A Co-Twin Control Study of the Relationship Between Adolescent Drinking and Adult Outcomes

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ABSTRACT. Objective: The effect of drinking during adolescence on adult functioning is a public health concern. A variety of mechanisms have been proposed where drinking in adolescence has an adverse impact on later outcomes; unfortunately, few studies have included methodologies that account for confounding influences that might link adolescent drinking with subsequent problems. To address this limitation, the current study used a co-twin control design, which uses members of twin pairs that differ from each other on their adolescent drinking. **Method:** We used a prospective longitudinal sample drawn from the Minnesota Twin Family Study, consisting of 2,764 twins (1,434 female) assessed at regular follow-ups from age 17 to age 29. Adolescent drinking was defined by measures of early initiation of use and a measure of overall consumption at age 17. Adult outcomes included indica-

tors of substance use, antisocial behavior, personality, socioeconomic status, and social functioning. **Results:** The co-twin control analyses suggested that many of the associations between adolescent drinking and later outcomes were largely influenced by genetic confounding. However, for the measure of adolescent alcohol consumption, results were consistent with a small causal impact of drinking on multiple domains of adult functioning. This pattern was less consistently observed for the measures of early initiation. **Conclusions:** These results provide empirical justification for policies designed to alleviate long-term consequences associated with adolescent drinking by reducing the level of alcohol consumption in adolescence. In contrast, the evidence did not suggest that delaying drinking would have a broad impact on later-life adjustment. (*J. Stud. Alcohol Drugs*, 79, 635–643, 2018)

IN RECENT YEARS, there has been a growing interest in the long-term effects of adolescent drinking on adult psychosocial functioning (see McCambridge et al., 2011). Although much of the research has focused on adult drinking and substance use problems, the literature has provided evidence of links between adolescent drinking and adult antisocial behaviors, lower socioeconomic status, mental health issues, and altered relationships (e.g., Dogan et al., 2010; Grant et al., 2012; Green et al. 2011; Haller et al., 2010; Latvala et al., 2014; Odgers et al., 2008; Viner & Taylor, 2007; Wells et al., 2004).

A variety of mechanisms have been proposed where adolescent alcohol use may exert a causal effect on adult outcomes—including a neurotoxic process, engagement with deviant peers, and missed educational opportunities—but, regardless of the specific mechanism, drinking is more than a marker of risk (Guttmannova et al., 2012; Zeigler et al., 2005). At issue in supporting a causal hypothesis, however, is the possibility that genetic confounding influences may account for the relationship between adolescent drinking and later functioning. A handful of recent studies (e.g., Richmond-Rakerd et al., 2016) have incorporated biometric

modeling to determine the familial source of the co-variation between adolescent drinking and later functioning. Most recently, Waldron et al. (2017) demonstrated that genes were important for explaining the relationship between a measure of adolescent alcohol consumption and adult outcomes, underscoring that genetic confounding is a potential concern that should be addressed in studies of the impact of adolescent alcohol use.

The co-twin control design has not been widely used in prospective studies of adolescent alcohol use, but it is a promising method to allow for stronger conclusions about causal links. This design accounts for unmeasured genetic confounders by using members of twin pairs that differ from each other on some measure of exposure (McGue et al., 2010). If the heavier-drinking member of a twin pair has more problems in adulthood compared with their lesser-drinking co-twin with the same genes and childhood environment, that finding would be consistent with a causal impact of drinking on later behavior. Because monozygotic (MZ) twins share 100% of their genes, they provide complete control for genetic and shared environmental influences, whereas dizygotic (DZ) twins, who share on average 50% of their segregating genes, provide partial control for genes and complete control for shared environmental factors. Of course, these approaches do not address the role of any unshared confounders that might influence both adolescent drinking and later functioning. An investigation of possible preexisting differences within twin pairs who differ on their alcohol exposure conducted in conjunction with the co-twin control design can help address this concern.

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Several studies have used the co-twin control design to investigate the impact of adolescent drinking (Grant et al., 2006, 2012; Malone et al., 2014; Prescott & Kendler, 1999); however, only two prospective longitudinal investigations implemented the co-twin control method to assess the long-term consequences of adolescent alcohol consumption. Rose et al. (2014) investigated “drinking-related problems” in late adolescence and their link to functioning in emerging adulthood, whereas Irons et al. (2015) addressed the impact of early initiation of alcohol consumption and early intoxication. These authors identified some evidence for negative consequences of adolescent drinking.

