to 3 (nearly every day). Items from the PHQ-2 and GAD-2 were summed to yield separate measures of depression and anxiety, respectively. The PHQ-2 and GAD-2 have shown strong criterion validity when compared to clinical diagnosis of major depression disorder and generalized anxiety disorder, respectively.[65,66]

2.2.4 *Covariates*

Sociodemographic characteristics ascertained from the baseline survey including biological sex (0: female; 1: male), past-year annual household income, marital status (married [reference], widowed/divorced/separated, never married, living with partner), and race and ethnicity were included in analyses. Age at injury was obtained from workers' compensation claims data. Self-reported race and ethnicity was categorized as: non-Hispanic White (reference), Hispanic/Latino or of Spanish origin, or non-Hispanic Other, which comprised of participants who identified as non-Hispanic Black or African American, Asian, American Indian or Alaska Native, Native Hawaiian or Other Pacific Islander, or Other. We adjusted for race and ethnicity due to the lower prevalence of medical cannabis use among racial and ethnic minorities, possibility due to decades of disproportionality aggressive enforcement of cannabis possession laws.[67] Additionally, racial disparities in access to and the quality of pain and mental health care are commonly reported, with racial and ethnic minorities receiving less adequate pain management and treatment,[68,69] as well as treatment of depression and anxiety.[70]

Injury severity was assessed using the Abbreviated Injury Scale (AIS),[3] which is an anatomical scoring system that describes injuries based on the type, location, and severity of injury. Scores were calculated using diagnosis codes in medical and hospital bill data for the first 7 days after injury. We used the maximum AIS across body regions, which ranges from 1 (minor injury) to 6 (maximal injury). Due to the small number of injured workers with higher scores, we created a binary indicator of injury severity using a cutoff score of 3, where scores of 1 and 2 indicated minor/moderate injuries and scores ranging from 3 to 6 indicated serious/critical injuries that likely required hospitalization.

Participants were asked about whether they used prescription opioids in the three months before their injury, their medical comorbidities in the past year, and current tobacco and alcohol use. Medical comorbidities were measured using the Functional Comorbidity Index (FCI), which assesses the presence or absence of 18 conditions that participants may have been affected by, diagnosed with, or treated for during the past year. Information was collected by self-report, with participants answering "yes" or "no" to each health condition and results in a sum score of the total number of comorbidities. Current tobacco use was assessed using questions adapted from the Global Adult Tobacco Survey (GATS), which asked participants if they "currently use tobacco on a daily basis, less than daily, or not at all". For the present analysis, we created a binary variable denoting current use by categorizing individuals who reported using tobacco "daily" or "less than daily" together. Hazardous alcohol use was measured using the 3-item Alcohol Use Disorders Identification Test-Consumption (AUDIT-C) screening tool that can be used to identify individuals who may be engaging in hazardous drinking. We used the total score, which ranged from 0-12, and in analysis, defined hazardous alcohol use as a binary indicator using a cutoff score of ≥3 (women) and ≥4 (men) in analysis.[71,72]

2.2.5 *Statistical analysis*

To account for clustering of observations within individuals, generalized estimating equations (GEE) models were used to examine each specified self-reported outcome, which were measured at baseline, 6 months, and 12 months. Exchangeable working correlation structure and robust standard errors were specified. For each outcome, the key variables of interest were the main effects of time, cannabis use for pain, and the interaction between these variables, which

indicates whether changes in outcomes over the first year after injury differed by cannabis use. Time was coded as a continuous variable, ranging from 0 (reflecting baseline measures) to 2 (reflecting 12-month measures). For binary outcomes, we specified a Poisson distribution to estimate prevalence ratios (PR) and 95% confidence intervals (CI).[73,74] Due to the positive skew and evidence of over-dispersion for measurements of pain intensity, interference, anxiety, and depression, we specified a negative binomial distribution to estimate count ratios (CR), which describes the proportional increase in the count associated with a 1-unit increase in the main parameter of interest (e.g., a CR of 1.29 for sex indicates that the predicted anxiety symptoms for men are 29% higher than for women on average).[75] For outcomes pertaining to clinically meaningful improvements in pain intensity and interference (≥30% improvement from baseline), regression models included outcome measures at 6-month and 12-month from baseline. All analyses adjusted for sex, marital status, age at injury, race and ethnicity, household income, self-reported prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use.

In the presence of missing data, the GEE modeling approach assumes data are missing completely at random; thus, we used Multiple Imputation with Chained Equations (MICE) in order to reduce potential bias from missing data over the course of the study and provide valid GEE estimates. Using MICE, we specified appropriate distributional forms (e.g., categorical, count, continuous) of missing variables in the data and generated 20 imputed datasets using all study variables included in regression models. GEE analyses were run across each of the 20 imputed datasets, with effect estimates and standard errors calculated based on Rubin's Rules that account for between- and within-imputation uncertainty.[76]

In sensitivity analyses assessing prescription opioid discontinuation using pharmacy billing data, we used Cox proportional hazard regression survival models to calculate adjusted hazard ratios (HR) and 95% CI for the risk of discontinuation, comparing workers who used cannabis for pain and those who did not. Time until prescription opioid discontinuation was calculated as the number of days from initiation of opioids post-injury to the last day of an opioid fill (prescription fill date + days supplied) that occurred prior to a 90-day period without any prescription opioids, or censoring event. Event times were defined relative to the date of prescription opioid initiation after the date of injury, with censoring defined by end of follow-up or death during follow-up. The assumption of proportional hazards was tested with Schoenfeld residuals. We used complete-case analysis methods and adjusted for covariates used in the adjusted GEE analyses. Additional sensitivity analyses were conducted by modifying the discontinuation definition from a 90-day period to a 180-day period, which has been used in previous studies.[77,78] All statistical analyses were conducted in Stata, version 15.1.

2.3 RESULTS

2.3.1 *Baseline characteristics of participants*

As shown in Table 2.1, the majority of participants were male (75.3%), married or living with a partner (55.3%), and had an annual household income of less than $50,000 (61.3%). Over half (53.5%) of the sample was non-Hispanic White, 34.5% were Hispanic/Latino or of Spanish origin, and 12.0% were non-Hispanic Other race. Mean age at time of injury was 42.0 (standard deviation [SD]: 12.8) years old, with most participants experiencing injuries of low severity (95.9%). Twenty percent of participants reported using cannabis for pain in the baseline survey. Participants who used cannabis for pain management, compared to those who did not, tended to

be younger (mean age: 38.4 years, compared to 42.9 years), were more likely to have never married, and were more likely to engage in current tobacco (49.0%, compared to 30.3%) or hazardous alcohol use (44.4%, compared to 23.3%). There were few differences when comparing the original, unimputed dataset to the imputed datasets, Supplemental Table 2.1.

Figure 2.1 shows model-predicted estimates of self-reported prescription opioid use, indicators of anxiety and depression, and pain intensity and interference based on findings from adjusted GEE models. Self-reported use of prescription opioids in the past week significantly declined over time in both groups, Figure 2.1 and Table 2.2. There was a significant group by time interaction, such that the reduction in the prevalence of self-reported prescription opioid use over time was slower among those using cannabis compared to those not using (Figure 2.1; interaction p-value=0.035). Full GEE model results are included in Supplemental Tables 2.2 and 2.3.

Using pharmacy records, time to prescription opioid discontinuation varied depending on the source of pharmacy records (Table 2.3). Median time to prescription opioid discontinuation was generally higher using pharmacy records ascertained from WA PMP (7 days, IQR [Interquartile Range]: 3, 33), compared to workers' compensation data (3 days, IQR: 4, 8). Using workers' compensation data, time to opioid discontinuation did not vary significantly by cannabis use for pain (adjusted HR: 1.00, 95% CI: 0.89, 1.12). However, using WA PMP data, cannabis use for pain was significantly associated with lower likelihood of opioid discontinuation (adjusted HR: 0.86, 95% CI: 0.76, 0.97). Results did not change substantially when we modified the discontinuation definition from a 90-day period to a 180-day period (workers' compensation:

adjusted HR: 0.93 [95% CI: 0.83, 1.05]; WA PMP data: adjusted HR: 0.85, [95% CI: 0.75, 0.96]).

2.3.2 *Secondary analysis*

Participants who used cannabis for pain had higher anxiety and depression at all time points, including baseline (Figure 2.1). However, there was no statistically significant difference in the change over time in these outcomes by cannabis use for pain. Across time points, pain intensity, pain interference with enjoyment of life, and pain interference with general activity decreased over time and showed similar levels between participants who used cannabis and those who did not. There were no statistically significant differences in the decrease over time in these pain-related outcomes between groups. Supplemental analyses found that there were no differences in the prevalence of clinical improvement over time (≥30% improvement from baseline) among those who used cannabis and those who did not (Supplemental Table 2.3 and Supplemental Figure 2.1).

2.4 DISCUSSION

In this prospective study involving people who were recently injured at work, participants experienced significant declines in self-reported past-week prescription opioid use, pain intensity, and pain interference with general activities one year after injury. Participants who used cannabis for pain experienced a less steep decline in likelihood of self-reported prescription opioid use, compared to those who did not use cannabis for pain. When using pharmacy records ascertained from the WA PMP, cannabis use for pain was significantly associated with lower likelihood of discontinuing prescription opioids; however, we did not find an association between cannabis use and prescription opioid discontinuation when examining pharmacy records

obtained from workers' compensation. Over the study period, there were no differences in self-reported anxiety, depression, and pain intensity and interference between cannabis use groups.

Over the past decade, considerable media attention has focused on the possible role of expanding access to and use of cannabis on decreasing opioid use and related harms.[7] Many have hypothesized that increasing access to cannabis can increase its *medical* use and thereby, allow for better management and treatment of pain while reducing the use of prescription opioids and overdoses.[18,19] In our study, we found that there was a significant difference in the change in prevalence of self-reported prescription opioid use, with participants who used cannabis for pain experiencing a slower reduction in prescription opioid use over time. Our findings are consistent with a recent prospective study which found that medically authorized cannabis patients who were using chronic opioids were less likely to cease prescription opioid medication use over one year, compared to those who did not have medical cannabis authorization.[24] Additionally, results from a 4-year prospective study on cannabis use among chronic non-cancer pain patients in Australia found cannabis use did not reduce prescription opioid use or increase rates of opioids discontinuation.[25] While some states are allowing patients with an opioid prescription or a condition in which opioids can be used to purchase cannabis at a registered dispensary,[7] our findings suggest a cautionary approach in the authorization of medical cannabis as a way to reduce prescription opioid use. Although our findings are in contrast to other prospective studies which found significant reductions in opioid use;[22,23] these previous findings are limited by either a lack of a comparison group[22] or a limited sample size.[23] While cannabis may have a lower risk of overdose than prescription opioids, cannabis use is not without harms. Nonmedical cannabis use has been associated with psychosis, cognitive effects, respiratory problems, and cannabis use

disorder.[61,79] A recent randomized clinical trial found that 17% of patients who immediately obtained a medical cannabis card developed a cannabis use disorder diagnosis throughout 12 weeks after acquiring a card, compared to 9% among patients who were required to wait for a cannabis card, suggesting that medical use may not be protective against harms.[61] Studies examining whether the frequency and potency of medical cannabis use can affect prescription opioid, functional, and psychological outcomes among people experiencing pain will continue to be important, given the increasingly high potency of cannabis products[80] and evidence indicating that more frequent and heavy use of cannabis is associated with increased risk for health consequences.[81] Given that cannabis use for pain varied by age and race and ethnicity in our study, future studies should assess whether use of cannabis for pain differentially affects prescription opioid use by these factors.

Associations assessing time to prescription opioid discontinuation varied based on the source of pharmacy billing data. While our findings using PMP data showed that cannabis use for pain was associated with a lower likelihood of prescription opioid discontinuation, which was consistent with results assessing self-reported prescription opioid use, we did not find an association when examining workers' compensation data. Conflicting findings may reflect differences in how prescription opioids are captured within workers' compensation and the PMP. As part of a policy enacted in 2013, WA workers' compensation pays for prescription opioids up to 6 weeks when prescribed to treat acute injury or after surgery. Workers' compensation stops paying for prescription opioids beyond 6 weeks if prescribers do not obtain prior authorization. In instances where prior authorization is not obtained, injured workers may receive prescription opioids from prescribers if they self-pay or use other types of payers (e.g., private insurance, Medicaid, or

Medicare); however, prescriptions not paid by workers' compensation are not included in workers' compensation pharmacy claims. As such, results using workers' compensation data may underestimate the use and duration of prescription opioids, which could be driving the null results. By utilizing PMP data, which captures prescription opioids regardless of payer, we were able to ascertain a more complete trajectory of prescription opioid use. However, linkage of L&I data to PMP records were completed by an external vendor, and it is unclear how the linkage was performed. PMP records were provided for the majority of workers in our study; however, workers with PMP records were more likely to be non-Hispanic White, use cannabis for pain, use tobacco products, and have a higher number of comorbidities compared to workers without missing PMP records (data not shown). As such, it is possible that the analysis using PMP data may overestimate the association between cannabis use and prescription opioid discontinuation.

