



# A Public Health Study on the Unintended Implications of Marijuana Legalization in the United States

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This report represents the work of one or more WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on the web without editorial or peer review.

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## **Chapter 1.0: Introduction**

In 2023, 38 States, 3 territories, and the District of Columbia have legalized medicinal marijuana; 21 States, 3 territories, and D.C. have also legalized recreational use. This is largely due to its medicinal properties in alleviating chronic pain and symptoms of severe psychological conditions and or disabilities. In addition, marijuana has been legalized for recreational uses due to its relaxing, stress relieving, and euphoric psychoactive effects. Marijuana's increased popularity has resulted in massive economic growth for the North American Cannabis industry. In 2022 the market grew to a \$15.2 billion valuation. While many cannabis consumers utilize traditional combustible products, the increased prevalence of dispensaries and marijuana products all over the United States has drawn in millions of first-time cannabis users. Many of these are nonsmokers pursuing discrete non-combustible cannabis products such as edibles. To address these demands the cannabis industry has seen major innovation in the potency and form of edible cannabis products. The development of psychoactive ingredients such as cannabutter and canna oil has made it possible to turn virtually any item into an edible cannabis product. While the establishment of thousands of dispensaries in the United States has had a very positive impact on the American economy, the impacts on public health have yet to be considered.

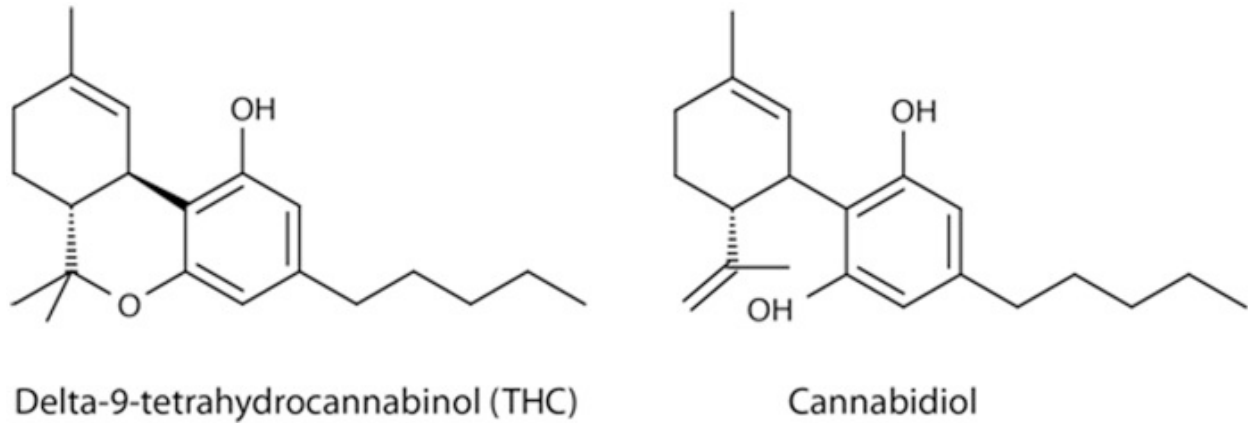
The purpose of this study is to investigate and quantify some of the most common psychological and physiological adverse impacts of marijuana legalization in the United States. My approach to assessing this is by segmenting the United States into regions and utilizing metrics that display the unintended impacts some of these adverse effects may have on the

general public. These effects were measured by analyzing trends in Motor Vehicle Fatalities and Cannabis Induced Hospital Discharges in both adolescents aged 12-17 and adults aged 18+.

## **Chapter 2.0: Literature Review**

### **2.1 Marijuana: Chemical Breakdown & History**

Marijuana originates from a plant known as hemp, or by its Scientific name Cannabis Sativa. Cannabis is the most widely used illicit drug in the world with around 2.5% of the world's population being regular users. It is a complex plant that contains over 400 chemical compounds of which 60 are cannabinoid compounds [39]. Cannabis itself has been constantly evolving in labs and private grow operations. Cultivators are constantly breeding and mutating Marijuana strains to alter the cannabis for different uses, effects, grow times, and even plant heights for storage. However, its major compounds remain unchanged, delta-9-tetrahydrocannabinol (THC) and cannabidiol (CBD), see Figure 5. THC is the cannabinoid most responsible for the psychoactive effects of the plant. CBD is the second most active compound in cannabis but does not provide any psychoactive effect[39].



**Figure 1 - Chemical Composition of THC and CBD[39]**

In 2019 a study reported that 48.2 million or 18% of Americans had tried marijuana in capacity at least once. This number is expected to increase to a minimum of 52 million Americans by the end of 2022 [19]. The increase in usage over time is due to the increased popularization of recreational marijuana as more and more US states continue to decriminalize or legalize the substance. California became the first state to legalize marijuana in 1996 with the passing of the Compassionate Use Act. Since then many states have followed suit, and marijuana has become the topic of national debate with supporters and opposition across various political backgrounds [19].

Marijuana has become increasingly popular in the USA following its legalization in select states. The cannabis industry has experienced tremendous growth. According to Fortune Business Insights, the global cannabis market size was 13.05 billion USD in the year 2019. In the year 2020, there was a 6.73 billion dollar increase in global market size[11]. Greatly due to the legalization of cannabis in Arizona, South Dakota, Montana, and New Jersey in the US and Canada Uruguay, and Thailand on a global scale. In addition, the market is expected to grow to be as large as 197.74 billion USD in the Year 2028 [11]. As the industry grows aggressive

marketing and production tactics have resulted in the normalization of cannabis use in many cultures that once held stigmas toward the substance. This shift in global attitude toward Marijuana products has resulted in many new customers and patients. As of 2022, 39 States and the District of Columbia officially legalized the medicinal and recreational use of Cannabis.

## **2.2 Forms of Cannabis Consumption**

In recent years cannabis companies have been constantly innovating cannabis products to cater to the increase in clientele. Especially their largest new clientele base that is not interested in smoking. Cannabis is traditionally consumed very similarly to tobacco products, in that the plant is harvested, dried, ground, and smoked. But the surge in cannabis consumers has brought forth new clients from both older and younger audiences that are seeking smoking alternatives[11]. This prompted the development of many new forms of cannabis consumption that are important to understand and consider for this study.

### **2.2.1 Traditional Combustibles (Fume Producing Products)**

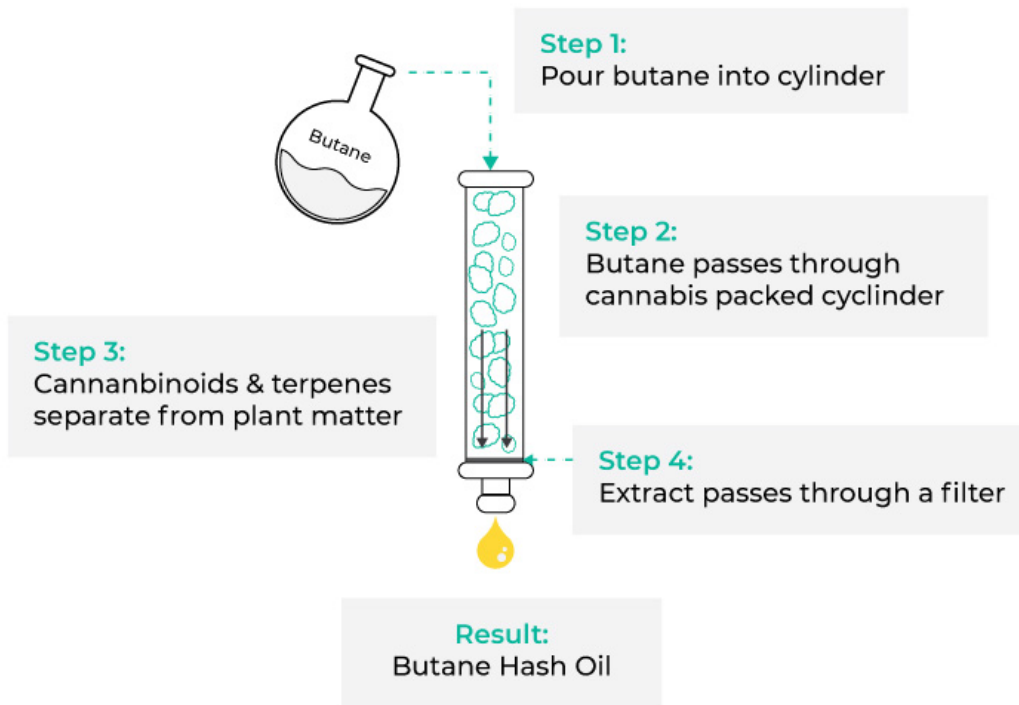
Cannabis is most commonly consumed in the purest form, the flower. Flower refers to a form of cannabis that is picked off the stem and served to the customer. The cannabis is not altered in any way and is usually served by the gram in the form of buds or nuggets. After it is sold, just like tobacco the flower is to be ground up and consumed through traditional rolled paper or glassware. In both instances, the cannabis is ignited and smoke is inhaled into the lungs. This form of consumption while still very potent is limited in the amount of THC delivered to the brain due to the flower's naturally lower potency. Cannabis flower usually contains 15-25% THC and the biological limit for flowers is 35% THC[40]. This is often a much safer option for

first-time users as they are much less likely to consume too much THC and suffer a bad experience, however, it is one of the most damaging to the lungs.



