Received: 22 February 2021 | Accepted: 29 July 2021

DOI: 10.1111/acer.14690

RESEARCH ARTICLE

ALCOHOLISM CLINICAL & EXPERIMENTAL RESEARCH

Forecasting future prevalence and gender differences in binge drinking among young adults through 2040

Jonathan M. Platt[1] | Justin Jager[2] | Megan E. Patrick[3] | Deborah Kloska[3] | John Schulenberg[3] | Caroline Rutherford[1] | Katherine M. Keyes[1]

[1]Columbia University, New York, New York, USA

[2]Arizona State University, Tempe, Arizona, USA

[3]University of Michigan, Ann Arbor, Michigan, USA

Correspondence
Jonathan M. Platt, Department of Epidemiology, Mailman School of Public Health, Columbia University, 722 West 168th Street, Suite 720D, New York, NY 10032, USA.
Email: jmp2198@cumc.columbia.edu

Funding information
National Institute on Alcohol Abuse and Alcoholism (R01AA026861)

Abstract

Background: Binge drinking among adolescents and young adults has changed over time, but patterns differ by age and gender. Identifying high-risk groups to target future efforts at reducing drinking in this population remains a public health priority. Forecasting methods can provide a better understanding of variation and determinants of future binge drinking prevalence.

Methods: We implemented regression-based forecasting models to estimate the prevalence and gender differences in binge drinking among cohort groups of U.S. young adults, ages 18, 23–24, and 29–30 through 2040. Forecasting models were adjusted for covariates accounting for changes in demographic, Big-5 social roles (e.g., residential independence), and drinking norms and related substance use, to understand the drivers of forecasted binge drinking estimates.

Results: From the last observed cohort group (years varied by age) through 2040, unadjusted binge drinking prevalence was forecasted to decrease from 26% (95% CI: 20, 33%) (2011–15) to 11% (95% CI: 4, 27%) at age 18, decrease from 38% (95% CI: 30, 45%) (2006–2010) to 34% (95% CI: 18, 55%) at ages 23/24, and increase from 32% (95% CI: 25, 40%) (2001–2005) to 35% (95% CI: 16, 59%) at ages 29/30. Gender-stratified forecasts show a continuation in the narrowing of binge drinking prevalence between young men and women, though the magnitude of narrowing differs by age. Estimated trends were partially explained by changing norms regarding drinking and other substance use, though these indirect effects explained less of the total trend as age increased.

Conclusions: Understanding how covariates influence binge drinking trends can guide public health policies to leverage the most important determinants of future binge drinking to reduce the harm caused by binge drinking from adolescence to adulthood.

KEYWORDS
adolescents, binge drinking, forecasting, gender differences, young adults

INTRODUCTION

Binge drinking is the consumption of a large amount of alcohol over a short period, typically defined as 5 or more drinks in a row, and is implicated in more than half of alcohol-attributable deaths in the United States (Naimi et al., 2003), through both acute and chronic health conditions (Chikritzhs et al., 2001). Reducing the prevalence of binge drinking is a significant public health goal, and efforts to do so must be guided by an understanding of the population-level variation and determinants of binge drinking over time.

There is evidence of substantial variation in binge drinking prevalence over time, though patterns differ by age. Among high school seniors, binge drinking has decreased across cohorts from 1976–2019 (Miech et al., 2020; Schulenberg et al., 2020). Among young adults, binge drinking trends have been uneven across cohorts. Decreasing trends have been consistent among 19- to 20-year-olds especially since 2005, while among those aged 21–30, binge drinking increased through about 2006–2010 and then leveled off in more recent years (Schulenberg et al., 2020). Gender differences in alcohol use have also been diminishing. Adolescent girls are now as likely as boys to initiate alcohol consumption and binge drink (Cheng & Anthony, 2017; Cheng et al., 2016; Miech et al., 2020), and increases in binge drinking prevalence have been greater in young adult women than men (Cheng & Anthony, 2017; Patrick et al., 2019; Slade et al., 2016; White et al., 2015). Research to identify causes of these changes is limited, but trends appear to be related to changing disapproval of alcohol (Keyes et al., 2012), as well as gender-specific changes in traditional gender roles (Seedat et al., 2009), attitudes toward drinking (Kuntsche et al., 2011), and the social contexts of drinking (Holmila & Raitasalo, 2005).

Together, trends suggest binge drinking should remain an important focus for future public health priorities. To galvanize support and optimize the resources needed to meet this priority, future levels of binge drinking can be estimated using forecasting models, which predict dynamic changes in health outcomes under prespecified conditions (detailed summaries of forecasting methods can be found here (Soyiri & Reidpath, 2012)). Forecasting models have been used to understand the future burden of other health conditions under current policies and conditions, such as infectious disease (Choi et al., 2016; Chretien et al., 2014), cancer (Bray & Møller, 2006), injuries (Ladrón de Guevara et al., 2004; O'Connor, 2005), and obesity (Robinson et al., 2013); however, they are underutilized in substance use research. One recent study forecasted the prevalence of alcohol-related hospital admissions, but estimates were limited to 2021 (de Vocht et al., 2017).

Also, most forecasting applications focus solely on variation by observed age, period, and cohort patterns, without consideration of other known determinants of observed rates. Historical trends in binge drinking are influenced by numerous factors, including parental socio-economic factors in adolescence (Lemstra et al., 2008; Patrick et al., 2012), alcohol norms and friends' alcohol use (Keyes et al., 2012), use of cigarettes and marijuana (Bobo & Husten, 2000; Midanik et al., 2007; Weitzman & Chen, 2005), and the fulfillment of young adult social roles in the transition to adulthood (Jager et al., 2015). These "Big 5" social roles (i.e., attending college, finding employment, residential independence, getting married, and having children) reflect the historical context of labor force and social structures and the normative expectations faced during this period of life (Settersten Jr, 2007), in ways that are associated with binge drinking (Bachman et al., 1997). Finally, binge drinking prevalence may vary according to the demographic composition of the population. Incorporating information from these covariates, including how they have changed over time, serves 2 key purposes. First, it informs more accurate forecasting models, overall and for key population groups, and second, it highlights important modifiable targets to reduce future binge drinking levels. A key purpose of forecasting is to guide effective public health policies and understanding how covariates influence binge drinking trends can be used to target those policies to effectively address the most important determinants of future binge drinking.

The current study developed forecasting models to estimate binge drinking prevalence and gender differences in cohorts of young adults from 2016 through 2040 and to understand the role of social and demographic determinants of binge drinking in forecasted estimates.

MATERIALS AND METHODS

Sample

The Monitoring the Future (MTF) study includes nationally representative samples of approximately 15,000 high school seniors (12th grade) surveyed annually since 1976 (Miech et al., 2020). From the annual survey, 2450 students are randomly selected for longitudinal follow-up, with oversampling for students who report drug use (Schulenberg et al., 2020). Those selected begin follow-up assessments either 1 (modal age 19) or 2 (modal age 20) years later and are followed biennially thereafter through modal age 29/30 (Schulenberg et al., 2020). An Institutional Review Board of University of Michigan approved the study.