Despite the existence of these recent investigations, the literature supporting causal links between adolescent drinking and later functioning remains limited. Irons et al. (2015) did not study measures of adolescent alcohol consumption, instead focusing on measures of early use. In light of the recent debate about the consequences of early alcohol initiation (e.g., Kuntsche et al., 2015; Windle, 2016) as well as more recent emphasis on the consequences of early intoxication (e.g., Asbridge et al., 2016; Kuntsche et al., 2013), a co-twin analysis investigating measures of consumption as well as early initiation and intoxication is important for clarifying which drinking phenotypes are linked with problems. Further, both Rose et al. (2014) and Irons et al. (2015) focused on adult outcomes during emerging adulthood. Given the tumultuous nature of this time, it is important to examine adult outcomes beyond emerging adulthood to understand the impact of adolescent drinking throughout the life span.

The current study sought to address limitations of the literature thus far and build on previous work (see Waldron et al., 2017) by implementing the first known longitudinal prospective co-twin control study of adolescent drinking and functioning in later adulthood. Although Waldron et al. (2017) used the current sample for biometric analyses of adolescent alcohol consumption and adult functioning, they did not incorporate measures of initiation, preventing comparisons of different adolescent drinking phenotypes. In addition, where biometric analyses use structural equation modeling to describe latent genetic or environmental influences, co-twin control studies are based on a counterfactual model that explicitly tests whether associations are due to confounding factors or exposure—this conceptual interpretation of the co-twin analyses is important given the need to gauge the causal impact of adolescent drinking.

It was hypothesized that relationships between adolescent drinking and the adult outcomes would be consistent with partial genetic confounding, such that similarity on adult outcomes would be greater in MZ twins who differ on their adolescent alcohol exposure than in DZ twins who differ on their alcohol exposure. It was further hypothesized that within twin pairs, the twin with greater adolescent drinking would have worse adult functioning than their co-twin, consistent with a causal effect.

Method

Sample

The Minnesota Twin Family Study (MTFS) is a longitudinal, population-based study of twins born in Minnesota (Iacono et al., 2006). The study was conducted under the University of Minnesota Institutional Review Board. The sample consisted of 2,764 individuals, first assessed at age 17 (older cohort, 1,252 individuals) or at age 11 (younger cohort, 1,512 individuals). These individuals made up 896 MZ twin pairs and 486 DZ twin pairs.

During day-long laboratory visits or telephone interviews, twins were interviewed by trained interviewers with a BA or MA in psychology. The current study primarily used data from the assessments conducted when the twins were approximately 17 years old and 29 years old. For the age 17 cohort, this was the intake visit and the third follow-up visit (93.29% follow-up rate). For the age 11 cohort, this was the second follow-up visit (87.30%) and the fifth follow-up visit (87.57%). Logistic regression analyses revealed that level of alcohol consumption at the age 17 assessment was not predictive of the likelihood of presenting to the age 29 assessment ($\beta = -.02$, $p = .77$); nor was early initiation of alcohol use during adolescence ($\beta = -.06$, $p = .06$) or early initiation of intoxication during adolescence ($\beta = .08$, $p = .67$).

We collected information about the younger cohort before the initiation of drinking. This allowed analyses to address if differences within the twin pair that predated alcohol exposure might confound an association between the exposure and the adult outcomes. Childhood risk factors were assessed using data available in the younger cohort's age 11 intake assessment. Since the vast majority of individuals had not started drinking at age 11, this strategy helped ensure that none of the childhood “risk” factors actually represented a potential consequence of adolescent drinking.

Adolescent measures

Three alcohol use phenotypes were included: early initiation of alcohol use (before age 15), early first intoxication (before age 15), and an alcohol consumption index (ACI) based on indicators of frequency of use, average use, lifetime intoxications, and maximum drinks consumed. Please see the online-only supplemental material for more detail.

Adult measures

At age 29, outcomes were selected based on other prospective studies that incorporated distinct measures of substance use, antisocial behaviors, socioeconomic standing, mental health, and social relationships (e.g., Chatterji, 2006; Dogan et al., 2010; Green et al., 2016; Rossow & Kuntsche, 2013; Skogen et al., 2016). The reliability and validity of the

selected measures are discussed in more detail in Hicks et al. (2010), Foster et al. (2014), and Waldron et al. (2017), as well as the supplementary material.

