Adolescent substance use and educational attainment: An integrative data analysis comparing cannabis and alcohol from three Australasian cohorts

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ABSTRACT

Background: The relative contributions of cannabis and alcohol use to educational outcomes are unclear. We examined the extent to which adolescent cannabis or alcohol use predicts educational attainment in emerging adulthood.

Methods: Participant-level data were integrated from three longitudinal studies from Australia and New Zealand (Australian Temperament Project, Christchurch Health and Development Study, and Victorian Adolescent Health Cohort Study). The number of participants varied by analysis (N=2179-3678) and were assessed on multiple occasions between ages 13-25. We described the association between frequency of cannabis or alcohol use prior to age 17 and high school non-completion, university non-enrolment, and degree non-attainment by age 25. Two other measures of alcohol use in adolescence were also examined.

Results: After covariate adjustment using a propensity score approach, adolescent cannabis use (weekly+) was associated with 1½ to 2-fold increases in the odds of high school non-completion (OR=1.60, 95%CI=1.09-2.35), university non-enrolment (OR=1.51, 95%CI=1.06-2.13), and degree non-attainment (OR=1.96, 95%CI=1.36-2.81). In contrast, adjusted associations for all measures of adolescent alcohol use were inconsistent and weaker. Attributable risk estimates indicated adolescent cannabis use accounted for a greater proportion of the overall rate of non-progression with formal education than adolescent alcohol use.

Conclusions: Findings are important to the debate about the relative harms of cannabis and alcohol use. Adolescent cannabis use is a better marker of lower educational attainment than adolescent alcohol use and identifies an important target population for preventive intervention.

Keywords: Cannabis; alcohol; adolescence; educational outcomes

1. Introduction

Successfully completing high school and attaining a university degree are critical developmental milestones linked to better health (Cutler and Lleras-Muney, 2010) and greater economic productivity (US Bureau of Labor Statistics, 2014). Alcohol and cannabis are commonly used by young people in the school-age years. Worldwide, 34% of 15-19 year olds are current drinkers (World Health Organization, 2014); European estimates suggest 12% of 15-16 year olds are past-month cannabis users although prevalence levels vary considerably between countries (European Monitoring Centre for Drugs and Drug Addiction, 2014). Adolescence may also be a vulnerable developmental period for the neurocognitive effects of substance use (Lisdahl et al., 2013). Heavy drinking and cannabis use have been linked to changes in central nervous system (CNS) structure and function in otherwise healthy adolescents (Lisdahl et al., 2013). Given the extent of exposure, the association of alcohol and cannabis use with subsequent levels of educational attainment is of increasing interest.

Research into the effects of cannabis has produced generally consistent findings to suggest that early use reduces the likelihood of progressing further in formal education (Macleod et al., 2004; Townsend et al., 2007). Typically, these associations attenuate but remain after control for potential confounders (Esch et al., 2014; Macleod et al., 2004). The picture is less clear in relation to alcohol use. Cross-sectional studies provide some evidence of an association between alcohol and educational attainment (Townsend et al., 2007) but the evidence from longitudinal studies is equivocal. Some have found little linkage between adolescent alcohol use and low school commitment (Hemphill et al., 2014), years in education (Arria et al., 2013), and academic failure (Hemphill et al., 2014), after adjustment for potential confounders. Others have found early alcohol use is weakly associated with lower school grades (Crosnoe et al., 2012) and future educational achievement (Latvala et al., 2014), particularly for males (Balsa et al., 2011).

Two issues emerge in the literature. First, evidence of the effects of adolescent alcohol use on educational attainment is equivocal (McCambridge et al., 2011). Specifically, questions remain about the extent to which the apparent effects of adolescent drinking might be due to potential confounding factors not adequately controlled for in studies to date (McCambridge et al., 2011). Second, the relative contributions of cannabis or alcohol use to explaining failure to progress further in formal education have not been investigated.

We address these issues through the integration of data from three longitudinal studies from Australia and New Zealand: the Australian Temperament Study (ATP) (Vassallo and Sanson, 2013), the Christchurch Health and Development Study (CHDS) (Fergusson and Horwood, 2001), and the Victorian Adolescent Health Cohort Study (VAHCS) (Patton et al., 2007). We integrated participant-level data rather than using the standard meta-analytic approach of combining study-level estimates. This approach increases sample size and statistical precision to investigate less common patterns of substance use (such as frequent use at a young age), provides the opportunity to include a wide range of potential confounding factors, and augments our ability to generalize findings to the region and internationally more realistically than is possible for any individual study (Curran and Hussong, 2009; Hofer and Piccinin, 2009). We build on earlier work which found that adolescent cannabis use was negatively associated with attaining secondary school and tertiary qualifications (Horwood et al., 2010; Silins et al., 2014) and extend the analysis to examine the relative contributions of cannabis and alcohol use to educational outcomes.

We examined the extent to which adolescent cannabis or alcohol use was associated with failure to progress further in formal education using data from three Australasian cohort studies. Specifically, we: (1) investigated the association between both frequency of cannabis use and frequency of alcohol use prior to age 17 and high school non-completion, university non-enrolment, and degree non-attainment by age 25 in each study and in combined data; (2) examined two other patterns of alcohol use (amount consumed and number of alcohol-related problems) prior to age 17;

(3) adjusted the associations for potential confounders drawn from similar domains across studies; and, (4) estimated the proportion of educational non-involvement attributable to adolescent cannabis or alcohol use if causality is assumed. The study has approval from the University of New South Wales Human Research Ethics Committee.

2. Methods

2.1. Design and participants

Integrative analyses were developed across the three studies (Hutchinson et al., 2015): ATP (Vassallo and Sanson, 2013), CHDS (Fergusson and Horwood, 2001), and VAHCS (Patton et al., 2007). Additional information about the longitudinal cohorts is provided in Appendix 1. Analyses were based on data from these studies assessed between ages 13-25. The number of participants varied by analysis (from 2179 to 3678).

2.2. Measures

We assessed three educational outcomes in young people which reflect a general dimension of failure to progress with formal education: high school non-completion, university non-enrolment, and degree non-attainment. We chose the outcomes based on research that established a link between educational achievement and the use of cannabis or alcohol in adolescence and the availability of similar measures across the cohorts. All studies obtained data on the completion of high school and university degree attainment. University enrolment was assessed only in CHDS and VAHCS. Using these data, a dichotomous variable was created for high school non-completion by age 25, university non-enrolment by age 21, and degree non-attainment by age 25 for each study with relevant data.

All studies included self-reported measures of frequency of cannabis or alcohol use during mid-adolescence over multiple assessments (Table 1). Using these data, a three-level measure of the maximum frequency of cannabis or alcohol use before age 17 was created for each study (never, less than weekly, weekly or more). Additional information about the derivation of harmonised variables is in Appendix 2. We noted small between-study variations in the prevalence of adolescent substance use and some outcomes (Appendix 3).

[Insert Table 1 about here]

2.3. Potential confounding factors

We selected potential confounding factors from each study based on research suggesting that they might be correlated with both substance use and educational attainment. These factors spanned individual background and functioning, and parental and peer factors (see Table 3).

