Published in final edited form as:

Headache. 2017 September ; 57(8): 1217–1227. doi:10.1111/head.13130.

Using Search Engines to Investigate Shared Migraine Experiences

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Abstract

Objectives—To investigate migraine patterns in the United States using Google search data and utilize this information to better understand societal-level trends. Additionally, we aimed to evaluate time-series relationships between migraines and social factors.

Background—Extensive research has been done on clinical factors associated with migraines, yet population-level social factors have not been widely explored. Migraine internet search data may provide insight into migraine trends beyond information that can be gleaned from other sources.

Methods—In this longitudinal analysis of open access data, we performed a time-series analysis in which about 12 years of Google Trends data (January 1st 2004 to August 15th 2016) was assessed. Data points were captured at a daily level and Google's 0 to 100 adjusted scale was used as the primary outcome to enable the comparison of relative popularity in the migraine search term. We hypothesized that the volume of relative migraine Google searches would be affected by societal aspects such as day of the week, holidays, and novel social events.

Results—Several recurrent social factors that drive migraine searches were identified. Of these, day of the week had the most significant impact on the volume of Google migraine searches. On average, Mondays accumulated 13.31 higher relative search volume than Fridays (95% CI: 11.12 to 15.51, $p < 0.001$). Surprisingly, holidays were associated with lower relative migraine search volumes. Christmas Day had 13.84 lower relative search volumes (95% CI: 6.26 to 21.43, $p < 0.001$) and Thanksgiving had 20.18 lower relative search volumes (95% CI: 12.55 to 27.82, $p < 0.001$) than days that were not holidays. Certain novel social events and extreme weather also appear to be associated with relative migraine Google search volume.

Conclusions—Social factors play a crucial role in explaining population level migraine patterns, and thus, warrant further exploration.

Keywords

Migraine; Headache; Time-series; ARIMA; Google Trends; Social Predictors

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No Conflicts of Interest

Introduction

Migraine is a burdensome experience associated with a substantial level of medical treatment for those affected with this debilitating disorder.¹ While much attention has been given to understanding individual risk factors for migraine, little is known about population-based and social risk factors. The biopsychosocial model suggests that biological, psychological, and social factors interact to affect the experience of illness.² Widely applied to chronic pain, this model is often used to aid in understanding the experiences of pain sufferers and to aid in patient treatment plans.³ In the study of migraine, the biopsychosocial model supports understanding of how biological factors (e.g., hormones), psychological factors (e.g., stress), and social factors (e.g., friends) interact to influence migraine activity.⁴ Some social aspects of migraine, specifically in the form of socioeconomic status, have received attention that suggests social facets affect the headache disease experience.⁵ On the other hand, population-level risks have historically been difficult to assess and, consequently, not well studied. For example, determining the effect of a widespread crisis (e.g., flooding) on migraine activity is challenging given the difficulty of sampling those affected in the short period of time surrounding the event.

In recent decades, society has increasingly been able to use internet resources to seek information and social media to interact and express thoughts and opinions. With widely available health information resources, individuals can seek solutions for ailments at any time and share their health concerns with their social connections. The use of social media in healthcare has received increasing attention⁶ and has shown promise as a mechanism for improving the care of chronic disease patients.⁷ Studies of social media use by migraine sufferers suggest that this platform has strong potential for increasing understanding of the migraine experience.^{8,9}

In addition to social media, internet search term patterns have potential to provide much insight into disease experiences. The web facility Google Trends provides access to search term volumes, making it possible to evaluate fluctuations in searches for specified terms, revealing changes in population behavior. Google Trends relative search volumes have proven to be highly predictive of present behaviors. For example, the volume of queries on automobile sales during the second week in June was shown to be predictive of the true June auto sales report.¹⁰ In the context of migraine searches, the extent to which searches reflect the actual experience of migraine is unknown. It is hypothesized that at least some portion of the migraine search volume is due to the experience of migraine. Google Trends has been used to track group behavior or suffering in a wide variety of illnesses. Google Flu Trends, which employed the service to provide information about flu activity in many countries, is perhaps the most well-known use of Google Trends data.^{11–13} Other areas where Google Trends has been used are foot and ankle pain,¹⁴ bariatric surgery,¹⁵ and Lyme disease.¹⁶ Tracking searches for disease terms can provide insight into possible reasons for searches of those terms. Fluctuations in search volume may reveal the influence of common factors on the population.^{17,18} In the case of health-related searches, it is possible that some event has brought about increased interest in a health condition across the population.