Respondents were grouped by cohort and age, in order to estimate prevalence across cohorts stratified by age. Cohorts were defined based on the year that respondents were seniors in high school and grouped in 5-year intervals. Observed cohort groups ranged from 1976–1980 to 2011–2015; forecasted cohorts continued to 2036–2040. Age was defined over the study period as the modal age(s) of respondents at baseline (age 18), third follow-up (ages 23–24), and sixth follow-up (ages 29–30). Ages were selected to broadly represent the beginning, middle, and end of the transition to adulthood (Waters et al., 2019).

Because of the longitudinal study design, the most recent observed cohort group (and the first forecasted group) differed by age. For ages 23–24, the first cohort group was surveyed in 1981 and the most recent observed cohort group was surveyed in 2006–2010, so forecasts begin with the 2011–2015 cohort group. At ages 29–30, the first cohort group was interviewed in 1986–1990 and the most recent observed cohort group was 2001–2005, and forecasts begin with the 2006–2010 cohort group (see Figure 1). The observed analytic sample sizes across all groups comprised 97,812 respondents at age 18, 85,559 respondents at age 23–24, and 73,298 respondents at age 29–30.

Variables

Binge drinking was defined at each wave as any versus none, based on their response to the question, "How many times have you had five or more drinks in a row over the past two weeks?"

To better understand determinants of binge drinking trends, we compared observed binge drinking trends without vs. with adjustment for 3 sets of covariates. Covariates were selected based on a priori associations with binge drinking and evidence of variation over time and included (1) baseline socio-demographics, including sex (male, female), high school GPA (9=A (93–100) 8=A- (90–92) 7=B+ (87–89) 6=B (83–86) 5=B- (80–82) 4=C+ (77–79) 3=C (73–76) 2=C- (70–72) 1=D (69 or below)), father's and mother's highest reported education (<HS degree, HS degree with/without some college, college degree or more), race/ethnicity (non-Hispanic Black, non-Hispanic White, Hispanic, Other (including multiple races)); (2) (binary) young adult Big-5 social roles (attend 2-/ 4-year college full-time, residential independence, have children, married, work full-time); and (3) drinking norms and substance use (disapprove of having 5 or more drinks on the weekend (1: Don't Disapprove–3: Strongly Disapprove), how many of your friends drink (1: None–5: All), perceived risk of 5 or more drinks on the weekend (1: No Risk–4: Great Risk), use of marijuana and tobacco (past-year marijuana use (yes/no), past-year cigarette use (yes/no)). Covariates were lagged by 1 year to establish temporality.

Baseline socio-demographics were recorded at age 18. Among big-5 social roles, college attendance, residential independence, and working full-time were only included among the 23–24 and 29–30 age groups. For all other variables (i.e., have children, married, drinking attitudes, and marijuana/cigarette use), responses varied at each age.

Attrition and missing data

Three variables were missing more than 10% of possible responses at age 18: marijuana use (17%), perceived risk of binge drinking (41%), and binge drinking disapproval (52%) (see Table S1). There were 2 main sources of missing data, study attrition and planned missingness.

To account for attrition, all models included attrition weights, calculated as the inverse of the probability of participation at each age group (i.e., 23–24, 29–30), based on the following baseline characteristics: gender, race/ethnicity, college plans, truancy, high school grades, number of parents in the home, religiosity, parental education, alcohol use, cigarette use, marijuana use, other illicit drug use, region, cohort, and sampling weight (correcting for oversampling of age 18 substance users).

Planned missingness arose due to the MTF study design. To reduce the survey participation burden, certain survey questions are only administered to 1 of 6 randomly assigned subsamples (i.e., forms), in addition to a core set of questions. This planned missingness study design feature resulted in some data that were missing completely at random. To maximize the study sample size, data were multiply imputed across forms. Where data are assumed to be missing completely at random, this approach has been shown to be a valid method to reduce type II error rates (Little & Rhemtulla, 2013; Noble & Nakagawa, 2018; Rhemtulla & Little, 2012; Wood et al., 2019), even when up to 90% of data are missing (Madley-Dowd et al., 2019). Twenty models were imputed using chained equations, based on all observed exposure, covariate, and outcome data and combined with corrected standard errors (Rubin, 2004). Covariate distributions did not vary between unimputed and imputed datasets (see Table S1).

Analysis

We utilized a linear regression-based approach to build forecasting models in a series of 8 steps. All steps were completed separately for each age group, and ages 23–24 and 29–30 included age 18 values as additional covariates to utilize the longitudinal data. We describe each step as applied to 1 covariate (GPA) for clarity.

	Year (1) 76-80	(2) 81-85	(3) 86-90	(4) 91-95	(5) 96-00	(6) 01-05	(7) 06-10	(8) 11-15	(9) 16-20	(10) 21-25	(11) 26-30	(12) 31-35	(13) 36-40
Age						*Cohort group (base year)*							
18	1	2	3	4	5	6	7	8	9	10	11	12	13
23-24		1	2	3	4	5	6	7	8	9	10	11	12
29-30			1	2	3	4	5	6	7	8	9	10	11
n	11888	12226	12331	12337	12266	12250	12261	12253	12200[a]	12200	12200	12200	12200

[a] forecasted population sizes are based on the approximate average sample size of observed cohort groups. Dotted red line delineates observed/forecasted values.

FIGURE 1 Correspondence between age, cohort group, and year in observed and forecasted samples. Note: [a]Forecasted population sizes are based on the approximate average sample size of observed cohort groups. Dotted red line delineates observed/forecasted values

Model fitting and validation

Prior to building the forecasting model, we identified the best-fitting model as a combination of the a priori specified covariates. Model fit was assessed using likelihood-ratio tests of nested models, sequentially adding demographic, big 5, and alcohol norms/other substance use covariates. To examine the validity of the forecasting model, we estimated the accuracy of the model in predicting observed binge drinking prevalence. To do this, we removed the observed binge drinking data for the 3 most recently observed cohort groups (e.g., 2001–2005, 2006–2010, and 2011–2015 for age 18) and then forecasted binge drinking prevalence using multiple imputation based on the best-fitting regression model. We compared the predicted vs. observed binge drinking values for these cohorts. The results are shown in Table S2. The best-fitting prediction model included all covariates, for which the area under the curve (AUC) ranged from 0.79 to 0.80 for each age group, indicating good accuracy.

Build a forecasting model with observed covariates

First, we visually assessed variation across cohort group in each covariate to determine the functional form of change (e.g., no change, linear increase/decrease, nonlinear). Covariates were standardized based on deviation of the within-cohort mean from the total sample mean (i.e., grand mean). While the values of these variables are not interpretable, they facilitate the visualization of trends over time and comparison between variables. Subsequent steps utilized unstandardized variables so that model estimates would be interpretable. With the specified functional form, we estimated the magnitude of change over time by regressing each covariate on cohort. For example, the unstandardized cohort mean GPA increased from 5.58 to 6.52 (on a scale from 1–9), across observed cohort groups. The linear regression estimate was 0.15 (SE = 0.003).

Second, the cohort-level covariate means were extrapolated based on the form of change across cohort group (see step 1) and the previous group mean, starting with the baseline cohort (2001–05, 2006–10, 2011–15, depending on the age group). For example, the average GPA has been linearly increasing by 0.15 points per cohort group, and the baseline (2011–15) mean was 6.52, so the 2016–20 mean was 6.52 + 0.15=6.67. If a variable did not meaningfully change across cohort, the baseline value was carried forward. For binary variables, the covariate means were assigned on the logit scale.