Anxiety and depression are commonly cited as reasons for medical cannabis use; however, research examining cannabis' effects on affective symptoms among patients with pain are limited.[82] In our study, we found higher anxiety and depressive symptoms among participants who used cannabis for pain across time. While there was a statistically significant decrease in both anxiety and depression among people who did not use cannabis, participants who reported using cannabis did not experience any significant changes in anxiety and depressive symptoms over the study period. However, this difference in the change in anxiety and depressive symptoms over time between the two groups was not statistically significant (interaction p-value=0.365 for anxiety; interaction p-value=0.172 for depression). Other prospective studies examining the effect of cannabis on affective symptoms among pain patients have been mixed, with some reporting greater anxiety, but not depression, among people who use cannabis,[25] while

other studies have reported improvements in anxiety among people who use cannabis[59] or no associations between cannabis use with depression and anxiety.[60]

Several factors may contribute to higher anxiety and depressive symptoms and likelihood to use prescription opioids seen among people who use cannabis for pain. Research suggests that cannabis can impact the affective, cognitive, and behavioral components associated with pain.[83] Painful events can produce immediate affective responses (e.g., discomfort, negative affect) that can manifest in emotional suffering (e.g., depression, anxiety) and influence behavioral pain responses (e.g., efforts to cope).[83] With this, pain can be a motivator for both cannabis and prescription opioid use,[12,13] with some postulating that use of these substances is related to the desire to reduce negative affect (e.g., anxiety, irritability) in addition to, or instead of, pain.[84] Reductions in prescription opioids can affect mood and pain in the short term, with many chronic pain patients concerned about their ability to manage their pain without prescription opioids and worsening quality of life.[85,86] However, the desire to reduce pain and pain-related negative emotions can lead to maladaptive behaviors that can lower self-efficacy, which is important in the management of pain, disability, and affective distress.[87] Recent research suggests that cannabis use, especially more frequent use, is associated with reduced self-efficacy in managing anxiety and depressive symptoms among people using medication-assisted treatment for opioid addiction.[88] Our findings may highlight the need to explore how self-efficacy in management of pain and affective symptoms can be improved among injured workers, especially among those who use cannabis. This may be critical, given that low self-efficacy for pain management can result in the maintenance and progression of both cannabis use and pain over time,[83] contributing to the development of substance use disorders.[25,89]

While we found significant declines in pain intensity and pain interference with enjoyment of life and general activities among participants, we found no evidence that the decline over time differed significantly between participants who use cannabis and those who did not. Our results are consistent with other prospective studies which found no improvements in pain severity and symptoms among people with pain and among those seeking cannabis for pain.[60,61] Our findings align with recent systematic reviews and recommendations from expert panels that do not recommend the general use of cannabis-based products for pain management and treatment.[79,90] While recommendations do not focus on specific pain etiologies, current evidence of the efficacy of cannabis for musculoskeletal disorders, which are common in the occupational setting, remains mixed.[91] Given that growing body of preclinical research examining the role of the endocannabinoid system in regulating pain, studies examining the role of cannabis-based products for pain therapeutics remain important.[79]

2.4.1 *Limitations*

Several limitations exist in this study. First, survey data were collected via phone interviews; thus, underreporting of cannabis use for pain may be possible due to social desirability and concerns about prosecution from employers, healthcare providers, and the workers' compensation agency. The extent of this underreporting may have been mitigated since L&I cannot reject a claim because of a positive drug test, and participants were informed that their participation would not affect the medical care they receive. While estimates on cannabis use among injured workers are sparse, the prevalence of cannabis use for pain in our study population is similar to that of the chronic pain population, where 15-18% of patients report using cannabis for pain relief.[92–94] While underreporting of prescription opioid use may also be

possible, we were able to measure prescription opioid use through the use of pharmacy billing records. Second, while we were able to account for prescription opioids dispensed beyond the workers' compensation system by using PMP data, it is unknown if prescription opioids in the PMP are due to work-related injuries. Prescribing data obtained from the PMP also excludes prescriptions prescribed for 24 hours or less or dispensed from a Department of Corrections pharmacy and federally operated pharmacies (e.g., Veterans Affairs) report information on a voluntary basis. Third, to be eligible for this study, participants were required to have an accepted workers' compensation claim; thus, workers with less severe injuries may not be included in our sample. Fourth, we did not have information on whether participants used cannabis prior to injury and whether participants used cannabis for other purposes besides pain from injury. Our primary exposure was cannabis use for pain management; thus, people who used cannabis for nonmedical purposes or for medical purposes besides pain from injury are not classified as having the exposure of interest. However, pain is a common reason cited for the use of cannabis,[11] and our study was able to examine whether there were benefits or harms in using cannabis for this reason. Fifth, while we adjusted for a number of variables that are hypothesized to confound the relationship between cannabis use for pain and our outcomes, other unmeasured confounders may exist. Importantly, however, we controlled for injury severity using the AIS, which has been used to predict total permanent disability in workers' compensation[95] and our sample was restricted to participants with injuries severe enough for an opioid prescription. Lastly, around 76% of participants who used cannabis for pain reported that they used other pain management strategies (e.g., physical therapy, yoga, massage therapy), compared to 60% of those who did not use cannabis for pain. Since using multiple pain management strategies might be a function of pain severity, we conducted several post-hoc analyses to further adjust for pain

severity in the association between cannabis use and prescription opioid use, and conclusions did not change (Supplemental Table 2.4).

2.5 CONCLUSIONS

Cannabis use is common among people experiencing pain, and interest in medical cannabis use has grown in recent years. In this longitudinal study of recently injured workers who were prescribed opioids, those using cannabis for pain were more likely to continue using prescription opioids over time. We found no evidence that cannabis use for pain improved anxiety, depression, or pain and interference outcomes. Future research should continue to examine the health implications of medical cannabis use.

Table 2.1. Baseline characteristics of the study sample (N=2,322)

Characteristics	Overall	Did not use cannabis for pain	Used cannabis for pain
Biological sex, %			
Female	24.7	24.8	24.1
Male	75.3	75.2	75.9
Age at injury, mean (SD)	42.0 (12.8)	42.9 (12.8)	38.4 (12.0)
Race and ethnicity, %*			
Hispanic	34.5	39.7	13.9
Non-Hispanic Other	12.0	10.4	18.5
Non-Hispanic White	53.5	49.9	67.7
Marital status, %			
Living with partner	14.7	43.9	27.4
Married	40.6	19.3	15.6
Never married	26.1	23.2	37.8
Widowed/divorced/separated	18.6	13.5	19.2
Past-year annual household income, %			
$25,000 or less	22.3	22.2	22.2
$25,001 - $50,000	39.0	38.7	40.1
$50,001 - $75,000	18.9	18.6	20.3
$75,001 - $100,000	9.9	10.5	7.3
$100,001 or more	10.0	10.0	10.0
Injury severity, %			
1-2 (low severity of injury)	95.9	95.9	95.9
3-6 (high severity of injury)	4.1	4.1	4.1
Number of comorbidities, mean (SD)	1.10 (1.50)	1.05 (1.41)	1.42 (1.75)
Hazardous alcohol use†, %	31.5	28.3	44.4
Current tobacco use, %	34.1	30.3	49.0
Used prescription opioids prior to injury, %	3.6	3.4	4.3
Used prescription opioids past week, %	21.0	21.7	18.1
Average pain intensity‡, mean (SD)	4.3 (2.7)	4.4 (2.8)	3.9 (2.5)
Pain interference with enjoyment of life‡, %	4.5 (3.3)	4.6 (3.3)	4.2 (3.3)
Pain interference with general activities‡, %	4.8 (3.4)	4.9 (3.4)	4.6 (3.4)
Anxiety symptom score§, %	1.8 (2.0)	1.3 (1.7)	1.5 (1.8)
Depressive symptom score§, %	1.3 (1.7)	1.7 (2.0)	2.1 (2.1)

* Non-Hispanic Other consists comprised of participants who identified as non-Hispanic Black or African American, Asian, American Indian or Alaska Native, Native Hawaiian or Other Pacific Islander, or Other race.

† Hazardous alcohol use was defined using an AUDIT-C (ranging from 0-12), with cutoff score of ≥3 (women) and ≥4 (men)

‡ Pain intensity and interference was measured using the PEG-3 scale, which ranged from 0 to 10 with higher scores indicating higher pain and interference.

§ Symptoms of anxiety and depression were assessed using the PHQ-4, which ranged from 0 to 6 with higher scores indicating more anxiety and depressive symptoms.

Table 2.2. Associations of cannabis use for pain with prescription opioid use, indicators of anxiety and depression, and pain intensity and interference

	Prescription opioid use		Anxiety		Depression		Average pain intensity		Pain interference with enjoyment of life		Pain interference with general activities	
Main effects	Crude PR	Adjusted PR	Crude CR	Adjusted CR	Crude CR	Adjusted CR	Crude CR	Adjusted CR	Crude CR	Adjusted CR	Crude CR	Adjusted CR
Cannabis use for pain	0.81 (0.65, 1.01)	0.88 (0.70, 1.11)	1.21 (1.10, 1.35)	1.19 (1.06, 1.32)	1.19 (1.06, 1.35)	1.15 (1.01, 1.30)	0.89 (0.84, 0.95)	0.98 (0.92, 1.05)	0.90 (0.83, 0.98)	1.01 (0.93, 1.11)	0.94 (0.87, 1.01)	1.03 (0.95, 1.12)
Time	0.43 (0.39, 0.49)	0.43 (0.39, 0.49)	0.95 (0.92, 0.98)	0.95 (0.92, 0.98)	0.95 (0.92, 0.98)	0.95 (0.92, 0.98)	0.89 (0.88, 0.91)	0.89 (0.87, 0.91)	0.83 (0.81, 0.85)	0.82 (0.80, 0.84)	0.82 (0.81, 0.84)	0.82 (0.80, 0.84)
Cannabis use × time interaction	1.31 (1.02, 1.69)	1.31 (1.02, 1.69)	1.03 (0.97, 1.09)	1.03 (0.97, 1.09)	1.04 (0.97, 1.12)	1.05 (0.98, 0.13)	1.02 (0.98, 1.06)	1.02 (0.97, 1.06)	1.01 (0.95, 1.07)	1.01 (0.95, 1.07)	0.99 (0.94, 1.05)	0.99 (0.93, 1.05)

Note: GEE equations were used to estimate the association between cannabis use for pain and self-reported outcomes, calculated based on 20 imputed datasets. For prescription opioid use, a Poisson distribution was specified to estimate prevalence ratios (PR) and 95% confidence intervals (CI). For depression, anxiety, and pain intensity and interference, a negative binomial distribution was specified to estimate count ratios (CRs), which describes the proportional change due to a 1-unit increase in the main parameter of interest. All analyses adjusted for sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use. Range of scores for anxiety and depression was 0 to 6 at each study visit; pain intensity and interference ranged from 0 to 10 at each study visit.

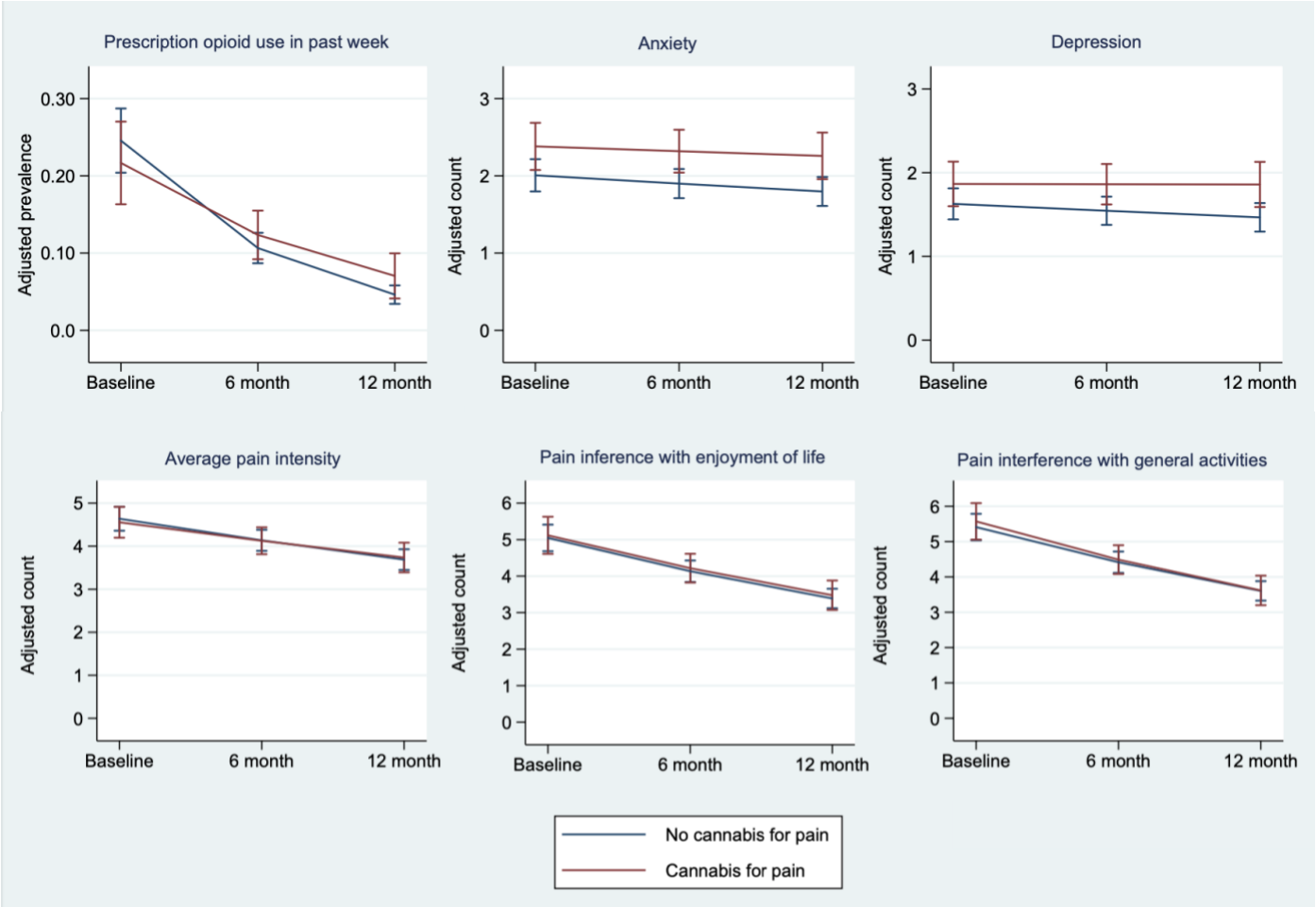


Figure 2.1. Model-predicted prescription opioid use, indicators of anxiety and depressive symptoms, and pain intensity and interference, adjusted for covariates, and 95% confidence intervals over the study period by cannabis use for pain

Note: Model-predicted estimates were obtained from GEE equations based on 20 imputed datasets. Covariates included sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use. Range of scores for anxiety and depressive symptoms was 0 to 6 at each study visit; pain intensity and interference ranged from 0 to 10 at each study visit.