Measures included largest number of standard drinks consumed in 24 hours, average number of drinks consumed per sitting, number of illicit drug classes tried, number of recent marijuana uses, symptoms of nicotine dependence according to the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV; American Psychiatric Association, 1994), symptoms of alcohol abuse and dependence (summed together), DSM-IV symptoms of marijuana abuse and dependence (summed together), DSM-IV symptoms of adult antisocial behavior, an index of legal problems, educational attainment, occupational status, an index of financial problems, DSM-IV symptoms of major depressive disorder, personality scales of negative emotionality and behavioral disinhibition, indices of engagement with antisocial and pro-social peers, number of recent sexual partners, an index of romantic partner's use of alcohol, and an index of romantic partner's permissiveness toward substance use.

The ascertainment period of all of the substance use measures, adult antisocial behavior symptoms, legal problems, financial problems, depressive symptoms, and recent sexual partners was since the age 24 assessment, whereas the other measures assessed functioning at age 29. All measures were coded such that a higher score on the measure would indicate more problematic functioning.

Childhood risk measures

Childhood risk factors that have been linked to adolescent alcohol use (Larsen & Wiers, 2016) were assessed at age 11 in the younger cohort, and they are discussed in further detail in the supplementary material. Measures included a prorated index of IQ, a composite of childhood externalizing symptoms, an index of conflict with parents, major depressive disorder symptoms, academic problems, academic motivation, academic performance (i.e., grade-point average), expectation of future educational progress (i.e., "educational stagnation"), an inventory of delinquent behaviors, total number of peer relationships, and a scale of pubertal development. With the exception of IQ, all variables were coded such that a higher score on the risk factor would be expected to correlate positively with greater adolescent alcohol involvement.

Data analyses

For each of the outcome variables of interest, using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC), separate individual-level regressions were completed with the indicators of adolescent drinking to demonstrate if there was an association between adolescent drinking and adult functioning. Family group was included as a random effect to account

for the correlated nature of twin observations. Cohort membership, gender, age at the assessments, and zygosity were included as covariates.

Next, before the co-twin control regression, a series of analyses addressed the concern that childhood risk factors unshared across members of a twin pair might contribute to within-twin pair differences in adolescent drinking and thereby represent a possible confounder in a relationship between adolescent drinking and adult outcomes. The R package CBPS (Covariate Balancing Propensity Score; Imai & Ratkovic, 2014) was used to generate propensity scores for each of the three adolescent drinking indicators, modeling exposure for each drinking measure as a function of the age 11 risk factors.

The CBPS procedure simultaneously optimizes prediction of the probability of exposure and covariate balance, thereby equating risk across different levels of alcohol exposure. Subsequent analyses examined if members of a twin pair differed from each other on their propensity for exposure to adolescent drinking. If members of the twin pairs were similar to each other on their risk for adolescent drinking, then an association in the co-twin analyses between adolescent drinking and adult problems could be more confidently interpreted as evidence of a causal effect.

Next, co-twin control regressions were completed. In these analyses, the individual-level regression term is replaced by a between-pair coefficient that informs on the predictive power of effects that are common to the twins (represented by the twin pair's mean level on the adolescent drinking measure) and a within-twin pair coefficient that informs on the predictive power of exposures unique to one twin (represented by each participant's deviation from the twin pair's mean).

The between and within-pair coefficients are orthogonal to each other, and if the within-pair coefficient is significantly different from zero, it suggests that at least part of the association between adolescent drinking and adult functioning is accounted for by individual factors that vary across members of a twin pair, consistent with a causal impact of adolescent drinking (see, e.g., Carlin et al., 2005). When the measure of exposure is dichotomous, members of a twin pair who differ from each other on the exposure are said to be discordant, and the co-twin control design approximates an experiment in which the exposed twin is assigned to the experimental group.

Twin pairs that are concordant and discordant for their alcohol exposure are both included in analyses. Concordant twins do not directly inform on the within-pair effect; however, they do inform on the between-pair effect. When the measure of exposure is continuous, the design is a co-twin control differences design; in this instance, the twin with greater levels of exposure is theorized to approximate the functioning of a lesser drinking twin had their exposure been greater. In the co-twin analyses, a zygosity by within-twin

TABLE 1. Descriptive statistics of adult outcome measures used and regression of adolescent drinking phenotypes on age 29 adult outcomes^a