Third, using these extrapolated means, we simulated each individual's covariate values in the forecasted cohorts. Each forecasted cohort group included 12,200 individuals (i.e., the average size of observed cohort groups). Individual covariate values were simulated from a distribution with the cohort mean (see step 2) and the standard deviation of the baseline cohort group. For example, the 2016–20 cohort GPA was simulated from $X \sim N(6.67, 1.93)$. Skew and kurtosis measures indicated that continuous variables were approximately normally distributed and were thus simulated from a normal distribution; binary variables were simulated from a binomial distribution.

Fourth, a column for binge drinking status was added to the simulated dataset, with all values set to missing, and merged the simulated and observed datasets.

Multiply impute binge drinking in forecasted cohorts

Fifth, we pooled the multiply imputed datasets with corrected standard errors (Rubin, 2004) to estimate binge drinking prevalence in forecasted cohort groups, converting the log odds to prevalence. We imputed 20 datasets using chained equations, combined with corrected standard errors, averaging coefficient vectors, variance–covariance matrices, and adding a nonnegative correction to variance–covariance matrices inversely proportional to the predictive ability of the imputation models, effectively widening confidence intervals where missing data values are poorly predicted by observed data (Pigott, 2009). To reflect the uncertainty around the forecasted point estimates, the model residuals were adjusted under the assumption of uncorrelated residuals, using the formula $\hat{\sigma}_h = \hat{\sigma}\sqrt{h}$, where $\hat{\sigma}_h$ is the standard deviation of the h-step forecast distribution, and $\hat{\sigma}$ is the residual standard deviation (Hyndman & Athanasopoulos, 2018).

Sixth, we added sequential covariate sets to estimate binge drinking trends accounting for concurrent patterns in (a) demographics; (b) (a and) Big-5 social roles; and (c) (a, b, and) drinking norms/substance use. This approach was to understand what might explain variation in binge drinking trends and was analogous to a decomposition approach to estimate distinct mediation pathways, rather than a confounding elimination strategy. The unadjusted estimates refer to the total cohort group trends (i.e., the effect of cohort on binge drinking through all pathways), whereas the covariate-adjusted estimates refer to the effect of cohort trends in binge drinking, not due to the model covariates (i.e., the controlled direct effect). We also calculated the relative difference in binge drinking prevalence between unadjusted and adjusted prevalence estimates, to quantify the effect of these covariates on binge drinking trends. For example, if unadjusted binge drinking forecasted prevalence estimates are greater than those adjusted for big-5 social roles, this would suggest that those covariates are important determinants of future binge drinking, and the percent change would represent the proportion of the estimates that were due to big-5 social role patterns. To reflect this interpretation, we subsequently refer to unadjusted and adjusted model estimates as total-effect and direct-effect estimates, respectively.

Seventh, we repeated step 7 in models stratified by gender to estimate gender differences in forecasted binge drinking.

All analyses were implemented in R (version 4.0.2), and multiple imputation was implemented with the "MICE" package (Buuren & Groothuis-Oudshoorn, 2010). Syntax to implement these steps can be found in the Supplementary materials.

ALCOHOLISM CLINICAL & EXPERIMENTAL RESEARCH

RESULTS

Trends in social determinants of binge drinking across cohorts

Figure 2 and Tables S3–S5 present trends across cohorts in covariates used to forecast binge drinking for age 18, 23–24, and 29–30 groups. The cohort trends were linear for all covariates, except non-Hispanic Black prevalence, which did not change over the study period. Cohort trends were generally similar for all ages, except perceived risk and disapproval of binge drinking, which increased at ages 18 and 23–24 and decreased at ages 29–30.

Forecasted binge drinking prevalence trends

Total- and direct-effect binge drinking prevalence trends across cohort are presented graphically in Figure 3 and estimates are provided in Table S6. For parsimony, we focus on contrasts in binge drinking estimates between models with no covariates versus those with all covariates. Differences between these 2 models were most appreciable, and the latter model had the best fit to the data. Sequentially adjusted model estimates are presented in Figures S1–S3.

Among age 18 respondents, total-effect (i.e., unadjusted) binge drinking prevalence decreased from 48% (95% CI: 42–55%) in the 1976–1980 cohort to 11% (95% CI: 4–27%) in the 2036–2040 cohort group. In the direct-effect (i.e., fully adjusted) models, age 18 decreases in binge drinking prevalence were much smaller, decreasing to 36% (95% CI: 14–65%) in the 2036–2040 cohort group. Among age 23–24 respondents, total-effect observed binge drinking prevalence decreased from 41% (95% CI: 34–49%) in the 1981–1985 cohort group to 34% (95% CI: 18–55%) in the 2036–2040 cohort group. In the direct-effect models, observed and forecasted binge drinking prevalence estimates ranged from 41% (95% CI: 33–51%) to 45% (95% CI: 36–54%) across cohort groups, with no clear pattern of change over time. Among age 29–30 respondents, total observed binge drinking prevalence was 29% (95% CI: 23–36%) in the 1986–1990 cohort group and 35% (95% CI: 16–59%) in the 2036–2040 cohort. The direct-effect binge drinking prevalence was 34% (95% CI: 15–59%) in the 2036–2040 cohort group.