**Figure 2 - Cannabis Flower [40]**

Another extremely popular fume-producing marijuana product is called a “dab” or “dabs” which is the colloquial name for concentrated extract or Butane Hash Oil (BHO). Dabs are extremely popular amongst long-time cannabis smokers due to their high potency which still induces a high despite a high tolerance. This substance is derived from traditional cannabis flower that undergoes a process known as Butane Extraction. During the extraction process, Butane gas passes through the cannabis in a sealed cylinder separating cannabinoids and terpenes from the flower of the marijuana plant[3]. The product is a wax-like concentrate with a higher THC concentration compared to traditional forms of cannabis. Butane hash oil can reach THC concentrations upwards of 70% to 90%, a significantly drastic increase compared to traditional flowers[36].



**Figure 3 - BHO Extraction [7]**

Dabs are traditionally consumed using a device called a “dab rig”. The rig is used by heating a glass or titanium bowl to 400-600°F using a blow torch. A dose of the concentrate is then placed on the heated banger while the user inhales the resulting superheated fumes[7]. The concentrate is then vaporized very quickly, allowing the user to inhale the vapors and quickly feel the effects. Dabs can also be consumed utilizing a device known as a dab pen or extract pen. This device is made up of two main components that are operated very similarly to a traditional vaporizer. The first component is the battery which is the lower part of the pen. This component is responsible for heating the extract to a range of 300-900°F and releasing the fumes for inhalation. The second component is called a cartridge, which is used to house the dabs or extract. The cartridge is screwed onto the battery and then heated up when the device is turned



on. This mode of cannabis consumption is extremely discrete and portable which has made it extremely popular amongst closeted smokers and adolescents/young adults[13].

### **2.2.2 Edible Cannabis**

As previously stated, the cannabis industry has been evolving over the past decade to accommodate nonsmoking cannabis customers. This has resulted in a surge of edible cannabis products for health-conscious customers. Edibles are different forms of everyday food items that are infused with THC and produce a high 0-3 hours following consumption[10]. The major difference between the ingestion of edibles and the inhalation of cannabis extracts is the delayed onset. Consumers often disregard or are unaware of the delayed onset and often underestimate the potency of the edibles. Leading them to consume large amounts before the THC has time to take effect, often resulting in very adverse and sometimes dangerous effects[10].

While the market is currently very diverse, edible production was once very limited to baked goods as those were the initial products sold illegally before the establishment of dispensaries and new THC extraction methods. Homemade street products such as “Pot-brownies” and “Pot-cookies” were the most common forms of edibles before legalization. Made using substances known as “cannabutter” or “canna-oil” that can be used as a substitute for traditional butter and oil in recipes[27]. Cannabutter and oil are infused with THC through Decarboxylation. This is the process of slowly heating cannabis flower over some time, to convert the THCA cannabinoids into psychoactive THC. As the cannabis and butter are heated, the cannabis decarboxylates and the THC clings to the fat molecules in the butter[27].

Recent advances have made it possible for dispensaries to turn virtually any food item into an edible. Many dispensaries now utilize THC extract in an oil form to give everyday food

items a psychoactive effect. The cannabis market has expanded far beyond baked goods in 2023. Products such as assorted gummies, chocolate bars, hard and soft candy, and assorted drinks have become massively popular in the United States. According to retail sales data, overall edibles sales grew by more than 20% from \$1.15 billion in 2020 to \$1.38 billion in 2021. Gummies are the dominant form of consumption grossing \$976 million in sales, followed closely by chocolate bars which grossed \$150 million in sales in the year 2021[27].

### 2.2.3 The Dangers of Edible Cannabis

The increased availability of edible cannabis products has resulted in a large increase in non-smoking marijuana users. These casual users are often consuming marijuana for the very first time in the edible form, and have little knowledge of how to safely consume these products. As previously discussed there is a delay between consuming edibles and their psychoactive effects. This can be extremely dangerous for inexperienced users as they may underestimate the potency of the edibles and consume far too many within a short period. This overdosing coupled with very low marijuana tolerance has proven to be very dangerous for adolescents and adults alike[16].

Dosage (mg)	Dose Category	Expected Effects
3-5mg	Low	Little to no intoxication, Full cognitive ability, minor psychoactive effect, Beginner dose
10-15mg	Moderate	Some Psychoactive Effects, Sleep, and Pain Relief, Ideal for users who are familiar with cannabis products
20-30mg	High	Strong psychoactive effects & Euphoria, Impaired

		Coordination/Perception, Experienced Edible Users
50-100mg	Acute	An effective dose for medical relief of extreme pain, Intense nausea, and emotional disruption, Veteran Users
100-500mg	Macrodose	Intense intoxication loss of cognitive ability and motor function, high risk of adverse effects

**Figure 4 - Marijuana Dosage by (mg) and the Resulting Effects**

Another common issue with edibles is their packaging and dosing information. Edibles are dosed with milligrams of THCA within them. However, the packages have no explanation of what effects are coupled with respective dosages. Making it very difficult for first-time or novice users to understand how much to take at once. The recommended dose for most beginner users is 5-10mg to feel some psychoactive effects while maintaining a safe experience and cognitive function. This usually translates to one gummy, a single square of a chocolate bar, etc. However, the entire package of edibles may contain over 300mg of THCA, and therein lies the major issue. Edibles are packaged in a way that makes them appear as everyday food items, a can of marijuana-infused seltzer is usually packaged in an identically sized can as a non-infused seltzer. This can be very dangerous and misleading to a less responsible user or adolescent who is not careful and attentive to the serving sizes depicted on the packaging. One may easily assume that one whole can is an appropriate dose for one person. When in fact many of these cans caution to only drink half or a quarter of the can as one serving. In the figure below the lemonade drink is portioned very similarly to a regular beverage yet contains 40 times the amount of THCA recommended for a beginner. The same can happen with a chocolate bar or bag of gummies, all

of which when not infused are usually eaten to completion in one sitting which results in many infused products being consumed similarly.



**Figure 5 - Edible Cannabis Packaging**

This phenomenon has become increasingly prevalent since the mass legalization and licensed sales of marijuana-infused food items. Dr. Michael Levine, a Medical Toxicologist at UCLA Medical Center, says “The number of people rushing to the emergency room because of a bad experience with marijuana use is growing”[24]. A study done at the University of California San Diego found that edible-related hospital visits in the state of California increased by 1800% between 2005 and 2019 among Californians over the age of 65[24]. Many of them reported eating too many or entire bags of edibles due to a lack of clear packaging. But senior citizens are not the only affected population. Many reports have found that adolescents make up the majority of patients admitted to the hospital for edible-related overdoses. A study done in Zuckerberg San Francisco General Hospital and Trauma Center found that of a total of 21 patients aged 6 to 60 years. Twelve (~57%) were pediatric patients younger than 18 years. This number is attributed to the inviting and familiar nature of marijuana products[10]. The industry has faced mass

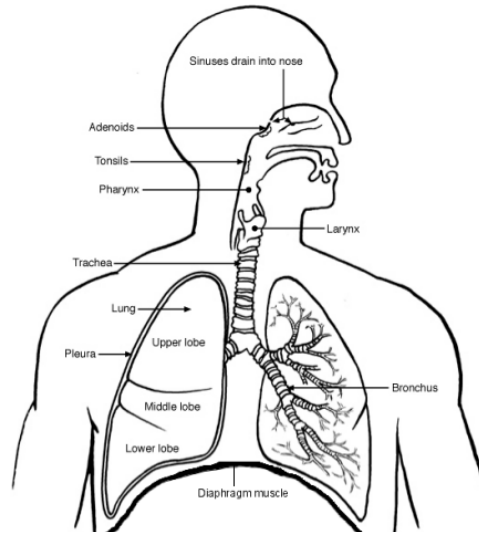
criticism for products being packaged too similarly to candies and other sweets normally intended for children.