Age 29 outcome variable	Descriptive statistics ^b				Regression of adult outcome on adolescent alcohol consumption index ^b	Regression of adult outcome on early first drink	Regression of adult outcome on early first intoxication
	<i>M</i>	<i>SD</i>	Min.	Max.	<i>B</i>	<i>B</i>	<i>B</i>
Substance use and substance use disorders							
Largest no. drinks consumed	9.26	7.29	0	72	.36 (.02)***	.27 (.04)***	.39 (.05)***
Avg. no. drinks consumed	3.16	2.36	0	24	.37 (.02)***	.31 (.04)***	.50 (.06)***
Drug classes tried	0.53	1.01	0	5+	.33 (.02)***	.44 (.04)***	.66 (.05)***
Recent marijuana uses	17.47	63.99	0	400	.29 (.02)***	.35 (.04)***	.55 (.06)***
Nicotine dependence sx	0.82	1.39	0	6	.30 (.02)***	.38 (.04)***	.45 (.06)***
Alcohol use disorder sx	0.57	1.34	0	11	.25 (.02)***	.29 (.04)***	.35 (.05)***
Marijuana use disorder sx	0.24	0.99	0	10	.21 (.02)***	.21 (.04)***	.34 (.06)***
Antisocial behavior and legal problems							
Adult antisocial behavior sx	0.73	0.87	0	6	.28 (.02)***	.38 (.04)***	.43 (.05)***
Legal problems	0.28	0.77	0	4	.16 (.02)***	.29 (.04)***	.35 (.05)***
Socioeconomic status							
Educational stagnation	5.32	2.69	0	12	.18 (.02)***	.28 (.04)***	.47 (.05)***
Occupational stagnation	3.47	1.58	0	7	.17 (.02)***	.27 (.05)***	.41 (.06)***
Financial problems	0.63	0.98	0	5	.09 (.02)***	.28 (.04)***	.36 (.06)***
Mental health and personality							
Major depressive sx	1.14	2.41	0	9	.05 (.02)*	.16 (.04)***	.12 (.06)*
Negative emotionality	79.41	13.57	40.90	131.80	.09 (.02)***	.24 (.04)***	.21 (.06)***
Behavioral disinhibition	125.91	15.63	74.60	195.00	.17 (.02)***	.21 (.04)***	.26 (.05)***
Social functioning							
Antisocial peers	33.79	4.79	23	60	.32 (.02)***	.45 (.04)***	.64 (.05)***
Prosocial peer disaffiliation	20.86	2.77	11	36	.14 (.02)***	.24 (.04)***	.36 (.06)***
Recent sexual partners	1.93	2.21	0	20	.21 (.02)***	.21 (.04)***	.21 (.06)***
Partner's alcohol misuse	0.00	0.82	-1.56	3.25	.22 (.02)***	.25 (.05)***	.23 (.06)***
Partner's permissiveness							
Toward substance use	26.87	6.31	11	44	.33 (.03)***	.43 (.05)***	.62 (.07)***

Notes: Min. = minimum; max. = maximum; avg. = average; no. = number; sx = symptoms. ^aMeans, standard deviation, and range of raw scores of each variable (prior to standardization or log transformation, for those variables with substantial skew) are shown above. In the right three columns, measures of adult functioning were separately regressed on the adolescent alcohol phenotypes; standard errors are shown in parentheses. All variables were standardized. All analyses adjusted for gender, cohort, zygosity, and ages at the adolescent and adult assessments. *Ns* for these analyses are drawn from all the individuals attending the age 17 and age 29 assessments, ranging from 1,762 (for age 29 outcomes relating to participant's romantic partner) to 2,411. ^bThe material in these columns ("Descriptive statistics" through "Regression of adult outcome on adolescent alcohol consumption index") is reprinted with permission from the American Psychological Association: Waldron, J. S., Malone, S. M., McGue, M., & Iacono, W. G. (2017). Genetic and environmental sources of covariation between early drinking and adult functioning. *Psychology of Addictive Behaviors*, 31, 589–600. doi:10.1037/ad0000283. These data are duplicated here merely for reference.

* $p < .05$; *** $p < .001$.

pair interaction term was included to indicate whether the within-twin pair effect differed significantly across MZ and DZ twins.

Genetic confounding would be evidenced by a significant within-twin pair effect in DZ twins, a nonsignificant within-twin pair effect in MZ twins, and a significant interaction term, whereas a causal effect would be supported by a significant within-twin pair coefficient in both MZ and DZ twins. Results could also be consistent with both partial genetic confounding and a causal effect, which would be evidenced by a significant zygosity interaction term and significant within-pair effects in both MZ and DZ twins.