Table 2.3. Adjusted model results for time until prescription opioid discontinuation using complete-case analysis in Washington State Labor & Industries workers' compensation and Washington State Prescription Monitoring Program pharmacy records

	Labor & Industries workers' compensation (n=1,983)	Washington State Prescription Monitoring Program (n= 1,638)
Days to opioid discontinuation, median, (IQR)		
Cannabis use for pain	4 (2, 10)	8 (3, 30)
No cannabis use for pain	4 (3, 8)	6 (3, 21)
Adjusted HR and 95% CI for discontinuation of prescription opioids		
	HR (95% CI)	HR (95% CI)
Cannabis use for pain vs. no cannabis use for pain	1.00 (0.89, 1.12)	0.86 (0.76, 0.97)

Acronyms: IQR: Interquartile Range (25^{th}, 75^{th} percentile); HR: Hazard ratio; CI: Confidence Interval

Note: Models adjusted for sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use.

Supplemental Table 2.1. Comparing baseline characteristics in the observed, unimputed dataset and imputed study sample

Characteristics	Original	Imputed
Biological sex, %		
Female	24.6	24.7
Male	75.0	75.3
Age at injury, mean (SD)	42.0 (12.8)	42.0 (12.8)
Race and ethnicity, %		
Hispanic	34.2	34.5
Non-Hispanic Other	11.9	12.0
Non-Hispanic White	53.0	53.5
Marital status, %		
Living with partner	14.6	14.7
Married	40.5	40.6
Never married	26.1	26.1
Widowed/divorced/separated	18.5	18.6
Past-year annual household income, %		
$25,000 or less	20.8	22.3
$25,001 - $50,000	37.0	39.0
$50,001 - $75,000	17.6	18.9
$75,001 - $100,000	9.5	9.9
$100,001 or more	9.4	10.0
Injury severity, %		
0-2 (low severity of injury)	95.9	95.9
3-6 (high severity of injury)	4.1	4.1
Number of comorbidities, mean (SD)	1.1 (1.5)	1.1 (1.5)
Hazardous alcohol use, %	31.2	31.5
Current tobacco use, %	33.9	34.1
Cannabis use for pain, %	20.0	20.0
Used prescription opioids prior to injury, %	3.5	3.6
Used prescription opioids past week, %	20.8	21.0
Average pain intensity, mean (SD)	4.3 (2.7)	4.3 (2.7)
Pain interference with enjoyment of life, %	4.5 (3.3)	4.5 (3.3)
Pain interference with general activities, %	4.8 (3.4)	4.8 (3.4)
Anxiety symptom score, %	1.8 (2.0)	1.8 (2.0)
Depressive symptom score, %	1.3 (1.7)	1.3 (1.7)

Supplemental Table 2.2. Adjusted regression results for associations of cannabis use for pain with prescription opioid use, pain intensity and interference, and indicators of anxiety and depression and anxiety

	Prescription opioid use		Anxiety		Depression		Average pain intensity		Pain interference with enjoyment of life		Pain interference with general activities	
	PR	95% CI	CR	95% CI	CR	95% CI	CR	95% CI	CR	95% CI	CR	95% CI
cannabis use for pain	0.88	0.70, 1.11	1.19	1.06, 1.32	1.15	1.01, 1.30	0.98	0.92, 1.05	1.01	0.93, 1.11	1.03	0.95, 1.12
time	0.43	0.39, 0.49	0.95	0.92, 0.98	0.95	0.92, 0.98	0.89	0.87, 0.91	0.82	0.80, 0.84	0.82	0.80, 0.84
cannabis*time	1.31	1.02, 1.69	1.03	0.97, 1.09	1.05	0.98, 0.13	1.02	0.97, 1.06	1.01	0.95, 1.07	0.99	0.93, 1.05
male	0.89	0.75, 1.06	0.80	0.73, 0.87	0.83	0.75, 0.91	0.93	0.88, 0.98	0.93	0.86, 0.99	0.93	0.87, 0.99
married (ref: married)												
widowed, divorced, separated	0.89	0.73, 1.09	1.05	0.94, 1.17	1.12	0.99, 1.26	1.00	0.93, 1.07	1.00	0.92, 1.09	0.99	0.91, 1.07
never married	0.77	0.62, 0.97	1.11	0.99, 1.24	1.22	1.08, 1.38	1.00	0.93, 1.07	1.04	0.95, 1.14	1.04	0.95, 1.13
living with partner	0.89	0.70, 1.12	1.05	0.92, 1.19	1.01	0.87, 1.18	1.10	1.02, 1.19	1.09	0.99, 1.20	1.06	0.96, 1.16
age at injury	1.01	1.00, 1.02	1.00	1.00, 1.00	1.00	1.00, 1.00	1.01	1.00, 1.01	1.01	1.01, 1.01	1.01	1.01, 1.01
prescription opioid use before injury	2.27	1.74, 2.96	0.84	0.67, 1.05	0.90	0.72, 1.12	1.07	0.95, 1.21	1.02	0.87, 1.18	1.01	0.87, 1.17
current tobacco use	1.07	0.90, 1.25	1.20	1.10, 1.31	1.26	1.14, 1.39	1.10	1.04, 1.16	1.11	1.04, 1.19	1.09	1.02, 1.17
high injury severity (ref: low)	1.75	1.35, 2.27	1.18	0.98, 1.41	1.30	1.07, 1.59	1.17	1.06, 1.30	1.33	1.18, 1.51	1.33	1.18, 1.49
race (ref: non-Hispanic white)												
Hispanic	1.09	0.92, 1.29	1.43	1.30, 1.56	1.54	1.38, 1.71	1.50	1.42, 1.59	1.51	1.41, 1.62	1.42	1.33, 1.52
Non-Hispanic other	0.96	0.75, 1.23	1.28	1.13, 1.44	1.38	1.21, 1.57	1.26	1.16, 1.36	1.24	1.13, 1.37	1.25	1.14, 1.37
Number of comorbidities	1.05	1.00, 1.10	1.15	1.12, 1.18	1.17	1.14, 1.20	1.07	1.05, 1.09	1.07	1.05, 1.09	1.07	1.05, 1.09
Past-year household income	1.03	0.96, 1.10	1.01	0.97, 1.05	0.99	0.95, 1.04	0.99	0.97, 1.02	1.01	0.98, 1.04	1.02	0.99, 1.05
Hazardous alcohol use	0.89	0.76, 1.05	0.99	0.91, 1.08	1.01	0.91, 1.11	0.90	0.85, 0.95	0.87	0.82, 0.93	0.90	0.84, 0.96

Acronyms: PR: Prevalence ratio; CI: Confidence Interval; CR: Count Ratio.

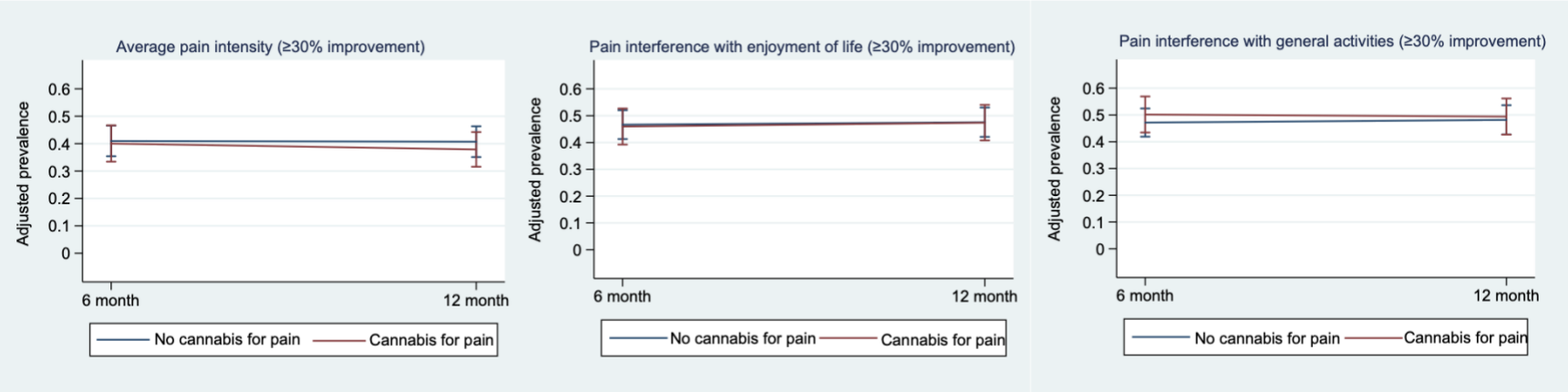
Note: Models adjusted for sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use.

Supplemental Table 2.3. Adjusted regression results for associations of cannabis use for pain with ≥30% improvement from baseline in pain intensity and interference

	Average pain intensity		Pain interference with enjoyment of life		Pain interference with general activities	
	CR	95% CI	CR	95% CI	CR	95% CI
cannabis use for pain	0.98	0.86, 1.11	0.98	0.87, 1.12	1.06	0.95, 1.20
time	0.99	0.93, 1.06	1.02	0.97, 1.08	1.02	0.96, 1.08
cannabis*time	0.95	0.82, 1.10	1.01	0.89, 1.15	0.96	0.86, 1.08
male	0.93	0.84, 1.02	0.96	0.87, 1.05	0.96	0.88, 1.06
married (ref: married)						
widowed, divorced, separated	0.93	0.82, 1.05	0.94	0.84, 1.05	0.96	0.86, 1.08
never married	0.97	0.87, 1.09	0.96	0.86, 1.07	0.97	0.87, 1.09
living with partner	0.97	0.84, 1.12	0.94	0.83, 1.07	0.95	0.84, 1.08
age at injury	1.00	1.00, 1.00	1.00	1.00, 1.01	1.00	1.00, 1.00
prescription opioid use before injury	0.96	0.76, 1.21	0.95	0.76, 1.19	0.97	0.78, 1.21
current tobacco use	0.91	0.82, 1.00	0.91	0.83, 1.00	0.93	0.85, 1.01
high injury severity (ref: low)	0.93	0.73, 1.19	1.04	0.86, 1.26	1.07	0.89, 1.30
race (ref: non-Hispanic white)						
Hispanic	0.85	0.77, 0.94	0.93	0.85, 1.03	0.91	0.83, 1.00
Non-Hispanic other	1.00	0.88, 1.14	1.02	0.90, 1.16	1.04	0.92, 1.18
Number of comorbidities	0.94	0.91, 0.97	0.97	0.94, 1.00	0.97	0.94, 1.00
Past-year household income	1.00	0.96, 1.04	1.02	0.98, 1.06	1.03	0.99, 1.07
Hazardous alcohol use	1.03	0.95, 1.13	1.04	0.95, 1.13	1.00	0.92, 1.09

Acronyms: CR: Count Ratio; CI: Confidence Interval

Note: Models adjusted for sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use.



Supplemental Figure 2.1. Adjusted model-predicted ≥30% improvement from baseline in pain intensity and interference and 95% confidence intervals over the study period by cannabis use for pain

Note: Covariates included sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use

Supplemental Table 2.4. Post-hoc analyses examining cannabis use for pain and self-reported prescription opioid use

	Main analysis			Restricting main analysis to people who had taken opioid medicine since the injury*		
Main effects	Crude PR	Adjusted PR†	+ adjusting for pain intensity	Crude PR	Adjusted PR†	+ adjusting for pain intensity
Cannabis use for pain	0.81 (0.65, 1.01)	0.88 (0.70, 1.11)	0.95 (0.76, 1.17)	0.77 (0.62, 0.95)	0.86 (0.69, 1.08)	0.92 (0.74, 1.14)
Time	0.43 (0.39, 0.49)	0.43 (0.39, 0.49)	0.50 (0.45, 0.56)	0.42 (0.37, 0.47)	0.42 (0.37, 0.47)	0.49 (0.44, 0.55)
Cannabis use × time interaction	1.31 (1.02, 1.69)	1.31 (1.02, 1.69)	1.24 (0.98, 1.57)	1.35 (1.04, 1.73)	1.34 (1.04, 1.73)	1.28 (1.01, 1.62)

*While all participants received a prescription opioid for their injury, 88% reported they "had taken opioid medicine since the injury" at the baseline survey. This analysis was restricted to participants who reported using opioid medication.
† Model adjusted for variables included in the main model (i.e., sex, marital status, age at injury, race and ethnicity, household income, prescription opioid use pre-injury, current tobacco use, injury severity, number of comorbidities, and hazardous alcohol use)
‡ Model adjusted for covariates included in the main model and pain intensity at baseline

Chapter 3. Association between cannabis retail outlet availability and use for pain among injured workers in Washington state

3.1 Introduction

Work-related injuries are a significant contributor to the high prevalence of non-cancer pain in the U.S. Specifically, the burdens associated with musculoskeletal disorders are common among workers of many occupations, with 26% of workers (representing almost 40 million workers) experiencing musculoskeletal pain.[46] Common musculoskeletal disorders can include carpal tunnel syndrome, muscle strains, and low back pain and can often stem from overexertion or repetitive forceful motions.[96] Musculoskeletal pain can manifest gradually, and if not addressed, can lead to a range of health problems, including anxiety, depression, reduced quality of life, and inability to work.[97,98] While musculoskeletal disorders are a major driver of acute and chronic pain among workers, roughly 10% of injured workers experience injuries that result in permanent impairment, contributing to long-term pain and functional disability.[99] Opioids have often been prescribed for workers who experience an on-the-job injury or chronic work-related pain; however, greater awareness of the modest benefits and risks of addiction and overdose death have spurred interest in alternative pain management strategies.[4,6,43,48]

Increasing access to medical and nonmedical (also called "recreational") cannabis has been promoted as a strategy for pain management in recent years.[7] Pain is a common qualifying condition in which medical cannabis can be obtained,[11] with surveys conducted at medical cannabis dispensaries showing that between 40 to 80% of participants report pain as the medical condition associated with their use of cannabis.[14] While studies examining medical cannabis use

among workers are sparse, ecological studies have reported associations between state legalization of medical and nonmedical cannabis and reductions in workplace fatalities,[100] work absentees,[101] and workers' compensation claiming.[18] These studies hypothesize that increasing access to cannabis can increase its *medical* use and thereby, allow for better management and treatment of pain among workers. However, cannabis use is not without harms. Nonmedical cannabis use has been associated with psychosis, cognitive effects, respiratory problems and cannabis use disorder,[61,79] with population-based studies using nationally-representative surveys showing that cannabis use is associated with increased incident prescription opioid use, opioid use disorder, as well as other drug use disorders.[51,52] While studies examining the harms of medical cannabis use are limited, recent studies have reported more frequent or daily use of cannabis[102–105] and high risk of cannabis use disorder among people who use cannabis medically[61] and among adults with pain.[106]

Research suggests that state cannabis legalization and local-level regulations of cannabis can affect cannabis use. Increased availability of retail outlets may reduce travel distance and search costs to obtain products.[107,108] Presence of cannabis retail outlets may also play a role in altering people's perceptions about perceived risks and benefits and shaping norms regarding acceptability, which can affect use.[32–34] Research shows that greater local geographical availability of medical cannabis dispensaries is associated with higher prevalence and frequency of cannabis use and positive perceptions of cannabis's effects.[109,110] Studies examining the availability of cannabis retail outlets in states with active retail markets for nonmedical use have found similar results.[111,112] While many studies examining cannabis outlet availability have focused on *nonmedical* cannabis use or *any* cannabis use, the impact of this increased availability

on *medical* cannabis use, especially among people experiencing pain, remains largely undetermined.[109–112] Among people with pain, increased availability of cannabis may influence cannabis use behaviors by increasing individual's access to a wide variety of cannabis products (e.g., edibles, concentrates marketed for pain) and by promoting beliefs that cannabis is safe and effective for pain relief through advertisting.[35–38] Given the potential for harms of cannabis use, examining the impact of increasing access to cannabis as it relates to cannabis use behaviors among adults with pain is necessary.