2.4. Statistical analysis

The first analysis examined the bivariate associations between maximum frequency of cannabis or alcohol use before age 17 and the educational outcomes in each study and in the combined data set. We tested statistical significance by fitting a series of logistic regression models to the data for each study and the combined data in which the log odds of each outcome was modelled as a linear function of the three level measure of the frequency of either cannabis or alcohol use (Appendix 4). Effect size estimates (odds ratios and 95% confidence intervals) for each outcome were obtained from the models fitted to the combined data set.

In the second analysis the bivariate associations were adjusted for confounding using a generalised propensity score approach (Imbens, 2000; Spreeuwenberg et al., 2010) in which the logistic regression models for the combined data were extended to incorporate study specific

propensity scores (see Appendix 4). Propensity scores were estimated from a multinomial logistic regression in which the frequency of cannabis or alcohol use was regressed on the full set of available confounding factors in each study. To account for the comorbidity between cannabis and alcohol use, alcohol use was included as a predictor in the propensity model for cannabis use and vice versa. Propensity scores were then included in the fitted regression models and adjusted effect size estimates (ORs and 95% CIs) were obtained. These analyses were repeated using two alternative measures of adolescent alcohol use (Appendix 5).

Estimates of the covariate adjusted attributable risk (AR) of cannabis use and each of the measures of alcohol use were derived from the fitted models for each outcome in the combined data. AR estimates were obtained by generating the marginal adjusted rate of each outcome for each level of cannabis or alcohol use in the pooled data and these were used to provide direct estimates of the adjusted relative risk of educational non-involvement (Lee, 1981).

The above models assumed a linear effect of cannabis or alcohol use on the log odds of each outcome, and a common slope parameter for the effect of cannabis or alcohol use across studies. To test these assumptions, we first did Wald chi square tests to examine the improvement in fit of a categorical representation of cannabis or alcohol use over and above the linear model. We then extended the models to allow the slope parameter to vary across studies, and used Wald chi square to test for between-study heterogeneity in the effect of cannabis or alcohol use.

Finally, to examine the possible implications of selection bias from sample attrition and missing data in each study, the regression models were re-analysed using data weighting procedures (Little and Rubin, 2002) (Appendix 6). The results from the weighted and unweighted analyses were negligibly different, suggesting that selection bias was unlikely to have influenced the findings reported.

3. Results

3.1. Associations between cannabis use, alcohol use and educational attainment

Table 2 shows the associations of maximum frequency of cannabis use and alcohol use, before age 17, classified in three levels (never, <weekly, weekly+) with the three measures of educational attainment. The associations are reported without covariate adjustment, both separately for each study and for the combined data set:

1. For cannabis there were clear ($p<0.001$) trends for increasing frequency of use to be associated with lower educational attainment both separately in each study and in the combined data. In the combined data, those who used cannabis at least weekly prior to age 17 had odds of high school non-completion, university non-enrolment, and degree non-attainment that were between 2.20-3.89 times higher than for those who had never used cannabis.
2. For alcohol there were significant associations between increasing frequency of use and lower educational attainment. However, these associations appeared more modest than those for cannabis, and at the individual study level were not always statistically significant. In the combined data those who used alcohol at least weekly had odds of high school non-completion, university non-enrolment, and degree non-attainment that were between 1.33-2.03 times higher than those who had never used alcohol.

[Insert Table 2 about here]

3.2. Adjustment for confounding

Table 3 shows results from analyses using combined data. After adjustment for confounding, all of the associations between frequency of cannabis use and educational non-involvement across levels of exposure remained ($p<0.02$): weekly cannabis users had adjusted odds of non-involvement that were 1.51-1.96 times higher than for those who had never used cannabis. For alcohol use all of

the adjusted associations were non-significant, and in two outcomes were reversed in direction after adjustment: the adjusted odds for weekly users ranged between 0.88-1.21 compared to never users.

[Insert Table 3 about here]

The alcohol frequency measure, while technically comparable to the cannabis frequency measure, may not necessarily characterise the range of alcohol use patterns in adolescence. To examine whether a similar pattern of results held for other measures of alcohol use in adolescence, we examined the associations between educational outcomes and measures of the maximum number of (a) standard drinks consumed on a typical drinking occasion, and (b) alcohol-related problems, prior to age 17. This analysis showed little evidence of associations between measures of alcohol use and educational outcomes after adjustment for confounding (Appendix 5).

Table 4 shows the attributable risk (AR) for cannabis use and the three measures of alcohol use estimated from the adjusted regression models fitted to the combined data for each educational outcome. The AR estimates the proportion of educational non-involvement attributable to cannabis use and alcohol use if causality is assumed. For all outcomes the AR estimates for cannabis use were greater than those for all measures of alcohol use: the AR estimates ranged from 4.8% to 7.2% for cannabis and from -3.7% to 6.4% for alcohol.

[Insert Table 4 about here]

3.3. Supplementary analysis

Tests for non-linearity were non-significant and the linear model was found to provide an adequate representation of the data, with one exception: for the association between frequency of cannabis use and non-enrolment in university there was evidence of a modest but statistically significant departure from linearity (p=0.03). However, re-analysis of the association with frequency of cannabis use treated as a categorical variable produced estimates of effect size and AR that were consistent with those of the linear model.

For one association (frequency of alcohol use and high school non-completion) there was evidence of significant (p=0.003) between-study heterogeneity in the effect of alcohol. This appeared to reflect the fact that for the CHDS the adjusted association between frequency of alcohol use and high school non-completion was stronger than in the Australian cohorts (ATP, VAHCS) and remained significant after covariate adjustment. For all other associations there was no evidence of between-study heterogeneity.

4. Discussion

Our findings show clear and consistent associations between the frequency of adolescent cannabis or alcohol use and non-attainment of secondary school and tertiary qualifications. The associations had dose-response characteristics across all outcomes, with effects strongest for weekly users. After controlling for a wide range of potential confounding factors, the magnitude of associations for cannabis use reduced substantially but remained significant. In contrast, for frequency of alcohol use, the adjusted associations with all outcomes were weak and statistically non-significant, and a similar pattern of results generally held for two other measures of alcohol use. Early cannabis use was found to account for a greater proportion of the overall rate of non-progression with formal education than early alcohol use.

Support for a causal link between cannabis use and educational attainment is provided by several aspects of the findings. First, there were strong bivariate associations between adolescent cannabis use and all three educational outcomes. Second, the associations had dose-response characteristics. Third, all associations remained with control for potential confounding factors assessed before and during adolescence.

The specificity of the adjusted associations for cannabis use across the three educational outcomes also has important implications in terms of the drug's purported causal effects. Traditional

criteria for establishing causality includes specificity of association, yet this criterion is inconsistently fulfilled in research (Macleod et al., 2004). Reviews have found alcohol and cannabis may show similar associations with some psychosocial outcomes (which does not support a causal relationship) (Macleod et al., 2004). Our findings are aligned with other studies which show some adverse psychosocial outcomes were more consistently associated with cannabis and others with alcohol (Palamar et al., 2014). Our analyses adjusted for major sources of potential confounding and accounted for the comorbidity between cannabis and alcohol use. Results suggest it may be cannabis use specifically, rather than substance use generally (as measured by alcohol consumption), that is associated with failure to progress with education. The health and developmental outcomes associated with cannabis or alcohol use may well be different. While alcohol has a critical role in some adverse outcomes, as witnessed by its burden of disease (Rehm et al., 2009), study findings do not support a direct link with educational attainment. The extent to which individual and contextual factors account for the association between adolescent substance use and educational attainment appears greater in relation to early alcohol use than early cannabis use.