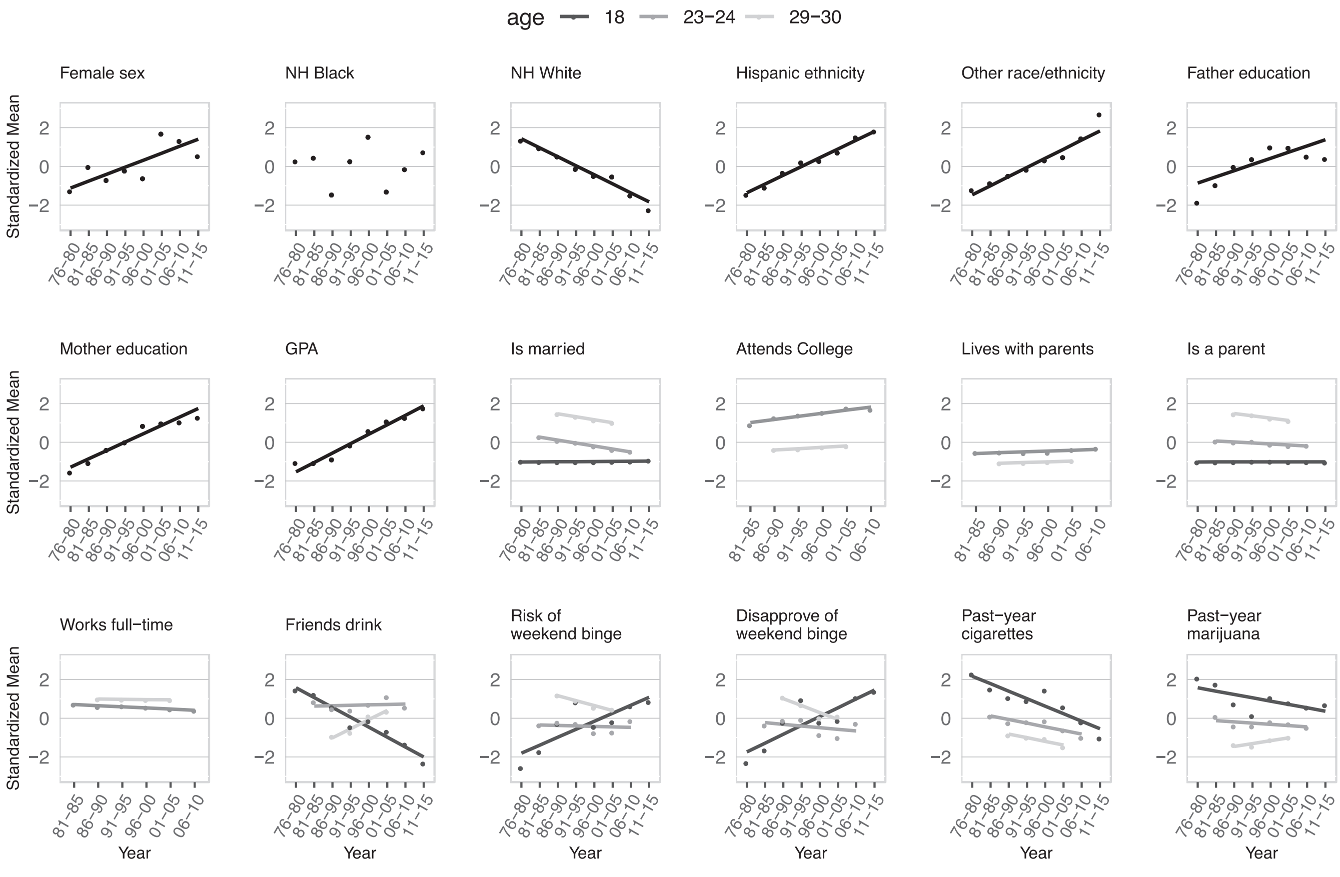

FIGURE 2 Ages 18, 23–24, and 29–30 observed trends across cohorts in covariates used to forecast binge drinking. Note: Standardized means correspond to the average value within each cohort, where 0 equals the average value across the total sample; no line indicates no change across cohorts; years vary by age, based on the number of observed cohorts; NH = non-Hispanic; Friends drink = How many of your friends drink alcoholic beverages? (None–All), Risk of weekend binge = How much do you think people risk harming themselves (physically or in other ways) if they have 5 or more drinks once or twice each weekend (No Risk–Great Risk), Disapprove of weekend binge = Do you disapprove of people (18 or older) having 5 or more drinks once or twice each weekend (Don't Disapprove–Strongly Disapprove)

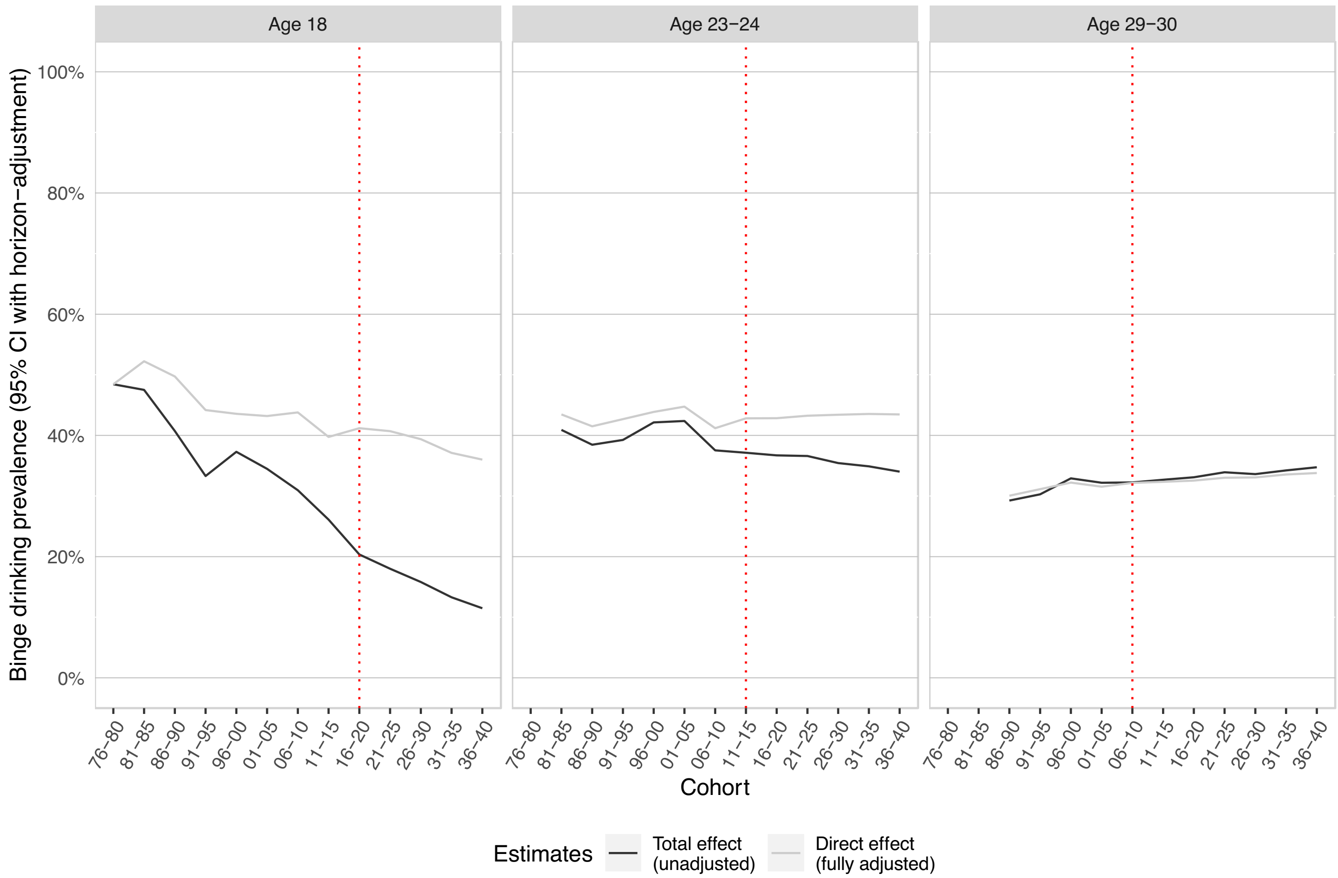

FIGURE 3 Ages 18, 23–24, and 29–30 binge drinking prevalence (with 95% prediction intervals) from 1976–2040. Adjusted for demographic, big 5 social roles, and drinking norms/substance use covariates. Note: Dotted red line depicts the beginning of the forecasted estimates; direct-effect models adjusted for demographics: sex, high school GPA, father's and mother's highest reported, race/ethnicity; Big-5 social roles: attending college full-time, not living with parents, have children, married, work full-time; Drinking norms & other substance use: disapproval of having 5 or more drinks on the weekend, proportion of friends who drink alcohol, perceived risk of 5 or more weekend drinks, and past-year use of marijuana and cigarettes

The relative difference between total- and direct-effect estimates are presented in Table S8 (shown visually in Figure 3), quantifying the magnitude of the effect that each set of covariates had on binge drinking rates for each cohort group. Compared with direct-effect estimates in the first cohort group, the total-effect estimates were 227% lower for age 18 (i.e., 11% vs. 36%), 26% lower for ages 23–24, and 3% higher for ages 29–30 in the 2036–2040 cohort group.