When applied to migraine, this can be described as the possibility that some wide-ranging event or condition has led to increased migraine activity in the population or increased interest in migraine across the population. Highly stressful events or time periods are conditions that may lead to increased migraine activity via the association between stress and migraine.^{19–21} Alternatively, mentions of migraine in the media may increase interest in and awareness of migraine and lead to increased searches.¹⁷ By identifying social predictors of migraines, we can better understand the complex patterns in migraine search volume. The awareness of societal trends can help forecast future migraine fluctuations, and the application of these forecasts could help prepare healthcare providers for the expected volume of incoming migraine patients.

What clinically relevant information can be learned from migraine search volumes? Stated differently, can anything about the migraine phenomena be inferred from the migraine searches? At its very core, the use of a search engine is aimed at retrieving information from the World Wide Web. A user generates a search strategy based on the desired information, and this search strategy can be easily altered based on the displayed results. Google searches have been related to the concept of issue salience or the degree to which an idea is on someone's mind.^{22,23} It is intuitive to contend that the behavior of typing (or speaking) a search query is indicative of an unprompted behavior that reflects considerable motivation on the part of the individual to learn more about the search term. In this way, a migraine related search might reflect an internal state where the issue of migraine has obtained cognitive prominence for an individual, prompting them to take some action in the form of a formal query. This prominence could be due to any number of causes including simple curiosity, a recent migraine attack, witnessing an attack in others, or even the colloquial use of the term (e.g., “this repair is a headache”). However, regardless of the unverifiable reasons for migraine gaining prominence at the time of a search, the aggregation of individual searches can be used to investigate if certain phenomena are associated with migraine gaining salience in the population. While the motives behind migraine Google searches are clearly multifaceted, at such a large scale, we infer that the relative migraine google search volume does reflect the relative migraine volume in the population, at least to some degree.

This study is designed to investigate migraine patterns in the United States using Google search data and utilize this information to better understand societal-level trends. The study also explores conditions, chosen for their broad geographical social impacts, which may affect relative search volume. Our expectation is that this information can be used to uncover insights into migraine that could not be gleaned from other sources. We hypothesized that the relative volume of migraine Google searches would be affected by societal aspects such as day of the week, holidays, and novel social events. With these hypotheses in mind, we aimed to evaluate time-series relationships between migraines and social factors.

Methods

Data Collection

Publically available Google Trends data was utilized (“Data source: Google Trends (www.google.com/trends)”) for all analyses. The search term “Migraine” with the descriptor “disorder” was queried as we were focused on identifying patterns based on searches

directly related to the medical term. Understanding that Google Trends bases calculations in the context of the number of searches in a specific time and place, the research team decided to restrict the location to the United States. The data collection period would begin when Google Trend data first became available on January 1st, 2004 and terminate on August 15th, 2016. Due to the search structure of Google Trends, multiple searches were used to capture all epochs. Google Trends data is ranked on a scale of 0 to 100 where each data point is based on a topic's proportion to all Google searches on all topics. This adjustment is necessary because, without it, places with the most search volume would always be ranked highest. Because this research project did not involve interaction with the individual nor identifiable private information, no ethics board review was required.

Planned Hypotheses

Examination of the data was guided by several a priori hypotheses. We assessed 1) cyclical variation, 2) holidays, 3) major social events and 4) peak high and low days. We hypothesized that cyclical variation could be identified through weekly, monthly and yearly patterns in the data. We selected Christmas, Thanksgiving, Halloween, New Year's Eve, and Independence Day as potentially impactful holidays in the USA. Because lower search volumes are observed on widely celebrated USA holidays, we hypothesized that days leading up to holidays and holidays themselves may be associated with low migraine search volumes, but days directly following a holiday would be associated with a fluctuation in migraine searches. To test this hypothesis, data from December 20th to January 5th was aggregated for every year. Three major social events were selected that likely had a wide-ranging impact. The first event analyzed was Hurricane Katrina in the state of Louisiana in August of 2005. To explore the effects of the hurricane on migraine search volumes, data from August 9th to October 31st was aggregated for every year (two weeks prior to the storm and two months after the storm). The second event analyzed was the Boston Marathon Bombing in the state of Massachusetts on April 15th, 2013. To explore the effects of the bombing on migraine search volumes, data from April 8th to April 29th was aggregated for every year (one week prior to the bombing and two weeks after the bombing). The final event analyzed was the legalization of marijuana in the state of Colorado on January 1st 2014. For this analysis, weekly migraine data was utilized from October 2011 to September 2016. Finally, we examined the five highest and five lowest days in migraine search volumes in the dataset. Upon determining these days, we attempted to find associated events through qualitative examination that may have led to increased or decreased migraine searches on these days.