Patients of all ages have reported edible-related marijuana overdoses to be extremely uncomfortable and traumatic. Another study conducted in San Francisco highlighted some of the key symptoms and experiences of patients who were admitted to the hospital. Patients reported Hallucinations, horizontal nystagmus, hypertension, nausea, mydriasis, tachycardia, tachypnea, dizziness, dry mucous membranes, increased tone, lethargy, vomiting, uncontrollable defecating, and general respiratory distress[37].

## **2.3 Anatomy and Physiology**

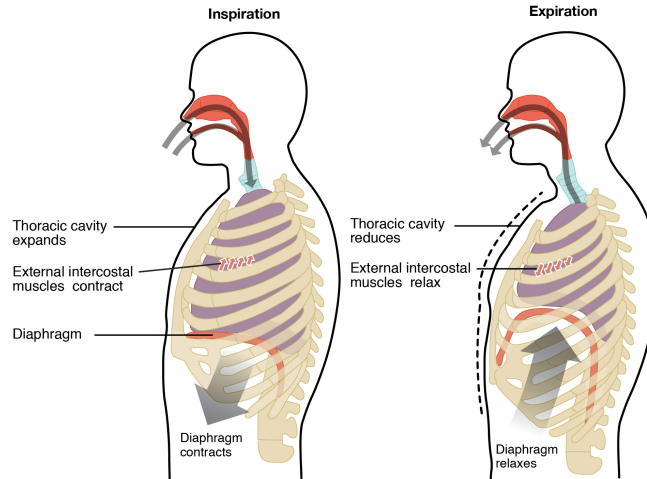
### **2.3.1 The Pulmonary Drive**

The respiratory system is composed of tissues and organs that are responsible for respiration in the human body. These organs are the lungs, the nose, the pharynx, the larynx, the trachea, and the bronchi. These organs harmonize to allow the body to saturate the blood with oxygen and release waste gases like carbon dioxide. Oxygen is the main input of the respiratory system, it is needed by cells to complete their daily functions. Carbon dioxide is the waste product of most cell processes and is exhaled as waste into the environment[8].



**Figure 6 - Human Respiratory System [25]**

The pulmonary drive begins with Ventilation, the process by which air is taken into and expelled from the lungs. Breathing is the movement of air through passages between the atmosphere and the lungs. Air moves through these passages due to changes in pressure gradients caused by contractions of the diaphragm and thoracic muscles[42]. The air flows from a region of higher pressure to a region with lower pressure. Muscular movements and recoil of elastic tissue whilst breathing produce these pressure gradients that result in ventilation. Pulmonary ventilation is a product of the manipulation of three pressures: Atmospheric Pressure, Intraalveolar Pressure, and Intrapleural Pressure. Each of these plays a role in the two parts of ventilation, inspiration, and Expiration, see Figure 2. Inspiration is the process of decreasing the Intraalveolar pressure and taking air into the lungs by contracting the diaphragm and increasing the volume of the thoracic cavity. Expiration is the process of increasing the Intraalveolar pressure and pushing air out of the lungs by contracting the diaphragm and decreasing the volume of the thoracic cavity[34].

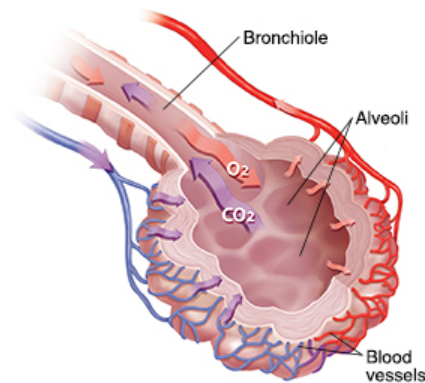


**Figure 7 - Inspiration vs. Expiration [32]**

When a breath is taken air travels through either the nose or mouth to the trachea. The trachea or windpipe is the central air passage that connects the voice box to the two main bronchi in the lungs. The lungs are the primary organs that make respiration possible. These two lungs resting within the rib cage, the right lung can be divided into three lobes while the left lung only has two. This structure makes the lungs uniquely equipped for efficient gas exchange. The lungs' main purpose is to serve as facilitators for gas exchanges between human cells and the environment. The two main bronchi within the lungs can be further divided into four lobar bronchi, which further divide into smaller bronchi. The bronchi moisturize and carry the air through many subdivisions that eventually lead to the respiratory bronchioles and alveolar sacs[33].

The human body has around 150 million alveoli. These alveoli are round and elastic, meaning they change in size and shape when filled with oxygen. Each of the alveoli contains a mesh of many capillaries, which are responsible for moving the blood to the arterial network and

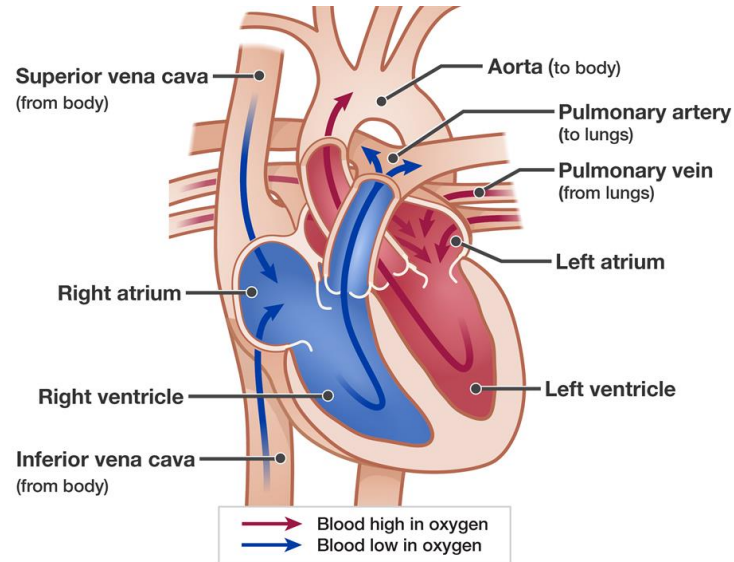
the rest of the body. Within the alveolar sacs occur the exchanges of O<sub>2</sub> and CO<sub>2</sub> between the lungs and blood, as seen in Figure 3. The CO<sub>2</sub>-saturated blood enters the lungs through the pulmonary artery and is delivered to the capillaries that surround the alveoli. The CO<sub>2</sub> moves from the blood into the air in the alveoli while oxygen simultaneously moves from the air into the blood in the capillaries[34]. Once the reaction is complete the oxygen-rich blood is ready to leave the lungs and the CO<sub>2</sub>-rich air is ready to be exhaled.



**Figure 8 - Gas Exchange Within the Alveoli [8]**

Once the blood is oxygenated it moves through the pulmonary veins and into the left side of the heart. The left side of the heart receives the oxygen-rich blood at the left atrium and pumps it through the mitral valve into the left ventricle. There the blood is pumped by the left ventricle through the aortic valve and to the rest of the circulatory system. Carbon Dioxide rich blood returns to the heart via the superior and inferior vena cava. The blood is then pumped through the pulmonary artery to the lungs to repeat the gas exchange cycle, see Figure 4. The carbon dioxide will be exhaled and replaced by oxygen to be distributed to the rest of the body.





**Figure 9 - Blood Circulation Through the Heart [15]**

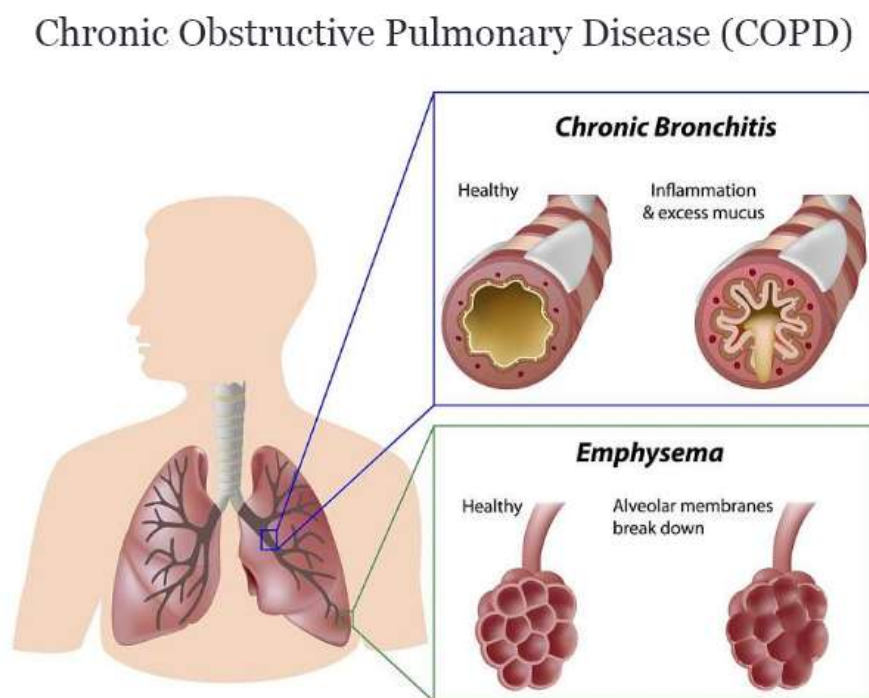
### **2.3.2 Pulmonary Diseases Linked To Cannabis Use**

The inhalation of heated marijuana fumes or extracts is known to cause damage to the lungs and respiratory system. Many studies have linked marijuana smoke to chronic pulmonary diseases such as COPD and Popcorn lung. Marijuana smoke is known to irritate and injure the lining of the lungs and has been connected to findings that suggest it can increase chronic cough, phlegm production, and wheezing[30]. The smoke damages the lung's natural defense against infection and inhaled impurities. It is believed that the temperature of marijuana smoke results in mass cell death making it difficult for the lungs to fight infection and filter impurities and can result in the chronic conditions listed above.