Gender-stratified estimates

Gender-stratified binge drinking prevalence estimates for the 1976–1980 through 2036–2040 cohort groups are presented in Figure 4 and Table S7. At age 18, total-effect binge drinking decreased from 60% (95% CI: 56–79%) to 14% (95% CI: 5–38%) among men and from 37% (95% CI: 30–45%) to 9% (95% CI: 2–23%) among women. After adjustment, direct-effect estimates were 44% (95% CI: 16–76%) and 29% (95% CI: 10–60%) among men and women in 2036–2040 cohort group. At ages 23–24, total-effect binge drinking decreased from 54% (95% CI: 44–63%) to 40% (95% CI: 20–65%) among men and decreased from 29% (95% CI: 21–37%) to 28% (95% CI: 12–51%) among women. After adjustment, direct-effect estimates were 54% (95% CI: 46–62%) among men and 33% (95% CI: 46–62%) among women in 2036–2040 cohort group. At ages 29–30, total-effect binge drinking trends did not change from 41% (95% CI: 34–49%) among men and increased from 20% (95% CI: 12–32%) to 28% (95% CI: 11–56%) among women. Compared with total effects, direct-effect binge drinking estimates were 43% (95% CI: 19–71%) among men and 24% (95% CI: 8–52%) among women in 2036–2040 cohort groups. The relative difference between total- and direct-effect estimates stratified by gender is presented in Table S8.

DISCUSSION

Forecasting provides useful information to estimate future burden from health outcomes and behaviors and understand important determinants of future health patterns, in order to determine resources and priorities accordingly. To our knowledge, this is the first paper to

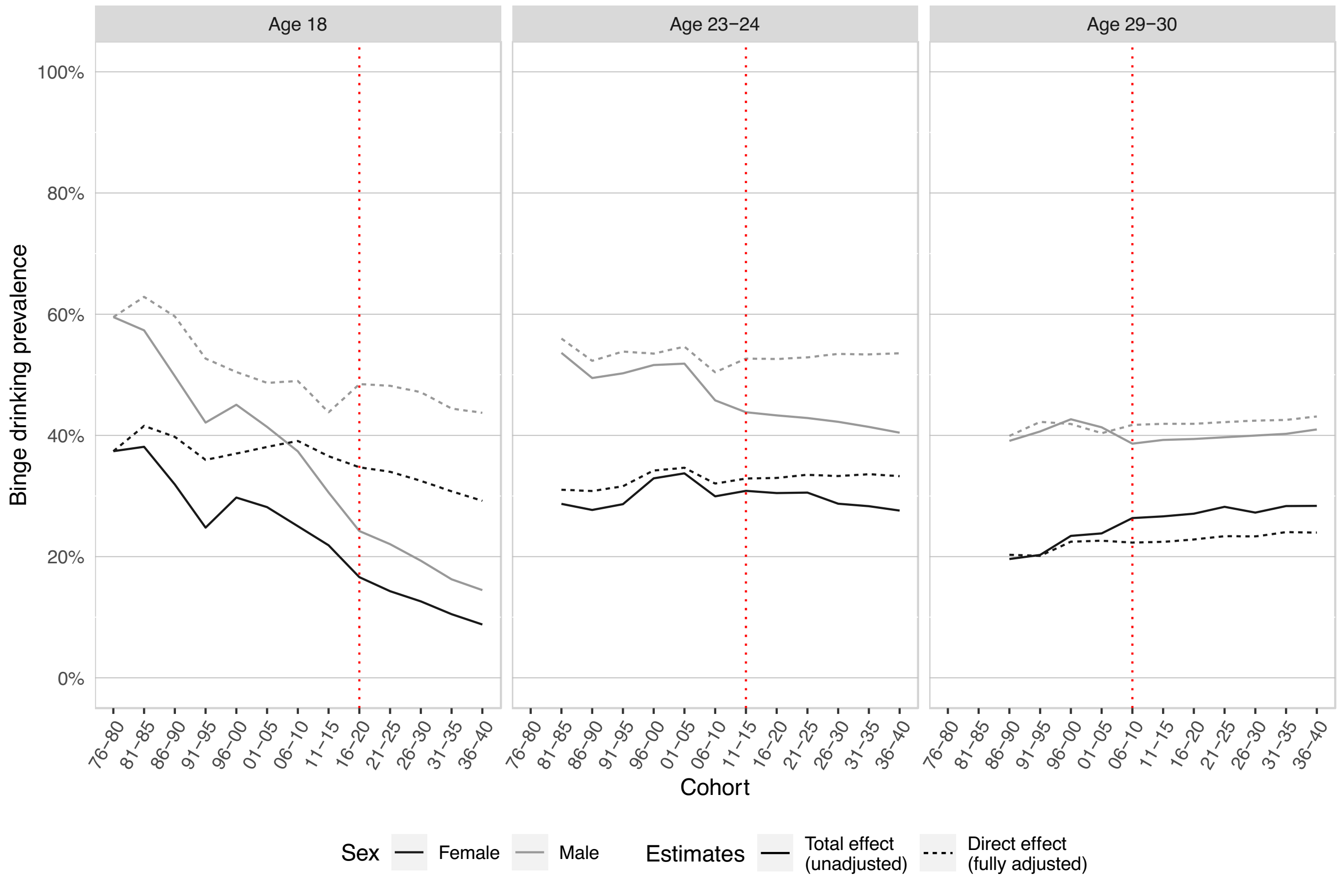

FIGURE 4 Ages 18, 23–24, and 29–30 binge drinking prevalence from 1976–2040, stratified by sex. Adjusted for demographic, big 5 social roles, and drinking norms/substance use covariates. Note: dotted red line depicts the beginning of the forecasted estimates; demographics: sex, high school GPA, father's and mother's highest reported, race/ethnicity; Big-5 social roles: attending college full-time, not living with parents, have children, married, work full-time; drinking norms & other substance use: disapproval of having 5 or more drinks on the weekend, proportion of friends who drink alcohol, perceived risk of 5 or more weekend drinks, and past-year use of marijuana and cigarettes

apply forecasting methods to estimate future binge drinking trends in young adults. We highlight 4 key findings. First, in line with observed trends in binge drinking, total-effect rates of binge drinking through 2040 were estimated to continue to decline at age 18, holding steady at ages 23–24, and increase slightly at ages 29–30. Second, these trends were partially due to changing drinking norms and related substance use, though these indirect effects explained less of the total trend as age increases. Third, gender-stratified forecasts suggested further convergence in binge drinking prevalence between men and women, though trends in base rates differ by age. Fourth, gender-specific convergences were partially due to changing trends in binge drinking norms and cigarette and marijuana use.

Binge drinking declined substantially among 18-year-olds from 1976 to 2015 (Miech et al., 2019; Patrick et al., 2017; Schulenberg et al., 2019), and our models extend those trends to forecast further decline, falling to nearly 10% by 2040. This echoes previous work in this (Patrick et al., 2019) and similar samples (Grucza et al., 2009), showing decreases among young adults. Among ages 23–24, similar trends were also forecasted, though less sharply across cohorts. Binge drinking has typically peaked between ages 20–23 (Patrick et al., 2019); therefore, decreasing trends in this age group are a hopeful sign that binge drinking will attenuate during the transition to adulthood. On the other hand, we found continued increases in binge drinking among ages 29–30, concordant with recent evidence of an upward shift in the peak ages of binge drinking (Patrick et al., 2019). While relatively small (i.e., from 30–35% over 13 cohorts), this trend suggests that strategies to reduce binge drinking should be prioritized throughout early adulthood.