In this study, we assessed the association between licensed cannabis retail outlet availability and cannabis use for pain management among workers with occupational injuries in Washington State (WA). WA was one of the first two states to legalize adult (21+) cannabis use, with licensed retailers opening in 2014.[113] The state has a single system which licenses all retail sales, regulated by the WA State Liquor and Cannabis Board. As such, every licensed cannabis retailer in WA has the opportunity to obtain a medical cannabis endorsement, which would allow them to serve patients with a medical cannabis card. As the legal availability of cannabis for both medical and nonmedical use continues to rapidly expand through the U.S, examining the impact of cannabis availability in an established market, such as WA, could aid in our understanding of the influence of cannabis retail markets for medical purposes, especially among people experiencing pain.

3.2 METHODS

3.2.1 *Study setting and participants*

This study used data from the Washington and Ohio Worker (WOW) study, a prospective cohort study examining the effectiveness of workers' insurance programs in reducing unsafe opioid

prescribing. Between 2019 and 2021, study staff identified eligible workers using the WA and Ohio (OH) state workers' compensation databases. Workers were eligible if they filed a new state fund workers' compensation claim and were covered under workers' compensation insurance programs; received at least one opioid prescription during the first 6 weeks of injury; and could speak English or Spanish. Eligible participants were contacted by mail, followed by telephone. Using computer-assisted telephone interviews (CATI), trained interviewers obtained verbal consent and administered a baseline survey capturing information on self-reported health status, pain management strategies, use of prescription opioid medications, and sociodemographic characteristics. Interviews for baseline survey were conducted between August 2019 and September 2021 and occurred around 4 to 8 weeks after date of injury (mean: 6.7 weeks).

The present analysis used baseline survey data from participants in WA, where retail outlets are present. We excluded participants from OH because nonmedical cannabis was not legalized and, thus, no cannabis retail outlets were present. In WA, the Department of Labor and Industries (L&I) is the sole regulator of workers' compensation. It is the direct insurer for approximately 70% of the non-Federal workforce, covering approximately 2.3 million workers via the state fund, with self-insured companies accounting for the remaining 30%. Of eligible WA workers, 54% consented to participate in the study. All study procedures were approved by the University of Washington Institutional Review board.

3.2.2 *Measures*

Outcome: cannabis use for pain management.

At the baseline survey, participants were read a list of things they may have done to treat the pain from their injury, with "Cannabis (CBD, medical cannabis)" listed as a possible response option. We created the primary outcome variable, cannabis use for pain management, indicating any or non-use of cannabis for pain. Of the 2,851 individuals who participated in the baseline survey, we excluded 13 participants (0.5%) who did not answer this question.

Exposure: cannabis retail outlet availability

Participant residential addresses were obtained from L&I prior to the baseline survey but were not updated during the course of cohort follow-up. Addresses reflect contact information provided by workers when filing a compensation claim. To determine each participant's local cannabis retail outlet availability, residential addresses were geocoded using ArcGIS Desktop 10.5.1, with Esri Business Analyst reference data. Addresses were matched to either rooftop or street-address interpolated reference data using a minimum match score ≥90. Match scores assess how closely candidates in the reference data match the address that is being geocoded, with scores ranging from 0 to 100, where 100 indicates a perfect match. Lower match scores can occur if components of the address being geocoded (e.g., street name, number, direction) are misspelled, incorrect, or missing. Prior to the geocoding process, we removed participants who listed a P.O. Box (n = 30) or a non-Washington residential address (n = 56). Of the 2,752 remaining participants, 51 (1.9%) were excluded from the final analytic sample because the addressees could not be geocoded. Spatial coordinates for each participant were used to determine retail cannabis availability at fixed network buffers and distances by incorporating data on retailers licensed between 2019 to 2021, obtained from the WA State Liquor and Cannabis Board. Information on whether retailers had a medically endorsed license was unknown.

To assess retail cannabis availability, we created a 1.0-mile road network buffer surrounding a participant's home and counted the number of licensed cannabis retailers within each buffer. For analysis, we created a binary variable, indicating the presence of any or no cannabis retailer within a 1.0-mile road network buffer. Road network buffers take into account street geography, as well as certain physical barriers (lakes, rivers, mountains), which are relevant in travel behaviors in order to define the accessible neighborhood for a given distance. See Supplemental Figure 3.1 for an example of a 1.0-mile road network buffer. A 1.0-mile buffer was chosen because the majority of participants included in our study resided in urban areas (84.0%, urbanicity defined below), where there can be wide variation in accessibility and availability over short distances, Table 3.1.[114] Additionally, a 1.0-mile buffer represents a local neighborhood area within walking distance (15-20 minutes) or a short drive for most,[115] with few adults across regions of the U.S. perceiving their neighborhood as an area beyond a 15-minute walk.[116] We conducted sensitivity analyses using various spatial scales to define retailer availability: 1) any vs. no cannabis retailer within a 0.5-mile road network distance; 2) any vs. no retailer within a 1.5-mile distance; and 3) proximity, defined as the shortest travel time (in minutes) along the street network from each participant's residence to the closest outlet.[117] Similar to studies assessing the impact of alcohol outlet proximity, we estimated the likelihood of cannabis use for pain for every 10 minute increase in drive time.[118–120]

Individual and neighborhood-level covariates

Participants reported their age of injury, biological sex (female; male), marital status (widowed, divorced, separated; never married; married; living with a partner), past-year annual household income, and race and ethnicity during the baseline survey. Annual household income was

classified into 5 categories: ≤$25,000, $25,001-$50,000, $50,001-$75,000, $75,001-$100,000, or ≥$100,001. We adjusted for race and ethnicity since research shows that cannabis retailers are often located in areas with more racial and ethnic minorities,[121–124] and a lower prevalence of medical cannabis use among racial and ethnic minorities, possibility due to decades of disproportionality aggressive enforcement of cannabis possession laws.[67] In analyses, we classified people who identified as Hispanic, regardless of race, together. For those who identified as non-Hispanic, we grouped individuals who identified as non-Hispanic White together and categorized those who identified as non-Hispanic American Indian/Alaska Native, Asian, Native Hawaiian, Pacific Islander, Black, and multi-racial together, given that there were similar distributions in cannabis use. We provide the non-aggregated distribution of cannabis use by race and ethnicity in Table 3.1.

Participant residential addresses were used to determine urban residency and neighborhood disadvantage. Urban and rural areas were classified based on participants' residential zip codes using the 2010 Rural-Urban Commuting Area (RUCA) codes. Participants who resided in metropolitan areas were classified as residing in an urban area, while those who reside in micropolitan, small town, and rural areas were designed as residing in a rural area. We created a composite neighborhood disadvantage index by linking participant residential addresses to the American Community Survey (ACS) at the census tract level. Five-year estimates for 2015-2019 were used, with the final year corresponding to the start of survey data collection. Similar to other studies, we selected 12 census tract variables that were related to domains associated with economic status, health behaviors, and health outcomes.[125] These domains consisted of poverty, education, employment, occupation, and housing conditions (more information in Supplemental

Table 3.1).[125] Consistent with other approaches,[126,127] we performed a preliminary principal component analysis (PCA) on these 12 variables. In order to find variables that contributed the most to the neighborhood disadvantage summary score, we calculated the average correlation between the first principal component and the 12 original variables, and we retained eight variables that had an above average correlation: median household income; % households receiving dividends, interest, or rental income; % households receiving public assistance; median home value; % households with incomes below poverty; % with college degree; % in management, business, science, or arts occupation; % female head of household with dependents.[127,128] We performed a final principal component analysis using these remaining eight variables, and the final neighborhood-level disadvantage summary score for each census tract was calculated using the first principal component. For analysis, neighborhood disadvantage was standardized into a z-score (mean=0; standard deviation=1), and we categorized neighborhood disadvantage into quartile, where higher quartiles indicated more neighborhood-level disadvantage.

3.2.3 *Statistical analysis*

To account for clustering of participants within census tracts, generalized estimating equations (GEE) models with an exchangeable working correlation structure were used to estimate the cross-sectional associations between retail cannabis availability and cannabis use for pain. GEE models were used since we were interested in the population average effects, as opposed to the neighborhood-specific effects obtained from mixed models.[129] We estimated prevalence ratios (PR) and 95% confidence intervals (CI) by specifying a Poisson distribution with robust standard errors.[73,74] Prevalence ratios were calculated because cannabis use for pain was not rare in our sample, and odds ratios may overestimate risk for common outcomes. Separate models were fit

for each retail cannabis availability measures. We used complete-case analysis methods and adjusted for individual-level covariates (age of injury, biological sex, marital status, past-year annual household income) and neighborhood-level covariates (urban residency, neighborhood disadvantage) in each model. All statistical analyses were conducted in R, version 4.1.1.

3.3 RESULTS

Our study included 2,520 participants in WA. As shown in Table 3.1, the majority of participants were male (75.5%), non-Hispanic White (54.8%), married or lived with a partner (55.4%), and resided in urban areas (84.2%). Approximately 20% of participants reported using cannabis for pain due to their injury. Participants who used cannabis use for pain management, compared to those who did not, tended to be younger (mean age: 38.9 years, compared to 42.9 years), were more likely to have never married, and were less likely to reside in disadvantaged neighborhoods. Approximately 26.1% of participants resided within a 1.0-mile buffer of at least one cannabis retailer. Workers lived an average of 7.2 minutes driving distance (range: 1 to 81 minutes) from the nearest cannabis retailer (data not shown).

As shown in Table 3.2, those living within a 1.0 road network buffer had a somewhat elevated likelihood of using cannabis for pain after adjusting for both individual and neighborhood-level covariates; however, this association was not statistically significant (adjusted PR: 1.11; 95% CI: 0.94, 1.30). Sensitivity analyses suggested stronger associations with the larger spatial scales (1.5-mile buffer: adjusted PR: 1.17; 95% CI: 1.00, 1.36) compared to the more proximal scale (0.5-mile buffer: adjusted PR: 1.04; 95% CI: 0.81, 1.33). There was no statistically significant association between driving time to nearest retailer and cannabis for pain (PR: 0.93; 95% CI: 0.82, 1.06). Full model results are shown in Supplemental Table 3.2.

3.4 DISCUSSION

To our knowledge, this is the first study to explore the association between retail cannabis availability and cannabis use for pain management. Despite policy changes aimed at expanding access to cannabis for medical use over the past years, very little is known regarding how cannabis availability affects medical use, notably for pain management. In our study, we found some evidence suggesting potential associations between retail cannabis outlet availability and cannabis use for pain management. While we found an elevated, albeit not statistically significant, association between retail cannabis outlet availability within 1.0-mile of one's residence and cannabis use, our sensitivity analysis incorporating a larger spatial metric found a stronger association with the likelihood of using cannabis to manage pain.

Results from this study are consistent with other studies highlighting the importance of the retail cannabis environment on cannabis use. While the geographical scale of interest may vary, other studies conducted in Washington and California have found that adults living in areas with greater cannabis availability show greater frequency of nonmedical cannabis use[111] or likelihood of any cannabis use (which combines both nonmedical and medical use).[109,112,130] Given that people who use cannabis nonmedically represent a large proportion of people who use cannabis, studies that do not distinguish between medical and nonmedical use may not reflect the experience of those using cannabis for medical use.[102,131,132] Adding to the literature on nonmedical and overall use, our results suggest that increased availability of retail cannabis outlets may increase *medical* use for pain management. While we were unable to examine the frequency of cannabis use, studies examining cannabis availability and use among young adults and the general population have reported more frequent margins of use, such as past-month or

daily/near-daily use.[109,112,130] It will be important to examine the effects of cannabis retail availability on the frequency and trajectory of medical and nonmedical cannabis use over time among people experiencing pain. Evidence indicates that more frequent and heavy use of cannabis is associated with increased risk for health consequences, such as intoxication-related injuries and cannabis use disorder.[81] These health concerns are also prevalent among people using cannabis medically, who are more likely to report frequent and daily use of cannabis, compared to those who use cannabis nonmedically.[102–105]

We found a stronger association between cannabis availability and use for pain in our sensitivity analysis incorporating a larger spatial scale of 1.5-mile. Prior work conducted in WA has shown that having a retailer within 1-km (0.6 miles) of home was associated with greater perceived access and nonmedical cannabis use among young adults, with results consistent when using larger spatial metrics of 2-km (1.2-mile) buffer and census tract-level measures.[111] This finding is supported by studies that examined cannabis availability within 4-miles near home among young adults[109,130] as well as other studies that examined cannabis retail availability at the zip-code or city-level among adults.[110,112] Given that most of daily activities can occur outside the residential neighborhood, such as at work or places for recreation, studies that are able to incorporate the full range of day-to-day activity may provide a more comprehensive assessment of the cannabis retail environment individuals are exposed to.[133,134]

Our study adds to the limited literature surrounding cannabis use in the occupational setting, where concerns for workers are emerging due to rapid changes in cannabis legalization. In our study, we found that roughly one in five injured workers reported using cannabis for pain for

their injury at the baseline survey, which occurred on average 6 weeks after injury. Estimates on the prevalence of medical cannabis use for pain can vary based on the study population and the measure of use.[135] Studies conducted in places where cannabis (either for medical or nonmedical use) was not legalized showed that roughly 6-11% of chronic pain patients report using cannabis in the past month for pain.[92,93] Estimates are higher in states that legalized either medical or nonmedical cannabis use, where roughly 18% of patients who are prescribed long-term opioid-therapy report using cannabis for pain in the past month.[94] In a study conducted within a large WA health system in 2019, around 28% of primary care patients reported using cannabis in the past-year to manage pain.[135] While more studies assessing the scope of medical cannabis use among people experiencing pain are needed, literature shows that adults with pain are increasingly vulnerable to cannabis-related harms, such as cannabis use disorder.[106] Health professionals treating injured workers with pain should ask patients about their cannabis use and the health reasons for cannabis use. This could help facilitate conversations regarding the potential benefits and risks of cannabis use and the availability of safe and effective treatment options for pain.[136] Relatedly, future studies should examine how cannabis use for pain after injury affects return-to-work outcomes, given that prolonged absence from the workforce is associated with long-term health consequences, such as depression, chronic pain, and disability.[137] Notably, we found that workers who used cannabis for pain in our study were less likely to reside in areas with the highest neighborhood disadvantage. This is in contrast with other studies which found that neighborhood disadvantage is associated with increased likelihood of cannabis use[111,138] and other substance use among adults.[139–141] Conflicting findings may be due to our study population, which was comprised of people healthy enough to be

employed prior to injury. More studies are needed to examine the contribution of neighborhood disadvantage on different intentions for cannabis use.