#### **2.3.2.1 Chronic Obstructive Pulmonary Disease**

Chronic obstructive pulmonary disease (COPD) is a chronic respiratory condition characterized by airflow limitation that is usually associated with an inflammatory response of

the lungs to noxious particles or gases. COPD is an umbrella term that encompasses several chronic respiratory conditions, including emphysema, chronic bronchitis, and asthma. The primary cause of COPD is exposure to irritants, such as cigarette or marijuana smoke, air pollution, and toxic chemical fumes. Repeated exposure to these irritants can damage the lining of the airways and lead to chronic inflammation. COPD can also lead to complications such as respiratory failure, heart problems, and depression [17].



**Figure 10 - COPD Bronchitis & Emphysema [18]**

Emphysema is characterized by damage to the alveoli or air sacs in the lungs, which causes them to expand thus reducing the surface area required for necessary gas exchanges. This limit in gas exchange is accompanied by symptoms that become progressively worse over time, greatly impacting a patient's ability to respire and overall quality of life. Symptoms include shortness of breath, chronic cough, wheezing, chest tightness, fatigue, and even weight loss.

Patients suffering from these symptoms have reported reduced mobility, inability to complete many daily tasks, and increased dependence on medical aid such as bronchodilators or steroids, oxygen therapy, and pulmonary rehabilitation[21].

Chronic bronchitis is characterized by chronic inflammation and narrowing of the airways, resulting in a chronic cough and excessive sputum production. Increased sputum or mucus production results in a build-up in the airways making it very difficult for patients to breathe. Symptoms of chronic bronchitis typically include a persistent cough that produces mucus, shortness of breath, wheezing, chest tightness, and fatigue. These symptoms may be mild at first, but they tend to worsen over time and can become disabling. Some patients report losing significant amounts of sleep due to persistent coughing and mucus buildup whilst sleeping. Treatment programs are usually long-term and are aimed at alleviating symptoms rather than curing them. The use of Bronchodilators, medications that help to open up the airways, are often prescribed to relieve symptoms and improve lung function[9].

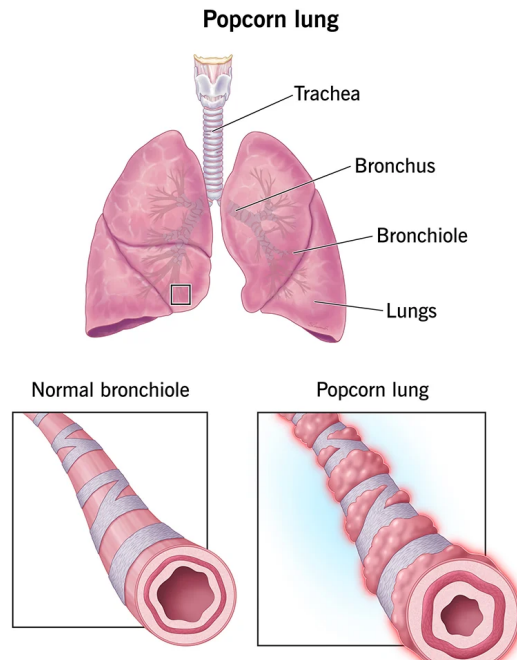
Refractory asthma is a severe and stubborn form of asthma that does not respond to traditional medical treatment. Patients with this condition experience heightened asthma symptoms and often suffer from life-threatening asthma attacks that require hospitalization. Smoking marijuana can exacerbate asthma symptoms and lead to airway inflammation, airway obstruction, and lung damage, which can make it more difficult to manage refractory asthma. Although there is still no concrete data to suggest that marijuana may be a causal agent in the development of refractory asthma[28].

Marijuana smoke has been found to exacerbate symptoms of COPD. The smoke contains many of the same harmful chemicals as tobacco smoke, including tar, carbon monoxide, and ammonia. These chemicals irritate the lungs and cause inflammation, which can worsen the

symptoms of the above conditions. Not to mention the smoking of dabs results in superheated vapors many times hotter than traditional marijuana smoke to be inhaled directly into the lungs. Dabs are known to cause extreme bouts of coughing and respiratory distress in all cases, regardless of dosage size or frequency of use. In addition, marijuana smoke superheated or not can lead to respiratory infections, which can further damage the lungs and exacerbate symptoms. People with COPD who smoke marijuana are advised to quit smoking to improve their lung function and reduce the risk of complications. Alternative forms of marijuana use, such as vaporizers or edibles, may also be considered to reduce the harmful effects of smoke on the lungs.

#### **2.3.2.2 Bronchiolitis Obliterans**

Bronchiolitis Obliterans, otherwise known as Popcorn Lung is a condition that affects the bronchioles. It is characterized by severe damage, scarring, and narrowing of the bronchioles, resulting in airway obstruction. In most cases, the lungs heal naturally following appropriate treatments and smoking cessation. But that is not always the case, in some instances, the healing process is over and excess scarring tissue begins to overwhelm the bronchioles. The mechanism involves injury and inflammation of epithelial and sub-epithelial cells. These cells lose the ability to regenerate the epithelial or outermost layer, leading to the excess growth of cells that cause scarring.



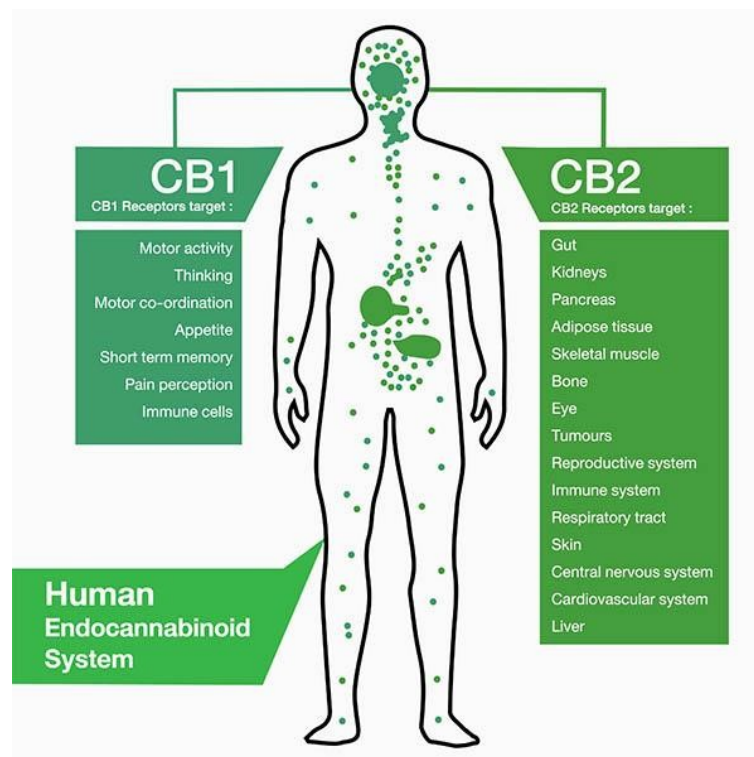
**Figure 11 - Popcorn Lung Anatomical Diagram [35]**

Symptoms of BO include shortness of breath, cough, wheezing, and fatigue. Patients that choose to smoke marijuana regularly, especially in the vapor form often develop this condition. Common toxins associated with the development of BO are Tar, Ammonia, Mustard Gas, Sulfur oxide, and metal oxides. Of these, a few are found in traditional marijuana smoke and even more, are found in marijuana vapor and dabs. Some cannabis extracts and vaping liquids contain diacetyl, which can lead to the development of this disease[28]. BO can range in its severity, with extreme cases sometimes resulting in full lung collapse and hospitalization. Treatment for BO typically involves smoking cessation and lifestyle changes.