Statistical Analyses

All analyses were conducted using R 3.2.2 (R Foundation for Statistical Computing, Vienne, Austria). All hypothesis testing was two-tailed with significance interpreted as $p < 0.05$. Where appropriate, point estimates are presented with 95% confidence intervals. The examination and dissemination of patterns within the time series was largely data driven. Since temporal data is often autocorrelated (the value at time x is affected by the value at time $x-1$), autoregressive integrated moving average (ARIMA) modeling was used for the overall time-series analysis.^{24,25} Generalized linear models (GLMs) were applied to test the association between migraine searches and a variety of social factors. In cases with multiple

comparisons, post hoc testing was applied to compare groups and all p-values were appropriately adjusted for multiple testing via Bonferroni or Tukey correction. To account for differences across the multiple search queries, a z-transformation was applied to migraine scores grouped by search number.

For the analyses involving the highlighted social events of interest, GLMS and interrupted time series analyses (ITSA) were utilized to better understand the influence of specific social events on migraine trends.²⁶ A priori events of interest included hurricane Katrina, the Boston marathon bombing, and marijuana legalization in Colorado (CO). For hurricane Katrina and the Boston marathon bombing, GLMs were applied with year set as a random effect. To evaluate the effect of marijuana legalization in Colorado (CO), a linear model using generalized least squares was applied through a segmented regression analysis.

Results

The relative migraine search activity (scaled from 0 to 100) between 2004 and 2016 is displayed in Figure 1A. Migraine searches were moderate by historical standards, appeared to decrease around 2006, but then increased consistently every year since 2010. Close examination of the migraine searches revealed that there were regular apparent cycles in the data. For example, there are regular peaks and troughs in the series corresponding to yearly fluctuations. For this reason, the cyclical variation was further examined. [See Figure 1]

Cyclical Variation in Google Searches

Several recurring patterns associated with migraine searches were identified. Statistically significant seasonal patterns were identified. Relative migraine search volume dropped towards the end of the year and peaked during certain summer months as well as at the beginning of the year. For example, December had by far the lowest relative search volume least square mean (SE) 62.5 (0.81) and November had the third lowest relative search volume with 68.8 (0.80). The relative search volume dips in the early summer months (May-June) and peaks in the later summer months. August had the highest search volume with 73.0 (0.68) closely followed by July with 72.8 (0.65). [See Figure 1B]

Day of the week was the most prominent source of variation. Mondays had the highest relative search volume least square mean (SE) 75.0 (0.53), followed by Tuesdays with 74.1 (dif=0.88, 95% CI: -1.32 to 3.07, p=0.225) and Wednesdays with 73.9 (dif=1.06, 95% CI: -1.13 to 3.26, p=0.159), neither of which were statistically different from Monday. However, Thursdays had 69.6 (dif=5.39, 95% CI: 3.20 to 7.58, p<0.001), Fridays had 61.6 (dif=13.31, 95% CI: 11.12 to 15.51, p<0.001), Saturdays had 62.86 (dif=12.10, 95% CI: 9.91 to 14.29, p<0.001), and Sundays had 72.44 (dif=2.50, 95% CI: 0.31 to 4.69, p=0.001); each of which was statistically lower than on Mondays. [See Figure 2A]

Holidays

Interestingly, the Google search data reveals a decrease in relative migraine searches around the widely celebrated USA holidays. This is contrary to popular current belief, since it is well proven that migraines are associated with stress, which in turn, is associated with the holidays. On average, Christmas had 13.84 lower relative search volumes (95% CI: 6.26 to