Ecological studies have reported population health benefits associated with cannabis legalization, including a reduction in workplace fatalities,[100] work absentees,[101] and workers' compensation claiming,[18] with many hypothesizing that increasing access to cannabis would allow better management and treatment of pain among workers. While we found some evidence that cannabis availability was associated with cannabis use for pain, it remains unknown if increasing cannabis availability can yield population health benefits for workers. Current evidence of the efficacy of cannabis for musculoskeletal disorders, which are common in the occupational setting, remains mixed.[91] Although cannabis has often been promoted as strategy for pain management, cannabis use, regardless of the indication of use, is not without risk. Data from the National Survey on Drug Use and Health have estimated that, from 2002 to 2017, prevalence of past-year cannabis use disorder increased from 2.1% (4.4 million) to 2.6% (6.4 million adults).[142] Meanwhile, potency of cannabis products has increased sharply, with average nationwide concentrations of tetrahydrocannabinol (THC) tripling from 4% to 12% in the past 2 decades.[80] In WA, the average THC concentration in herbal cannabis products according to a 2020 study was 22%.[143] This may be of particular concern given the mounting evidence suggesting that higher potency cannabis use increases the risk of adverse health outcomes such as vehicle accidents[144] and cognitive impairment,[145] which may affect the risk of occupational injuries. Findings from our study highlight the need to continue examining the role of cannabis among workers and people experiencing pain.

Our findings emphasize the need to examine mechanisms through which the retail market shapes medical cannabis use. Messages about cannabis as an effective treatment for pain is pervasive, with one study finding that nearly two-thirds of surveyed adults believing cannabis is beneficial for pain management.[146] While retail markets in states with active retail sales are prohibited from advertising or making claims about cannabis's medical, curative, or therapeutic effects,[37,147] little regulation and oversight exists over the promotion and marketing of cannabis products as medicinal.[38] A study examining online advertising practices in Weedmaps, a popular online directory for cannabis retailers, found that 40% of retailers in WA made beneficial health claims about cannabis products, such as reducing anxiety or treating depression, insomnia, and pain, with no retailers warning of potential health risks associated with the use of cannabis.[37] This reduced oversight may lead to heavy promotion and marketing of cannabis as a safe and effective treatment for pain. Additionally, many consumers rely on advice from retail employees ("budtenders") to select cannabis products for medical use,[148] with recommendations from employees often stemming from their own personal opinion or experience and less based on clinician input.[149] In the presence of limited evidence of cannabis to effectively manage pain, tighter regulation of health claims made may be needed.[38]

3.4.1 *Limitations*

Several limitations of this study should be considered. Data were collected via phone interviews; thus, underreporting of cannabis use for pain may be possible due to social desirability and concerns about prosecution from employers, healthcare providers, and the workers' compensation agency. However, L&I cannot reject a claim because of a positive drug test, and participants were informed that their participation would not affect the medical care they receive. Participants were required to have an accepted State Fund workers' compensation claim in order

to be eligible for this study. As such, workers with less severe injuries may not be included in our sample. While the State Fund covers the majority (70%) of the non-federal workforce in WA, workers covered by self-inured employers and those who are classified as independent contractors (under strict exemption definitions) are not included in our sample. It is possible that we may be underestimating the association between cannabis retail outlet availability and use if these workers have more hazardous occupations with higher risk of injuries. However, self-insured employers represent some of the largest companies in WA, such as Microsoft, Boeing, and city employees,[150] and on average, risk of severe injury may be lower for these job characteristics. In WA, legal sales of cannabis are restricted to adults 21 and older. While our study population consisted of workers 18 years and older, less than 3% of our sample was under 21 years old. Future studies should examine whether the association varies by age.

We did not have information on whether participants used cannabis prior to injury and whether participants used cannabis for other purposes besides pain from injury. Our primary outcome was cannabis use for pain management; thus, people who used cannabis for nonmedical purposes or for medical purposes besides pain from injury would be classified as not having the primary outcome of interest. It is possible that we may have underestimated the association between retail outlet availability and cannabis use for pain by including workers who used cannabis for other purposes. Many studies have highlighted the complexity in distinguishing medical from nonmedical cannabis use. Among individuals who use cannabis, designation of use can change from medical to nonmedical or vice versa over time,[151] and high overlap in medical and nonmedical use have been reported, with around 50% of participants who report medical use also reporting nonmedical use.[152] However, differences in demographic and clinical characteristics

between people who use cannabis medically and those who use cannabis nonmedically are small,[102,103] compared to differences between people who use any cannabis and those who do not use any cannabis.[153] Additionally, pain is a common reason cited for the use of cannabis,[11] and our study was able to examine how cannabis availability affected cannabis use for this reason.

Our results are not generalizable to other areas where medical or nonmedical cannabis is not legalized and those with different regulatory policies surrounding cannabis (e.g., more liberal marketing and advertising, fewer regulation on hours or location of operations). We could not account for illegal drug market activity or presence, such as unlicensed cannabis outlets, which may have underestimated our metric for cannabis availability. A study conducted in Los Angeles County found that unlicensed outlets made up 62% of all outlets in 2018 and 2019.[130] However, in WA around 71% of adults 21 and older are purchasing cannabis from a licensed retail store, and there are active enforcement efforts to identity businesses that may sell cannabis without a license.[111,154] In addition, we did not have information on whether a cannabis retail outlet had a medical cannabis endorsement or not. However, a recent study found that average THC concentration of products did not differ when comparing retail outlets and medical dispensaries in WA.[143] Future studies should assess whether medical endorsements affect cannabis use behaviors. Similar to other studies, our neighborhood disadvantage index was constructed using variables related to domains of economic status, health behaviors, and health outcomes,[125] and we conducted a data-driven approach to reduce the number of variables while maximum the variance.[126,127] However, this approach may have omitted theoretical aspects, such as unemployment, that contributes to neighborhood disadvantage.[155] Given that cannabis usage and presence of retail outlets can vary across urban and rural contexts, future studies should assess

heterogeneity by urbanicity.[112,156] Lastly, individuals may also be exposed to retail outlets in places outside their residential neighborhoods (e.g., around work, school, places for recreation), which would not be captured in this study.

3.5 CONCLUSIONS

Increasing access to cannabis is often promoted as a strategy for pain management. Despite limited evidence for the efficacy of cannabis for pain, especially for musculoskeletal disorders, cannabis use for pain was common among recently injured workers in our study. We found some evidence that cannabis retail outlets availability was associated with higher likelihood of using cannabis for pain. A deeper understanding of the implications of cannabis use and availability through the lens of occupational safety and health is needed to improve health outcomes for people experiencing pain.

Table 3.1. Demographics by cannabis use for pain managements (N=2,520)

Characteristics	Total (N=2,520)	Did not use cannabis for pain management (n=1,996)	Used cannabis for pain management (n=524)
Biological sex, n (%)			
Female	617 (24.5)	491 (24.6)	126 (24.0)
Male	1903 (75.5)	1505 (75.4)	398 (76.0)
Age at injury, mean (SD)	42.1 (12.7)	42.9 (12.8)	38.9 (12.1)
Race and ethnicity, n (%)			
Hispanic	824 (32.7)	754 (37.8)	70 (13.4)
Non-Hispanic American Indian/Alaska Native	29 (1.2)	22 (1.1)	7 (1.3)
Non-Hispanic Asian, Native Hawaiian, or Other Pacific Islander	54 (2.1)	45 (2.3)	9 (1.7)
Non-Hispanic Black	75 (3.0)	54 (2.7)	21 (4.0)
Non-Hispanic Other	34 (1.3)	23 (1.2)	11 (2.1)
Non-Hispanic White	1381 (54.8)	1017 (51.0)	364 (69.5)
Non-Hispanic, multi-racial	123 (4.9)	81 (4.1)	42 (8.0)
Current marital status, n (%)			
Married	1027 (40.8)	872 (43.7)	155 (29.6)
Widowed, divorced, separated	461 (18.3)	379 (19.0)	82 (15.6)
Never married	663 (26.3)	475 (23.8)	188 (35.9)
Living with a partner	369 (14.6)	270 (13.5)	99 (18.9)
Past-year total household income, n (%)			
$25,000 or less	544 (21.6)	431 (21.6)	113 (21.6)
$25,001 to $50,000	984 (39.0)	779 (39.0)	205 (39.1)
$50,001 to $75,000	481 (19.1)	373 (18.7)	108 (20.6)
$75,001 to $100,000	261 (10.4)	211 (10.6)	50 (9.5)
$100,001 or more	250 (9.9)	202 (10.1)	48 (9.2)
Residence in urban area, n (%)*			
No	398 (15.8)	325 (16.3)	73 (13.9)
Yes	2122 (84.2)	1671 (83.7)	451 (86.1)
Neighborhood disadvantage, mean (SD)†			
Quartile 1 (least disadvantaged)	632 (25.1)	465 (23.3)	167 (31.9)
Q2	629 (25.0)	491 (24.6)	138 (26.3)
Q3	630 (25.0)	498 (24.9)	132 (25.2)
Quartile 4 (most disadvantaged)	629 (25.0)	542 (27.2)	87 (16.6)
Travel time to the nearest outlet – minutes, mean (SD)	7.2 (6.9)	7.3 (6.9)	6.8 (6.8)
Count of cannabis retail outlets within 0.5-mile buffer, n (%)			

0	2293 (91.0)	1818 (91.1)	475 (90.6)
1+	227 (9.0)	178 (8.9)	49 (9.4)
Count of cannabis retail outlets within 1.0-mile buffer, n (%)			
0	1862 (73.9)	1487 (74.5)	375 (71.6)
1+	658 (26.1)	509 (25.5)	149 (28.4)
Count of cannabis retail outlets within 1.5- mile buffer, n (%)			
0	1499 (59.5)	1210 (60.6)	289 (55.2)
1+	1021 (40.5)	786 (39.4)	235 (44.8)

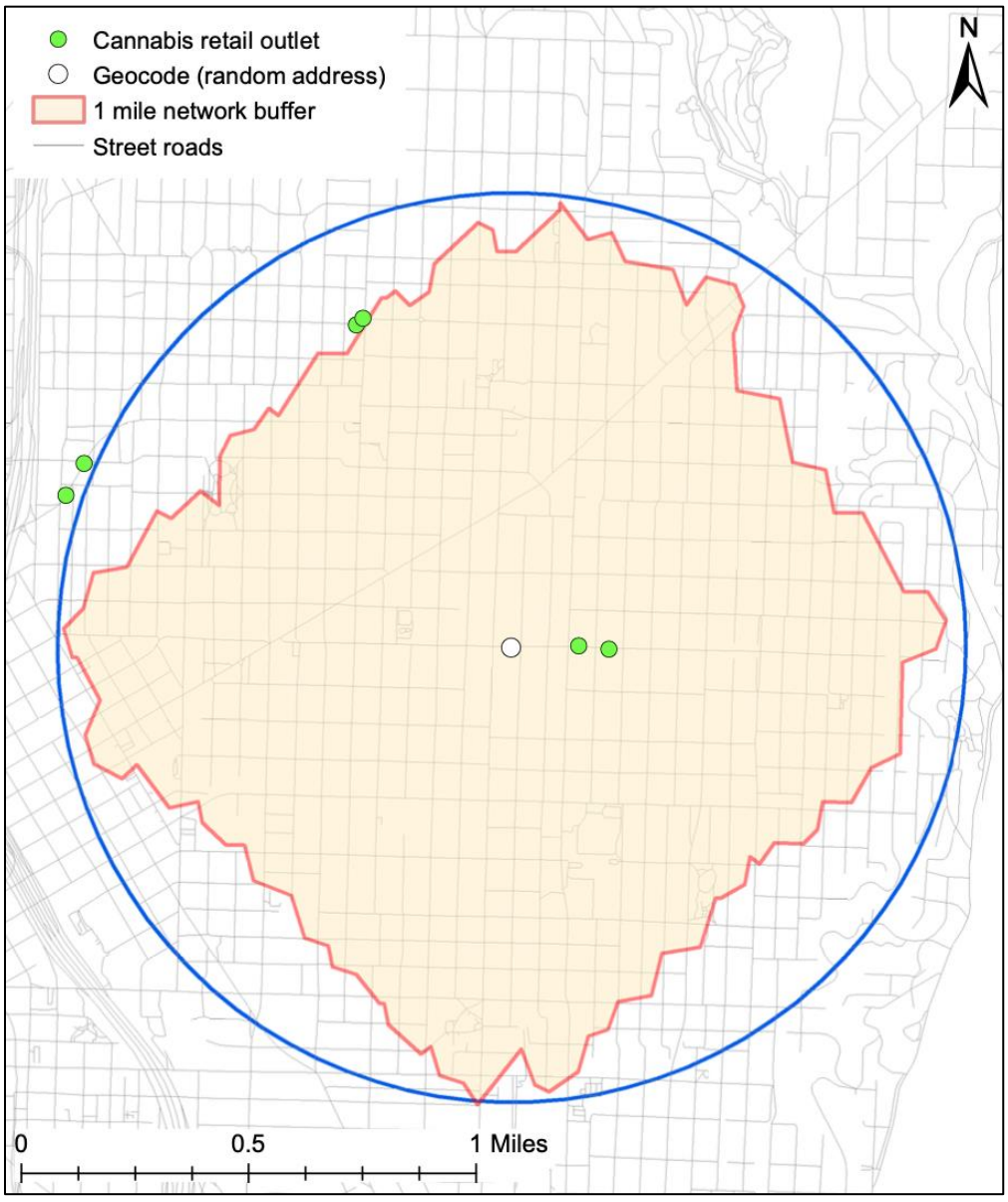
* Urban or rural residency was classified based on participants' residential zip codes using the 2010 Rural-Urban Commuting Area codes