Across all ages, adjustment for several sets of sociodemographic determinants of binge drinking suggested that the strongest drivers of past and future binge drinking patterns are related to alcohol norms, peer use, and use of cigarettes and marijuana. In other words, had these variables not changed in the way they did, change in binge drinking trends would have been far less substantial. This builds on prior work showing the importance of binge drinking disapproval (Keyes et al., 2012), by examining multiple measures of norms about substance use, and forecasting how these measures may influence future rates of binge drinking. By age, we found evidence that trends in drinking norms have been reversing across early adulthood. Specifically, disapproval and perceived risk of binge drinking have been increasing among 18-year-olds and decreasing among ages 29–30 (age 23–24 time trends are somewhat static). Likewise, trends in any drinking among the respondent's friends have followed similar patterns. Concordant with other surveys, we found that use of cigarettes and marijuana also decreased across all ages. Use of these substances often co-occurs with alcohol (Bobo & Husten, 2000; Midanik et al., 2007; Weitzman & Chen, 2005), and while their decreasing popularity can be considered public health successes in their own right, they also appear to be meaningfully related to decreasing binge drinking trends. Additionally, the effects of adjusting for covariates diminished with age, suggesting that either any cohort effects at age 29–30 are completely mediated by age 18 trends, or different determinants of binge drinking behavior are more important at later ages (e.g., income). Taken together, these findings suggest that future prevention activities should continue to focus on changing norms among young adults and consider additional determinants of binge drinking trends that may be more salient among adults approaching middle adulthood.

Gender-stratified forecasts show a continuation in the narrowing of binge drinking prevalence between young men and women (Keyes et al., 2019); however, patterns in the gender-specific base rates changed with age. Among those ages 18 and 23–24, the narrowing was due to greater decreases in binge drinking among men than women, while among ages 29–30, the narrowing was driven by greater increases in binge drinking among women than men. In line with prior research (Keyes et al., 2019), these estimates highlight the need to integrate historical and developmental perspectives to accurately describe age differences in the present and future burden of binge drinking. Attenuating alcohol use among women as they approach middle adulthood should be a priority.

At all ages, adjustment for alcohol use norms and co-occurring substances diminished the observed gender convergence, which implies that historical variation in these covariates has been a partial driver of gender convergence. That is, had covariates not changed the way they did, gender convergence would be less evident at every age. However, there were distinct patterns in rates among men and women. At ages 18 and 23–34, trends in total effects (i.e., unadjusted estimates) were lower than direct effects (i.e., covariate-adjusted estimates) for both genders; however, the gap between total effects and direct effects was larger for men than women. However, at ages 29–30, trends in total effects were lower than direct effects for males but higher for females, suggesting that for females the changes in binge drinking determinants have increased binge drinking levels. This finding for females is contrary to what was found at other ages; however, it is consistent with prior research that has found changing acceptability of heavy alcohol use among adult women (Keyes et al., 2012; Skog, 1985). These norms have changed in concert with (or as a result of) targeted marketing toward women in this age group through marketing (Kindy & Keating, 2016; Petticrew et al., 2017) and targeted social media campaigns (Lyons et al., 2017). These trends appear to be especially strong among women with higher socio-economic status (Kuntsche et al., 2011; Lui et al., 2018), a group which has grown substantially during the study period, driven by increasing college attendance and employment.

This study highlighted the role of modifiable risk factors in influencing binge drinking prevalence. Norms may be modified through targeted interventions to increase knowledge of the danger and decrease the social acceptability of heavy alcohol use, adapting prior research on college campuses (Borsari & Carey, 2003; Scott-Sheldon et al., 2009) as well as decades of successful smoking cessation interventions (Bruvold, 1993; Viswesvaran & Schmidt, 1992). The impact of decreased cigarette and marijuana use on binge drinking suggests that policies to diminish the use of one harmful substance may have spillover effects for other co-occurring substances. These types of interventions are consistently needed, in order to counteract the actions of alcohol producers to influence norms for alcohol use in emerging priority groups (e.g., young adult women).

Limitations

These findings should be interpreted in light of the following limitations. All survey responses were based on self-report, the sample design excluded high school dropouts, and attrition was higher among substance users than nonusers. These issues are addressed by using attrition weights; however, there may be residual selection bias. There were additional limitations concerning the forecasting approach. First, forecasting introduces inherent uncertainty into regression models, which in the MTF were amplified by the imputation-based forecasting procedure. However, we accounted for this uncertainty given the MTF data structure at 3 points in the methods: (1) Future covariate values are randomly chosen (from a known distribution); (2) individual forecasted binge drinking status is multiply imputed with 20 imputed datasets, which are then pooled and corrected to avoid spuriously small standard errors; and (3) confidence intervals were horizon-adjusted, to acknowledge the uncertainty in forecasting long-term future values. Furthermore, the utility of forecasting methods is not to provide one correct estimate, but rather predict general trends. We have transparently described how we derived and validated model estimates to understand the levels of morbidity that might be expected, given patterns of several sets of binge drinking determinants. Second, we sought to identify the potential effect of determinants of future binge drinking by lagging covariates; however, lag time may differ for specific determinants (i.e., short for norms, longer for having children). In general, prior research suggests that norm changes typically precede behavior changes (Borsari & Carey, 2003) and interventions that reduce multiple comorbid substance use outcomes would be highly effective from a public health standpoint. Third, from 1976 to 2004, racial identification was limited to one response per person. Beginning in 2005, respondents were able to select multiple races; however, to maintain consistency across all years of observation, we limited race to a single response and included multiple responses in the "Other" category. Future research should include a more detailed study of binge drinking trends among individuals who identify as having multiple races. Finally, unmeasured covariates may be important determinants of forecasted estimates. However, the initial validation steps suggested that the forecasting model performed well overall. While beyond the scope of the current analysis, future research could optimize forecasting models by age and gender, incorporating more variables and effect modifiers.

Fourth, in building the forecasting models, we made the unverifiable assumption that the observed variables will follow the same future trends. Trends in most covariates were relatively consistent from 1976 through 2015, increasing our confidence that a similar continuation was the most valid assumption regarding future trends. However, unanticipated events may substantially impact forecasted estimates. For example, our forecasting did not account for the COVID-19 pandemic, which has influenced widespread social, economic, and health trends that will likely impact short- and long-term rates of binge drinking (Clay & Parker, 2020). While empirical evidence is currently limited (Dumas et al., 2020; Pollard et al., 2020), public health researchers have issued growing concern around an increase in alcohol intake and alcohol-related harms (Clay & Parker, 2020; Ramalho, 2020). More research is needed to further understand the long-term effects of the pandemic on binge drinking, and future forecasting models should incorporate additional predictors as they become available.

CONCLUSION

This paper utilized data from a large US nationally representative study of 40 cohorts of high school seniors followed into adulthood, in order to understand historical and developmental trends in alcohol use and related factors and forecast future binge drinking through 2040. Overall, we identified important gender- and age-specific differences in forecasted future levels of binge drinking, and important determinants of those trends. No one study can estimate a true observed effect, much less a true future effect; however, forecasting methods are valuable tools, and robust future patterns that emerge across multiple studies will be useful to inform a proactive model of public health planning to reduce the harm caused by binge drinking from adolescence to adulthood.

