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Demographic Changes in the Prevalence of Marijuana use in the United States, 2005 to 2016

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Title

Demographic Changes in the Prevalence of Marijuana use in the United States, 2005 to 2016.

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Marijuana, marijuana use, drug use, illicit, legalization

Abstract

Importance: Understanding trends of marijuana use in the United States (US) throughout a period of particularly high adoption of marijuana legalization, and understanding which demographics are most at risk of use, is important in managing evolving healthcare policy and intervention.

Objective: To study the demographic-specific changes in the prevalence of marijuana use in the US between 2005-2016.

Design, Setting and Participants: Analysis of National Health and Nutrition Examination Survey weighted US survey data. A total of 30,402 adults between 18-69 years old participated between January 2005-December 2016.

Primary Outcome Measured: Lifetime use, recent use and use in adolescence of marijuana.

Results: The majority of US adults reported ever using marijuana. While the overall prevalence of lifetime marijuana use remained stable (p=0.17), recent use increased significantly between 2005 and 2016 (p=0.01) with highest rate of recent use among younger age groups (p<0.001), males (p<0.001), and those with income below poverty level (p<0.001). Recent marijuana use was most common among non-Hispanic blacks, and less common among Hispanic/Mexican populations (p<0.05). Trends in recent use increased among older adults (p<0.001), females (p=0.003), and those with high school education or above (p=0.04).

Conclusions: While lifetime marijuana use remained stable, recent use significantly increased over the 12-year period. While recent use was remained commonest in younger age groups, males, non-Hispanic blacks and those with lower income; increasing trends in recent use were significant for older, female, and highly-educated populations. With high legalization adoption during this period, our results may suggest an associated increase in recent marijuana use.

An accurate understanding of those most at risk can help inform decisions of healthcare policy makers and healthcare professionals, and facilitate a safe transition of changing marijuana legalization and use in the US.

Article Summary

- This is the most recent study of trends of marijuana use in the United States, during a period of particularly high rates of adoption of marijuana legalization laws.
- The National Health and Nutrition Examination Survey (NHANES) database is a publicly-available and nation-wide database. The NHANES database is weighted (standardized), to accurately represent the entire population of the United States.
- The NHANES database is self-reported, and limited by reporter bias.
- Missing data was primarily from participants who were older and female, potentially underestimating the true prevalence of marijuana use among this demographic.
- State-based legalization information was not available, and could not be accurately correlated to changing trends of marijuana use.

Manuscript

Introduction:

While remaining illegal at the federal level in the United States (US), marijuana is now legal for recreational use by adults over the age of 21 in 11 states, and for medical use in 33 states (1, 2). With particularly high adoption rates of medical marijuana legalization between 2007 and 2016 (3), and increasing social acceptability of marijuana use (4-6), describing trends in use among different demographics in the US is important in understanding which populations might be most affected by changing laws.

Prior studies have described increases in both marijuana use and misuse trends since medical marijuana legalisation (4, 7, 8) in marijuana users both domestically and overseas (9, 10). However, some studies have shown no changes to trends of recent use since legalisation (11, 12), and others have shown only increases in marijuana misuse (12). A recent analysis even described a significant decrease in marijuana misuse disorder since legalisation (13). There have also been inconsistent reports of the demographics of those most affected by changing medical and recreational marijuana legalisation; some studies describing increasing trends across all gender, age and ethnic demographics (7), some showing trend changes particularly for young, black, and Hispanic men (12), and others showing changes particularly among older individuals (4, 6, 14). Importantly, changing trends in medical and non-medical marijuana use do not appear to be restricted only to states with changing marijuana laws (15), despite being higher in states where laws have been passed (7). An understanding of both the social and the economic cost-effectiveness of legalising marijuana (16, 17), coupled with an understanding of trends of changing use, may be useful for those working in public health, public policy, and healthcare, responsible for policy intervention or caring for populations most affected by marijuana use.

The current paper uses data from the US National Health and Nutrition Examination Survey (NHANES), a nationally-representative sample of US adults, to examine the most recent 12-year trends in marijuana use in the United States. Additionally, we examine sociodemographic factors associated with marijuana use. We explore recent literature regarding the cost-effectiveness of medical and social marijuana legalization, adding to the current body of literature important for those in policy, or caring for those most affected.

Methods:

The National Health and Nutrition Examination Survey (NHANES) is an on-going biennial cross-sectional survey representing a non-institutionalized civilian US population, performed by the National Centre for Health Statistics and Centres for Disease Control and Prevention.

Participants undergo a home interview and a comprehensive physical examination in a mobile examination centre (MEC). The 2005-2016 NHANES protocol was approved by the National Centre for Health Statistics research ethics review board and written informed consent obtained from all participants.

Demographics data including age, gender, race/ethnicity, education and income were collected during the home interview. The drug use questionnaire was conducted in the MEC and aimed to assess lifetime and current usage of illicit drugs. Questions are self-administered using the Audio Computer-Assisted Self-Interview (ACASI) system. The ACASI was conducted in English, Spanish, Korean, Vietnamese, or Chinese (Mandarin and Cantonese). Participants reported lifetime use, age at first use and use within prior 12 months of marijuana. We defined *recent use* as any survey responses stating use within the previous 12 months.

All analyses were restricted to adults aged 18 to 69 years. Given the NHANES complex probability sampling design, 2-year interview weights computed by the National Center for Health Statistics were used to calculate prevalence estimates and 95% confidence interval. Differences in prevalence estimates were compared using chi-square tests. Univariate regression models were used to test for significant linear trends while multivariable regression models were used to determine characteristics associated with recent marijuana use. Statistical analysis was performed using STATA (version 15).

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

Results:

A total of 30,402 adults between 18-69 years old participated in NHANES 2005-2016 surveys. Of these 9,987 (27.13%) had missing survey data. Those with missing data were significantly more likely to be older (p<0.001), female (p<0.001) and have less than high school education (p<0.001).

Overall, 59.2% (CI 57.7% - 60.7%) of the US adult population reported ever using marijuana between 2005-2016. The prevalence of lifetime marijuana use remained stable between 2005 and 2016 (p=0.17) (Table 1). Overall 18.8% (CI 15.2-23.5) of US adults reported using marijuana within the last year. The weighted prevalence of recent marijuana use increased significantly during the study period from 19.1% (95% CI 15.3-23.7%) in 2005/06 to 24.9% (95%CI 20.0-30.5) (p=0.02) in 2015/16.

The prevalence of recent marijuana use was higher among younger age groups (p<0.001), males (p<0.001), and those with income below poverty level (p<0.001) (Table 2). Recent

marijuana use was more common among non-Hispanic blacks, and less common among Hispanic/Mexicans (p<0.002 (excluding 2011-2012)). Between 2005 - 2016 the prevalence of recent marijuana use increased among older adults (age 50-69, p<0.001), females (p=0.003), all racial categories (p<0.05 for all groups), and those with high school education or above (p=0.04 for both)

Multivariate logistic regression analysis demonstrated higher odds of recent marijuana use among males (p<0.001), non-Hispanic blacks (p=0.008) and those with income within 2x or below the poverty level (p<0.001 for both) (Table 3). Recent use was less likely among older individuals (p<0.001), Hispanic and Mexican Americans (p<0.001) and those with more than high school education (p<.001) (Table 3).

Discussion:

While lifetime marijuana use remained stable, overall prevalence of recent use within the previous 12-months significantly increased over the 12-year period. While recent use was more common in younger age groups, males, non-Hispanic blacks and those with lower income, significant trends of increasing recent use were most notable for older, female, and highly-educated populations.

Our demographic findings of those most likely to have used marijuana are consistent with previous studies, demonstrating highest overall use among younger, males, non-Hispanic blacks, and lower income groups (4, 7). Native American populations, those living in urban areas, and those living in western states, have also been shown to be more likely to have recently used marijuana; but these demographic factors were not included in our analyses. The characteristics of those most likely to have used medical-marijuana have been shown to be altogether different; tending to be in slightly older age groups (30-50 years old), males, white, and with higher annual incomes (15).