### **2.3.3 The Brain and Endocannabinoid System**

Marijuana has become very popular due to its compounds' psychoactive effects on the brain. Studying these compounds led to the discovery of a neurotransmitter system known as the endocannabinoid system. This system is distributed across the entire body and brain and is

responsible for several significant functions. One of these major functions is to regulate not only the central and peripheral mechanisms of food intake but also lipids synthesis and turnover in the liver and adipose tissue. as well as glucose metabolism in muscle cells. This system functions by implementing millions of receptors known as CB1 and CB2 receptors. The CB1 receptors are located in the brain and central nervous system. The CB2 is located in the peripheral organs and cells that comprise the immune system.

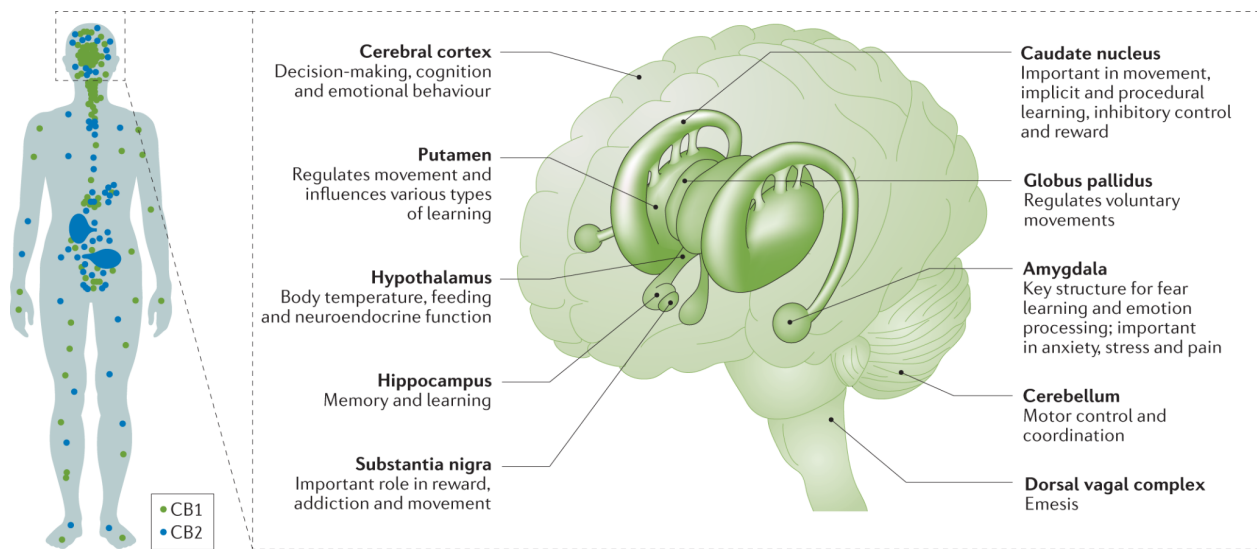


**Figure 12 - Human Endocannabinoid System [23]**

THC affects the brain by binding to the CB1 receptors. The main effects can be observed in the parts of the brain that control motor function, memory, and thinking. THC can alter the normal function of the hippocampus and orbital frontal cortex, the areas of the brain that enable humans to form new memories and shift their focus between tasks. In addition, THC stimulates neurons in the reward system to release dopamine at exceptionally high levels[1]. Over time the

brain can develop a tolerance to repeated use and develop dopamine cravings and in some cases dependencies.

Marijuana has been studied extensively for years before and following its initial legalization in 2012. Decades of research suggest that marijuana can have serious negative impacts on cognitive, physical, and emotional development in both adults and adolescents. Rising concerns regarding the long-term impacts of marijuana use on the brain have called for an investigation into potential risks that accompany short and long-term use[1].



**Figure 12 - The Brain and its Function**

Many studies have shown that marijuana can lead to cognitive impairment for infrequent and frequent users. One of the major impacts is on executive function, the planning of tasks, reasoning, interference control, and problem-solving, in some studies. Cannabis use has been found to have adverse impacts on decision-making, especially when it involves risk-taking. Self-report questionnaires and laboratory risk-taking tasks have demonstrated differences between cannabis users and non-users, possibly related to the severity of cannabis use. The Iowa Gambling Task delayed discounting tasks, and risk-taking decision-making tasks have been used.

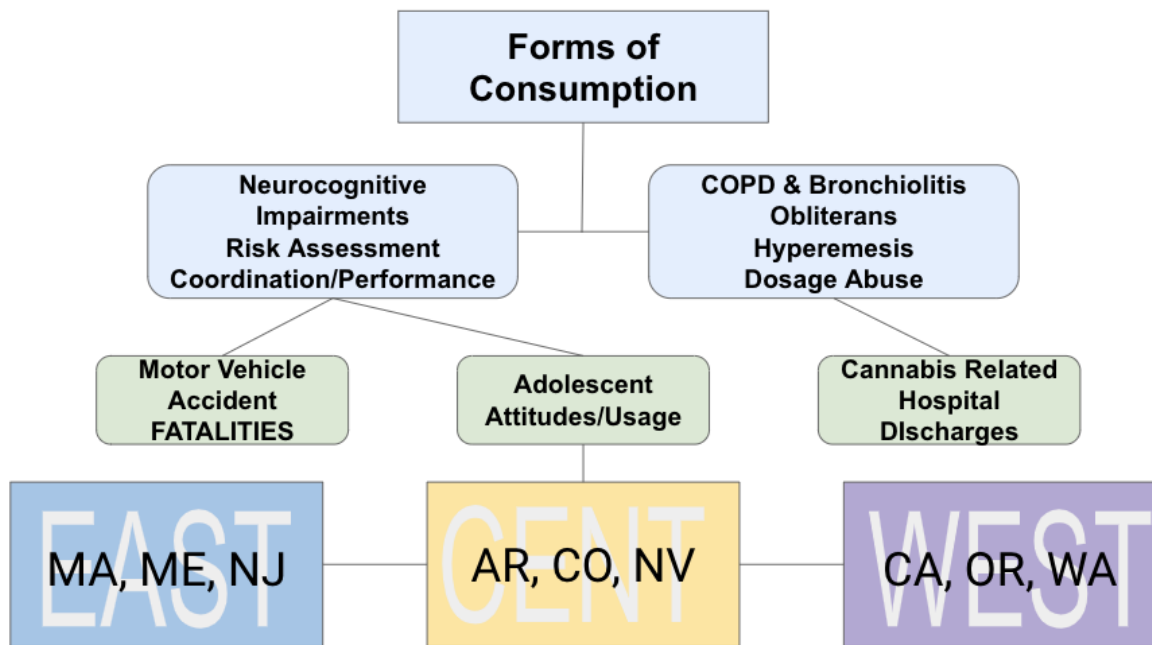
Acute administration of THC altered sensitivity to reward and punishment and increased risk-taking behavior in infrequent and regular users, but not all relevant studies found impaired decision-making[1].

## **Chapter 3: Project Approach**

### **3.1: Research Strategy**

My approach to assessing the public health impact marijuana legalization has had on the United States began with a comprehensive literature review. The literature review was first focused on identifying what marijuana legalization truly meant for states that have either or both medicinal/recreational dispensaries. I began by identifying different forms of marijuana products available in these dispensaries. I specifically focused on combustible and noncombustible forms of marijuana and their potency levels and adverse effects. By understanding the products on the market and how they affect the body I would then be able to evaluate metrics to measure their impact on public health.





**Figure 13 - Project Strategy Diagram**

After establishing a strong understanding of how the body reacts to cannabis in the forms of flower buds, extracts/dabs, and infused edible products, I highlighted the major and most common complications of these forms of consumption. I separated the impacts of these products on the human body into two categories. The first category was the impact on mental performance and cognitive function. I was able to identify four well-studied short and long-term side effects of cannabis abuse including the development of neuro-cognitive impairments, risk assessment, hand-eye coordination, and general performance in daily tasks. The second category I researched in the literature review was adverse physical effects that often result in the development of cannabis-induced medical complications. I focused my research on diseases or conditions that result in hospitalizations. Including Marijuana edible overdoses, pulmonary complications such as general episodes of respiratory distress, and more chronic conditions like COPD, Bronchitis Obliterans, and hyperemesis that result from long-term marijuana use.