Study findings in relation to the association between adolescent cannabis use and lower educational attainment are consistent with previous research (Esch et al., 2014; Horwood et al., 2010; Macleod et al., 2004; Silins et al., 2014; Townsend et al., 2007). The association between cannabis use and high school non-completion probably does not arise from a reverse causal association (Fergusson et al., 2003), however it remains plausible (Townsend et al., 2007). Studies such as ours have limited capacity to explain the underlying mechanisms. Some research suggests that heavy cannabis use in adolescence might affect CNS development as the drug has characteristic neurophysiological effects which vary by pattern of use (Lisdahl et al., 2013). Alternatively, study findings may reflect the different social and cultural contexts of early cannabis or alcohol use. Adolescent cannabis use (arguably less normative than adolescent alcohol use) (European Monitoring Centre for Drugs and Drug Addiction, 2014; World Health Organization, 2014) may be a

marker for underlying problems or contexts such as peer affiliations or family environments which increase the risk of lower educational attainment (Busch et al., 2014). Although we controlled for many potential confounding factors, the possibility that the associations with cannabis use might show the effects of unmeasured or uncontrolled confounding can never be completely ruled out (Macleod et al., 2004). The absence of an incremental effect of cannabis use on progressively higher levels of educational achievement suggests that most of the risk for lower educational outcomes beyond high school could be accounted for by influences prior to the completion of secondary school. While the outcomes examined reflect a general dimension of failure to progress with formal education, in the current context of youth unemployment, some who leave school and find secure employment soon after may do better than those who go on to university in terms of transitions to independence in young adulthood (Eisenberg et al., 2015).

This study had some limitations. First, weekly alcohol use in adolescence is more normative than weekly cannabis use and may not necessarily encapsulate high-end use. However, a sensitivity analysis which included frequency of heavier drinking (10+ drinks in a typical session) produced results consistent with the main findings (Appendix 7). Second, there was some between-study variation in the levels of outcomes which was greater for alcohol than for cannabis. This could have been shown by variations in estimates of effect size across studies and failure to find a statistically significant association. However, such estimates were very similar, with Wald tests (in adjusted models) providing no evidence of significant between-study heterogeneity except for frequency of alcohol use and failure to complete high school. Further, the estimate of the pooled AR from a model that assumed different regression parameters in each study for the association between alcohol use and high school non-completion was similar to the AR estimate reported in Table 4. Third, the adjusted associations for cannabis use and educational outcomes are slightly weaker than those reported in a previous integrated analysis using the same data (Silins et al., 2014), possibly due to the use of a more sophisticated form of covariate control in the current study. Fourth, measures were obtained by self-report, which might be subject to socially desirable response bias, the extent

of which can vary with age (Brener et al., 2003). Fifth, similarities in the cultural and social context and epidemiology of substance use between Australia, New Zealand, and other high-income countries (UNICEF Office of Research, 2013) suggests findings are generalizable to those settings. Generalizability to lower-income countries where the epidemiology and socio-economic context of cannabis use is not well understood remains to be established.

This study extends previous research on the link between adolescent substance use and non-progression with formal education by integrating data from three sources and controlling for a broader range of covariates than possible in traditional meta-analysis. Weekly adolescent cannabis use had a profound adverse effect across all three educational outcomes. In contrast, much of the association between early alcohol use and educational non-involvement was explained by individual, parental and peer factors. Findings strengthen the case for cannabis' harmful effects on adolescent development and are important to the debate about the relative harms of cannabis and alcohol use. While alcohol has a major role in some adverse outcomes (Rehm et al., 2009), the claim that cannabis use is less harmful than alcohol use (Lachenmeier and Rehm, 2015) is unsupported by results in relation to the critical domain of educational attainment. Study findings show that adolescent cannabis use is a better marker of lower educational attainment than adolescent alcohol use and identifies an important target population for preventive intervention. Addressing adolescent cannabis use provides a means of improving education outcomes with potential economic benefits (Day and Newburger, 2002).

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Table 1. Cannabis and alcohol measures used in the derivation of harmonised exposure variables

Harmonised exposure variable[1]	Constituent measures		
	ATP	CHDS	VAHCS
Maximum frequency of cannabis use prior to age 17 (Never, <weekly, weekly+)	Frequency of use in past month (number of days use) at age 15-16. Less frequent than monthly use not assessed. Such use was defined using the assessment of lifetime cannabis use at age 15-16 and age 13-14.	Frequency of use in each of the 12 month periods from age 14-15, 15-16, 16-17 years, obtained from assessments conducted at ages 15, 16, 18 years respectively (classified as: not used, once or twice, less than once a month, at least once a month, at least once a week, nearly every day).	Frequency of use in past 6 months assessed at each of 6 biannual assessments between ages 15-17½ years, on average (response categories: never, not in past 6 months, a few times a year, monthly, weekly, daily).
Maximum frequency of alcohol use prior to age 17 (Never, <weekly, weekly+)	Lifetime use (3+ drinks in lifetime; yes/no) and number of drinking days in past month at age 13 and 15.	Frequency of use in past year at ages 15 and 16 (response categories were: never, very occasionally, less than once a month, at least once a month, at least once a week, almost every day).	Current drinking status (non-drinker, light, moderate, heavy) and number of drinking days in the past week were assessed using a 7-day retrospective drinking diary at each of 6 biannual assessments between ages 15-17½.
Maximum number of standard drinks consumed on a single drinking occasion prior to age 17 (0-2, 3-6, 7-12, 13+)	Number of drinks consumed not assessed.	Amount of alcohol consumed (in millilitres of pure alcohol) on a typical drinking occasion at ages 14, 15, and 16.	Average number of standard drink units (10 grams of alcohol) consumed per drinking day in the past week at 6 biannual assessments between ages 15-17½.
Maximum number of alcohol-related problems prior to age 17 (None, 1-2, 3-4, 5+)	Frequency of 5 drinking-related problems over the lifetime at age 15.	Number of alcohol abuse/dependence symptoms (Rutgers Alcohol Problems Index[2]) in the past 12 months at age 15 and 16 (23 items).	Number of drinking-related problems (13 items) in past 6 months at 6 biannual assessments between ages 15-17½.

ATP=Australian Temperament Project. CHDS=Christchurch Health and Development Study. VAHCS=Victorian Adolescent Health Cohort Study. [1]Maximum value based on multiple assessments in adolescence. [2]White & Labouvie, 1989.