Particularly high uptake of medical and recreational marijuana legalization in the US between 2007-2016 (3), with paralleled increasing marijuana-use trends particularly during this period (4), may suggest an association between marijuana legalization and use. However, specific demographics most affected by changing laws, whether recreational or medical users are more affected, and changes in marijuana misuse trends, remain inconsistently described (12). Where previous studies have concluded comparably increased use across ages and gender (4, 6, 7, 12), changing trends in adolescents remains unclear. While younger people have appeared likelier to use recreational marijuana after legalization in some instances (8), Harpin and colleagues describe no significant change to use among college students after legalization (despite changes to perceived ease of access) (11), supported by more recent reviews describing stable adolescent trends (6). In fact, a recent study describes that recent marijuana

misuse appears to have *decreased* among US adolescents during the highest periods of legalization uptake (13). More recent reviews outline that marijuana legalization results in significantly increased use in older populations only, without affecting adolescents (6, 14); corroborated by recent findings by Salas-Wright and colleagues demonstrating increasing trends of recent use among late middle-aged adults between 2002-2014 (5). The extent to which different demographics remain most at risk of medical or recreational use or misuse remains unclear.

Importantly, increasing trends of marijuana use appears not to be restricted to states with changing legalization laws. Hasin and colleagues demonstrate significantly increased use seen both in states with and without marijuana legalization (4, 7), albeit fractionally higher in states where marijuana was legalized. However, a recent analysis by Han and colleagues demonstrated a significantly higher trend of increasing medical marijuana use in states without legalization (AOR 1.4, 95% CI 1.05-1.90), compared to states with legalization (AOR 1.3, 95% CI 1.03-1.61) (15). This underlines the fact that evolving legalization laws are also of relevance to states where recreational and medical marijuana use remains illegal.

In addition to demographic risk factors indicating potential marijuana use, an understanding of other risk factors is important for those involved in fields of public policy and healthcare. While age and gender remain somewhat inconsistently described risk factors, tobacco smoking has been demonstrated a significant risk factor for marijuana use. A recent study demonstrated that current smokers have almost 6x increased odds of recent marijuana use compared to non-smokers (18), outlining another sub-population particularly at risk. Another group at risk of increasing marijuana use are non-medical users of prescription drugs (NMUPD). A recent study by Karjalainen and colleagues demonstrated significantly increasing trends of illicit drug use among NMUPD (92% of whom had used cannabis in the last year), that could not otherwise be explained by age or gender (19).

Exploring the economic and societal cost-effectiveness of marijuana legalization is important for those involved in healthcare policy and decision making. Marijuana legalization was posited to lower price, increase availability, and thereby increase marijuana use (6), with early fears that profit motive would take precedence over public health issues (20, 21). The retail price of marijuana on the legal cannabis market had sharply fallen by almost 70%, just three-years after legalization in Washington State (22, 23). Some reports described an initial increase in self-reported street prices of marijuana in response to legalization as demand increased, by up to 36% (24), with limited price change thereafter. However, similarly to results aforementioned, medical legalization appears to have affected only adult marijuana use, with minimal significant changes to adolescent use (14). While studies of the effect of recreational marijuana legalization on its use are still emerging, there appears to be no/minimal effect on adolescent or college marijuana use (14). The passage of legalization laws also offers an important social justice benefit (25); by removing mechanisms for unfair,

damaging disparities in law enforcement (26). While more permissive marijuana laws may appeal to social justice aims (reducing racial disparity in law enforcement), and increase revenue to state and local government through taxation (6), the public health trade-offs and overall costs of use-related adverse physical and psychosocial consequences (27) in response to changing laws remains difficult to accurately describe (6).

Strengths and Limitations: Limitations to our study include reliance on self-reported data and reporter-bias. Missing data was primarily from participants who were older and female, potentially underestimating the true prevalence of marijuana use among this demographic. Our dataset excluded youth aged 12-17 years old, a potentially at-risk population. Strengths of our study include the size and heterogeneity of our population, the timespan, and the standardization of the NHANES data.

Conclusion:

Our primary two findings describing characteristics of those most at risk of using marijuana, and those where trends of use have most significantly increased, adds to the current body of literature and understanding of marijuana trends in the United States. Given ongoing changes to legalization in the US, with the evolving public perception of marijuana safety and accessibility, an accurate understanding of which populations are most likely to be implicated, which additional predictive tools can identify those most at risk, and a balanced presentation of healthcare, social and economic costs of legalization, is warranted. Identification of these factors can help inform the decisions of healthcare policy makers and professionals, and facilitate a safe transition of changing marijuana legalization and use in the US.

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Author contributions:

Dr William Mitchell: Analysis plan, data interpretation, manuscript generation and editing, submission, correspondence

Dr Roma Bhatia: Analysis plan, data interpretation, manuscript editing

Dr Nazlee Zebardast: Analysis plan, data extraction, analysis and interpretation, manuscript editing

Data Statement:

Data is fully accessible from the following website:
https://wwwn.cdc.gov/nchs/nhanes/default.aspx

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Table 1: Prevalence of marijuana and cocaine/heroine/methamphetamine use in US adults, NHANES 2005-2016

	2005-2006		2007-2008		2009-2010		2011-2012		2013-2014		2015-2016		P
	Total N	**Prevalence % (95% CI)**	**Total N**	**Prevalence % (95% CI)**	**Total N**	**Prevalence % (95% CI)**	**Total N**	**Prevalence % (95% CI)**	**Total N**	**Prevalence % (95% CI)**	**Total N**	**Prevalence % (95% CI)**	
Lifetime use	2922	61.5 (57.2-65.7)	3255	60.5 (57.2-63.7)	3739	57.2 (53.0-61.3)	3333	59.9 (56.0-63.6)	3692	59.2 (55.6-62.7)	3422	57.3 (53.1-61.5)	0.17
Age at First used (<18 years old)	1617	59.6 (56-7-62.7)	1799	60.7 (58.0-63.5)	1937	62.7 (59.0-66.4)	1770	60.1 (56.0-64.0)	1984	61.4 (58.8-63.9)	1715	60.1 (56.5-63.7)	0.91
Recent use (≤ 12 months)	2922	19.1 (15.3-23.7)	3255	19.1 (17.5-20.7)	3739	20.6 (18.2-23.3)	3333	22.4 (19.8 - 25.2)	3696	22.3 (19.9-24.8)	3422	24.9 (20.0-30.6)	0.02

Key:
N denotes unweighted total number of participants in each category
Prevalence percentage with 95% (CI), computed using 2-year MEC weights to provide estimates for the total US population, and age-standardized to 2000 Census population.
P values test overall trend in prevalence estimates in each category
NHANES = National Health and Nutrition Examination Survey

Table 2: Prevalence of self-reported recent marijuana use by demographic factors, NHANES 2005-2016.

	2005-2006	2007-2008	2009-2010	2011-2012	2013-2014	2015-2016	P value
	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	
Age of participants							
- 18-29	34.0[a] (26.7-42.0)	35.1 (30.0-40.6)	34.4 (30.7-38.3)	36.2 (31.7-41.1)	38.1 (35.1-41.2)	37.3 (30.4-44.8)	P=0.28[c]
- 30-49	16.1 (12.3-20.7)	16.2 (14.3-18.2)	17.5 (14.7-20.7)	17.0 (14.4-20.1)	16.3 (13.8-19.1)	21.1 (16.0-27.3)	P=0.15
- 50-69	10.5 (7.4-14.6)	8.1 (6.0-10.9)	10.3 (7.8-13.4)	15.5 (11.4-20.8)	14.3 (9.2-21.5)	18.0 (13.0-23.7)	P<0.001
	P<0.001[b]	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	
Gender							
- Male	24.8 (20.3-29.9)	23.1 (20.8-25.7)	24.8 (22.0-27.8)	27.3 (24.6-30.1)	26.3 (23.2-29.7)	29.2 (23.1-36.3)	P=0.09
- Female	13.6 (10.1-18.1)	15.1 (13.1-17.3)	16.3 (13.6-19.3)	17.3 (14.0-21.2)	18.2 (15.3-21.6)	20.6 (16.5-25.4)	P=0.003
	P<0.001	P<0.001	P<0.001	P<0.001	P=0.001	P<0.001	
Race							
- Non-Hispanic White	20.1 (15.6-25.7)	19.4 (17.7-21.3)	21.1 (18.4-24.1)	22.7 (19.4-26.3)	22.0 (18.3-26.3)	26.7 (20.4-34.1)	P=0.049
- Non-Hispanic Black	23.56 (18.4-29.1)	26.9 (22.6-31.7)	27.6 (24.6-30.9)	27.3 (22.1-33.2)	32.9 (29.8-36.1)	32.5 (28.8-36.5)	P=0.001
- Hispanic/Mexican	11.7 (8.3-16.2)	13.6 (9.8-18.5)	16.6 (13.0-20.9)	18.9 (15.2-23.2)	17.9 (15.5-20.6)	16.3 (13.1-20.2)	P=0.03
- Other	13.2(7.9-21.2)	13.3 (7.5-22.6)	12.7 (7.4-21.1)	18.7 (14.2-24.1)	18.0 (13.7-23.3)	19.9 (13.3-28.7)	P=0.06
	P=0.003	P=0.002	P<0.001	P=0.06	P<0.001	P=0.001	
Educat.							
- <High School	22.5 (16.5-30.0)	22.1 (17.6-27.3)	23.3 (19.5-27.6)	27.5 (22.6-33.0)	27.9 (23.6-32.6)	24.7 (20.0-30.1)	P=0.13
- High School	21.6 (15.1-30.0)	19.6 (17.5-21.8)	24.7 (21.2-28.5)	25.8 (20.8-31.5)	25.4 (21.1-30.3)	27.5 (22.3-33.4)	P=0.04
- >High School	17.4 (13.2-22.7)	18.0 (15.4-20.8)	18.2 (15.1-21.9)	20.2 (17.2-23.4)	19.8 (16.9-23.0)	24.1 (18.2-31.3)	P=0.04
	P=0.25	P=0.21	P=0.006	P=0.01	P=0.01	P=0.42	
Poverty							
- >2x Poverty Level	17.7 (13.5-22.8)	16.3 (14.4-18.5)	17.1 (14.2-20.5)	18.3 (15.6-21.3)	18.5 (15.7-21.6)	22.4 (17.3-28.4)	P=0.09
- 1-2X Poverty Level	22.0 (16.4-28.8)	24.5 (20.8-28.6)	22.4 (18.0-27.7)	27.9 (23.8-32.3)	25.3 (21.6-29.5)	29.4 (21.8-38.4)	P=0.08
- < Poverty Level	24.3 (19.2-30.2)	25.2 (19.5-32.0)	34.6 (30.9-38.6)	31.1 (27.1-35.4)	33.2 (28.3-38.6)	29.8 (23.6-37.0)	P=0.07
	P=0.05	P=0.001	P<0.001	P<0.001	P<0.001	P=0.004	