21.43, $p < 0.001$) and Thanksgiving had 20.18 lower relative search volumes (95% CI: 12.55 to 27.82, $p < 0.001$) than days that were not holidays. On average, New Year's Eve had 6.79 lower relative search volumes (95% CI: -0.47 to 14.05, $p = 0.067$) and Independence Day had 7.28 lower relative search volumes (95% CI: -0.30 to 14.87, $p = 0.060$) than days that were not holidays. Halloween is not associated with lower search volumes than days with no holiday (dif=1.43, 95% CI: -6.14 to 8.99, $p = 0.712$). On some years, Halloween appears to have surprisingly high migraine search volumes. It is possible that the day of the week is the driving factor in these instances (i.e. 2005 was a Monday, 2006 was a Tuesday, 2007 was a Wednesday and 2011 was a Monday). [See Figure 2C]

Major Social Events

The first event analyzed was Hurricane Katrina in the state of Louisiana in August of 2005. To explore the effects of the hurricane on expected relative migraine search volumes, data from August 9th to October 31st was aggregated for non-hurricane years (two weeks prior to the storm and two months after the 2005 storm). Only search data in the state of Louisiana was assessed for this analysis. There is some supporting evidence that Hurricane Katrina had an influence on relative migraine search volumes. For example, the third and fourth days of the hurricane (August 26th and 27th of 2004), were respectively associated with 63.2 and 66.7 higher migraine relative search volumes than expected based on all other years of data (adjusted $p = 0.082$ and adjusted $p = 0.042$). Although it appears that there is a peak in relative migraine searches during the hurricane and a drop in relative migraine searches in the days immediately following the storm, only the p -value on August 27th survives the Bonferroni correction. [See Figure 3]

The second event analyzed was the Boston Marathon Bombing in the state of Massachusetts (MA) on April 15th, 2013. To explore the effects of the bombing on relative migraine search volume, data from April 8th to April 29th was aggregated for every non-bombing year in MA (one week prior to the bombing and two weeks after the bombing). None of the daily migraine searches included in this analysis differed significantly from the data from other years. The Boston Marathon bombing appeared to have no influence on the relative volume of migraine searches in the state of Massachusetts compared with historical averages. [See Figure 4]

The final event analyzed was the legalization of marijuana in the state of Colorado (CO) on January 1st 2014. For this analysis, weekly migraine data was utilized from October, 2011 to September 2016. Prior to the legalization of marijuana in CO, there was a 0.001 difference between the slopes of CO and the USA in migraine searches over time (95% CI -0.007 to 0.010, $p = 0.779$). Both CO and the entire USA have experienced an increase in migraine search volume since 2014. After the legalization of marijuana in CO, there was a 0.005 difference between the slopes of CO and the USA in migraine searches over time (95% CI -0.003 to 0.013, $p = 0.180$). Although it appears that the USA as a whole has experienced a more drastic increase in relative migraine search volume than CO since 2014, the difference is not statistically significant which suggests that the legalization of marijuana did not influence trends in migraine searches over time. [See Figure 5]

Peak High and Low Days

Lastly, the five highest and five lowest days in migraine search volumes were assessed. Some of the highlighted dates have clear explanations, whereas others require some degree of speculation. The day with the highest relative migraine search volume was the 17th of February, 2011. On this day, CBS news reporter, Serene Brandson, suffered a migraine on national television resulting in severely slurred speech. Videos of the incident flooded news channels and social media. This event might also explain the day with the third highest relative search volume on the 18th of February 2011, the day after the incident. On the 11th of March, 2014, the FDA put out a press release about the marketing of the first medical device to prevent migraine headaches, possibly explaining the peak in migraine searches on this day. On the 19th of July, 2011, another peak in relative migraine search volume can perhaps be explained by presidential candidate, Michelle Bachmann's, announcement to the public that she suffers chronic migraine attacks. Bachmann's ability to act as president was publically questioned due to her condition. On Monday the 15th of August, 2016, the Seattle Times published a high-profile article titled, "Goodbye to gluten- and migraines". The three lowest days of relative migraine search volumes fell on Christmas Eve in 2008, 2013, and 2014. On Saturday the 3rd of May, 2008, violent tropical storms resulted in several casualties in highly populated central USA. On Friday the 16th of December, 2008, there is no one clear explanation for the low relative volume of migraine Google searches. On this day, Christmas was quickly approaching, President George Bush had recently renewed the controversial Patriot Act, US military troops remained stationed in Iraq, and winter ice storms caused power outages for nearly 3/4 million people along the Atlantic coast effecting South Carolina, North Carolina and Virginia. It is possible that day of the week is also a strong driving factor in some of the extreme highs and lows of relative migraine search volumes. [See Figure 2D]