Table 2. Associations between maximum frequency of cannabis or alcohol use before age 17 and educational outcomes in each study and when the data were combined

	Frequency of substance use			
Measure	Never	<Weekly	Weekly +	p value[1]
Outcome: Did not complete high school[2]				
Cannabis use				
ATP	64/897 (7%)	26/202 (13%)	11/37 (30%)	<0.001
CHDS	311/618 (50%)	215/339 (63%)	78/89 (88%)	<0.001
VAHCS	126/977 (13%)	69/372 (19%)	38/147 (26%)	<0.001
Combined data	501/2492 (20%)	310/913 (34%)	127/273 (47%)	<0.001
OR (95% CI)	1	1.82 (1.60-2.07)	3.33 (2.57-4.30)	
Alcohol use				
ATP	21/270 (8%)	46/581 (8%)	34/253 (13%)	0.028
CHDS	45/103 (44%)	386/699 (55%)	127/165 (77%)	<0.001
VAHCS	40/365 (11%)	75/392 (19%)	123/754 (16%)	0.062
Combined data	106/738 (14%)	507/1672 (30%)	284/1172 (24%)	<0.001
OR (95% CI)	1	1.42 (1.25-1.62)	2.03 (1.56-2.64)	
Outcome: Did not enrol in university[3,4]				
Cannabis use				
CHDS	362/596 (61%)	222/329 (67%)	69/79 (87%)	<0.001
VAHCS	373/978 (38%)	153/373 (41%)	88/147 (60%)	<0.001
Combined data	735/1574 (47%)	375/702 (53%)	157/226 (69%)	<0.001
OR (95% CI)	1	1.48 (1.31-1.68)	2.20 (1.71-2.83)	
Alcohol use				
CHDS	62/102 (61%)	434/673 (64%)	110/157 (70%)	0.109
VAHCS	133/366 (36%)	167/392 (43%)	324/755 (43%)	0.052
Combined data	195/468 (42%)	601/1065 (56%)	434/912 (48%)	0.014
OR (95% CI)	1	1.15 (1.03-1.29)	1.33 (1.06-1.66)	

Outcome: Did not attain university degree[2]

Cannabis use				
ATP	375/734 (51%)	111/156 (71%)	22/30 (73%)	<0.001
CHDS	415/596 (70%)	252/320 (79%)	76/81 (94%)	<0.001
VAHCS	563/978 (58%)	261/373 (70%)	128/147 (87%)	<0.001
Combined data	1353/2308 (59%)	624/849 (74%)	226/258 (88%)	<0.001
OR (95% CI)	1	1.97 (1.73-2.25)	3.89 (2.98-5.08)	
Alcohol use				
ATP	122/222 (55%)	257/472 (54%)	118/194 (61%)	0.249
CHDS	74/102 (73%)	483/666 (73%)	133/157 (85%)	0.010
VAHCS	210/366 (57%)	238/392 (61%)	516/755 (68%)	<0.001
Combined data	406/690 (59%)	978/1530 (64%)	767/1106 (69%)	<0.001
OR (95% CI)	1	1.25 (1.14-1.39)	1.57 (1.29-1.92)	

Data are n/N (%). ATP=Australian Temperament Project. CHDS=Christchurch Health and Development Study. VAHCS=Victorian Adolescent Health Cohort Study. [1]P value of the association between adolescent alcohol use and each outcome in each study, and in combined data adjusted for study-specific effects. [2]Assessed at age 25 years. [3]Assessed at age 21 years. [4]Only CHDS and VAHCS assessed university enrolment.

Table 3. Associations (ORs, 95% CI) between maximum frequency of cannabis or alcohol use before age 17 and educational outcomes in combined data after adjustment[4] for confounding

	Frequency of substance use			
Measure	Never	<Weekly	Weekly +	p value
Outcome: Did not complete high school[1]				
Cannabis use	1	1.27 (1.05-1.53)	1.60 (1.09-2.35)	0.016
Alcohol use	1	1.10 (0.91-1.34)	1.21 (0.83-1.78)	0.323
Outcome: Did not enrol in university[2,3]				
Cannabis use	1	1.23 (1.03-1.46)	1.51 (1.06-2.13)	0.021
Alcohol use	1	0.94 (0.80-1.10)	0.88 (0.64-1.21)	0.420
Outcome: Did not attain university degree[1]				
Cannabis use	1	1.40 (1.17-1.68)	1.96 (1.36-2.81)	<0.001
Alcohol use	1	0.95 (0.83-1.09)	0.90 (0.68-1.18)	0.470

Data are odds ratios (95% CIs). [1]Assessed at age 25 years. [2]Assessed at age 21 years. [3]Only CHDS and VAHCS assessed university enrolment. [4]Adjusted using a multiple propensity score approach, with propensity scores computed for each individual based on the available likely predictors of adolescent cannabis or alcohol use and combined across studies (ATP: school problems, 14-15 years; conduct disorder 13-16 years; attentional problems, 13-16 years; tobacco use, 13-16 years; other illicit drug use before 17 years; depression, 13-16 years; sex; ethnicity; parental socio-economic status; parental alcohol and tobacco use; parental education; parental divorce; antisocial peer activities, 13-16 years. CHDS: Grade point average, 11-13 years; conduct problems, 7-9 years; attentional problems, 7-9 years; tobacco use, 10-15 years; other illicit drug use before 17 years; major depression, 14-16 years; sex; ethnicity; socio-economic status at birth; family living standards, 1-10 years; parental history of criminal offending, parental tobacco use; parental history of alcohol problems; parental illicit drug use; parental history of mental health problems; parental education level at birth, parental separation, 0-10 years; deviant peer affiliations, 15 years. VAHCS: antisocial behaviour before 17 years; tobacco use before 17 years; other illicit drug use before 17 years; symptoms of depression/anxiety before 17 years; sex; ethnicity; parental tobacco use; parental alcohol use; parental education; parental divorce/separation; peer alcohol use before 17 years; peer tobacco use before 17 years; peer other illicit drug use before 17 years). See Silins et al. (2014) for specific details about the potential confounding factors and assessment ages across studies. Propensity score models included alcohol use before age 17 as a predictor of cannabis use and cannabis use before age 17 as a predictor of alcohol use in all studies.

Table 4. Estimates of attributable risk (AR) for measures of cannabis or alcohol use before age 17 on educational outcomes after adjustment[4] for confounding

Outcome	Cannabis (Max frequency)	Alcohol (Max frequency)	Alcohol (Max amount drunk)	Alcohol (Alcohol-related problems)
Did not complete high school[1]	7.2%	6.4%	0.8%	5.2%
Did not enrol in university[2,3]	4.8%	-3.7%	1.6%	-0.8%
Did not attain university degree[1]	5.0%	-2.0%	1.4%	0.2%

[1]Assessed at age 25 years. [2]Assessed at age 21 years. [3]Only CHDS and VAHCS assessed university enrolment.
[4]Adjusted using a multiple propensity score approach, with propensity scores computed for each individual based on the available likely predictors of adolescent cannabis or alcohol use and combined across studies (see Table 2 for specific predictors included).

Supplementary material

The appendices referred to in the manuscript are included on the following pages.

Appendix 1: Description of cohort studies involved

Additional information about the three longitudinal cohorts involved in this study is provided below and summarised in Table 1.1:

1.1. The Australian Temperament Project (ATP) (Vassallo and Sanson, 2013) is a longitudinal study of social and emotional development that commenced in 1983 as a sample of 2443 infants (aged 4-8 months) and their parents. The ATP has been studied on a total of 15 occasions in childhood through to young adulthood (age 28 years);

1.2. The Christchurch Health and Development Study (CHDS) (Fergusson and Horwood, 2001) is a longitudinal study of a birth cohort of 1265 children born in the Christchurch, New Zealand, urban region in 1977. The cohort has now been studied on a total of 23 occasions from birth to age 35 years; and,

1.3. The Victorian Adolescent Health Cohort Study (VAHCS) (Patton et al., 2007). is a longitudinal study of a representative sample of 1943 mid-secondary school adolescents in Victoria, Australia. Participants were assessed at least once during the recruitment phase in Year 9 or Year 10, and on four other occasions during adolescence with a further three follow-ups in young adulthood to approximately age 30 years.