Key:

Prevalence percentage with 95% confidence intervals (CI), computed using 2-year interview weights to provide estimates for the total US population and are age-standardized to the US 2000 Census population.

[a] percentage interpretation: of those aged 18-29, 34% reported marijuana use within the past 12 months. Poverty defined using poverty income ratio, accounting for family size

[b] P values test global within group differences in prevalence

[c] P values test overall trend in prevalence estimates in each category

NHANES = National Health and Nutrition Examination Survey

Table 3: Multivariable logistic regression analysis predicting recent marijuana use within the past 12 months NHANES 2005-2016

Demographic variable	Recent marijuana use (past 12 months) OR (95% CI)
Age of participants	
- **18-29**	1.0 (reference)
- 30-49	0.39 (0.35-0.43)
- 50-69	0.27 (0.23-0.31)
Gender	
- Female	1.0 (reference)
- Male	1.77 (1.62-1.92)
Race	
- Non-Hispanic White	1.0 (reference)
- Non-Hispanic Black	1.20 (1.05-1.38)
- Hispanic/Mexican	0.47 (0.41-0.55)
- Other	0.63 (0.53-0.75)
Education	
- < High School	1.0 (reference)
- High School	0.93 (0.79-1.10)
- > High School	0.81 (0.70-0.92)
Poverty	
- >2x Poverty Level	1.0 (reference)
- 1-2X Poverty Level	1.41 (1.24-1.59)
- < Poverty Level	1.69 (1.49-1.92)

Key:

Odds ratio (OR) with 95% confidence intervals (CI) computed using 12-year interview weights to provide estimates for the total US population and are age-standardized to the US 2000 Census population.

Poverty defined using poverty income ratio, which accounts for family size

NHANES = National Health and Nutrition Examination Survey

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Title

A Retrospective Cross-Sectional Analysis of the Changes in Marijuana Use in the United States, 2005-2018

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Abstract

Objectives: Understanding trends of marijuana use in the United States (US) throughout a period of particularly high adoption of marijuana-legalization, and understanding demographics most at risk of use, is important in evolving healthcare-policy and intervention. This study analyzes the demographic-specific changes in the prevalence of marijuana use in the US between 2005-2018.

Design, Setting and Participants: A fourteen-year retrospective cross-sectional analysis of the National Health and Nutrition Examination Survey (NHANES) database, a publicly-available biennially-collected national survey, weighted to represent the entire US population. A total of 35,212 adults between 18-69 years old participated in the seven-cycles of surveys analysed (2005-2018).

Primary Outcome Measured: Lifetime-use, first-use before 18-years-old, and past-year use of marijuana.

Results: The majority of adults reported ever using marijuana. While the overall prevalence of lifetime marijuana use remained stable (p=0.53), past-year use increased significantly between 2005-2018 (p<0.001) with highest rate of past-year use among younger age groups (p<0.001), males (p<0.001), and those with income below poverty level (p<0.001). Past-year use was commonest among non-Hispanic blacks, and less common among Hispanic/Mexican populations (p<0.002). Trends in past-year use increased among all age categories, males/females, all ethnicities, those with high-school education/above, and those at all income levels (p<0.01 for all).

Conclusions: While lifetime marijuana-use remained stable, past-year use significantly increased between 2005-2018. While past-year use remained commonest in younger age groups, males, non-Hispanic blacks and those with lower income; increasing trends in past-year use were significant for all age, sex, race and income categories, and for those with high-school education/above. With high adoption of marijuana-legalization laws during this period, our results suggest an associated increase in past-year marijuana use.

An accurate understanding of those most at risk can help inform decisions of healthcare policy makers and professionals, and facilitate a safe transition of changing marijuana legalization and use in the US.

Article Summary

- This is the most recent study of trends of marijuana use in the United States, during a period of particularly high rates of adoption of marijuana legalization laws.
- The National Health and Nutrition Examination Survey (NHANES) database is a publicly-available and nation-wide database. The NHANES database is weighted (standardized), to accurately represent the entire population of the United States.
- The NHANES database is self-reported, and limited by reporter bias.
- Missing data was primarily from participants who were older and female, potentially underestimating the true prevalence of marijuana use among this demographic.
- State-based legalization information and use amongst adolescents less than 18-years-old was not available, and could not be accurately correlated with changing trends of marijuana use.

Manuscript

Introduction:

While remaining illegal at the federal level in the United States (US), marijuana is now legal for recreational use by adults over the age of 21 in 11 states, and for medical use in 33 states (1, 2). With particularly high adoption rates of medical marijuana legalization between 2007 and 2016 (3), and increasing social acceptability of marijuana use (4-6), describing trends in use among different demographics in the US is important in understanding which populations might be most affected by changing laws.

Prior studies have described increases in both marijuana use and misuse trends since medical marijuana legalisation (4, 7, 8) in marijuana users both domestically and overseas (9). However, some studies have shown no changes to trends of past-year use since legalisation (10, 11), and others have shown only increases in marijuana misuse (11). A recent analysis even described a significant decrease in marijuana misuse disorder since legalisation (12). There have also been inconsistent reports of the demographics of those most affected by changing medical and recreational marijuana legalisation; some studies describing increasing trends across all gender, age and ethnic demographics (7), some showing trend changes particularly for young, black, and Hispanic men (11), and others showing changes particularly among older individuals (4, 6, 13). Importantly, changing trends in medical and non-medical marijuana use do not appear to be restricted only to states with changing marijuana laws (14), despite being higher in states where laws have been passed (7). An understanding of both the social and the economic cost-effectiveness of legalising marijuana (15, 16), coupled with an understanding of trends of changing use, may be useful for those working in public health, public policy, and healthcare, responsible for policy intervention or caring for populations most affected by marijuana use.

The current paper uses data from the US National Health and Nutrition Examination Survey (NHANES), a nationally-representative sample of US adults, to examine the most recent 12-year trends in marijuana use in the United States. Additionally, we examine sociodemographic factors associated with marijuana use. We explore recent literature regarding the cost-effectiveness of medical and social marijuana legalization, adding to the current body of literature important for those in policy, or caring for those most affected.

Methods:

The National Health and Nutrition Examination Survey (NHANES) is an on-going biennial cross-sectional survey representing a non-institutionalized civilian US population, performed by the National Centre for Health Statistics (NCHS) and Centres for Disease Control and

Prevention (CDC). NHANES has been a continuous survey program providing health statistics for the US since 1999, examining a nationally-representative sample of about 5,000 people each year, located in counties across the US. Study teams consisting of multilingual physicians, medical and health technicians, and dietary health interviewers conduct interviews and perform examinations, and information collected is intended to be used to determine the prevalence of major diseases and risk factors for diseases, and for health promotion and disease prevention. The sample for the survey is selected to represent the US population of all ages. To produce reliable statistics, NHANES over-samples persons 60 and older, African Americans, and Hispanics (17).