Results

See Table 1 for descriptive statistics of the adult outcome variables. Thirty-three percent of the sample reported drinking before age 15, whereas 16% reported intoxication before age 15. The ACI was standardized for all analyses

(minimum score = -1.39, maximum score = 2.11). Table 1 includes the results of the linear mixed models in which each age 29 outcome was regressed on the adolescent drinking measures.¹ The three adolescent drinking measures were significantly associated with all of the adult outcome variables. Measures of substance use and social functioning were the most strongly associated, whereas associations with socioeconomic status and mental health and personality were more modest.

Analyses of childhood risk factors

As discussed above, given the possibility that preexisting childhood differences within a twin pair could confound the

¹In Table 1, the descriptive statistics and regression of the adult outcomes on the ACI were originally reported in Waldron et al. (2017); they are duplicated here merely for reference. The novel analyses are the regression of the adult outcomes on measures of early alcohol use.

TABLE 2. Descriptive statistics of age 11 risk factors and relationship between age 11 risk factors and adolescent drinking phenotypes^a

Age 11 risk factor	Descriptive statistics				Relationship with adolescent drinking phenotype					
					Correlation between risk factor and adolescent alcohol consumption		Standardized difference between individuals with early alcohol use and unaffected individuals		Standardized difference between individuals with early intoxication and unaffected individuals	
	<i>M</i>	<i>SD</i>	Min.	Max.	Original	After balancing	Original	After balancing	Original	After balancing
IQ	104.40	14.05	50	156	-.07 [-.13, -.02]	.00	-.09 [-.21, .02]	-.03	-.10 [-.25, .05]	-.10
Externalizing composite	-0.03	0.74	-2.45	2.55	.17 [.11, .23]	.03	.41 [.30, .54]	.09	.52 [.38, .68]	.05
Major depressive sx	0.29	1.06	0	8	-.01 [-.05, .06]	.02	.16 [.05, .28]	.06	.03 [-.12, .18]	.04
Conflict with parents	20.59	4.69	12	44.50	.10 [.04, .15]	.02	.30 [.18, .42]	.09	.30 [.15, .45]	.02
Academic problems	10.44	2.92	6	22	.15 [.09, .21]	.02	.28 [.17, .40]	.08	.40 [.25, .55]	.05
Academic decline (GPA)	-2.02	0.86	-3.48	1.44	.12 [.06, .18]	.01	.24 [.12, .36]	.09	.31 [.17, .47]	.06
Expected academic stagnation	2.65	0.72	1.50	6.00	.01 [-.04, .07]	.01	.13 [.02, .25]	.07	.23 [.08, .38]	.03
Academic amotivation	11.82	2.29	9	24	.04 [-.02, .09]	.00	.02 [-.09, .14]	.03	.04 [-.11, .19]	.00
Delinquent behaviors	0.97	1.29	0	14	.24 [.18, .29]	.04	.45 [.34, .57]	.07	.62 [.48, .79]	.03
Number of friends	15.84	15.89	1	100	.16 [.10, .21]	.00	.25 [.13, .36]	.03	.24 [.10, .39]	.06
Pubertal development					.07 [.01, .13]	.01	.13 [.01, .24]	.03	.21 [.07, .35]	.01
Females	8.74	2.42	0	16						
Males	4.95	1.85	0	13						

Notes: Min. = minimum; max. = maximum; sx = symptoms; GPA = grade-point average. ^aMeans, standard deviation, and range of scores of each variable are shown above on the left side of the table. Variables are represented by raw scores on the relevant scale, prior to standardization (or log transformation, for those variables with substantial skew). Note that the externalizing composite and the academic stagnation measures are composites of the mean *z* score of parent-child and teacher ratings. The right side of the table displays the relationship between each childhood risk factor and the three adolescent drinking phenotypes before the propensity score balancing procedure [95% confidence intervals are shown in brackets] and after the procedure; *ns* for all the analyses in this table range from 1,163 individuals to 1,263 individuals.

relationship between within-pair differences on adolescent drinking and later functioning, before the co-twin regressions, a series of propensity score analyses examined if age 11 measures explained subsequent within-twin pair differences in adolescent drinking. Table 2 provides descriptive statistics of childhood risk factors used. The standardized mean difference on each of the childhood risk factors between early first drinkers and individuals who did not drink early, and between the group of individuals with early intoxication and individuals without early intoxication, is also reported in Table 2, along with the correlation between the ACI and each childhood risk factor.