Table 1.1: Summary of study characteristics

	ATP	CHDS	VAHCS
Region	Australia	New Zealand	Australia
Sampling frame	Victoria	Christchurch urban region	Victoria
Number invited	3000[2]	1310	2032
Number who entered the study	2443	1265	1943
Response proportion	81%[2]	97%	96%
Year of recruitment	1983	1977	1992
Age at recruitment	4-8 months	Birth	14 years
Number of waves (assessments)	15	23	10
Year of last wave	2011	2012	2006-2008
Age at last wave	28 years	35 years	29 years
Contactable (retained) sample[1]	1701 (70%)	1026 (81%)	1637 (84%)[3]
Annual attrition rate[4]	1.1%	0.5%	1.1%

Note: ATP: Australian Temperament Project; CHDS: Christchurch Health and Development Study; VAHCS: Victorian Adolescent Health Cohort Study.

[1]Excludes deceased participants and those who have permanently withdrawn

[2]Approximate figure

[3]Based on assessment at age 29 years, as data collection at age 35 years not yet completed

[4]Annual attrition rate = ((baseline sample – retained sample)/baseline sample) / (year of last wave – year of recruitment)) x 100; Where a wave took more than a year to complete the first year of data collection was used to calculate the attrition rate

References

Fergusson, D., Horwood, J., 2001. The Christchurch Health and Development Study: Review of findings on child and adolescent mental health. Aust NZ J Psychiatry 35, 287-296.

Patton, G., Coffey, C., Lynsky, M., Reid, S., Hemphill, S., Carlin, J., Hall, W., 2007. Trajectories of adolescent alcohol and cannabis use into young adulthood. Addiction 102, 607-615.

Vassallo, S., Sanson, A., 2013. The Australian Temperament Project: The first 30 years. Australian Institute of Family Studies, Melbourne.

Appendix 2: Description of measures and derivation of variables for main analyses

2.1. Educational attainment prior to age 25

All studies obtained data on the completion of high school and university degree attainment. In ATP these data were gathered in the course of interviews conducted in 2002 and 2006 when participants were aged 19-20 and 23-24 years respectively. In CHDS, educational attainment was assessed on three occasions between 1995-2002 when participants were aged 18, 21, and 25 years. In VAHCS these data were collected in 1998 (wave seven) and 2003 (wave eight) when participants were aged 21 and 24 years respectively. Enrolment in university was assessed in the CHDS in 1997 and the VAHCS in 1998 (wave seven) when participants were aged 21 years. The ATP did not assess university enrolment. Using these data, a dichotomous (0, 1) variable was created for high school non-completion by age 25 years, university non-enrolment by age 21 years, and degree non-attainment by age 25 years, for each study which had relevant data.

The education systems in Australia and New Zealand that applied during the course of these studies were very similar. In both countries school enrolment was compulsory from age six to age 15. In both countries it takes 12 years in education to complete high school and enrolment in university is subject to attaining satisfactory grades in high school.

2.2. Maximum frequency of cannabis use prior to age 17

All studies included self-reported measures of frequency of cannabis use during mid-adolescence. For the ATP, frequency of use in the past month (number of days use) was assessed when participants were aged 15-16 years (in 1998). Since the ATP did not directly assess use which was less frequent than monthly, such use was defined based on a criterion of 'ever used but not in the past month' using the assessment of lifetime cannabis use at age 15-16 years (in 1998) and age 13-14 years (in 1996). In the CHDS, data on adolescent cannabis use was gathered as part of assessments conducted at ages 15, 16 and 18 years (1992, 1993, 1995). This questioning included information on the frequency of cannabis use in each of the 12 month intervals from age 14-15, 15-16 and 16-17 years. These data were used to classify participants on an ordinal scale reflecting frequency of use in each interval (not used, once or twice, less than once a month, at least once a month, at least once a week, nearly every day). For VAHCS, frequency of use was assessed over the past six months at each of six biannual assessment waves between 1992-1995 when participants were aged 15-17½ years, on average (response categories: never, not in past six months, a few times a year, monthly, weekly, daily). Using these data, a three-level measure of the maximum frequency of cannabis use prior to age 17 was created for each study (with 0 as never, 1 as less than weekly, and 2 as weekly or more).

2.3. Maximum frequency of alcohol use prior to age 17

All studies included self-reported measures of lifetime and frequency of alcohol use during mid-adolescence. For ATP, data were collected on lifetime use (3+ drinks in lifetime; yes/no) and number of drinking days in the past month in 1996 and 1998 when participants were aged 13 and 15 years respectively. The CHDS assessed the frequency of use in the past 12 months in 1991 and 1992 when participants were aged 15 and 16 years respectively (response categories were: never, very occasionally, less than once a month, at least once a month, at least once a week, almost every day). The VAHCS assessed: current drinking status (non-drinker, light, moderate, heavy); and, number of drinking days in the past week using a 7-day retrospective drinking diary (administered after answering other questions about frequency of alcohol consumption). Both items were assessed at each of six biannual assessment waves between 1992-1995 when participants were aged 15-17.5 years (on average). Using these data, a three-level measure of the maximum frequency of alcohol use before age 17 was created for each study (with 0 as never, 1 as less than weekly, and 2 as weekly or more).

2.4. Maximum number of standard drinks consumed on a typical drinking occasion prior to age 17

This measure was assessed for only CHDS and VAHCS. The CHDS assessed the amount of alcohol consumed (in millilitres of pure alcohol) on a typical drinking occasion at ages 14, 15, and 16 years. The VAHCS assessed the average number of standard drink units (10 grams of alcohol) consumed per drinking day in the past week at six adolescent waves of data collection. The distribution of maximum number of drinks consumed on a typical drinking occasion was classified into four levels for each study: 0-2 standard drinks; 3-6 standard drinks; 7-12 standard drinks; 13+ standard drinks.

2.5. Maximum number of alcohol-related problems reported prior to age 17

The ATP asked about the frequency of five drinking-related problems over the lifetime at age 15 years (i.e., have trouble at school the next day, get into arguments with your family, get injured or have an accident, become violent and get into a fight, have sex with someone you later regretted). The CHDS assessed the number of alcohol abuse/dependence symptoms (Rutgers Alcohol Problems Index; White and Labouvie, 1989) in the past 12 months at age 15 and 16 years (23 items). The VAHCS assessed 13 drinking-related problems in the past six months at six adolescent waves of data collection (e.g., drinking so much that the next day you couldn't remember what you said or did, wanted to stop drinking but couldn't, had trouble at school or work the next day). The distribution of maximum number of alcohol-related problems was classified into four levels for each study: no problems, 1-2 problems, 3-4 problems, 5+ problems.

References

White, HR., Labouvie, EW., 1989. Towards the assessment of adolescent problem drinking. J Stud Alcohol 50, 30-37.

Appendix 3: Prevalence of cannabis or alcohol use and educational outcomes by cohort

There were small between-study variations in the prevalence of adolescent substance use and some outcomes which might be expected to occur in cohorts drawn from regions of similar cultural and socio-demographic backgrounds (Table 3.1). These were greater for alcohol than for cannabis.