In the present study, seven two-year cycles of NHANES survey data between 2005-2018 (inclusive) have been retrospectively analysed for baseline demographic information, and drug use questionnaire data. A total of 35,212 adults (US citizens) between 18-69 years old participated in the seven-cycles of surveys analysed. Of these, 32.9% had missing marijuana survey data. Those with missing data were significantly more likely to be older ($p<0.001$), female ($p<0.001$) and have less than high school education ($p<0.001$). Missing data was handled by pairwise deletion to optimize data available for analysis. Participants undergo a home interview, and a comprehensive physical examination in a mobile examination centre (MEC). The 2005-2018 NHANES protocol was approved by the National Centre for Health Statistics research ethics review board and written informed consent obtained from all participants.

Demographics data including age, gender, race/ethnicity, education and income were collected during the home interview. The drug use questionnaire was conducted in the mobile examination centre (MEC), and aimed to assess lifetime, past-year, and current usage of marijuana. Questions are self-administered using the Audio Computer-Assisted Self-Interview (ACASI) system. The ACASI was conducted in English, Spanish, Korean, Vietnamese, or Chinese (Mandarin and Cantonese). Participants reported lifetime use, age at first use and use within the past-year of marijuana.

Given the NHANES complex probability sampling design, 2-year interview weights computed by the NCHS were used to calculate prevalence estimates and 95% confidence intervals (Taylor linearization), age-standardized to the 2000 US Census population as recommended by the NCHS. Differences in prevalence estimates were compared using chi-square tests. Univariate regression models were used to test for significant linear trends while multivariable regression models were used to determine characteristics associated with recent marijuana use. Results at the $p<0.05$ level considered statistically significant. Statistical analysis was performed using STATA version 15.0 (StataCorp LP, College Station, TX).

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

Results:

Overall, 53.5% (95% CI 52.8-54.1%) of the US adult population reported ever using marijuana between 2005-2018. The prevalence of lifetime marijuana use, and first use before the age of 18, remained stable between 2005 and 2018 (p=0.53 and p=0.68, respectively) (Table 1). Overall 22.6% (95% CI 22.1-23.1%) of US adults reported using marijuana within the last year. The weighted prevalence of past-year marijuana use increased significantly during the study period from 19.1% (95% CI 15.3-23.7%) in 2005/06 to 29.1% (95% CI 26.0-32.5%) (p=0.001) in 2017/18.

The prevalence of past-year marijuana use was higher among younger age groups (p<0.001), males (p<0.05), and those with income below poverty level (p<0.05) (Table 2). Past-year marijuana use was more common among non-Hispanic blacks, and less common among Hispanic/Mexicans (p<0.002 (excluding 2011/12 and 2017/18)). Between 2005 - 2018 the prevalence of past-year marijuana use increased among all age categories (p<0.001), males and females (p<0.001), all racial categories (p<0.01 for all groups), those with high school education or above (p<0.001 for both) and those at all levels of income (p<0.01).

Multivariate logistic regression analysis demonstrated higher odds of past-year marijuana use among younger age groups (p<0.001), males (p<0.001), non-Hispanic blacks (p<0.001), and those with income below the poverty level (p<0.001 for both) (Table 3). Past-year use was less likely among older individuals (p<0.001), and Hispanic and Mexican Americans (p<0.001) and those with higher levels of education (p=0.003) (Table 3).

Discussion:

The current study presents the most recent changes in marijuana use in the US during a period of particularly high legalization. It finds that while lifetime marijuana use, and first-use before the age of 18, has remained stable, the overall prevalence of past-year marijuana use has significantly increased over the 14-year period. While past-year use was still more common among younger age groups, males, non-Hispanic blacks and those with lower income, significant trends of increasing past-year use were seen in all age categories, males and females, all racial categories, highly-educated populations, and all income levels. Age-specific marijuana use trends in response to legalization laws has been studied elsewhere; but with inconsistent findings. There has been growing consensus that increasing recent-use of marijuana is seen among late to middle-aged adults after legalization (6, 13); a recent study by Salas-Wright and colleagues showing trends of increasing past-year use among late to middle-aged adults in the US between 2002-2014 (5), findings that are supported by the present study. Whether this pattern of recent-use among older populations is associated with

increasing marijuana-use for medicinal purposes (seen most prominently among older, white, male, and high-income populations in the US) (14), is unclear, and such data was not available for analysis in the present study. However, there has been less consensus about recent-use trends among adolescent populations. While a comprehensive study by Harpin and colleagues described no change in adolescent-use after legalization (10) (further supported by more recent findings (6)), a 2019 review by Bae and colleagues described increasing recent-use amongst adolescents in the US after legalization (8). Contrastingly, a 2016 US study by Grucza and colleagues describes that past-year marijuana use actually *decreased* among adolescents, during the highest periods of legalization (12). Information about marijuana-use trends in adolescents less than 18-years-old was not publicly available on NHANES for the present study, but it has been noted that over the 14-year study period, there has been no significant change in reported first-use before the age of 18 (table 1).

Our findings of younger, male, non-Hispanic black and lower income populations being most likely to use marijuana overall, are also consistent with previous findings not aforementioned (4, 7). Native American populations, those living in urban areas, and those living in western states, have also been shown to be more likely to have recently used marijuana; but this information was not available on NHANES in sufficient detail, for the present analyses.

In addition to demographic risk factors indicating potential marijuana use, an understanding of other risk factors is important for those involved in fields of public policy and healthcare. While age and gender remain somewhat inconsistently described risk factors, tobacco smoking is a demonstrated risk factor for marijuana use. Though not analyzed in the present study, a recent study demonstrated that current smokers have almost 6x increased odds of recent marijuana use compared to non-smokers (18), outlining another sub-population particularly at risk. Another group at risk of increasing marijuana use are non-medical users of prescription drugs (NMUPD). A recent study by Karjalainen and colleagues demonstrated significantly increasing trends of illicit drug use among NMUPD (92% of whom had used cannabis in the last year), that could not otherwise be explained by age or gender (19).

Important to consider in the context of the present findings is that marijuana-use trends may not to be restricted only to states with marijuana legalization. In 2017, Hasin and colleagues demonstrated significantly increased marijuana use both in states with and without marijuana legalization laws (4, 7), albeit fractionally higher in states where marijuana was legalized. However, a recent analysis by Han and colleagues demonstrated a significantly higher trend of increasing medical-marijuana use in states without legalization (AOR 1.4, 95% CI 1.05-1.90), compared to states with legalization (AOR 1.3, 95% CI 1.03-1.61) (14); underlining the fact that evolving legalization laws are also of relevance to states where recreational and medical marijuana use remains illegal.

Exploring the economic and societal cost-effectiveness of marijuana legalization is also important for those involved in healthcare policy and decision making. Marijuana legalization was posited to lower price, increase availability, and thereby increase marijuana use (6), with early fears that profit motive would take precedence over public health issues (20, 21). The retail price of marijuana on the legal cannabis market had sharply fallen by almost 70%, just three-years after legalization in Washington State (22, 23). Some reports described an initial increase in self-reported street prices of marijuana in response to legalization as demand increased, by up to 36% (24), with limited price change thereafter. However, similarly to results aforementioned, medical legalization appears to have affected only adult marijuana use, with minimal significant changes to adolescent use (13). While studies of the effect of recreational marijuana legalization on its use are still emerging, there appears to be no/minimal effect on adolescent or college marijuana use (13). The passage of legalization laws also offers an important social justice benefit (25); by removing mechanisms for unfair, damaging disparities in law enforcement (26). While more permissive marijuana laws may appeal to social justice aims (reducing racial disparity in law enforcement), and increase revenue to state and local government through taxation (6), the public health trade-offs and overall costs of use-related adverse physical and psychosocial consequences (27) in response to changing laws remains difficult to accurately describe (6).

Strengths and Limitations: Strengths of our study include the size and heterogeneity of our population, the timespan, and the age-standardization of the NHANES data. Limitations to our study include reliance on self-reported data and reporter-bias, which may not have affected all demographics equally. Missing data was primarily from participants who were older and female, potentially underestimating the true prevalence of marijuana use among this demographic. Our dataset did not include youth aged 12-17 years old, a potentially at-risk population, nor include analysis of other risk factors associated with marijuana use (use of tobacco, or NMUPD). Certain ethnicity data (i.e. Native American identifiers) and geographical data (i.e. whether collected from states with or without legalization) were not available for analysis, nor was detail of marijuana use for medicinal or recreational purposes.