After identifying the major cognitive and physical adverse effects of increased marijuana availability and usage, I was tasked with finding relevant metrics to quantify these effects. This was difficult as the majority of the desired data was private or not recorded. To best assess the cognitive impacts and their relation to public health I decided to analyze fatal crash data across the United States. To assess the physical health complications related to marijuana usage I analyzed hospital discharge data related to cannabis-induced health complications, with a sub-focus on adolescents in addition to the general population.

### **3.1.1 Motor Vehicle Fatalities**

I selected Motor Vehicle fatalities as one of my metrics for several reasons. In many previous studies motor vehicle accidents and fatalities have been used to evaluate the impact of psychoactive and impairing drugs on public health. Driving under the influence is one of the lead killers of citizens in the United States, in 2020 alone 11,654 people died in drunk driving accidents[12]. A survey issued in the united states found that 60% of marijuana users in the united states report that they drive under the influence or shortly after using marijuana products. 40% of users claimed to drive under the influence and smoke whilst driving, while 20% say they avoid driving while high when they can but still do on occasion[12].

It is hypothesized that the legalization of marijuana in the united states will only further increase this number as marijuana has been found to immensely impact motor skills/hand-eye coordination, focus, and overall task performance[4]. With the recent innovation of much more potent marijuana products in dispensaries, new research is necessary to identify the impact of higher-potency products on American drivers. In addition to this, public understanding of the dangers of drunk driving is very well established while little research has been done to identify

the impact of driving under the influence of marijuana. There are also very clear guidelines for those who consume alcohol on the appropriate durations of time to wait before driving respective to their alcohol consumption. These guidelines do not exist for marijuana consumption. There are even debates that some drivers are safer when driving under the influence of marijuana. For this reason, I found it integral to assess the effect of marijuana on drivers in the United States.

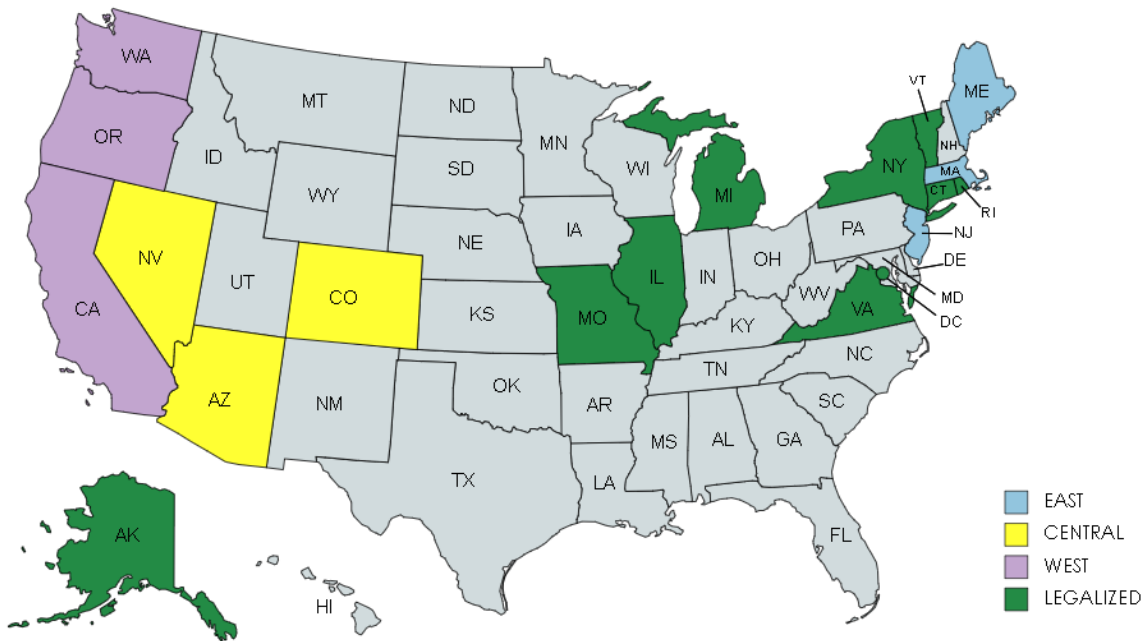
### **3.1.2 Hospital Discharges**

I chose cannabis-related hospital discharges as my second metric for evaluating the effects of marijuana on public health. This is a valuable metric to consider as there are large quantities of data that have been published in each state both before and after legalization/licensed sales. Hospital discharges while less focused would allow me to consider all forms of health complications related to marijuana use including some of which I may not have considered in my literature review. It would be a much more comprehensive approach to assessing the public health impact of marijuana legalization on the various regions and age groups considered. On that note, this data is very strategic as it is almost always accompanied by demographical information including age and race, for this study only age was considered. The two age groups considered were adolescents ages 12-17 and adults 18+. This would allow me to identify both general trends of percent change in hospitalizations since legalization and identify specific trends as they relate to adolescents, one of the most vulnerable populations that make up the public.

In the past, the majority of cannabis-related hospitalization studies were limited to specific hospitals, counties, or isolated contamination events. One such example occurred in Connecticut in 2018 where a study was conducted to assess the impact of a mass overdose event caused by contaminated K2 synthetic marijuana. Researchers focused their efforts on local

hospitals and only looked for patients affected by the specific K2 strain[38]. There is still a need for general research into national trends regarding all cannabis hospitalizations across multiple regions.

### 3.2 State Clusters



**Figure 14 - Legalized States and Established Regions Considered for Analysis**

After establishing the necessary metrics for data analysis I segmented the United States into three regions. These regions were the EAST, WEST, and CENTRAL United States. The eastern region consisted of the states of Massachusetts, Maine, and New Jersey. The western region consisted of the states of California, Oregon, and Washington. The central region consisted of the states of Arizona, Colorado, and Nevada. Each state cluster initially consisted of five states however the lack of data resulted in purging to only allow for states with sufficient data to be considered. A total of 12 States that have legalized marijuana were considered for this

study across all three regions. The states considered makeup 55% of all states and territories that have legalized marijuana in the United States.

The reasoning behind segmenting the states into regions was to control for variable external factors that may have affected the public health in those regions. The goal was to select states that border each other and share similar geography, political attitudes, and biomes. This was to identify trends in different regions while accounting for natural disasters, global pandemics, and any other factors that may have generally affected the data collected. This approach also allowed for variation in legalization dates as most states within the same regions legalized marijuana many years apart. Allowing each region to consist of states that have legalized marijuana both recently and in the past. In addition to this, it limited the amount of data collected as one of the major limitations of this project was the allotted time to gather and analyze the data collected.

#### **Chapter 4: Results**

Motor vehicle fatality and Hospital Discharge data were considered for each of the three states in each of the three respective regions. For example, the data in the Eastern region was gathered from three separate reports issued by Massachusetts, Maine, and New Jersey. Hospital discharge data were gathered from a database curated by the Substance Abuse and Mental Health Services Administration. The data considered were the number of all motor vehicle fatalities and hospital discharges in that state by year. The states were strategically selected so that all or most of the data for each year was available to calculate a pre and post-legalization weighted average. These averages were three-year averages taken, as the names suggest before legalization by three years and after legalization by three years to develop a general understanding of how the

legalization of the substance alone impacted the number of people perishing in motor vehicle accidents. Percent change in the number of fatalities across the 6 years was then calculated to display change in the number of fatalities over time. In addition, the Pre-legalization and Post-legalization averages of all three states were respectively averaged again to create a total for the entire region, a percent change for the region was then calculated in the same manner to identify regional trends across all three states. This was possible because the averages calculated were over three years and there are three states in each cluster making it significant and possible to calculate an average of averages without weighing the data incorrectly.

#### **4.1 Immediate Licensed Sales Effect (ILSE)**

In addition to this, a new metric called the Immediate Licensed Sales Effect (ILSE) was developed for this study. The ILSE is a metric that refers to not only the date Cannabis products were legalized or decriminalized in a state but when the state allows for legal dispensaries and marijuana sales within state borders. A date often falls multiple years after the initial legalization and/or decriminalization of cannabis products.

In my research, I identified that studies regarding marijuana legalization started and ended around the marijuana legalization date. This is an issue because although marijuana is legalized, it doesn't mean that it is approved for licensed sale from dispensaries. The purpose of this study was to focus on the impact of products being distributed by dispensaries and their impact on public health. Only focusing on the legalization date would result in missing some very significant trends regarding when dispensaries were able to sell marijuana to the general public.

## 4.2 Motor Vehicle Fatality Data - EAST COAST

The eastern region was made up of three states, Massachusetts, Maine, and New Jersey.