Table 3.1: Observed prevalence of cannabis or alcohol use and educational outcomes by cohort

% (N[1])	ATP	CHDS	VAHCS
Maximum frequency of cannabis use <17 years			
Never	79.3 (1431)	59.4 (1065)	64.9 (1904)
<Weekly	17.2 (1431)	32.1 (1065)	24.6 (1904)
Weekly+	3.5 (1431)	8.5 (1065)	10.5 (1904)
Maximum frequency of alcohol use <17 years			
Never	24.7 (1383)	10.6 (977)	25.7 (1936)
<Weekly	51.8 (1383)	72.5 (977)	25.0 (1936)
Weekly+	23.5 (1383)	16.9 (977)	49.3 (1936)
Did not complete high school	9.6 (1249)	57.8 (1053)	15.9 (1518)
Did not enrol in university[2]	-	65.1 (1011)	41.5 (1520)
Did not attain a university degree	55.7 (992)	74.5 (1003)	63.9 (1520)

[1]Marginal N. [2]Only assessed in CHDS and VAHCS

Note: ATP=Australian Temperament Project; CHDS=Christchurch Health and Development Study; VAHCS=Victorian Adolescent Health Cohort Study

Appendix 4: Statistical procedure

The first analysis examined the bivariate associations between maximum frequency of cannabis or alcohol use before age 17 and the educational outcomes in each study and in the combined data set. We tested for statistical significance by fitting a series of logistic regression models to the data for each study and the combined data in which the log odds of each outcome was modelled as a linear function of the three level measure of the frequency of either cannabis or alcohol use. The models fitted to the combined data were of the form:

$$\text{logit}(Y_{ij}) = B0_j + B1\, X_{ij}$$

where logit (Yij) was the log odds of outcome Y for participant i in study j and Xij was the corresponding frequency of either cannabis or alcohol use. The effect parameter B1 was assumed to be constant across studies. However, the model allowed study specific random intercepts (B0j) to account for random sources of between study heterogeneity that were not otherwise represented in the model. Effect size estimates (odds ratios and 95% confidence intervals) for each outcome were obtained from the models fitted to the combined data set.

In the second analysis the bivariate associations were adjusted for confounding using a generalised propensity score approach (Spreeuwenberg et al., 2010; Imbens, 2000) in which the logistic regression models for the combined data were extended to incorporate a series of study specific propensity scores of the form:

$$\text{logit}(Y_{ij}) = B0_j + B1\, X_{ij} + \Sigma\, B_{jk}\, P_{ijk}$$

where Pijk was the estimated propensity (probability) that individual i from study j would be assigned to level k of the measure of cannabis or alcohol use (Xij).

References

Spreeuwenberg, M., Bartak, A., Croon, M., Hagenaars, J., Busschbach, J., Andrea, H., Twisk, J., Stijnen, T., 2010. The multiple propensity score as control for bias in the comparison of more than two treatment arms. Med Care 48, 166-174.

Imbens, G., 2000. The role of the propensity score in estimating dose-response functions. Biometrika 87, 706-710.

Appendix 5: Analysis of alternative measures of alcohol use

To examine the sensitivity of conclusions from the main analyses to alternative measures of alcohol use in adolescence, the analysis of frequency of alcohol use was supplemented by analysis of maximum number of standard drinks consumed on a single drinking occasion prior to age 17, and maximum number of alcohol-related problems reported prior to age 17 (described in Appendix 2).

Table 5.1 shows the associations between the maximum number of drinks on a single occasion prior to age 17 and the three measures of educational underachievement, in each study and in the combined data pooled across studies. Table 5.2 shows the corresponding associations for the number of alcohol related problems reported prior to age 17. Examination of the tables show the presence of significant (P<.05) associations between the maximum number of drinks consumed or alcohol-related problems and measures of educational underachievement in all comparisons. In the combined data participants who reported drinking 13 or more standard drinks in a single session prior to age 17 had odds of educational underachievement that were between 1.90-2.60 times higher than for those who reported maximum consumption of 0-2 standard drinks. Similarly those who reported 5 or more alcohol-related problems had odds of educational underachievement that were between 1.80-3.82 times higher than for those who reported no alcohol-related problems.

Tables 5.3, 5.4 show the adjusted effects size estimates for each association in the combined data after control for confounding using the multiple propensity score approach. After adjustment all of the associations were substantially reduced and generally became statistically non-significant. The adjusted odds ratios for those reporting 13 or more standard drinks ranged from 1.05-1.17 and for those who reported five or more alcohol related problems the adjusted odds ratios ranged from 0.91-1.71.

Table 5.1: Outcomes according to maximum quantity[5] of alcohol use before age 17 years in each study and when data were combined

	Maximum number of drinks				
Outcome	0-2	3-6	7-12	13+	p value[1]
High school non-completion[2]					
CHDS	287/565 (51%)	159/254 (63%)	74/102 (73%)	43/54 (80%)	<0.001
VAHCS	134/938 (14%)	24/204 (12%)	26/147 (18%)	54/222 (24%)	0.001
Combined data	421/1503 (28%)	183/458 (40%)	100/249 (40%)	97/276 (35%)	<0.001
OR (95% CI)	1	1.34 (1.22-1.47)	1.80 (1.50-2.16)	2.41 (1.83-3.17)	
University non-enrolment[3,4]					
CHDS	337/551 (61%)	156/244 (64%)	80/98 (82%)	38/47 (81%)	<0.001
VAHCS	360/939 (38%)	83/205 (40%)	66/147 (45%)	115/222 (52%)	<0.001
Combined data	697/1490 (47%)	239/449 (53%)	146/245 (60%)	153/269 (57%)	<0.001
OR (95% CI)	1	1.24 (1.14-1.34)	1.53 (1.31-1.80)	1.90 (1.50-2.41)	
Degree non-attainment[2]					
CHDS	374/539 (69%)	190/245 (78%)	84/98 (86%)	47/51 (92%)	<0.001
VAHCS	548/939 (58%)	145/205 (71%)	104/147 (71%)	167/222 (75%)	<0.001
Combined data	922/1478 (62%)	335/450 (74%)	188/245 (77%)	214/273 (78%)	<0.001
OR (95% CI)	1	1.38 (1.26-1.51)	1.89 (1.58-2.27)	2.60 (1.99-3.42)	

Data are n/N (%). ATP=Australian Temperament Project. CHDS=Christchurch Health and Development Study. VAHCS=Victorian Adolescent Health Cohort Study. [1]p value of the association between adolescent alcohol use and each outcome in each study, and in combined data adjusted for study-specific effects. [2]Assessed at age 25 years. [3]Assessed at age 21 years. [4]Only CHDS and VAHCS assessed university enrolment. [5]Only CHDS and VAHCS assessed quantity of alcohol use.