Conclusion:

Our primary two findings describing characteristics of those most at risk of using marijuana, and those where trends of use have most significantly increased, adds to the current body of literature and understanding of marijuana trends in the United States. Given ongoing changes to marijuana legalization in the US, with the evolving public perception of marijuana safety and accessibility, an accurate understanding of which populations are most likely to be implicated, which additional predictive tools can identify those most at risk, and a balanced presentation of healthcare, social and economic costs of legalization, is warranted. Identification of these factors can help inform the decisions of healthcare policy makers and

professionals, and facilitate a safe transition of evolving marijuana legalization and use in the US.

Author statements:

There are no competing or conflicting interests to declare by any of the authors.

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Author contributions:

Dr William Mitchell: Analysis plan, data interpretation, manuscript composition and editing, submission, correspondence

Dr Roma Bhatia: Analysis plan, data interpretation, manuscript editing

Dr Nazlee Zebardast: Analysis plan, data extraction, analysis and interpretation, manuscript composition

Data Statement:

Data is fully accessible from the following website:
https://wwwn.cdc.gov/nchs/nhanes/default.aspx

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Table 1: Prevalence of marijuana use in adults in the United States, NHANES 2005-2018

	2005-2006		2007-2008		2009-2010		2011-2012		2013-2014		2015-2016		2017-2018		P
	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	
Lifetime use	2922	61.5 (57.2-65.7)	3255	60.5 (57.2-63.7)	3739	57.2 (53.0-61.3)	3333	59.9 (56.0-63.6)	3690	59.2 (55.6-62.7)	3422	57.3 (53.1-61.5)	3199	60.9 (57.9-63.7)	0.53
Age <18 at First used	1617	59.6 (56-7-62.7)	1799	60.7 (58.0-63.5)	1937	62.7 (59.0-66.4)	1770	60.1 (56.0-64.0)	1984	61.4 (58.8-63.9)	1715	60.1 (56.5-63.7)	1737	61.8 (57.1-66.3)	0.68
Past-year use	2922	19.1 (15.3-23.7)	3255	19.1 (17.5-20.7)	3739	20.6 (18.2-23.3)	3333	22.4 (19.8 - 25.2)	3690	22.3 (19.9-24.8)	3422	24.9 (20.0-30.6)	3199	29.1 (26.0-32.5)	0.001

Key:

N denotes unweighted total number of participants in each category

Prevalence percentage with 95% (CI), computed using 2-year MEC weights to provide estimates for the total US population, and age-standardized to 2000 Census population.

P values test overall trend in prevalence estimates in each category

NHANES = National Health and Nutrition Examination Survey

Table 2: Prevalence of self-reported past-year marijuana use in adults in the United States, by selected demographic factors, NHANES 2005-2018

	2005-2006	2007-2008	2009-2010	2011-2012	2013-2014	2015-2016	2017-2018	P value
	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	
Age								
- 18-29	34.0[a] (26.7-42.0)	35.1 (30.0-40.6)	34.4 (30.7-38.3)	36.2 (31.7-41.1)	38.1 (35.1-41.2)	37.3 (30.4-44.8)	46.3 (42.5-50.2)	P=0.001[c]
- 30-49	16.1 (12.3-20.7)	16.2 (14.3-18.2)	17.5 (14.7-20.7)	17.0 (14.4-20.1)	16.3 (13.8-19.1)	21.1 (16.0-27.3)	24.6 (20.6-29.1)	P=0.001
- 50-69	10.5 (7.4-14.6)	8.1 (6.0-10.9)	10.3 (7.8-13.4)	15.5 (11.4-20.8)	14.3 (9.2-21.5)	18.0 (13.0-23.7)	17.0 (12.4-22.8)	P<0.001
	P<0.001[b]	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	
Gender								
- Male	24.8 (20.3-29.9)	23.1 (20.8-25.7)	24.8 (22.0-27.8)	27.3 (24.6-30.1)	26.3 (23.2-29.7)	29.2 (23.1-36.3)	32.0 (28.6-35.6)	P=0.001
- Female	13.6 (10.1-18.1)	15.1 (13.1-17.3)	16.3 (13.6-19.3)	17.3 (14.0-21.2)	18.2 (15.3-21.6)	20.6 (16.5-25.4)	26.3 (22.1-31.0)	P<0.001
	P<0.001	P<0.001	P<0.001	P<0.001	P=0.001	P<0.001	P=0.02	
Race								
- NH White	20.1 (15.6-25.7)	19.4 (17.7-21.3)	21.1 (18.4-24.1)	22.7 (19.4-26.3)	22.0 (18.3-26.3)	26.7 (20.4-34.1)	30.0 (25.5-34.5)	P<0.001
- NH Black	23.56 (18.4-29.1)	26.9 (22.6-31.7)	27.6 (24.6-30.9)	27.3 (22.1-33.2)	32.9 (29.8-36.1)	32.5 (28.8-36.5)	36.8 (32.5-41.3)	P<0.001
- Hispanic/Mexican	11.7 (8.3-16.2)	13.6 (9.8-18.5)	16.6 (13.0-20.9)	18.9 (15.2-23.2)	17.9 (15.5-20.6)	16.3 (13.1-20.2)	25.0 (22.2-28.1)	P<0.001
- Other	13.2(7.9-21.2)	13.3 (7.5-22.6)	12.7 (7.4-21.1)	18.7 (14.2-24.1)	18.0 (13.7-23.3)	19.9 (13.3-28.7)	22.9 (18.3-28.3)	P=0.003
	P=0.003	P=0.002	P<0.001	P=0.06	P<0.001	P=0.001	P=0.002	
Education								
- <High School	22.5 (16.5-30.0)	22.1 (17.6-27.3)	23.3 (19.5-27.6)	27.5 (22.6-33.0)	27.9 (23.6-32.6)	24.7 (20.0-30.1)	27.8 (23.3-32.8)	P=0.06
- High School	21.6 (15.1-30.0)	19.6 (17.5-21.8)	24.7 (21.2-28.5)	25.8 (20.8-31.5)	25.4 (21.1-30.3)	27.5 (22.3-33.4)	34.1 (28.1-40.6)	P<0.001
- >High School	17.4 (13.2-22.7)	18.0 (15.4-20.8)	18.2 (15.1-21.9)	20.2 (17.2-23.4)	19.8 (16.9-23.0)	24.1 (18.2-31.3)	27.1 (23.4-31.2)	P<0.001
	P=0.25	P=0.21	P=0.006	P=0.01	P=0.01	P=0.42	P=0.05	
Poverty								
- >2x PL	17.7 (13.5-22.8)	16.3 (14.4-18.5)	17.1 (14.2-20.5)	18.3 (15.6-21.3)	18.5 (15.7-21.6)	22.4 (17.3-28.4)	26.3 (22.2-30.8)	P=0.001
- 1-2X PL	22.0 (16.4-28.8)	24.5 (20.8-28.6)	22.4 (18.0-27.7)	27.9 (23.8-32.3)	25.3 (21.6-29.5)	29.4 (21.8-38.4)	32.1 (28.3-36.2)	P=0.002
- < PL	24.3 (19.2-30.2)	25.2 (19.5-32.0)	34.6 (30.9-38.6)	31.1 (27.1-35.4)	33.2 (28.3-38.6)	29.8 (23.6-37.0)	37.0 (32.2-42.1)	P=0.002
	P=0.05	P=0.001	P<0.001	P<0.001	P<0.001	P=0.004	P=0.001	

Key:

Prevalence percentage with 95% confidence intervals (CI), computed using 2-year interview weights to provide estimates for the total US population and are age-standardized to the US 2000 Census population.