	EAST COAST			
STATE	ME	MA	NJ	REGION AVG
PRE AVG	1239	2579	512	1443.33
POST AVG	1314	2670	697	1560.33
% CHANGE	6.05%	3.53%	36.13%	8.12%
ILSE	9.98%	4.10%	18.74%	10.94%

**Figure 15 - East Coast Fatal Crash Summary Statistics**

The data collected for Maine came from the MaineDOT Public Crash Statistics Query Tool[29]. Maine legalized marijuana in 2017 and legalized licensed sales in 2020. Maine had a pre-legalization average of 1239 fatalities per year. This number increased by 6.05% to an average of 1314 fatal crashes per year. In addition to this, In the year 2020, the ILSE was 9.98% jumping from 1272 fatal crashes in 2019 to 1399 crashes by the end of 2020. Maine is an amazing example of how crucial it is to consider the ILSE as the true impacts of licensed sales were not experienced until 3 years following legalization.

The data collected for Massachusetts came from the Mass.gov online crash report database called IMPACT[31]. Massachusetts legalized marijuana on December 15, 2016, and legalized licensed sales on January 1st of 2018. The state had a three-year average of 2579 fatal crashes a year before marijuana legalization in 2016. Post Legalization the state experienced an increase of 3.53% in the next three years. Totalling an average of 75 more fatalities each year. In addition to this, in 2018 alone the state experienced an increase of 4.10% in fatal crashes as compared to the previous year.

The data collected for New Jersey came from the NJ.gov online 2022 New Jersey Department of Transportation fatal crash report by county by year[41]. The data for each of the counties were totaled by year and analyzed utilizing the previous methods, however, adjustments were made for insufficient data. Projections produced by the NJDOT were used to calculate the averages instead of recorded data. The state legalized marijuana in 2021 and approved licensed sales the next year. According to the previously reported data NJ experienced an average of 512 motor vehicle fatalities per year pre-marijuana legalization. According to the calculated projection provided by the NJDOT, the state will experience an average of 697 fatalities per year post-legalization. There is a projected increase of 36.13% in the average number of fatalities per year. In addition to this, there was sufficient data to calculate the ILSE, the state experienced an increase of 18.74% or 100 more fatalities directly following licensed sales.

### 4.3 Motor Vehicle Fatality Data - CENTRAL

The eastern region was made up of three states, Arizona, Colorado, and Nevada.

	CENTRAL			
STATE	AZ	CO	NV	REGION AVG
PRE AVG	967	420	1498	961.67
POST AVG	1117	642	1438	1065.67
% CHANGE	15.51%	52.86%	-4.01%	10.82%
ILSE	11.96%	12.20%	6.98%	10.38%

**Figure 16 - Central Fatal Crash Summary Statistics**

The data collected for Arizona came from the ADOT 2021 Motor Vehicle Crash Facts Report. Arizona legalized marijuana in 2020 and legalized licensed sales in 2021[2]. Arizona had



a pre-legalization average of 967 fatalities per year. This number increased by 15.51% to an average of 1117 fatal crashes per year. In addition to this, In the year 2021, the ILSE was 11.96% suggesting that licensed sales that year may have contributed to the increase in crashes that year.

The data collected for Colorado originated from the CDOT Online Colorado Crash Data Dashboard. Colorado was one of the first states to legalize marijuana in the year 2012. The state legalized licensed sales in 2014. Colorado had a pre-legalization average of 420 fatalities per year. This number increased by a drastic 52.86% to an average of 642 fatal crashes per year. In addition to this, In the year 2014, the ILSE was 12.20% which reflected an increase of 55 fatalities.

The data collected for the state of Nevada came from the NevadaDOT Crash Data Web Map[15]. Nevada legalized marijuana and licensed sales of marijuana in 2017. The state experienced a percent change of -4.01% following legalization. Suggesting a decrease in average fatalities per year following marijuana legalization. However, the ILSE was roughly 7% immediately following legalization.

#### 4.4 Motor Vehicle Fatality Data - WEST COAST

WEST COAST				
STATE	CA	OR	WA	REGION AVG
PRE AVG	1613	304	420	779
POST AVG	1700	443	553	899
% CHANGE	5.39%	45.72%	31.67%	14.12%
ILSE	-6.86%	9.27%	6.98%	3.13%

Figure 16 - West Coast Fatal Crash Summary Statistics

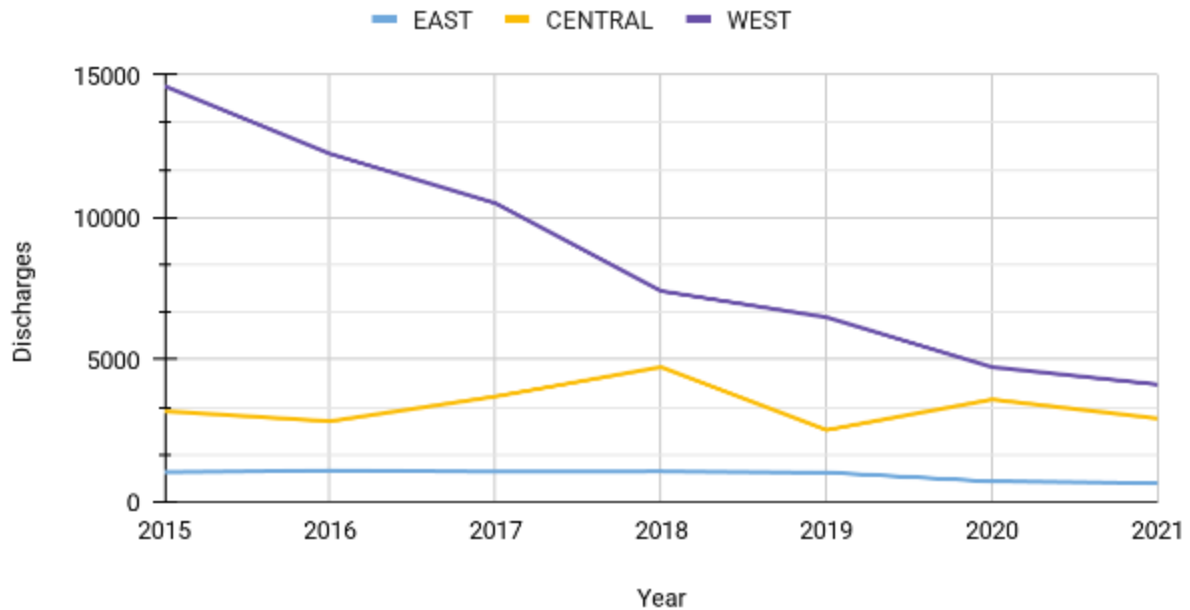
The data collected for California came from the State of California DMV 202 Annual Report Of The California DUI Management Information System[5]. California legalized marijuana in 2016 and legalized licensed sales in 2018. California had a pre-legalization average of 1613 fatalities per year. This number increased by 5.39% to an average of 1700 fatal crashes per year. In addition to this, In the year 2018, the ILSE was 11.96% suggesting that licensed sales that year may have contributed to the increase in crashes that year.

The data collected for Oregon originated from the ODOT Online Crash Analysis Report. Oregon legalized marijuana in the year 2015 and had legally licensed sales that same year. Oregon had a pre-legalization average of 304 fatalities per year[18]. This number increased by a drastic 45.72% to an average of 443 fatal crashes per year. In addition to this, In the year 2015, the ILSE was 9.27%.

The data collected for the state of Washington came from the Washington Traffic Safety Commission Coded Fatal Crsh Files[22]. Washington legalized marijuana in 2012 and legalized licensed sales in 2014. The state experienced a percent change of 31.67% following legalization. The ILSE was roughly 7% immediately following legalization.

#### **4.5 Hospital Discharge Data - Regional**

## Cannabis-Related Discharges By Region ( 2015 - 2021)



**Figure 17 - Cannabis-Related Discharges by Region (2015-2021)**

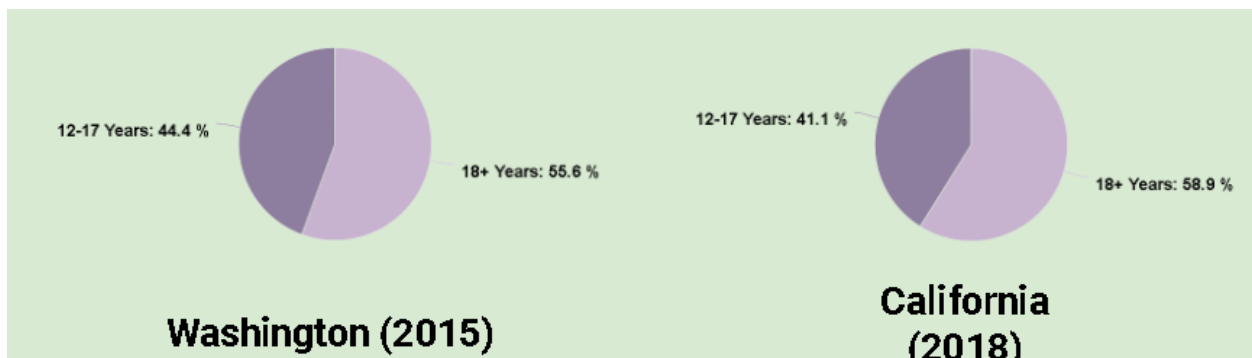
The hospital discharge data were gathered from a database curated by the Substance Abuse and Mental Health Services Administration. This database compiled data regarding various substances and their associated hospital discharges by state per year starting in the year 2014. For this study, the only data that were considered were cannabis-related discharges from the year 2014 and ending in the year 2021. The data for each state were summed and averaged for each respective region. This was to reveal regional trends in marijuana-related hospitalizations as legalization and licensed sales increased.