Based on the lower relative search volumes observed on widely celebrated USA holidays, we hypothesized that days leading up to holidays and holidays themselves may be associated with low relative migraine search volumes, but days directly following a holiday would be associated with a fluctuation in relative migraine searches. To test this hypothesis, data from December 20th to January 5th was aggregated for every year. Christmas Day has a relative migraine search score that is 15.76 points lower than the reference day (December 20th) and has the lowest relative search volume out of the entire analyzed time period (95% CI 9.34 to 22.17, adjusted $p < 0.001$). Days immediately following the beginning of the New Year are associated with the highest relative migraine search volumes out of the analyzed time period. For example, January 3rd has 13.02 higher relative migraine search volumes than our reference day (95% CI 6.60 to 19.45, adjusted $p = 0.002$). [See Figure 2B]

Discussion

This analysis found meaningful patterns of when individuals search for information related to migraine. Several consistent sources of variation were identified, and each support the notion that Google's search engine is being used to find information related to migraine in regular patterns. The first pattern is that migraine searches in the United States have been increasing in relative popularity (i.e., after adjusting for simultaneous increases in search

volume) since about 2010. The reason for this increase is unclear, but compared to before 2010, the relative search volume has increased each year. A second pattern is that there is a rhythm to the searches throughout the year. Migraine searches are at their nadir in December and increase remarkably in January through March where they then decrease in relative volume into the summer months. Searches increase again in relative volume near the end of summer and peak again in the fall (Sept – Nov). This pattern is remarkably consistent from year-to-year and only varies by degree. A final pattern is that there is strong daily variability in the course of a week, with Monday and Tuesday exhibiting the greatest relative search volume. The start of the weekend (Friday and Saturday) exhibits the least search volume with Sunday exhibiting an increasing volume heading into Monday. Each of these patterns overlay each other to produce fluctuations in migraine searches that are easily described.

The migraine search volume also meaningfully varied around social events and customs. For example, commonly observed US holidays such as Christmas, Hanukkah, and Thanksgiving are associated with some of the lowest search volumes of the entire year. Other US holidays such as Independence Day and Halloween were not consistently lower than similar days in the year. Finally, we especially selected several broad social/environmental events that we hypothesized to be related to search volume either because of the intense nature of the stresses associated with these events, or because of their huge environmental impact. Mixed evidence was found for these hypotheses as the impact of hurricane Katrina (social and environmental stress) on the Gulf region was associated with alterations in search patterns, whereas the impact of the Boston Marathon bombing (social stress) on the greater Boston areas was not found to impact search patterns. Further, the legalization of marijuana in Colorado (social norms) was also not found to impact the pattern of search patterns compared with the rest of the nation. Taken together, the differences in the associated pattern of these social events leads to a conclusion that not all social events have identical impacts on migraine search frequency but that migraine searches are initiated at least in part based on social influences that either encourage or discourage their volume.

Regardless of the triggering event that led to increased saliency of migraine, we can infer several things from the patterns in the search terms. Migraine searches are the least salient when individuals are most expected to be engaging in pleasurable or distracting activities (e.g., weekends, holidays). This is somewhat counterintuitive to the idea that holidays are stressful times and that stress is associated with greater migraine activity. It is also entirely possible that the stress of the holiday exerts itself on migraine saliency after the end of the holiday, in a pattern similar to Figure 2B. Migraine is more salient at the beginning of the workweek and this could reflect several different scenarios ranging from the experience of recent attacks to mere boredom at work. Additionally, days and seasons where most individuals are working have higher relative migraine search volumes than days and seasons where most individuals have time off. The data also support the idea that the saliency of migraine can be impacted by events in the media, such as the CBS reporter suffering verbal fluency problems as a result of migraine on live TV (this event was the single greatest relative volume search day in the history of the Google Trend series). The seasonal fluctuations in migraine saliency could be due to weather related phenomena, though this is difficult to demonstrate in the aggregated data. Finally, the saliency of migraine has been

increasing in recent years, and while it is not immediately apparent why this might be the case, the advent of direct-to consumer advertising may play a role.