† Census tract level composite index created using the 2015-2019 American Community Survey, where higher numbers indicate greater disadvantage

Table 3.2. Prevalence ratios (PR) estimating cross-sectional association between cannabis retail availability and cannabis use for pain using complete-case analysis (n=2,520)

	Unadjusted PR (95% CI)	P-value	Adjusted PR (95% CI)[†]	P-value
Primary analysis				
Any cannabis retail outlets within 1.0-mile buffer	1.12 (0.95, 1.33)	0.170	1.11 (0.94, 1.30)	0.222
Sensitivity analyses				
Any cannabis retail outlets within 0.5-mile buffer	1.04 (0.80, 1.35)	0.758	1.04 (0.81, 1.33)	0.753
Any cannabis retail outlets within 1.5-mile buffer	1.20 (1.03, 1.39)	0.020	1.17 (1.00, 1.36)	0.047
Travel distance to nearest retail outlet per 10-minute drive	0.92 (0.80, 1.05)	0.199	0.93 (0.82, 1.06)	0.266

[†] Models adjusted for individual-level covariates (age of injury, biological sex, marital status, race and ethnicity, past-year annual household income) and neighborhood-level covariates (urban residency, neighborhood disadvantage)



Supplemental Figure 3.1. Example of 1-mile road-network buffer (red outline) around a random address (white point), along with locations of cannabis retail outlets (green points), and a 1-mile Euclidean (radial) buffer (blue circle).

Supplemental Table 3.1. Correlation coefficients between variables and the first principal components

Indicators	Preliminary PCA	Final PCA*
Wealth and income		
Median household income	-0.90	-0.90
Percent of households receiving dividends, interest, or rental income	-0.87	-0.87
Percent of households receiving public assistance	0.86	0.84
Median home value (dollars)	-0.81	-0.86
Percent of families with incomes below the poverty level	0.76	0.71
Education		
Percent with a Bachelor's degree or higher	-0.82	-0.89
Occupation		
Percent in a management, business, science, or arts occupation	-0.84	-0.88
Percent unemployed	0.49	
Housing conditions		
Percent of households that are female headed with children under 18	0.69	0.67
Percent of housing units that are owner occupied	-0.52	
Percent of households without a telephone	0.41	
Percent of households without complete plumbing facilities	0.18	
Eigenvalue	6.11	5.51
Proportion of variance explained by first principal component	50.9%	68.9%
Mean of correlations in the first component	0.68	

* In order to find variables that contribute the most to the neighborhood disadvantage summary score, we calculated the average correlation between the first principal component and the 12 original variables and performed a final principal component using variables that had an above average correlation in the preliminary PCA (0.68).[127,128]

Supplemental Table 3.2. Full regression models for prevalence ratios estimating cross-sectional association between cannabis retail availability and cannabis use for pain

	Primary analysis	Sensitivity analysis		
	Model 1	Model 2	Model 3	Model 4
Intercept	0.38 (0.26, 0.55)	0.38 (0.26, 0.56)	0.37 (0.25, 0.54)	0.42 (0.27, 0.63)
Cannabis retail outlet availability				
Any retail outlets within 1.0-mile buffer	1.11 (0.94, 1.30)			
Any retail outlets within 0.5-mile buffer		1.04 (0.81, 1.33)		
Any retail outlets within 1.5-mile buffer			1.17 (1.00, 1.36)	
Minutes to nearest outlet, for every 10 minutes				0.93 (0.82, 1.06)
Individual-level covariates				
Biological sex				
Female (reference)				
Male	1.06 (0.89, 1.27)	1.06 (0.89, 1.26)	1.06 (0.89, 1.26)	1.06 (0.89, 1.26)
Race and ethnicity				
Non-Hispanic White (reference)				
Hispanic	0.32 (0.25, 0.41)	0.32 (0.25, 0.41)	0.32 (0.25, 0.42)	0.32 (0.25, 0.41)
Non-Hispanic Other*	1.04 (0.86, 1.25)	1.04 (0.86, 1.26)	1.03 (0.85, 1.25)	1.03 (0.85, 1.25)
Past year total household income, $	0.95 (0.88, 1.02)	0.95 (0.88, 1.02)	0.97 (0.78, 1.19)	0.95 (0.88, 1.02)
$25,000 or less (reference)				
$25,001 to $50,000	0.95 (0.78, 1.16)	0.95 (0.78, 1.16)	0.95 (0.78, 1.16)	0.95 (0.78, 1.15)
$50,001 to $75,000	0.92 (0.73, 1.17)	0.93 (0.73, 1.18)	0.93 (0.73, 1.18)	0.92 (0.73, 1.17)
$75,001 to $100,000	0.84 (0.62, 1.14)	0.84 (0.62, 1.14)	0.85 (0.62, 1.15)	0.84 (0.61, 1.14)
$100,001 or more	0.82 (0.59, 1.14)	0.81 (0.58, 1.13)	0.83 (0.60, 1.16)	0.81 (0.58, 1.13)
Age at injury (years)	0.98 (0.98, 0.99)	0.98 (0.98, 0.99)	0.98 (0.98, 0.99)	0.98 (0.98, 0.99)
Marital Status				
Married (reference)				

Widowed, divorced, separated	1.15 (0.89, 1.48)	1.15 (0.89, 1.48)	1.14 (0.89, 1.47)	1.14 (0.88, 1.47)
Never married	1.33 (1.07, 1.65)	1.33 (1.07, 1.65)	1.33 (1.07, 1.65)	1.33 (1.07, 1.65)
Living with a partner	1.54 (1.23, 1.93)	1.54 (1.23, 1.93)	1.54 (1.23, 1.92)	1.55 (1.24, 1.94)
Neighborhood-level covariates				
Urbanicity				
Residence in rural area (reference)				
Residence in urban area	0.98 (0.79, 1.21)	0.99 (0.80, 1.22)	0.97 (0.78, 1.20)	0.95 (0.76, 1.18)
Neighborhood disadvantage				
Quartile 1 (least disadvantaged) - reference				
Q2	0.91 (0.75, 1.11)	0.91 (0.75, 1.11)	0.92 (0.76, 1.12)	0.91 (0.75, 1.11)
Q3	0.86 (0.71, 1.05)	0.87 (0.72, 1.06)	0.85 (0.70, 1.04)	0.86 (0.71, 1.05)
Quartile 4 (most disadvantaged)	0.71 (0.56, 0.91)	0.72 (0.56, 0.92)	0.69 (0.54, 0.89)	0.71 (0.55, 0.91)

*Non-Hispanic Other consists of participants who identified as non-Hispanic American Indian/Alaska Native; Asian, Native Hawaiian, or Other Pacific Islander; Black, multi-racial or other non- Hispanic racial identities

Chapter 4. County cannabis retail outlet availability and county occupational injuries in Washington State, 2014-2019

4.1 Introduction

Concerns for workplace safety are emerging due to the rapidly evolving landscape of cannabis legalization and commercialization in the U.S. Since 1996, 37 states and the District of Columbia have legalized the medical use of cannabis products, while 18 states have legalized cannabis for nonmedical (or recreational) use.[27] Cannabis is the most commonly used substance in the U.S., with 48 million people reporting past-year cannabis use in 2019, many of whom are working-aged adults.[39] Among workers, cannabis use and frequency of use have increased over time. From 2013 to 2019, national survey data show that past-year cannabis use among full-time employees increased from 13% to 19% while past-month cannabis use increased from 8% to 13%.[39] While studies examining cannabis use in the workplace are limited, with most conducted prior to the widespread legalization of cannabis,[9] a recent study in Canada showed that almost 30% of workers reported using cannabis in the past year, a quarter of whom reported using cannabis in the workplace, either within 2 hours of starting work or at the end of the shift at the workplace.[157] Additionally, over half of workers who reported using cannabis in the workplace were also involved in hazardous work, such as operating heavy machinery or driving a motor vehicle, compared to just over a third of respondents who reported not using cannabis in the workplace.[157] While some people can use cannabis without harm, studies examining the acute and chronic effects of cannabis intoxication have reported impairment in cognition, especially in the domains of attention, memory, and psychomotor function.[40] This raises concerns for occupational injuries, especially in safety-sensitive industries, such as construction, warehousing,

or transportation, where impairment on the job can affect a worker's own safety and the safety of others.[41] Given the significant health and economic burden attributable to occupational injuries,[158] with 2.4 million workers in the U.S. sustaining a work-related injury in 2019,[3] the implications of cannabis legalization and commercialization on cannabis use and downstream outcomes, such as occupational injuries, are important for policymakers, healthcare systems, employers, and workers.

Cannabis retail outlet availability may increase cannabis use and cannabis-related impairment at work, which predisposes workers to occupational injury. Research suggests that state cannabis legalization and local availability of cannabis can affect cannabis use behaviors. Similar to research in the alcohol and tobacco literature, greater geographical availability to cannabis retail outlets may increase cannabis use by reducing travel distance and search costs to obtain products, shaping norms regarding acceptability, and altering perceived risks and benefits of cannabis.[32–34,107,108] Studies conducted in Washington and California show that adults living in areas with greater cannabis availability have greater likelihood and frequency of cannabis use.[109,111,112,130] Meanwhile, availability of high potency cannabis products has increased over the past two decades,[80] with mounting evidence suggesting that higher potency cannabis use increases the risk of health consequences such as vehicle accidents, which are the leading fatal occupational injuries.[144,159,160] As such, studies investigating the impact of increasing cannabis availability on occupational injuries, especially in safety-sensitive industries which involve more hazardous work, are needed.

Previous studies have found that legalizing medical and nonmedical cannabis was associated with a reduction in workplace fatalities,[100] work absentees,[101] and workers' compensation claiming.[18] Many hypothesize that cannabis legalization could increase its medical use, allowing workers to manage preexisting conditions or symptoms arising from work-related illnesses and injuries, such as insomnia or pain.[18] However, these studies often do not account for state differences over time that are likely to affect occupational outcomes. For example, many states have enacted their own programs and policies aimed at protecting workplace safety, such as State Plans, which are approved by the Occupational Safety and Health Administration (OSHA),[161] mandatory injury and illness prevention programs, and joint labor-management safety committees.[162] If implementation of programs that protect workplace safety is correlated with cannabis policies, this may contribute to the apparent protective effects of cannabis legalization on occupational outcomes seen in states that legalize cannabis use. Additionally, most studies evaluating the impact of cannabis legalization on occupational health have often treated cannabis legislation as a policy indicator that affects all residents within a state equally, failing to account for the wide range of actions each jurisdiction can take to regulate cannabis availability and use.[113,163] It can take up to several years after state legalization for regulatory policies to develop and for the cannabis retail market to become operational. For example, Washington was one of the first U.S. states to legalize the production and sale of nonmedical cannabis use in 2012; however, legislation dictated that the first retail cannabis outlet could not open until July 2014. Substantial variation in cannabis availability exists across counties in Washington, where each county can enact its own laws regulating the production and sale of cannabis products. Two years after the cannabis retail market began, a third of Washington residents lived in areas where cannabis retail sales were banned, and 77% of counties had passed

local ordinances aimed at regulation of cannabis retail sales (e.g., permanent or temporary bans, zoning laws, store limits, or regulating hours of operation).[164] Studies that are able to account for variability in the local retail environment can provide information on the influence of increasing cannabis availability on occupational health.

In this study, we conducted a retrospective, longitudinal county-level analysis examining the association between cannabis outlet retail availability and subsequent occupational injury rates in Washington State. By examining counties in Washington over time, our analysis can provide a more nuanced evaluation of the changing local cannabis environment and their effects on occupational injuries[18] and can be useful in shaping local policies regarding the density of cannabis outlets. In secondary analyses, we examined the association between county-level cannabis availability and industry-specific occupational injuries, given that certain industries have higher injury risks than others (e.g., construction, transportation, and manufacturing have higher risks of injury, compared to professional, technical, and educational sectors).[165,166] We hypothesize that counties with a greater increase in cannabis outlet retail availability will also experience a greater increase in occupational injuries, possibility due to increased cannabis use and impairment. Additionally, we hypothesize that county-level cannabis outlet retail availability will be associated with higher injury rates among workers in safety-sensitive industries, such as construction, transportation, and manufacturing, given that impairment in these high-risk industries may further expose workers to injuries.[41]

4.2 METHODS

4.2.1 *Study setting and procedures*

We used data made available as part of the Washington and Ohio Worker (WOW) study, which aimed to examine the effectiveness of workers' insurance programs in reducing unsafe opioid prescribing in Washington and Ohio (OH). WOW study investigators obtained workers' compensation claims data from the Washington Department of Labor and Industries (L&I) for all injured workers, aged 18 or older, who were covered under state-funded workers' compensation insurance programs in Washington from 2010 to 2019. Briefly, workers' compensation provides no-fault industrial insurance coverage for most employers and workers in Washington. For workers who experience an occupational injury or illness due to their work activities, coverage can include medical services and wage replacement benefits. Washington is one of 4 states that does not allow private workers' compensation coverage. Compensation benefits are administered through either a public State Fund, which covers 70% of Washington's workforce, or through self-insured employers, which covers the remaining 30%.[62]

For the present study, we used claims data for workers who received workers' compensation benefits through the State Fund from January 2014 through December 2019. The dataset included claims for 459,975 injured workers, where roughly 90,000 new claims are accepted each year, and includes information on their date of injury, county of residence, and occupational industry at the time of injury. Claim records were aggregated to the year of injury and county of residence levels and then merged with county-level data on licensed cannabis retail outlets. All study procedures were approved by the University of Washington institutional review board.