The results were variable depending on each region. However, some overarching trends seemed to be clear across all three regions. The data depicted that hospitalizations generally increased following legalization for a maximum of one year but eventually decreased in the following years as dispensaries became more established.

In the eastern region, the average of cannabis-related discharges in 2015 was 1050. By 2020 all three states in the region had legalized licensed sales and established dispensaries. The average cannabis-related discharge in the eastern region in 2020 decreased by approximately 32% to 719 this was, the greatest decrease experienced in the previous 5 years. This depicts a clear decline across all three states as marijuana products become more readily available. That following year in 2021 the region experienced the second-greatest decrease in the region's history to 669 discharges. Suggesting that the increase in dispensaries could be correlated to a decrease in cannabis-induced hospitalizations.

The Western region experienced similar trends. In 2015 the region had an average of 14,617 cannabis-related hospital discharges across all three states. By the year 2018, all states in the region had both legalized the use and licensed sales of cannabis products. In 2018 the regional average of discharges decreased by approximately 49% since 2015 to 7411 discharges. After 3 years of established licensed sales via dispensaries, the region experienced another drastic decrease in discharges. In 2021 the average discharge was 4127 for the entire region or a little over 75% less than the original number in 2015. While these trends of decreased hospital discharges across multiple regions could be a result of many factors, it is still very clear that the prevalence of dispensaries and in turn reduced street sales of marijuana products may be correlated to a decrease in cannabis-induced hospitalizations.

#### 4.6 Hospital Discharge Data - Adolescents



### **Figure 18 - State-Level Percentages of Adolescent Hospitalizations**

The data regarding adolescents came from a database curated by the Substance Abuse and Mental Health Services Administration. This database consisted of hospital discharge data by state per year. In addition to this, the data set highlighted the demographics of individuals discharged. For the focus of this analysis data collected in the year immediately following licensed sales, regarding adolescents aged 12-17 was considered and compared to the total number of patients discharged with cannabis-induced health complications. The data displayed a very alarming trend that adolescents made up almost half of all individuals discharged with cannabis health complications, across many states. In the state of Washington adolescents aged 12-17 made up 44.4% of all individuals discharged in the year 2015. California legalized licensed sales in the year 2018, in that year adolescents made up 41.1% of all patients discharged from hospitals with cannabis-induced health complications. This data is extremely alarming considering that such a small demographic is affected the most negatively by licensed sales.

### **Chapter 5: Discussion**

Many arguments for the benefits of marijuana legalization have been made to promote increased access to medical care for those who need it. Marijuana has been heavily praised for its medicinal benefits to those suffering from severe medical conditions such as seizures, cancer, autism, and many more. In addition to this, marijuana has been praised as a safer recreation alternative to drinking alcohol, with many saying there are reduced health risks and even benefits to smoking and consuming cannabis products. The purpose of this study was to evaluate if these benefits to the American public are outweighed by the potential health risks associated with the adverse effects of using cannabis products.

In the case of general motor vehicle safety, the data suggests that there is a serious risk of increased motor vehicle fatalities in states that legalize marijuana use and sales. All three regions analyzed in this study experienced significant increases in motor vehicle fatalities per year following legalization. The eastern region experienced an average increase of 8.12% in motor vehicle fatalities. The western region experienced a 14.12% increase in annual motor vehicle fatalities. The central region experienced a 10.82% increase in annual motor vehicle fatalities. These trends depict that the presence of marijuana dispensaries in states that have legalized marijuana has suggested an increase in impaired or distracted drivers. Many studies have shown that marijuana can reduce the ability to complete daily tasks and reduce motor skills. This is a major concern for drivers as motor skills are a necessity for individuals operating vehicles at any speed in public. One such study conducted in Australia on occasional and frequent smokers found that people may have more difficulty controlling a car, dividing their attention, and reacting at normal speeds. Participants in this study smoked marijuana for 3.5 hours before attempting a driving simulation and various tasks that would assess reaction times and general motor skills. In addition, the data from this study suggested cannabis significantly impaired psychomotor function up to 3.5 h after smoking, with more impairment in occasional smokers and less. Suggesting that the influx of first-time cannabis users may be contributing to these fatalities[39].

According to the data collected in this study and previous research on how cannabis products affect psychomotor skills, cannabis legalization proves to be a serious threat to the average American driver. There are clear trends that suggest that legalizing marijuana and making it more available to the public outside of a medical setting can result in catastrophic results. Irresponsible or uneducated users who choose to drive shortly after or whilst under the

influence of cannabis products pose a very real threat to the property, pedestrians, other drivers, and themselves. To combat these issues federal and state road safety institutions should dedicate time and capital to researching appropriate safety precautions and regulations to impose on cannabis users before driving. Establishing known waiting periods for intoxication to subside would be an essential step to help protect all cannabis users from operating a vehicle while under the influence.

In the case of hospitalizations, the data suggested that over time the establishment of cannabis dispensaries reduces the amount of cannabis-induced hospitalizations in each region. All regions displayed a trend of decreased hospitalizations post-legalization. The eastern region experienced a 31% decrease in annual cannabis-induced hospitalizations, the western region experienced a 75% decrease, and the central region experienced an 8% decrease. This data suggests that increased access to high-potency marijuana products does not necessarily mean that a significant amount of irresponsible users will experience edible overdoses. In addition, this also suggests that not enough time has been allotted to allow for the development of respiratory complications as the majority of them develop after many years of substance abuse. More time and research are needed to accurately assess the impact that combustible cannabis products have on pulmonary health in the United States.

This data does however suggest that there may be underlying benefits to the establishment of dispensaries. While dispensaries do increase the availability of high-potency and potentially dangerous products, it also limits the sales of uncontrolled cannabis products. One of the major criticism of marijuana is that purchasing it from a street market or dealer provides no guarantee that the product is not laced or cut with some other drug to enhance its potency. Most commonly, street cannabis is laced with opioids and fentanyl that have resulted in

many hospitalizations and some cases death. The legalization of marijuana has almost eliminated the need for users to purchase potentially contaminated cannabis products from street markets. An NIH study conducted in 2019 investigated a link between Marijuana Legalization Laws and reduced opioid-related hospitalizations. Their study concluded that marijuana seems to be reducing the rate of opioid-induced hospitalizations, but more time and research are needed to truly gauge the impact of dispensaries in opioid-saturated communities [37].

This study has uncovered that adolescents make up a very large percentage of individuals hospitalized with cannabis health complications. Adolescents are one of the most vulnerable and important populations to consider when assessing the impact of a substance on public health. While adolescents are less responsible and more likely to inaccurately dose cannabis products, some of these hospitalizations have also occurred without intention. The cannabis industry has been scrutinized for packaging materials in easy-to-access and familiar containers that would appeal to younger audiences. Many states are now passing restrictions on cannabis packaging making products harder to open, but not many are addressing the appearance of these products. The ILSE data collected in this study suggests that the increased legalization of marijuana has also increased the availability of cannabis products to adolescents. With rates of adolescent hospitalizations increasing across multiple states. State and federal legislators need to take action and regulate the cannabis industry to reduce the number of cannabis products attained by adolescents. I recommend increasing regulations on the potency of cannabis products. This would be to reduce the negative impact associated with an adolescent either intentionally or unintentionally ingesting a cannabis product. I would also recommend stronger restrictions on cannabis packaging more focused on the appearance of cannabis products and their appeal to



children. This would hopefully reduce the risk of adolescents mistaking an infused gummy, chocolate, or even fizzy drink for sweets they are familiar with.

More time and data are necessary to truly assess the impact of legalized licensed sales of marijuana products on public health in the United States. While the data suggests that there may be very real health and public safety risks associated with legalization, it seems that stricter regulations and legislation can limit these negative impacts.

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