[a] percentage interpretation: of those aged 18-29, 34% reported marijuana use within the past 12 months. Poverty defined using poverty income ratio, accounting for family size

[b] P values test global within group differences in prevalence

[c] P values test overall trend in prevalence estimates in each category

NH = Non-Hispanic

PL = Poverty Level

NHANES = National Health and Nutrition Examination Survey

Table 3: Adjusted odds of past-year marijuana use in adults in the United States, NHANES 2005-2018

Demographic variable	Past-year marijuana use OR (95% CI)	P value
Age of participants		
- **18-29**	1.0 (reference)	
- 30-49	0.39 (0.36-0.43)	P<0.001
- 50-69	0.26 (0.22-0.30)	P<0.001
Gender		
- Female	1.0 (reference)	
- Male	1.67 (1.55-1.81)	P<0.001
Race		
- Non-Hispanic White	1.0 (reference)	
- Non-Hispanic Black	1.23 (1.09-1.39)	P=0.001
- Hispanic/Mexican	0.51 (0.44-0.58)	P<0.001
- Other	0.63 (0.54-0.73)	P<0.001
Education		
- < High School	1.0 (reference)	
- High School	0.95 (0.81-1.12)	P=0.58
- > High School	0.82 (0.73-0.93)	P=0.003
Poverty		
- >2x Poverty Level	1.0 (reference)	
- 1-2X Poverty Level	1.41 (1.24-1.59)	P<0.001
- < Poverty Level	1.69 (1.49-1.92)	P<0.001
Year of survey	1.10 (1.05-1.14)	P<0.001

Key:

Odds ratio (OR) with 95% confidence intervals (CI) computed using 12-year interview weights to provide estimates for the total US population and are age-standardized to the US 2000 Census population.

Poverty defined using poverty income ratio, which accounts for family size

Year covariate modelled as a continuous variable

NHANES = National Health and Nutrition Examination Survey

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*5*
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5
		(*b*) Describe any methods used to examine subgroups and interactions	5
		(*c*) Explain how missing data were addressed	5
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	5
		(*e*) Describe any sensitivity analyses	-
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5, 6
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6
		(b) Indicate number of participants with missing data for each variable of interest	5
Outcome data	15*	Report numbers of outcome events or summary measures	6
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6

		(*b*) Report category boundaries when continuous variables were categorized	6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	6
Discussion			
Key results	18	Summarise key results with reference to study objectives	6, 7
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8
Generalisability	21	Discuss the generalisability (external validity) of the study results	8
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	10

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Title

A Retrospective Cross-Sectional Analysis of the Changes in Marijuana Use in the United States, 2005-2018

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Marijuana, marijuana use, drug use, illicit, legalization

Abstract

Objectives: Understanding trends of marijuana use in the United States (US) throughout a period of particularly high adoption of marijuana-legalization, and understanding demographics most at risk of use, is important in evolving healthcare-policy and intervention. This study analyzes the demographic-specific changes in the prevalence of marijuana use in the US between 2005-2018.

Design, Setting and Participants: A fourteen-year retrospective cross-sectional analysis of the National Health and Nutrition Examination Survey (NHANES) database, a publicly-available biennially-collected national survey, weighted to represent the entire US population. A total of 35,212 adults between 18-69 years old participated in the seven-cycles of surveys analysed (2005-2018).

Primary Outcome Measured: Lifetime-use, first-use before 18-years-old, and past-year use of marijuana.

Results: The majority of adults reported ever using marijuana. While the overall prevalence of lifetime marijuana use remained stable (p=0.53), past-year use increased significantly between 2005-2018 (p<0.001) with highest rate of past-year use among younger age groups (p<0.001), males (p<0.001), and those with income below poverty level (p<0.001). Past-year use was commonest among non-Hispanic blacks, and less common among Hispanic/Mexican populations (p<0.002). Trends in past-year use increased among all age categories, males/females, all ethnicities, those with high-school education/above, and those at all income levels (p<0.01 for all).

Conclusions: While lifetime marijuana-use remained stable, past-year use significantly increased between 2005-2018. While past-year use remained commonest in younger age groups, males, non-Hispanic blacks and those with lower income; increasing trends in past-year use were significant for all age, sex, race and income categories, and for those with high-school education/above. With high adoption of marijuana-legalization laws during this period, our results suggest an associated increase in past-year marijuana use.

An accurate understanding of those most at risk can help inform decisions of healthcare policy makers and professionals, and facilitate a safe transition of changing marijuana legalization and use in the US.

Article Summary

- This is the most recent study of trends of marijuana use in the United States, during a period of particularly high rates of adoption of marijuana legalization laws.
- The National Health and Nutrition Examination Survey (NHANES) database is a publicly-available and nation-wide database. The NHANES database is weighted (standardized), to accurately represent the entire population of the United States.
- The NHANES database is self-reported, and limited by reporter bias.
- Missing data was primarily from participants who were older and female, potentially underestimating the true prevalence of marijuana use among this demographic.
- State-based legalization information and use amongst adolescents less than 18-years-old was not available, and could not be accurately correlated with changing trends of marijuana use.

Manuscript

Introduction:

While remaining illegal at the federal level in the United States (US), marijuana is now legal for recreational use by adults over the age of 21 in 11 states, and for medical use in 33 states (1, 2). With particularly high adoption rates of medical marijuana legalization between 2007 and 2016 (3), and increasing social acceptability of marijuana use (4-6), describing trends in use among different demographics in the US is important in understanding which populations might be most affected by changing laws.

Prior studies have described increases in both marijuana use and misuse trends since medical marijuana legalisation (4, 7, 8) in marijuana users both domestically and overseas (9). However, some studies have shown no changes to trends of past-year use since legalisation (10, 11), and others have shown only increases in marijuana misuse (11). A recent analysis even described a significant decrease in marijuana misuse disorder since legalisation (12). There have also been inconsistent reports of the demographics of those most affected by changing medical and recreational marijuana legalisation; some studies describing increasing trends across all gender, age and ethnic demographics (7), some showing trend changes particularly for young, black, and Hispanic men (11), and others showing changes particularly among older individuals (4, 6, 13). Importantly, changing trends in medical and non-medical marijuana use do not appear to be restricted only to states with changing marijuana laws (14), despite being higher in states where laws have been passed (7). An understanding of both the social and the economic cost-effectiveness of legalising marijuana (15, 16), coupled with an understanding of trends of changing use, may be useful for those working in public health, public policy, and healthcare, responsible for policy intervention or caring for populations most affected by marijuana use.

The current paper uses data from the US National Health and Nutrition Examination Survey (NHANES), a nationally-representative sample of US adults, to examine the most recent 12-year trends in marijuana use in the United States. Additionally, we examine sociodemographic factors associated with marijuana use. We explore recent literature regarding the cost-effectiveness of medical and social marijuana legalization, adding to the current body of literature important for those in policy, or caring for those most affected.

Methods:

The National Health and Nutrition Examination Survey (NHANES) is an on-going biennial cross-sectional survey representing a non-institutionalized civilian US population, performed by the National Centre for Health Statistics (NCHS) and Centres for Disease Control and

Prevention (CDC). NHANES has been a continuous survey program providing health statistics for the US since 1999, examining a nationally-representative sample of about 5,000 people each year, located in counties across the US. Study teams consisting of multilingual physicians, medical and health technicians, and dietary health interviewers conduct interviews and perform examinations, and information collected is intended to be used to determine the prevalence of major diseases and risk factors for diseases, and for health promotion and disease prevention; making NHANES an ideal data source to describe marijuana use trends in a nationally-representative population. The sample for the survey is selected to represent the US population of all ages. To produce reliable statistics, NHANES over-samples persons 60 and older, African Americans, and Hispanics (17).

In the present study, seven two-year cycles of NHANES survey data between 2005-2018 (inclusive) have been retrospectively analysed for baseline demographic information, and drug use questionnaire data. A total of 35,212 adults (US citizens) between 18-69 years old participated in the seven-cycles of surveys analysed. Of these, 32.9% had missing marijuana survey data. Those with missing data were significantly more likely to be older ($p<0.001$), female ($p<0.001$) and have less than high school education ($p<0.001$). Missing data was handled by pairwise deletion to optimize data available for analysis. Participants undergo a home interview, and a comprehensive physical examination in a mobile examination centre (MEC). The 2005-2018 NHANES protocol was approved by the National Centre for Health Statistics research ethics review board and written informed consent obtained from all participants.

Demographics data including age, gender, race/ethnicity, education and income were collected during the home interview. The drug use questionnaire was conducted in the mobile examination centre (MEC), and aimed to assess lifetime, past-year, and current usage of marijuana. Questions are self-administered using the Audio Computer-Assisted Self-Interview (ACASI) system. The ACASI was conducted in English, Spanish, Korean, Vietnamese, or Chinese (Mandarin and Cantonese). Participants reported lifetime use, age at first use and use within the past-year of marijuana.

Given the NHANES complex probability sampling design, 2-year interview weights computed by the NCHS were used to calculate prevalence estimates and 95% confidence intervals (Taylor linearization), age-standardized to the 2000 US Census population as recommended by the NCHS. Differences in prevalence estimates were compared using chi-square tests. Univariate regression models were used to test for significant linear trends while multivariable regression models were used to determine characteristics associated with recent marijuana use. Results at the $p<0.05$ level considered statistically significant. Statistical analysis was performed using STATA version 15.0 (StataCorp LP, College Station, TX).