4.2.2 *Exposure and outcomes*

The exposure of interest was county-level cannabis retail outlet availability, assessed at every year from 2014 to 2018. Cannabis retail outlet availability was calculated by dividing the number of licensed outlets within each county and year by the total annual county population from 2014 to 2018. County population denominators for each of Washington's 39 counties were obtained from the corresponding 5-year estimates of the American Community Survey (ACS). Data on licensed cannabis retail outlets and their locations were obtained from the Washington State Liquor and Cannabis Board, which has regulated businesses with licenses to sell cannabis since July 2014, when the retail cannabis market opened.

The outcome of interest was the county-level number of occupational injuries per year. We aggregated counts of new workers' compensation claims occurring from January 2015 to December 2019 to the county-year level. Injury counts were lagged by one year to ensure temporal ordering between cannabis retail outlet availability and injury. We excluded workers' compensation claims that had a missing county of residence, which comprised around 4% of all claims yearly from 2015 and 2019 and did not vary substantially between years. We then conducted an analysis of industry-specific injury for the following 5 industry groups, using the North American Industry Classification System (NAICS) codes: transportation and warehousing; professional, scientific, technical services; educational services, health care, and social assistance; manufacturing; and construction. Definitions for each industry, obtained from the Bureau of Labor Statistics, are provided in Supplemental Table 4.1.

4.2.3 *Covariates*

As described in more detail later, we employed a fixed-effects modelling approach where each county serves as its own control. Given that all unobserved time-invariant confounders were controlled for by this design, we identified potential time-varying confounders based on the hypothesized relationship between cannabis retail availability and injury. These potential time-varying confounders were county unemployment rate and county poverty, both obtained from the annual five-years estimates of the American Community Survey from 2013 to 2017. We hypothesized that higher unemployment may reduce the number of occupational injuries. Additionally, county-level poverty has been associated with higher rates of intentional and unintentional injuries,[167] and previous research has found higher cannabis retail availability in neighborhoods with more economic and social deprivation.[127,168]

4.2.4 *Statistical analysis*

Descriptive statistics were calculated for all variables of interest across counties. We used negative binomial regression models to estimate incidence rate ratios (IRRs) and their corresponding 95% confidence intervals, for the association between cannabis retail outlet availability and subsequent rates of occupational injury. Cluster robust standard errors were used to account for repeated observations within counties over time. County fixed effects were included to control for unmeasured characteristics of counties that remained consistent over the study period. Year fixed effects were included to control for secular changes and events affecting all counties, such as increasing THC potency of cannabis products or state-level workplace regulations. Occupational injury rates were estimated by using the number of employees in the corresponding county as the offset, with population denominators for employees obtained from the ACS and comprised of people in the civilian employed population, 16 years and over. We

then modeled changes in industry-specific injury rates for each of the five industries of interest. For each industry-specific model, the number of people employed in the corresponding industry among civilian employed population, 16 years and over, for each county was obtained from the ACS and used as the offset. In all models, we lagged time-varying county unemployment and poverty, such that these covariates preceded the exposure variable (cannabis retail outlet availability) by one year. Analyses were conducted in R, version 4.1, using the MASS package for negative binomial regression models.

4.3 Results

The study sample included all 39 counties in Washington, contributing to a total of 195 county-years. Table 4.1 shows county-level characteristics for each study year. Across counties, the overall occupational injury rate declined over time, changing from 315 injuries per 10,000 employees in 2014 to 298 injuries per 10,000 employees in 2019. When examining injuries among specific industries, construction had the highest injury rates throughout the study period (averaging 517 injuries per 10,000 employees), whereas the injury rates for professional, scientific, and technical services were the lowest (averaging 137 injuries per 10,000 employees). There were wide variations in occupational injury rates between counties, Figure 4.1. Across all years, 25% of counties had an overall injury rate below 242 injuries per 10,000 while 25% had injury rates above 366 injuries per 10,000 employees. Among industries, variation in injury rates per 10,000 employees between counties were highest in construction (interquartile range: 275, 674) and lowest in educational services, health care, and social assistance (interquartile range: 129, 208). Within counties, occupational injuries tended to be lower in 2019, compared to 2015. Specifically, 64% of counties (25 counties) had lower occupational injury rates in 2019 than in 2015.

Cannabis availability increased over the study period, with 97% of counties (38 out of 39) having a least one cannabis retail outlet in 2018, Figure 4.2. In contrast, 53.9% (n=21) of counties had at least one licensed cannabis retail outlet in 2014. Across counties, the mean cannabis outlet retail availability was 0.12 outlets per 10,000 residents in 2014 and increased to 1.31 outlets per 10,000 residents in 2019, Table 4.1.

We observed no association between within-county increases in cannabis retail outlets and subsequent injury rates (IRR = 1.00; 95% CI: 0.97, 1.04), Table 4.2. When examining injury rates among specific industries, a within-county increase of 1 retail outlet per 10,000 residents was associated with an 12% increase in injury rates among workers in transportation and warehousing, although the confidence interval contained the null (IRR = 1.12; 95% CI: 0.99, 1.27). No statistically significant associations were observed for workers in professional, scientific, technical services; educational services; manufacturing; and construction.

4.4 Discussion

To our knowledge, this is the first study to assess the association between cannabis retail outlet availability and subsequent changes in occupational injuries at the county-level over time. While we found little evidence of an association between county-level cannabis retail outlet availability and overall rates of occupational injuries, our findings suggest that there may be an increase in transportation and warehousing injuries. These findings add to the limited understanding of the implications of increasing cannabis availability on occupational injuries. Given that our findings only highlight county-level associations, studies that examine the longitudinal relationship

between cannabis availability and use on occupation injuries at the individual-level will be useful in verifying these findings.

Our study hypothesized that exposure to cannabis retail outlet may increase cannabis use, leading to an increase in occupational injury. However, research examining these pathways are limited. While studies have found associations between cannabis retail outlet availability and use, no studies have examined whether these policies affect cannabis-related work impairment.[131] Additionally, despite the biological plausibility, evidence regarding the impact of cannabis use on occupational injuries remains mixed, with many studies conducted prior to the legalization and commercialization of cannabis products.[169] Research shows that impairments in psychomotor skills, mood, and complex executive function tasks can persist for about 4 hours after using smoked cananbis[40,170] and can linger up to 1 week, depending on potency and mode of administration.[171] However, assessing the impact of cannabis use on occupational injury is an ongoing challenge due to the difficulty in determining when workers are impaired on the job and whether impairment represents a safety risk.[172] Studies that can elucidate the pathways between cannabis outlet availability, impairment, and occupational injuries are needed, especially in the current legalized context.

Although not reaching statistical significance, we observed some evidence for increases in injury rates associated with cannabis retail outlet availability among workers in transportation and warehousing. These findings may suggest the need for strategies that will reduce the burden of injuries in these industries, which already has some of the highest rates of workplace fatalities[173] due to transportation incidents, falls, or being struck by objects or equipment.[174] In regards to

transportation, our findings are consistent with research showing that driving under the influence of cannabis is associated with an increased risk of traffic collisions,[144,160,175] as well as other state-level studies which found higher motor vehicle fatality after the opening of cannabis retail outlets.[176–179] Beyond local retail availability, future studies should consider regulations related to cannabis marketing, advertising, and sales, which may vary within counties over time.

Previous studies examining cannabis legalization and occupational health have suggested that increasing access to cannabis may yield health benefits, such as reduced workers' compensation claiming and non-fatal workplace.[18,180] These studies have often examined the effects over the span of around two decades or more, where social, economic, and political changes that can affect occupational safety have occurred concurrently with cannabis legalization. Our findings suggest the importance of examining cannabis retail outlet availability beyond legalization. Although some hypothesize that cannabis legalization would allow workers to manage pre-existing illnesses or work-related injuries and thereby, may be less likely to file workers' compensation,[18] evidence of effectiveness for many health conditions that medical cannabis is purported to treat, including pain, is often limited or inconclusive.[181] Moreover, increasing cannabis availability may impact the use of other substances, such as alcohol and opioid prescriptions.[20,182,183] While research examining the effect of cannabis legalization, availability, and use on other substance use are ongoing, the implications on workplace safety may vary depending on whether cannabis is used as a substitute for other substances (e.g., prescription opioids for pain) or alongside other substances, such as alcohol.[182]

4.4.1 *Limitations*

Several limitations of this study exist. Counties represent large, heterogenous areas, and we could not account for variability or clustering of retail outlets within counties. Future studies should assess the more local effects of cannabis retail outlet availability on occupational injuries. Due to the ecological design, our results can only be applied at the county-level. While we were able to minimize confounding by using counties as their own control and adjusting for other potential confounders, confounding by factors that changed concurrent with expanding cannabis retail outlet availability is possible. One confounding factor may be changes in workplace-based drug testing, which may vary depending on the industry. Except for federal employees and workers in industries regulated by the federal government, most states allow employers to establish their own decisions regarding drug testing. In our study, it is possible that industries in counties with greater cannabis retail outlet availability may implement more drug testing over time as a strategy to reduce occupational injuries attributable to cannabis. However, there is limited evidence that mandatory drug testing is effective in preventing occupational injuries.[184,185]

Due to data availability, there are several limitations in our calculation of injury rates. For example, employees 16 years or older are included in the denominator, while only those 18 years or older were included in the numerator. Future studies should examine whether cannabis outlet availability and occupational injuries varied by age, given the high prevalence of occupational injuries and cannabis use among younger people.[186,187] People in the federal workforce are included in the denominator; however, our workers' compensation data only include of people injured in the non-federal workforce. It is unlikely, though, that these discrepancies would affect

our findings since the number of injuries remained stable over the study period. Additionally, we used 5-year ACS population estimates since 1-year ACS estimates were not available for half of WA counties. While 5-year estimates may provide stable estimates over time, they may underestimate county demographics if estimates fluctuated rapidly year to year, which may result in residual confounding.

Data on occupational injuries came from State Fund workers' compensation databases, which are more likely to capture acute injuries, as opposed to chronic occupational illnesses or cumulative trauma disorders, such as asthma.[188] While the State Fund covers the majority (70%) of the non-federal workforce in WA, workers covered by self-inured employers and those who are classified as independent contractors (under strict exemption definitions) are not included in our injury counts. As such, we may have underestimated county-level injury rates; however, it is likely that this underestimation is consistent within counties over time. While county-level data on the number of workers covered by self-insured employers are not available, the number of workers who are covered by self-insured employers has remained stable over time statewide. Studies that can include populations not captured by workers' compensation claims are needed. We did not differentiate between fatal and non-fatal injuries in our analysis, and future studies should do so. Given that our analysis only incorporated 195 county-year observations, studies that incorporate more years or counties of observations may enhance the precision of some of these estimates. Lastly, we examined injury rates by industry, which represents the primary type of activity at one's place of work. Among warehousing and transportation industries, for example, workers can engage at a variety of occupations, from clerical and technical activities to the transportation of products, and each occupation within an industry can have different types of injury risks.

4.5 CONCLUSIONS

Given the greater availability of cannabis, evaluating the extent to which local variation in cannabis regulatory approaches affects workplace safety is important. This study provides preliminary evidence suggesting that the effect of cannabis retail outlet availability can differentially affect workers in different industries. Future research is needed to precisely characterize cannabis availability and work-related impairment, to examine the patterns of use that may increase the risk of occupational injury, and to examine the different approaches to regulate cannabis marketing and sales that may affect occupational injuries. Until then, our results suggest the need to monitor for increases in occupational injuries, especially in transportation and warehousing.

Table 4.1. County-level characteristics for the 39 counties in Washington from 2014 to 2019

	All years	2014	2015	2016	2017	2018	2019
Overall injury rate	307.03 (113.14)	315.37 (111.78)	309.76 (110.46)	309.74 (112.18)	307.52 (115.86)	301.15 (116.76)	298.63 (118.15)
No. of employees	86802.73 (192358.23)	81907.23 (181083.71)	83586.59 (185970.01)	85418.49 (190914.63)	87644.18 (196489.29)	90098.87 (202785.48)	92161.00 (207956.03)
No. of injuries	2257.77 (4044.68)	2215.95 (4009.59)	2232.18 (4060.97)	2249.41 (4108.95)	2264.21 (4100.05)	2308.44 (4165.73)	2276.44 (4085.10)
Construction injury rate	517.18 (205.92)	511.36 (200.67)	511.11 (176.52)	521.57 (220.68)	526.96 (211.56)	525.13 (235.98)	506.93 (197.62)
No. of employees	5497.91 (10466.41)	4945.46 (9318.61)	5081.44 (9645.19)	5228.23 (10016.62)	5563.62 (10635.50)	5901.72 (11366.22)	6267.03 (12158.95)
No. of injuries	336.82 (679.95)	303.77 (619.93)	318.18 (665.60)	337.82 (696.34)	345.31 (708.03)	369.36 (749.73)	346.46 (675.63)
Manufacturing injury rate	379.57 (254.01)	435.35 (382.35)	369.54 (228.69)	393.39 (210.90)	359.74 (225.44)	351.49 (197.81)	367.89 (240.50)
No. of employees	8926.14 (20074.08)	8604.44 (20117.51)	8740.79 (20022.30)	8980.33 (20482.71)	9057.49 (20529.54)	9086.64 (20345.77)	9087.15 (20249.89)
No. of injuries	223.65 (367.67)	234.72 (400.74)	231.46 (387.22)	221.31 (367.25)	215.85 (357.19)	224.56 (365.38)	214.03 (349.34)
Transportation and warehousing injury rate	215.90 (121.41)	233.08 (140.55)	214.24 (96.44)	215.79 (122.01)	215.50 (118.29)	210.69 (124.36)	206.09 (128.66)
No. of employees	4542.90 (9524.50)	4166.46 (8623.01)	4342.46 (8967.49)	4457.33 (9357.74)	4563.92 (9646.27)	4772.51 (10283.30)	4954.69 (10708.57)
No. of injuries	101.56 (210.59)	98.97 (209.23)	100.92 (211.49)	102.92 (223.97)	103.64 (208.03)	97.62 (196.12)	105.31 (226.89)
Educational services, health care, and social assistance injury rate	172.22 (72.10)	187.57 (78.75)	171.20 (76.62)	178.68 (78.76)	170.25 (74.68)	153.44 (64.88)	172.16 (56.20)
No. of employees	18687.78 (39170.66)	17667.15 (37096.87)	17967.41 (38092.81)	18303.28 (38834.52)	18900.13 (39974.72)	19433.28 (41148.50)	19855.41 (42161.88)