ACKNOWLEDGEMENTS

We gratefully acknowledge all MTF respondents for their participation

CONFLICT OF INTEREST

The authors report no conflicts of interest.

ORCID

Jonathan M. Platt https://orcid.org/0000-0002-5475-0494
Megan E. Patrick https://orcid.org/0000-0003-3594-4944
Katherine M. Keyes https://orcid.org/0000-0002-5624-021X

REFERENCES

Bachman, J.G., Wadsworth, K.N., O'Malley, P.M., Schulenberg, J. & Johnston, L.D. (1997) Marriage, divorce, and parenthood during the transition to young adulthood: impacts on drug use and abuse. In J. Schulenberg, J.L. Maggs, & K. Hurrelmann (Eds.), *Health risks and developmental transitions during adolescence* (pp. 246–279). Cambridge: Cambridge University Press.

Bobo, J.K. & Husten, C. (2000) Sociocultural influences on smoking and drinking. *Alcohol Research & Health*, 24, 225.

Borsari, B. & Carey, K.B. (2003) Descriptive and injunctive norms in college drinking: a meta-analytic integration. *Journal of Studies on Alcohol*, 64, 331–341.

Bray, F. & Møller, B. (2006) Predicting the future burden of cancer. *Nature Reviews Cancer*, 6, 63–74.

Bruvold, W.H. (1993) A meta-analysis of adolescent smoking prevention programs. *American Journal of Public Health*, 83, 872–880.

van Buuren, S. & Groothuis-Oudshoorn, K. (2010) mice: Multivariate imputation by chained equations in R. Journal of Statistical Software 1–68.

Cheng, H.G. & Anthony, J.C. (2017) A new era for drinking? Epidemiological evidence on adolescent male–female differences in drinking incidence in the United States and Europe. *Social Psychiatry and Psychiatric Epidemiology*, 52, 117–126. https://doi.org/10.1007/s00127-016-1318-0

Cheng, H.G., Cantave, M.D. & Anthony, J.C. (2016) Taking the first full drink: epidemiological evidence on male-female differences in the United States. *Alcoholism, clinical and experimental research*, 40, 816–825. https://doi.org/10.1111/acer.13028

Chikritzhs, T.N., Stockwell, T.R., Jonas, H.A., Heale, P.F. & Dietze, P.M. (2001) Mortality and life-years lost due to alcohol: a comparison of acute and chronic causes. *Medical Journal of Australia*, 174, 281–284.

Choi, J., Cho, Y., Shim, E. & Woo, H. (2016) Web-based infectious disease surveillance systems and public health perspectives: a systematic review. *BMC Public Health*, 16, 1238.

Chretien, J.-P., George, D., Shaman, J., Chitale, R.A. & McKenzie, F.E. (2014) Influenza forecasting in human populations: a scoping review. *PLoS One*, 9, e94130.

Clay, J.M. & Parker, M.O. (2020) Alcohol use and misuse during the COVID-19 pandemic: a potential public health crisis? *The Lancet Public Health*, 5, e259.

Dumas, T.M., Ellis, W. & Litt, D.M. (2020) What does adolescent substance use look like during the COVID-19 pandemic? Examining changes in frequency, social contexts, and pandemic-related predictors. *Journal of Adolescent Health*, 67, 354–361.

Grucza, R.A., Norberg, K.E. & Bierut, L.J. (2009) Binge drinking among youths and young adults in the United States: 1979–2006. *Journal of the American Academy of Child & Adolescent Psychiatry*, 48, 692–702.

Holmila, M. & Raitasalo, K. (2005) Gender differences in drinking: why do they still exist? *Addiction*, 100, 1763–1769.

Hyndman, R.J. & Athanasopoulos, G. (2018) Forecasting: principles and practice. OTexts.

Jager, J., Keyes, K.M. & Schulenberg, J.E. (2015) Historical variation in young adult binge drinking trajectories and its link to historical variation in social roles and minimum legal drinking age. *Developmental Psychology*, 51, 962.

Keyes, K.M., Jager, J., Mal-Sarkar, T., Patrick, M.E., Rutherford, C. & Hasin, D. (2019) Is there a recent epidemic of women's drinking? A critical review of national studies. *Alcoholism: Clinical and Experimental Research*, 43, 1344–1359.

Keyes, K.M., Schulenberg, J.E., O'Malley, P.M., Johnston, L.D., Bachman, J.G., Li, G. et al. (2012) Birth cohort effects on adolescent alcohol use: the influence of social norms from 1976–2007. *Archives of General Psychiatry*, 69, 1304–1313. https://doi.org/10.1001/archgenpsychiatry.2012.787

Kindy, K. & Keating, D. (2016) For women, heavy drinking has been normalized. That's dangerous. The Washington Post [Internet]. Washington, DC: The Washington Post.

Kuntsche, S., Knibbe, R.A., Kuntsche, E. & Gmel, G. (2011) Housewife or working mum—each to her own? The relevance of societal factors in the association between social roles and alcohol use among mothers in 16 industrialized countries. *Addiction*, 106, 1925–1932.

Ladrón de Guevara, F., Washington, S.P. & Oh, J. (2004) Forecasting crashes at the planning level: simultaneous negative binomial crash model applied in Tucson, Arizona. *Transportation Research Record*, 1897, 191–199. https://doi.org/10.3141/1897-25

Lemstra, M., Bennett, N.R., Neudorf, C., Kunst, A., Nannapaneni, U., Warren, L.M. et al. (2008) A meta-analysis of marijuana and alcohol use by socio-economic status in adolescents aged 10–15 years. *Canadian Journal of Public Health*, 99, 172–177. https://doi.org/10.1007/BF03405467

Little, T.D. & Rhemtulla, M. (2013) Planned missing data designs for developmental researchers. *Child Development Perspectives*, 7, 199–204. https://doi.org/10.1111/cdep.12043

Lui, C.K., Kerr, W.C., Mulia, N. & Ye, Y. (2018) Educational differences in alcohol consumption and heavy drinking: an age-period-cohort perspective. *Drug and Alcohol Dependence*, 186, 36–43.

Lyons, A., McCreanor, T., Goodwin, I. & Barnes, H.M. (2017) *Youth drinking cultures in a digital world: alcohol, social media and cultures of intoxication*. Oxfordshire, UK: Taylor & Francis.

Madley-Dowd, P., Hughes, R., Tilling, K. & Heron, J. (2019) The proportion of missing data should not be used to guide decisions on multiple imputation. *Journal of Clinical Epidemiology*, 110, 63–73. https://doi.org/10.1016/j.jclinepi.2019.02.016

Midanik, L.T., Tam, T.W. & Weisner, C. (2007) Concurrent and simultaneous drug and alcohol use: results of the 2000 National Alcohol Survey. *Drug and Alcohol Dependence*, 90, 72–80.

Miech, R., Johnston, L.D., O'Malley, P.M., Bachman, J.G., Schulenberg, J.E. & Patrick, M.E. (2019) *Monitoring the Future national survey results on drug use, 1975–2018: Volume I, Secondary school students*. Ann Arbor: Institute for Social Research, The University of Michigan.