Table 5.2: Outcomes according to maximum number of alcohol-related problems before age 17 years in each study and when data were combined

	Maximum number of alcohol-related problems				
Outcome	0	1-2	3-4	5+	p value[1]
High school non-completion[2]					
ATP	64/841 (8%)	24/179 (13%)	6/33 (18%)	2/5 (40%)	<0.001
CHDS	430/789 (55%)	72/106 (68%)	33/44 (75%)	23/28 (82%)	<0.001
VAHCS	80/741 (11%)	72/424 (17%)	56/233 (24%)	26/99 (26%)	<0.001
Combined data	574/2371 (24%)	168/709 (24%)	95/310 (31%)	51/132 (39%)	<0.001
OR (95% CI)	1	1.56 (1.40-1.76)	2.44 (1.96-3.05)	3.82 (2.74-5.32)	
University non-enrolment[3,4]					
CHDS	485/765 (63%)	66/98 (67%)	33/42 (79%)	22/27 (81%)	0.008
VAHCS	278/742 (37%)	181/424 (43%)	110/234 (47%)	47/99 (48%)	0.003
Combined data	763/1507 (51%)	247/522 (47%)	143/276 (52%)	69/126 (55%)	<0.001
OR (95% CI)	1	1.22 (1.10-1.34)	1.48 (1.22-1.80)	1.80 (1.34-2.41)	
Degree non-attainment[2]					
ATP	367/682 (54%)	87/140 (62%)	24/27 (89%)	2/4 (50%)	0.001
CHDS	553/760 (73%)	79/98 (81%)	37/42 (88%)	21/25 (84%)	0.008
VAHCS	423/742 (57%)	277/424 (65%)	175/234 (75%)	78/99 (79%)	<0.001
Combined data	1343/2184 (61%)	443/662 (67%)	236/303 (78%)	101/128 (79%)	<0.001
OR (95% CI)	1	1.47 (1.32-1.63)	2.15 (1.75-2.65)	3.16 (2.32-4.31)	

Data are n/N (%). ATP=Australian Temperament Project. CHDS=Christchurch Health and Development Study. VAHCS=Victorian Adolescent Health Cohort Study. [1]p value of the association between adolescent alcohol use and each outcome in each study, and in combined data adjusted for study-specific effects. [2]Assessed at age 25 years. [3]Assessed at age 21 years. [4]Only CHDS and VAHCS assessed university enrolment.

Table 5.3: Associations (ORs 95% CIs) between maximum quantity of alcohol use before age 17 and educational outcomes, in combined data after adjustment[4] for confounding

	Maximum number of drinks					
Outcome (OR 95%CI)	0-2	3-6	7-12	13+	p value	N
High school non-completion[1]	1	1.02 (0.90-1.15)	1.04 (0.80-1.33)	1.05 (0.72-1.54)	0.784	2218
University non-enrolment[2,3]	1	1.04 (0.94-1.15)	1.09 (0.89-1.33)	1.13 (0.84-1.54)	0.424	2203
Degree non-attainment[1]	1	1.06 (0.94-1.18)	1.11 (0.89-1.39)	1.17 (0.84-1.64)	0.346	2197

Data are odds ratios (95% CIs). [1]Assessed at age 25 years. [2]Assessed at age 21 years. [3]Only CHDS and VAHCS assessed university enrolment. [4]Adjusted using a multiple propensity score approach, with propensity scores computed for each individual based on the available likely predictors of adolescent alcohol use and combined across studies (ATP: school problems, 14-15 years; conduct disorder 13-16 years; attentional problems, 13-16 years; tobacco use, 13-16 years; other illicit drug use before 17 years; depression, 13-16 years; sex; ethnicity; parental socio-economic status; parental alcohol and tobacco use; parental education; parental divorce; antisocial peer activities, 13-16 years. CHDS: Grade point average, 11-13 years; conduct problems, 7-9 years; attentional problems, 7-9 years; tobacco use, 10-15 years; other illicit drug use before 17 years; major depression, 14-16 years; sex; ethnicity; socio-economic status at birth; family living standards, 1-10 years; parental history of criminal offending, parental tobacco use; parental history of alcohol problems; parental illicit drug use; parental history of mental health problems; parental education level at birth, parental separation, 0-10 years; deviant peer affiliations, 15 years. VAHCS: antisocial behaviour before 17 years; tobacco use before 17 years; other illicit drug use before 17 years; symptoms of depression/anxiety before 17 years; sex; ethnicity; parental tobacco use; parental alcohol use; parental education; parental divorce/separation; peer alcohol use before 17 years; peer tobacco use before 17 years; peer other illicit drug use before 17 years). Propensity score models included cannabis use before age 17 as a predictor of alcohol use in all studies.

Table 5.4: Associations (ORs, 95% CIs) between number of alcohol-related problems before age 17 and educational outcomes, in combined data after adjustment[4] for confounding

	Maximum number of alcohol-related problems					
Outcome (OR 95%CI)	0	1-2	3-4	5+	p value	N
High school non-completion[1]	1	1.19 (1.02-1.40)	1.42 (1.04-1.97)	1.71 (1.05-2.77)	0.029	2987
University non-enrolment[2,3]	1	0.97 (0.85-1.11)	0.94 (0.72-1.24)	0.91 (0.61-1.37)	0.661	2171
Degree non-attainment[1]	1	1.01 (0.88-1.15)	1.01 (0.77-1.33)	1.02 (0.67-1.54)	0.939	2816

Data are odds ratios (95% CIs). [1]Assessed at age 25 years. [2]Assessed at age 21 years. [3]Only CHDS and VAHCS assessed university enrolment. [4]Adjusted using a multiple propensity score approach, with propensity scores computed for each individual based on the available likely predictors of adolescent cannabis or alcohol use and combined across studies (see Table S3 for specific predictors included).

<u>Appendix 6</u>: Data weighting procedures to examine possible selection bias from sample attrition and missing data

To examine the possible implications of selection bias arising from sample attrition and missing data in each study, the propensity adjusted regression models were re-analysed using data weighting procedures (Little and Rubin, 2002). This involved a two-stage process. First, estimating a selection bias model predicting inclusion in the analysed sample from variables assessed on everyone at the inception of each study (see Table 6.1). Second, re-running the propensity adjusted regression model for a given outcome/exposure combination weighted by the inverse of the selection bias probability estimate. This process weights individuals who were more likely to be lost from the analysis sample relative to individuals who were more likely to be included in the analysis. Specifically, for each analysis (outcome/exposure combination) the following steps were completed.

In each study:

1. A dichotomous (0/1) indicator variable was defined to classify participants according to whether they were included (1) or excluded (0) from the propensity adjusted analysis.
2. A series of variables were identified that were assessed on everyone at the inception of the study.
3. A logistic regression model was fitted to the data to predict the inclusion/exclusion indicator from the available predictors in Step 2. These models were refined to produce a final fitted model which included a core set of significant predictors of sample inclusion for each study.
4. The predicted probability (p_{ij}) of sample inclusion for participant i in study j from the final fitted model was generated in each study. The weight was calculated as the inverse of the predicted probability ($wgt = 1/p_{ij}$).

In the integrated dataset:

5. The propensity adjusted regression model for each outcome/exposure combination was re-run with the data for each individual weighted by w_{ij} using the pweight option in Stata.
6. We then compared the estimated effect for the cannabis/alcohol exposure from the unweighted and weighted analyses.

Table 6.1 shows that the results (ORs 95%CIs) from the weighted and unweighted analyses were negligibly different. This suggests that possible selection bias arising from sample attrition and missing data in each study was unlikely to have influenced the results reported.

References

Little, R., Rubin, D., 2002. Statistical analysis with missing data (2nd ed). Wiley, Hoboken.