Patient and public involvement: Patients or the public were not involved in the development of the research question or study design, in the measurement of the outcomes, or in the dissemination of results for the present study.

Results:

Overall, 53.5% (95% CI 52.8-54.1%) of the US adult population reported ever using marijuana between 2005-2018. The prevalence of lifetime marijuana use, and first use before the age of 18, remained stable between 2005 and 2018 (p=0.53 and p=0.68, respectively) (Table 1). Overall 22.6% (95% CI 22.1-23.1%) of US adults reported using marijuana within the last year. The weighted prevalence of past-year marijuana use increased significantly during the study period from 19.1% (95% CI 15.3-23.7%) in 2005/06 to 29.1% (95% CI 26.0-32.5%) (p=0.001) in 2017/18.

The prevalence of past-year marijuana use was higher among younger age groups (p<0.001), males (p<0.05), and those with income below poverty level (p<0.05) (Table 2). Past-year marijuana use was more common among non-Hispanic blacks, and less common among Hispanic/Mexicans (p<0.002 (excluding 2011/12 and 2017/18)). Between 2005 - 2018 the prevalence of past-year marijuana use increased among all age categories (p<0.001), males and females (p<0.001), all racial categories (p<0.01 for all groups), those with high school education or above (p<0.001 for both) and those at all levels of income (p<0.01).

Multivariate logistic regression analysis demonstrated higher odds of past-year marijuana use among younger age groups (p<0.001), males (p<0.001), non-Hispanic blacks (p<0.001), and those with income below the poverty level (p<0.001 for both) (Table 3). Past-year use was less likely among older individuals (p<0.001), and Hispanic and Mexican Americans (p<0.001) and those with higher levels of education (p=0.003) (Table 3).

Discussion:

The current study presents the most recent changes in marijuana use in the US during a period of particularly high legalization. It finds that while lifetime marijuana use, and first-use before the age of 18, has remained stable, the overall prevalence of past-year marijuana use has significantly increased over the 14-year period. While past-year use was still more common among younger age groups, males, non-Hispanic blacks and those with lower income, significant trends of increasing past-year use were seen in all age categories, males and females, all racial categories, highly-educated populations, and all income levels. Age-specific marijuana use trends in response to legalization laws has been studied elsewhere; but with inconsistent findings. There has been growing consensus that increasing recent-use of marijuana is seen among late to middle-aged adults after legalization (6, 13); a recent study

by Salas-Wright and colleagues showing trends of increasing past-year use among late to middle-aged adults in the US between 2002-2014 (5), findings that are supported by the present study. Whether this pattern of recent-use among older populations is associated with increasing marijuana-use for medicinal purposes (seen most prominently among older, white, male, and high-income populations in the US) (14), is unclear, and such data was not available for analysis in the present study. However, there has been less consensus about recent-use trends among adolescent populations. While a comprehensive study by Harpin and colleagues described no change in adolescent-use after legalization (10) (further supported by more recent findings (6)), a 2019 review by Bae and colleagues described increasing recent-use amongst adolescents in the US after legalization (8). Contrastingly, a 2016 US study by Grucza and colleagues describes that past-year marijuana use actually *decreased* among adolescents, during the highest periods of legalization (12). Information about marijuana-use trends in adolescents less than 18-years-old was not publicly available on NHANES for the present study, but it has been noted that over the 14-year study period, there has been no significant change in reported first-use before the age of 18 (table 1).

Our findings of younger, male, non-Hispanic black and lower income populations being most likely to use marijuana overall, are also consistent with previous findings not aforementioned (4, 7). Native American populations, those living in urban areas, and those living in western states, have also been shown to be more likely to have recently used marijuana; but this information was not available on NHANES in sufficient detail, for the present analyses.

In addition to demographic risk factors indicating potential marijuana use, an understanding of other risk factors is important for those involved in fields of public policy and healthcare. While age and gender remain somewhat inconsistently described risk factors, tobacco smoking is a demonstrated risk factor for marijuana use. Though not analyzed in the present study, a recent study demonstrated that current smokers have almost 6x increased odds of recent marijuana use compared to non-smokers (18), outlining another sub-population particularly at risk. Another group at risk of increasing marijuana use are non-medical users of prescription drugs (NMUPD). A recent study by Karjalainen and colleagues demonstrated significantly increasing trends of illicit drug use among NMUPD (92% of whom had used cannabis in the last year), that could not otherwise be explained by age or gender (19).

Important to consider in the context of the present findings is that marijuana-use trends may not to be restricted only to states with marijuana legalization. In 2017, Hasin and colleagues demonstrated significantly increased marijuana use both in states with and without marijuana legalization laws (4, 7), albeit fractionally higher in states where marijuana was legalized. However, a recent analysis by Han and colleagues demonstrated a significantly higher trend of increasing medical-marijuana use in states without legalization (AOR 1.4, 95% CI 1.05-1.90), compared to states with legalization (AOR 1.3, 95% CI 1.03-1.61) (14);

underlining the fact that evolving legalization laws are also of relevance to states where recreational and medical marijuana use remains illegal.

Exploring the economic and societal cost-effectiveness of marijuana legalization is also important for those involved in healthcare policy and decision making. Marijuana legalization was posited to lower price, increase availability, and thereby increase marijuana use (6), with early fears that profit motive would take precedence over public health issues (20, 21). The retail price of marijuana on the legal cannabis market had sharply fallen by almost 70%, just three-years after legalization in Washington State (22, 23). Some reports described an initial increase in self-reported street prices of marijuana in response to legalization as demand increased, by up to 36% (24), with limited price change thereafter. However, similarly to results aforementioned, medical legalization appears to have affected only adult marijuana use, with minimal significant changes to adolescent use (13). While studies of the effect of recreational marijuana legalization on its use are still emerging, there appears to be no/minimal effect on adolescent or college marijuana use (13). The passage of legalization laws also offers an important social justice benefit (25); by removing mechanisms for unfair, damaging disparities in law enforcement (26). While more permissive marijuana laws may appeal to social justice aims (reducing racial disparity in law enforcement), and increase revenue to state and local government through taxation (6), the public health trade-offs and overall costs of use-related adverse physical and psychosocial consequences (27) in response to changing laws remains difficult to accurately describe (6).

Strengths and Limitations: Strengths of our study include the size and heterogeneity of our population, the timespan, and the age-standardization of the NHANES data. Limitations to our study include reliance on self-reported data and reporter-bias, which may not have affected all demographics equally. Missing data was primarily from participants who were older and female, potentially underestimating the true prevalence of marijuana use among this demographic. Our dataset did not include youth aged 12-17 years old, a potentially at-risk population, nor include analysis of other risk factors associated with marijuana use (use of tobacco, or NMUPD). Certain ethnicity data (i.e. Native American identifiers) and geographical data (i.e. whether collected from states with or without legalization) were not available for analysis, nor was detail of marijuana use for medicinal or recreational purposes.

Conclusion:

Our primary two findings describing characteristics of those most at risk of using marijuana, and those where trends of use have most significantly increased, adds to the current body of literature and understanding of marijuana trends in the United States. Given ongoing changes to marijuana legalization in the US, with the evolving public perception of marijuana safety and accessibility, an accurate understanding of which populations are most likely to be

implicated, which additional predictive tools can identify those most at risk, and a balanced presentation of healthcare, social and economic costs of legalization, is warranted. Identification of these factors can help inform the decisions of healthcare policy makers and professionals, and facilitate a safe transition of evolving marijuana legalization and use in the US.

Author statements:

There are no competing or conflicting interests to declare by any of the authors.

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Author contributions:

Dr William Mitchell: Analysis plan, data interpretation, manuscript composition and editing, submission, correspondence

Dr Roma Bhatia: Analysis plan, data interpretation, manuscript editing

Dr Nazlee Zebardast: Analysis plan, data extraction, analysis and interpretation, manuscript composition

Data Statement:

Data is fully accessible from the following website:
https://wwwn.cdc.gov/nchs/nhanes/default.aspx

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Table 1: Prevalence of marijuana use in adults in the United States, NHANES 2005-2018

	2005-2006		2007-2008		2009-2010		2011-2012		2013-2014		2015-2016		2017-2018		P
	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	Total N	Prevalence % (95% CI)	
Lifetime use	2922	61.5 (57.2-65.7)	3255	60.5 (57.2-63.7)	3739	57.2 (53.0-61.3)	3333	59.9 (56.0-63.6)	3690	59.2 (55.6-62.7)	3422	57.3 (53.1-61.5)	3199	60.9 (57.9-63.7)	0.53
Age <18 at First used	1617	59.6 (56-7-62.7)	1799	60.7 (58.0-63.5)	1937	62.7 (59.0-66.4)	1770	60.1 (56.0-64.0)	1984	61.4 (58.8-63.9)	1715	60.1 (56.5-63.7)	1737	61.8 (57.1-66.3)	0.68
Past-year use	2922	19.1 (15.3-23.7)	3255	19.1 (17.5-20.7)	3739	20.6 (18.2-23.3)	3333	22.4 (19.8 - 25.2)	3690	22.3 (19.9-24.8)	3422	24.9 (20.0-30.6)	3199	29.1 (26.0-32.5)	0.001

Key:

N denotes unweighted total number of participants in each category

Prevalence percentage with 95% (CI), computed using 2-year MEC weights to provide estimates for the total US population, and age-standardized to 2000 Census population.