Miech, R., Johnston, L., O'Malley, P., Bachman, J., Schulenberg, J. & Patrick, M. (2020) *Monitoring the Future national survey results on drug use, 1975-2019: Volume I, Secondary school students*. Ann Arbor: Institute for Social Research, The University of Michigan.

Naimi, T.S., Brewer, R.D., Mokdad, A., Denny, C., Serdula, M.K. & Marks, J.S. (2003) Binge drinking among US adults. *JAMA*, 289, 70–75.

Noble, D.W.A. & Nakagawa, S. (2018) Planned missing data design: stronger inferences, increased research efficiency and improved animal welfare in ecology and evolution. bioRxiv 247064. https://doi.org/10.1101/247064

O'Connor, P.J. (2005) Forecasting of spinal cord injury annual case numbers in Australia. *Archives of Physical Medicine and Rehabilitation*, 86, 48–51.

Patrick, M.E., Terry-McElrath, Y.M., Miech, R.A., Schulenberg, J.E., O'Malley, P.M. & Johnston, L.D. (2017) Age-specific prevalence of binge and high-intensity drinking among US young adults: changes from 2005 to 2015. *Alcoholism: Clinical and Experimental Research*, 41, 1319–1328.

Patrick, M.E., Terry-McElrath, Y.M., Lanza, S.T., Jager, J., Schulenberg, J.E. & O'Malley, P.M. (2019) Shifting age of peak binge drinking prevalence: historical changes in normative trajectories among young adults aged 18 to 30. *Alcoholism: Clinical and Experimental Research*, 43, 287–298.

Patrick, M.E., Wightman, P., Schoeni, R.F. & Schulenberg, J.E. (2012) Socioeconomic status and substance use among young adults: a comparison across constructs and drugs. *Journal of studies on Alcohol and Drugs*, 73, 772–782.

Petticrew, M., Shemilt, I., Lorenc, T., Marteau, T., Melendez-Torres, G., O'Mara-Eves, A. et al. (2017) Alcohol advertising and public health: systems perspectives versus narrow perspectives. *Journal of Epidemiology and Community Health*, 71, 308–312.

Pigott, T.D. (2009) Handling missing data. *The handbook of research synthesis and meta-analysis*. New York, NY: Russell Sage Foundation, pp. 399–416.

Pollard, M.S., Tucker, J.S. & Green, H.D. (2020) Changes in adult alcohol use and consequences during the COVID-19 pandemic in the US. *JAMA Network Open*, 3, e2022942. https://doi.org/10.1001/jamanetworkopen.2020.22942

Ramalho, R. (2020) Alcohol consumption and alcohol-related problems during the COVID-19 pandemic: a narrative review. *Australasian Psychiatry*, 28, 524–526. https://doi.org/10.1177/1039856220943024

Rhemtulla, M. & Little, T. (2012) Tools of the trade: planned missing data designs for research in cognitive development. *Journal of Cognition and Development*, 13, https://doi.org/10.1080/15248372.2012.717340

Robinson, W.R., Keyes, K.M., Utz, R.L., Martin, C.L. & Yang, Y. (2013) Birth cohort effects among US-born adults born in the 1980s: foreshadowing future trends in US obesity prevalence. *International Journal of Obesity*, 37, 448–454. https://doi.org/10.1038/ijo.2012.66

Rubin, D.B. (2004) *Multiple imputation for nonresponse in surveys*. New York: John Wiley & Sons.

Schulenberg, J.E., Johnston, L.D., O'Malley, P.M., Bachman, J.G., Miech, R.A. & Patrick, M.E. (2019). *Monitoring the Future national survey results on drug use, 1975-2018: Volume II, college students and adults ages 19–60*. Ann Arbor: Institute for Social Research, The University of Michigan.

Schulenberg, J., Johnston, L., O'Malley, P., Bachman, J., Miech, R. & Patrick, M. (2020). *Monitoring the Future national survey results on drug use, 1975-2019: Volume II, college students and adults ages 19–60*. Ann Arbor: Institute for Social Research, The University of Michigan

Scott-Sheldon, L.A., Demartini, K.S., Carey, K.B. & Carey, M.P. (2009) Alcohol interventions for college students improves antecedents of behavioral change: results from a meta-analysis of 34 randomized controlled trials. *Journal of Social and Clinical Psychology*, 28, 799–823.

Seedat, S., Scott, K.M., Angermeyer, M.C., Berglund, P., Bromet, E.J., Brugha, T.S. et al. (2009) Cross-national associations between gender and mental disorders in the World Health Organization World Mental Health Surveys. *Archives of General Psychiatry*, 66, 785–795. https://doi.org/10.1001/archgenpsychiatry.2009.36

Settersten, R.A. Jr (2007) The new landscape of adult life: Road maps, signposts, and speed lines. *Research in Human Development*, 4, 239–252.

Skog, O. (1985) The collectivity of drinking cultures: a theory of the distribution of alcohol consumption. *British Journal of Addiction*, 80, 83–99.

Slade, T., Chapman, C., Swift, W., Keyes, K., Tonks, Z. & Teesson, M. (2016) Birth cohort trends in the global epidemiology of alcohol use and alcohol-related harms in men and women: systematic review and metaregression. *British Medical Journal Open*, 6, e011827.

Soyiri, I.N., Soyiri, I.N. & Reidpath (2012) Evolving forecasting classifications and applications in health forecasting. *International Journal of General Medicine*, 5, 381–389. https://doi.org/10.2147/IJGM.S31079

Viswesvaran, C. & Schmidt, F.L. (1992) A meta-analytic comparison of the effectiveness of smoking cessation methods. *Journal of Applied Psychology*, 77, 554.

de Vocht, F., Tilling, K., Pliakas, T., Angus, C., Egan, M., Brennan, A. et al. (2017) The intervention effect of local alcohol licensing policies on hospital admission and crime: a natural experiment using a novel Bayesian synthetic time-series method. *Journal of Epidemiology and Community Health*, 71, 912–918.

Waters, M.C., Carr, P.J., Kefalas, M. & Holdaway, J.A. (2019) *Coming of age in America: the transition to adulthood in the twenty-first century*. Berkeley: University of California Press.

Weitzman, E.R. & Chen, Y.-Y. (2005) The co-occurrence of smoking and drinking among young adults in college: national survey results from the United States. *Drug and Alcohol Dependence*, 80, 377–386.

White, A., Castle, I.P., Chen, C.M., Shirley, M., Roach, D. & Hingson, R. (2015) Converging patterns of alcohol use and related outcomes among females and males in the United States, 2002 to 2012. *Alcoholism: Clinical and Experimental Research* 39, 1712–1726.

Wood, J., Matthews, G.J., Pellowski, J. & Harel, O. (2019) Comparing different planned missingness designs in longitudinal studies. *Sankhya B*, 81, 226–250. https://doi.org/10.1007/s13571-018-0170-5

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Platt, J. M., Jager, J., Patrick, M. E., Kloska, D., Schulenberg, J., Rutherford, C., & Keyes, K. M. (2021). Forecasting future prevalence and gender differences in binge drinking among young adults through 2040. *Alcoholism: Clinical and Experimental Research*, 45, 2069–2079. https://doi.org/10.1111/acer.14690