Table 6.1 Estimated effect (ORs, 95% CI) of substance use exposure from unweighted and weighted[4] analyses in combined data after adjustment[5] for confounding

	Frequency of Substance Use			
Measure	Never	<Weekly	Weekly +	p value
Outcome: Did not complete high school[1]				
Cannabis use	1	1.27 (1.05-1.53)	1.60 (1.09-2.35)	0.016
Weighted	1	1.24 (1.01-1.53)	1.55 (1.02-2.35)	0.040
Alcohol use	1	1.10 (0.91-1.34)	1.21 (0.83-1.78)	0.323
Weighted	1	1.11 (0.90-1.36)	1.22 (0.81-1.84)	0.332
Outcome: Did not enrol in university[2,3]				
Cannabis use	1	1.23 (1.03-1.46)	1.51 (1.06-2.13)	0.021
Weighted	1	1.22 (1.02-1.45)	1.48 (1.04-2.10)	0.028
Alcohol use	1	0.94 (0.80-1.10)	0.88 (0.64-1.21)	0.420
Weighted	1	0.93 (0.79-1.08)	0.86 (0.63-1.17)	0.330
Outcome: Did not attain university degree[1]				
Cannabis use	1	1.40 (1.17-1.68)	1.96 (1.36-2.81)	<0.001
Weighted	*1*	1.37 (1.13-1.66)	1.87 (1.27-2.75)	0.001
Alcohol use	1	0.95 (0.83-1.09)	0.90 (0.68-1.18)	0.470
Weighted	1	0.92 (0.77-1.08)	0.84 (0.60-1.17)	0.299

Data are odds ratios (95% CIs). [1]Assessed at age 25 years. [2]Assessed at age 21 years. [3]Only CHDS and VAHCS assessed university enrolment. [4]Weights were computed based on estimating a selection bias model which predicted inclusion in the analysed sample from variables assessed on everyone at the inception of each study (ATP: sex, parental socio-economic status, maternal ethnicity, maternal age. CHDS: sex, socio-economic status, paternal education, maternal education. VAHCS: sex, location of school, parental divorce). The adjusted regression models were then re-run with data for each individual weighted by the computed weights. [5]Adjusted using a multiple propensity score approach, with propensity scores computed for each individual based on the available likely predictors of adolescent cannabis or alcohol use and combined across studies (ATP: school problems, 14-15 years; conduct disorder 13-16 years; attentional problems, 13-16 years; tobacco use, 13-16 years; other illicit drug use before 17 years; depression, 13-16 years; sex; ethnicity; parental socio-economic status; parental alcohol and tobacco use; parental education; parental divorce; antisocial peer activities, 13-16 years. CHDS: Grade point average, 11-13 years; conduct problems, 7-9 years; attentional problems, 7-9 years; tobacco use, 10-15 years; other illicit drug use before 17 years; major depression, 14-16 years; sex; ethnicity; socio-economic status at birth; family living standards, 1-10 years; parental history of criminal offending, parental tobacco use; parental history of alcohol problems; parental illicit drug use; parental history of mental health problems; parental education level at birth, parental separation, 0-10 years; deviant peer affiliations, 15 years. VAHCS: antisocial behaviour before 17 years; tobacco use before 17 years; other illicit drug use before 17 years; symptoms of depression/anxiety before 17 years; sex; ethnicity; parental tobacco use; parental alcohol use; parental education; parental divorce/separation; peer alcohol use before 17 years; peer tobacco use before 17 years; peer other illicit drug use before 17 years). Propensity score models included alcohol use before age 17 as a predictor of cannabis use and cannabis use before age 17 as a predictor of alcohol use in all studies.

Appendix 7: Sensitivity analysis

A sensitivity analysis using CHDS data examined the associations between educational outcomes and a quantity x frequency measure of high-end alcohol use prior to age 17.

Maximum frequency of high-end drinking before age 17

The CHDS assessed the amount of alcohol consumed (in millilitres of pure alcohol) on a typical drinking occasion at ages 14, 15, and 16 years. This was divided by the amount of alcohol in one standard drink (12.7ml) to provide an estimate of the number of standard drinks consumed. This was used in conjunction with past 12 months frequency of alcohol use (response categories were: never, very occasionally, less than once a month, at least once a month, at least once a week, almost every day) to create a three-level measure of the maximum frequency of high-end drinking (10+ standard drinks in a typical session) before age 17 years (with 0 as never, 1 as less than weekly, and 2 as weekly or more).

Statistical procedure

The statistical procedure is described in Appendix 4 and summarized here. We first examined the bivariate associations between maximum frequency of high-end drinking before age 17 and the educational outcomes. We tested for statistical significance by fitting a series of logistic regression models to the data in which the log odds of each outcome was modelled as a linear function of the three level measure of the frequency of high-end drinking.

In the second analysis the bivariate associations were adjusted for confounding using a generalised propensity score approach in which the logistic regression models were extended to incorporate a series of propensity scores. Propensity scores were estimated from a multinomial logistic regression in which the frequency of high-end drinking was regressed on the full set of available confounding factors in CHDS. Propensity scores were then included in the fitted regression models. Effect size estimates were expressed as odds ratios and 95% confidence intervals.

Results

Table 7.1 shows the associations of maximum frequency of high-end drinking before age 17 classified in three levels (never, <weekly, weekly+) with the three measures of educational underachievement. There were significant associations between increasing frequency of high-end drinking and poorer educational attainment. After adjustment for confounding, all of the associations between frequency of high-end drinking in adolescence and educational underachievement weakened and were non-significant. Results were consistent with the previous analyses and support the main findings.

Table 7.1. Unadjusted and adjusted[3] associations between maximum frequency of high-end drinking (10+ drinks in a typical session) before age 17 and educational outcomes in CHDS

	Frequency of high-end drinking			
Outcome	Never	<Weekly	Weekly +	p value
Did not complete high school[1]	510/906 (56%)	27/34 (79%)	21/27 (78%)	
OR (95% CI)	1	2.29 (1.50-3.48)	5.24 (2.26-12.14)	<0.001
AOR (95% CI)	1	1.01 (0.62-1.64)	1.02 (0.38-2.70)	0.970
Did not enrol in university[2]	564/879 (64%)	25/30 (83%)	17/23 (74%)	
OR (95% CI)	1	2.23 (1.43-3.48)	4.97 (2.03-12.14)	<0.001
AOR (95% CI)	1	0.96 (0.59-1.58)	0.93 (0.34-2.50)	0.886
Did not attain university degree[1]	640/896 (74%)	29/31 (94%)	21/25 (84%)	
OR (95% CI)	1	3.70 (2.08-5.59)	13.69 (4.32-43.41)	<0.001
AOR (95% CI)	1	0.94 (0.51-1.72)	0.88 (0.26-2.96)	0.835

Data are n/N (%), odds ratios (95% CIs) and adjusted odds ratios (95% CIs). CHDS=Christchurch Health and Development Study. [1]Assessed at age 25 years. [2]Assessed at age 21 years. [3]Adjusted using a multiple propensity score approach, with propensity scores computed for each individual based on the available likely predictors of adolescent high-end drinking: Grade point average, 11-13 years; conduct problems, 7-9 years; attentional problems, 7-9 years; tobacco use, 10-15 years; other illicit drug use before 17 years; major depression, 14-16 years; sex; ethnicity; socio-economic status at birth; family living standards, 1-10 years; parental history of criminal offending, parental tobacco use; parental history of alcohol problems; parental illicit drug use; parental history of mental health problems; parental education level at birth, parental separation, 0-10 years; deviant peer affiliations, 15 years.