This analysis is limited by the nature of the available data. We have inferred that the relative migraine Google search volume does reflect proportional migraine activity in the population, at least to some degree. However, in the absence of additional clinical data, this assumption is unverifiable. If true, the patterns of migraine activity observed through search volume somewhat contradict common beliefs about the seasonal timing of migraine (e.g. migraines are thought to occur more often around the holidays, not less often). In this analysis we queried the search volumes related to migraine as a syndrome, and not just “migraine” as a search term (Google Trends provides this option for many medical conditions). This means that search terms related to migraine, searches on either treatments or symptoms, are captured as part of the query. It is not known to what extent the uncovered searches are due to those seeking treatment, those learning about symptoms, or to any other aspect of the migraine disorder. Additionally, Google limits the availability of the methods utilized in the TRENDS algorithm such that we were not able to uncover the methods used to adjust for search volume or even individual items included in the search strategy.

Conclusions

Although migraine is often considered to be a disorder that primarily impacts an individual, this study provides evidence that there are at least some elements of migraine that are being shared across wide groups of individuals in distinct patterns. These patterns in searches indicate that there are broad social trends when individuals are searching for migraine related topics, and that these group searches are indicative of increased migraine saliency in the population. The exact reason for this increased saliency is unknown, but the use of Google Trends does provide a tool for researchers to examine novel elements of the social nature of migraine.

Acknowledgments

Financial Support: NIH/NINDS RO1NS06525701

Abbreviations

ARIMA	Auto-regressive integrated moving average
ITSA	interrupted time series analyses
CO	Colorado
GLM	generalized linear model

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Figure 1.

The actually observed Google relative search volume for migraine on a yearly basis (black line) from 2004 to 2016 modeled using trigonometric functions of seasonal components (red line) (A). Decomposition of additive time series with the actually observed series (top), the broad trend in searches, the 12 month season cycle after being de-trended, and the variance remaining after removing trend and seasonal cycle (bottom) (B).

Figure 2.

The detrended (z-score) analysis of Google relative search volume for migraine on a weekly basis displaying a cyclic pattern with Monday having the highest search volume, Friday having the lowest search volume with a progressive increase in volume of searches on Saturday and Sunday from Friday. Each line represents an actual week between 2004 and 2016 (A). The expected variation in relative migraine search volume represented by gray areas and the average search volume by a black line. The volume of searches was lower on Christmas but increased during the period between Christmas and New Year's Day then

diminished on New Year's Day to increase again after New Year's Day (B). The de-trended and decomposed daily z-score of Google relative search volume for migraine overlayed with regularly celebrated American holidays. Christmas, Thanksgiving, and New Year's Eve consistently exhibit low Z-scores comparative to the mean ($z\text{-score}=0$) while the z-scores of Independence Day and Halloween fluctuate from year to year (C). Qualitative analysis of the high and low z-scores from Figure 1C with possible societal explanations for the given z-scores (D).

Figure 3.

The Google relative search volume for migraine during the weeks preceding and following hurricane Katrina. The grey areas represent the historical variation in average search volumes for this time during non-hurricane years. The red line represents the search volume during the hurricane year. The volume of searches was higher than historical averages during the storm, but diminished substantially afterward. Given the other patterns in the series, and the need for multiplicity corrections, it is difficult to assign fluctuations to any aspect of the storm.

Figure 4.

The Google relative search volume for migraine during the weeks preceding and following the Boston Marathon bombing specific to Massachusetts. The grey areas represent the historical variation in average search volumes for non-marathon years. The red line represents the search volume of the marathon bombing year. As can be seen, the fluctuations in migraine searches after the bombing are not meaningfully different from non-bombing years.

Figure 5.

The weekly Google relative search volume for migraine preceding and following the legalization of marijuana in Colorado. The grey lines represent the raw search data for the United States and Colorado. The blue and green lines represent the trend lines of best fit for the United States and Colorado respectively. Relative migraine search volumes for Colorado are consistently lower than in the United States, and although the United States has a slightly increased slope as compared to Colorado after the legalization of marijuana, the pre-legalization differences remain constant during the observation period (i.e., both series increase over time, but the slopes do not differ).