P values test overall trend in prevalence estimates in each category

NHANES = National Health and Nutrition Examination Survey

Table 2: Prevalence of self-reported past-year marijuana use in adults in the United States, by selected demographic factors, NHANES 2005-2018

	2005-2006	2007-2008	2009-2010	2011-2012	2013-2014	2015-2016	2017-2018	P value
	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	Prevalence % (95% CI)	
Age								
- 18-29	34.0[a] (26.7-42.0)	35.1 (30.0-40.6)	34.4 (30.7-38.3)	36.2 (31.7-41.1)	38.1 (35.1-41.2)	37.3 (30.4-44.8)	46.3 (42.5-50.2)	P=0.001[c]
- 30-49	16.1 (12.3-20.7)	16.2 (14.3-18.2)	17.5 (14.7-20.7)	17.0 (14.4-20.1)	16.3 (13.8-19.1)	21.1 (16.0-27.3)	24.6 (20.6-29.1)	P=0.001
- 50-69	10.5 (7.4-14.6)	8.1 (6.0-10.9)	10.3 (7.8-13.4)	15.5 (11.4-20.8)	14.3 (9.2-21.5)	18.0 (13.0-23.7)	17.0 (12.4-22.8)	P<0.001
	P<0.001[b]	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	
Gender								
- Male	24.8 (20.3-29.9)	23.1 (20.8-25.7)	24.8 (22.0-27.8)	27.3 (24.6-30.1)	26.3 (23.2-29.7)	29.2 (23.1-36.3)	32.0 (28.6-35.6)	P=0.001
- Female	13.6 (10.1-18.1)	15.1 (13.1-17.3)	16.3 (13.6-19.3)	17.3 (14.0-21.2)	18.2 (15.3-21.6)	20.6 (16.5-25.4)	26.3 (22.1-31.0)	P<0.001
	P<0.001	P<0.001	P<0.001	P<0.001	P=0.001	P<0.001	P=0.02	
Race								
- NH White	20.1 (15.6-25.7)	19.4 (17.7-21.3)	21.1 (18.4-24.1)	22.7 (19.4-26.3)	22.0 (18.3-26.3)	26.7 (20.4-34.1)	30.0 (25.5-34.5)	P<0.001
- NH Black	23.56 (18.4-29.1)	26.9 (22.6-31.7)	27.6 (24.6-30.9)	27.3 (22.1-33.2)	32.9 (29.8-36.1)	32.5 (28.8-36.5)	36.8 (32.5-41.3)	P<0.001
- Hispanic/Mexican	11.7 (8.3-16.2)	13.6 (9.8-18.5)	16.6 (13.0-20.9)	18.9 (15.2-23.2)	17.9 (15.5-20.6)	16.3 (13.1-20.2)	25.0 (22.2-28.1)	P<0.001
- Other	13.2(7.9-21.2)	13.3 (7.5-22.6)	12.7 (7.4-21.1)	18.7 (14.2-24.1)	18.0 (13.7-23.3)	19.9 (13.3-28.7)	22.9 (18.3-28.3)	P=0.003
	P=0.003	P=0.002	P<0.001	P=0.06	P<0.001	P=0.001	P=0.002	
Education								
- <High School	22.5 (16.5-30.0)	22.1 (17.6-27.3)	23.3 (19.5-27.6)	27.5 (22.6-33.0)	27.9 (23.6-32.6)	24.7 (20.0-30.1)	27.8 (23.3-32.8)	P=0.06
- High School	21.6 (15.1-30.0)	19.6 (17.5-21.8)	24.7 (21.2-28.5)	25.8 (20.8-31.5)	25.4 (21.1-30.3)	27.5 (22.3-33.4)	34.1 (28.1-40.6)	P<0.001
- >High School	17.4 (13.2-22.7)	18.0 (15.4-20.8)	18.2 (15.1-21.9)	20.2 (17.2-23.4)	19.8 (16.9-23.0)	24.1 (18.2-31.3)	27.1 (23.4-31.2)	P<0.001
	P=0.25	P=0.21	P=0.006	P=0.01	P=0.01	P=0.42	P=0.05	
Poverty								
- >2x PL	17.7 (13.5-22.8)	16.3 (14.4-18.5)	17.1 (14.2-20.5)	18.3 (15.6-21.3)	18.5 (15.7-21.6)	22.4 (17.3-28.4)	26.3 (22.2-30.8)	P=0.001
- 1-2X PL	22.0 (16.4-28.8)	24.5 (20.8-28.6)	22.4 (18.0-27.7)	27.9 (23.8-32.3)	25.3 (21.6-29.5)	29.4 (21.8-38.4)	32.1 (28.3-36.2)	P=0.002
- < PL	24.3 (19.2-30.2)	25.2 (19.5-32.0)	34.6 (30.9-38.6)	31.1 (27.1-35.4)	33.2 (28.3-38.6)	29.8 (23.6-37.0)	37.0 (32.2-42.1)	P=0.002
	P=0.05	P=0.001	P<0.001	P<0.001	P<0.001	P=0.004	P=0.001	

Key:

Prevalence percentage with 95% confidence intervals (CI), computed using 2-year interview weights to provide estimates for the total US population and are age-standardized to the US 2000 Census population.

[a] percentage interpretation: of those aged 18-29, 34% reported marijuana use within the past 12 months. Poverty defined using poverty income ratio, accounting for family size

[b] P values test global within group differences in prevalence

[c] P values test overall trend in prevalence estimates in each category

NH = Non-Hispanic

PL = Poverty Level

NHANES = National Health and Nutrition Examination Survey

Table 3: Adjusted odds of past-year marijuana use in adults in the United States, NHANES 2005-2018

Demographic variable	Past-year marijuana use OR (95% CI)	P value
Age of participants		
- **18-29**	1.0 (reference)	
- 30-49	0.39 (0.36-0.43)	P<0.001
- 50-69	0.26 (0.22-0.30)	P<0.001
Gender		
- Female	1.0 (reference)	
- Male	1.67 (1.55-1.81)	P<0.001
Race		
- Non-Hispanic White	1.0 (reference)	
- Non-Hispanic Black	1.23 (1.09-1.39)	P=0.001
- Hispanic/Mexican	0.51 (0.44-0.58)	P<0.001
- Other	0.63 (0.54-0.73)	P<0.001
Education		
- < High School	1.0 (reference)	
- High School	0.95 (0.81-1.12)	P=0.58
- > High School	0.82 (0.73-0.93)	P=0.003
Poverty		
- >2x Poverty Level	1.0 (reference)	
- 1-2X Poverty Level	1.41 (1.24-1.59)	P<0.001
- < Poverty Level	1.69 (1.49-1.92)	P<0.001
Year of survey	1.10 (1.05-1.14)	P<0.001

Key:

Odds ratio (OR) with 95% confidence intervals (CI) computed using 12-year interview weights to provide estimates for the total US population and are age-standardized to the US 2000 Census population.

Poverty defined using poverty income ratio, which accounts for family size

Year covariate modelled as a continuous variable

NHANES = National Health and Nutrition Examination Survey

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*5*
Bias	9	Describe any efforts to address potential sources of bias	5
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	5
		(*b*) Describe any methods used to examine subgroups and interactions	5
		(*c*) Explain how missing data were addressed	5
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	5
		(*e*) Describe any sensitivity analyses	-
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5, 6
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6
		(b) Indicate number of participants with missing data for each variable of interest	5
Outcome data	15*	Report numbers of outcome events or summary measures	6
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6

		(*b*) Report category boundaries when continuous variables were categorized	6
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	6
Discussion			
Key results	18	Summarise key results with reference to study objectives	6, 7
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8
Generalisability	21	Discuss the generalisability (external validity) of the study results	8
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	10

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.