No. of injuries	316.12 (585.93)	323.15 (604.95)	311.00 (595.25)	315.87 (599.72)	311.26 (581.30)	313.59 (587.99)	321.85 (584.25)
Professional, scientific, and technical services injury rate	137.12 (117.37)	127.56 (93.27)	149.74 (117.17)	123.52 (93.22)	132.73 (147.39)	136.83 (111.80)	152.32 (135.71)
No. of employees	7560.91 (26911.39)	6683.69 (23466.81)	6942.10 (24610.56)	7307.87 (26105.04)	7669.82 (27505.03)	8167.05 (29550.45)	8594.90 (31149.56)
No. of injuries	66.97 (162.00)	58.77 (144.52)	62.49 (154.80)	61.51 (153.39)	66.03 (161.10)	75.59 (181.67)	77.46 (182.39)
Number of cannabis retail outlet per 10,000 residents	0.85 (0.86)	0.12 (0.18)	0.37 (0.34)	0.75 (0.47)	1.15 (0.80)	1.39 (1.13)	1.31 (0.90)
Percentage of population below poverty level in the past 12 months	15.21 (4.33)	16.60 (4.65)	16.26 (4.29)	15.65 (4.29)	15.07 (3.92)	14.24 (4.10)	13.45 (4.13)
Unemployment rate	7.45 (2.21)	9.71 (2.26)	8.84 (1.96)	7.59 (1.73)	6.70 (1.44)	6.07 (1.30)	5.78 (1.30)

Note: Data presented are mean (standard deviations). Injury rates are presented as per 10,000 employees per year. The number of employees were obtained from the American Community Survey and comprised of people in the civilian employed population, 16 years and over. Poverty rate and unemployment rate were obtained from annual five-years estimates of the American Community Survey from 2013-2017.

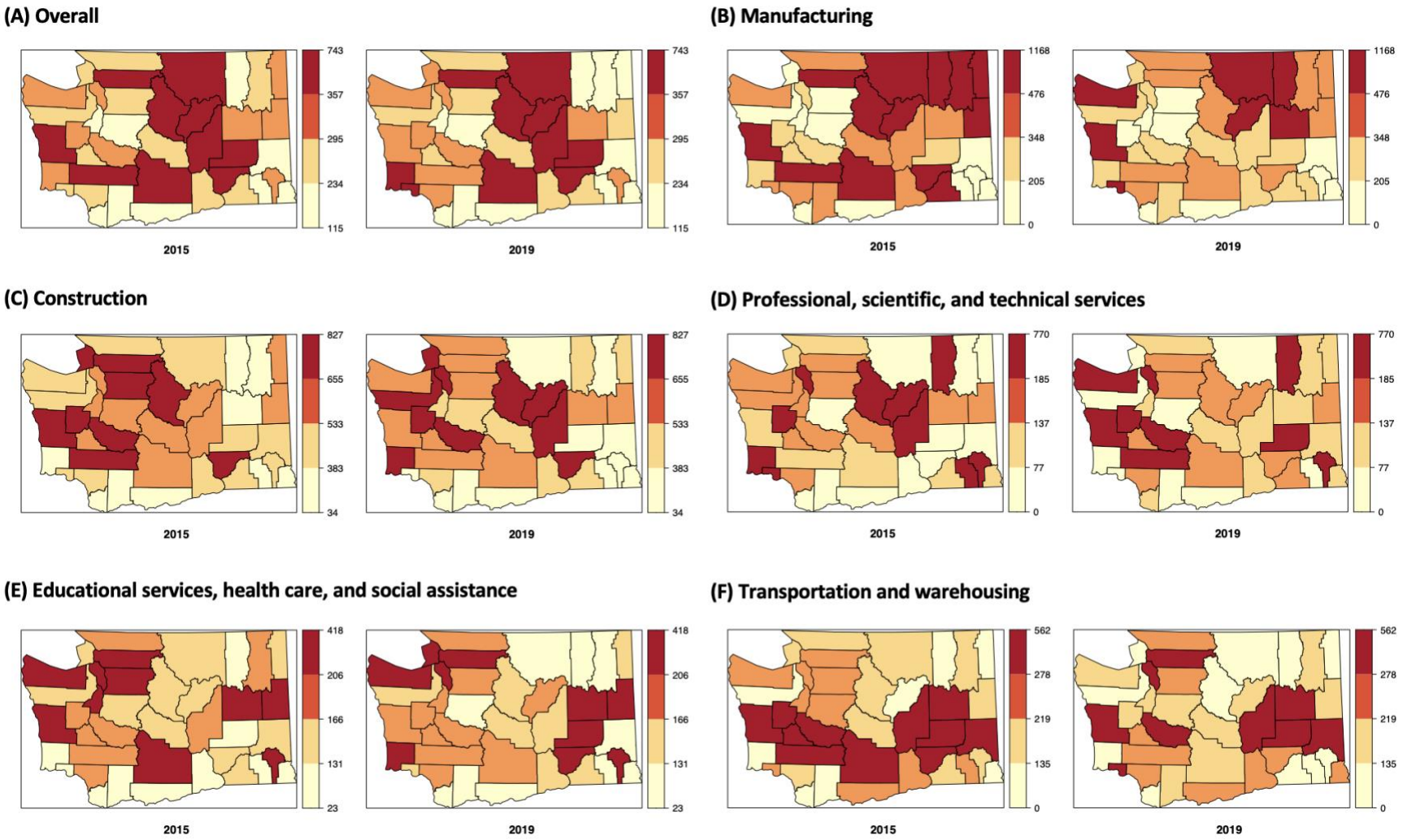


Figure 4.1. County-level occupational injury rates per 10,000 employees in Washington State, overall and by specific industries from 2015 to 2019

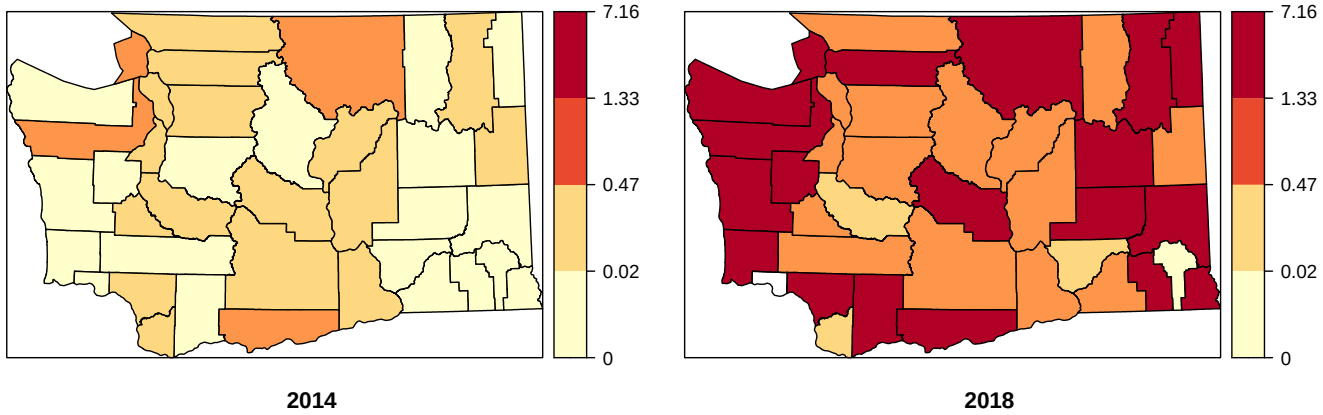


Figure 4.2. County-level cannabis retail outlet availability per 10,000 residents in Washington for 2014 and 2018

Table 4.2. Unadjusted and adjusted overall and industry-specific incidence rate ratios (IRR; 95% confidence intervals [CI]) for the association between cannabis availability per 10,000 residents and subsequent occupational injury

	Unadjusted IRR (95% CI)	Adjusted IRR* (95% CI)
Overall	1.01 (0.98, 1.04)	1.00 (0.97, 1.04)
Industry-specific		
Construction	1.04 (0.98, 1.11)	1.03 (0.97, 1.10)
Educational services, health care, and social assistance	0.99 (0.93, 1.07)	0.99 (0.92, 1.06)
Manufacturing	1.00 (0.91, 1.11)	0.99 (0.88, 1.11)
Professional, scientific, and technical services	0.85 (0.69, 1.06)	0.86 (0.70, 1.06)
Transportation and warehousing	1.12 (1.01, 1.24)	1.12 (0.99, 1.27)

*Models adjusted for time-varying county unemployment and poverty, which were lagged by one year before the exposure variable (cannabis retail outlet availability).

Supplemental Table 4.1. Description of industries, obtained from the Bureau of Labor Statistics

Transportation and warehousing	Establishments that provide transportation of passengers and cargo, warehousing and storage for goods, scenic and sightseeing transportation, and support activities related to modes of transportation (i.e., air, rail, water, road, and pipeline).
Professional, Scientific, and Technical	Establishments that conduct professional, scientific, and technical activities for others, which often require a high degree of expertise and training. Activities performed can include: legal advice and representation; accounting, bookkeeping, and payroll services; architectural, engineering, and specialized design services; computer services; consulting services; research services; advertising services; photographic services; translation and interpretation services; veterinary services; and other professional, scientific, and technical services.
Educational services, health care, and social assistance	Services provided by establishments are delivered by trained professionals, such as health practitioners or social workers, and are often defined based on the educational degree held by the practitioners.
Manufacturing	Establishments engaging in the mechanical, physical, or chemical transformation of materials, substances, or components into new products (e.g., plants, factories, or mills and characteristically use power-driven machines and materials-handling equipment). Bakeries, candy stores, and custom tailors may also be included in this sector.
Construction	Establishments participating in the construction of buildings or engineering projects (e.g., highways and utility systems) and primarily engaged in the preparation of sites for new construction and subdividing land for sale as building sites.

Chapter 5. Conclusions

5.1 Summary of findings

This dissertation examined the associations between cannabis use and availability on prescription opioid use and related outcomes among injured workers in Washington. We found that cannabis use for pain is prevalent among injured workers, with 20% reporting that they use cannabis for pain management. Among recently injured workers who were prescribed opioids, those using cannabis for pain were more likely to continue using prescription opioids over the one-year period after injury. We found no evidence that cannabis use for pain improved anxiety, depression, pain intensity, or pain interference with enjoyment of life and general activities (Chapter 2). In a cross-sectional study, we found some evidence that local cannabis retail outlet availability was associated with higher likelihood of using cannabis for pain (Chapter 3). Sensitivity analyses suggested stronger associations with the larger spatial scales (1.5-mile buffer: adjusted prevalence ratio [aPR]: 1.17; 95% CI: 1.00, 1.37) compared to the more proximal scale (0.5-mile buffer: aPR: 1.04; 95% CI: 0.81, 1.33). Lastly, while we found little evidence of an association between county-level cannabis retail outlet availability and overall rates of occupational injuries, there was some evidence to suggest that there may be an increase in transportation and warehousing injuries in counties with greater cannabis outlet availability.

5.2 Implications and future directions

This dissertation focused on the associations of cannabis use for pain and cannabis availability on health outcomes, which is an emerging area of interest due to the rapidly changing landscape of cannabis legalization in the U.S. Specifically, our study adds to the limited literature surrounding cannabis use in the occupational setting, where concerns for workers and workplace

safety are emerging.[41] Findings from our study shows that cannabis use for pain management is prevalent among injured workers. As such, health professionals treating injured workers with pain should consider asking patients about their cannabis use and the health reasons for cannabis use. This could help facilitate conversations regarding the potential benefits and risks of cannabis use and the availability of safe and effective treatment options for pain.[136] Given that adults with pain are increasingly vulnerable to cannabis-related harms, such as cannabis use disorder,[106] providing information about the signs of disordered cannabis use and how to minimize the risks associated with cannabis use will be important.

While considerable media attention has focused on the possible role of expanding access to and use of cannabis on decreasing opioid use and related harms,[7] our findings suggest a cautionary approach in promotion of cannabis as a method to reduce prescription opioid use and manage pain. These findings align with recent systematic reviews and recommendations from expert panels that do not recommend the general use of cannabis-based products for pain management and treatment.[79,90] Studies examining whether the frequency and potency of cannabis can affect prescription opioid, functional, and psychological outcomes among people experiencing pain will continue to be important, given the increasingly high potency of cannabis products[80] and evidence indicating that more frequent and heavy use of cannabis is associated with increased risk for health consequences.[81] Additionally, a growing body of preclinical research shows the role of the endocannabinoid system in regulating pain; thus, studies examining the role of cannabis-based products for pain therapeutics remain important.[79]

Our findings also emphasize the need to examine mechanisms through which the cannabis retail market shapes cannabis use for pain. One such mechanism includes the marketing that cannabis is safe and effective for pain relief.[35–38] Messages about cannabis as an effective treatment for pain are pervasive, with one study finding that nearly two-thirds of surveyed adults believe cannabis is beneficial for pain management.[146] While retail markets in states with active retail sales are prohibited from advertising or making claims about cannabis's medical, curative, or therapeutic effects,[37,147] little regulation and oversight exists over the promotion and marketing of cannabis products as medicinal.[38] In the presence of limited evidence of cannabis to effectively manage pain, stricter regulation of cannabis health claims made may be needed.[38]

Lastly, our study also provides preliminary evidence that cannabis retail availability may be associated with occupational injuries within certain occupational industries. Large multilevel studies that examine the longitudinal impact of area-level outlet availability on individual worker injury outcomes will be important for policymakers, healthcare systems, employers, and workers. Additionally, future research is needed to verify these findings among injured workers not captured in workers' compensation claims and to elucidate the mechanisms linking cannabis availability on cannabis impairment in the workplace. Until then, our results suggest the need to monitor for increases in occupational injuries, especially in transportation and warehousing.

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