Individuals with more involvement in adolescent drinking were different on the age 11 childhood risk factors. Before the propensity score weighting procedure, correlations between the ACI and each risk factor reached as high as .24; after the procedure, none exceeded .04. Similarly, whereas standardized mean differences between individuals with and without early drinking or intoxication exposure reached as high as .62 before the procedure, afterward none exceeded .10, which is substantially below the threshold of .25 that has been suggested in the literature to ascertain the success of the procedure (Rubin, 2001).

Although these childhood measures accounted for variance in adolescent drinking, there was minimal evidence that they were actually related to within-twin pair differences in adolescent drinking. For both early first drink and early first intoxication, discordant twins were not significantly different from each other on the propensity scores that reflected

probability of belonging to the affected group. For early first drink: mean difference on propensity score within discordant MZ twin pairs = .01 (*SE* = .01), within discordant DZ twin pairs = .02 (*SE* = .02). For early first intoxication: mean difference on propensity score within discordant MZ twin pairs = .01 (*SE* = .01), within discordant DZ twin pairs = .02 (*SE* = .02).

Although the within-twin pair difference of the ACI propensity scores was weakly correlated with the within-twin pair difference in the actual value of the ACI for DZ twins (*r* = .17), within MZ twins, there was not a significant correlation (*r* = -.03). These results indicate that these childhood risk factors were unlikely to have confounded the co-twin analyses of the association between adolescent drinking and later functioning.² In sum, there is a stronger rationale for interpreting significant results from the co-twin control analyses as evidence of a causal process.

Co-twin control analyses

Twenty-five percent of twin pairs were discordant for early first drink, whereas 14% were discordant for early first intoxication. The standard deviation of the within-twin pair difference on the standardized ACI index was .80. Results of

²Because only MZ twin pairs provide complete control for genetic and shared environmental variables, that preexisting childhood differences were not present within MZ pairs who differed from each other on the ACI is most important for interpretation of the co-twin analyses.

TABLE 3. Regression coefficients from co-twin analyses of adolescent drinking phenotypes and age 29 adult outcomes^a

Outcome variable	Adolescent alcohol consumption index				Early first drink				Early first intoxication			
	Btwn-pair	MZ within-pair	DZ within-pair	Zyg × Within-Pair	Btwn-pair	MZ within-pair	DZ within-pair	Zyg × Within-Pair	Btwn-pair	MZ within-pair	DZ within-pair	Zyg × Within-Pair
Substance use and substance use disorders												
Largest no. drinks consumed	.41***	.15**	.32***	.17*	.26***	-.01	.05	.06	.28***	.00	.25***	.25**
Avg. no. drinks consumed	.43***	.19***	.28***	.09	.28***	.03	.05	.03	.31***	.15**	.24***	.09
Drug classes tried	.36***	.17***	.44***	.26***	.32***	.08*	.23***	.14*	.41***	.12*	.49***	.36***
Recent marijuana uses	.31***	.15**	.38***	.22**	.26***	.06	.16**	.11	.36***	.05	.42***	.37***
Nicotine dependence sx	.34***	.15**	.31***	.16*	.31***	.06	.09	.03	.40***	-.03	.02	.05
Alcohol use disorder sx	.26***	.15**	.29***	.13	.21***	.03	.10	.07	.25***	-.03	.10	.13
Marijuana use disorder sx	.23***	.09	.23**	.14	.18***	.04	.01	-.02	.25***	-.07	.33***	.40***
Antisocial behavior and legal problems												
Adult antisocial behavior sx	.31***	.13*	.34***	.21*	.30***	.02	.10	.08	.32***	-.03	.21**	.24**
Legal problems	.17***	.15*	.16*	.01	.20***	.05	.04	-.01	.26***	-.07	.08	.15
Socioeconomic status												
Educational stagnation	.23***	.10*	.12*	.02	.28***	.08**	.02	-.06	.38***	.16***	.07	-.09
Occupational stagnation	.18***	.12*	.07	-.06	.21***	.08	.003	-.07	.25***	.17**	.07	-.10
Financial problems	.09***	.10	.02	-.08	.19***	.06	.05	-.02	.26***	-.08	.11	.19*
Mental health and personality												
Major depressive sx	.04	.11	.03	-.08	.08**	.06	.12	.06	.07	-.01	.11	.13
Negative emotionality	.09***	.09	-.01	-.11	.15***	.06	.09	.03	.13**	.07	.05	-.02
Behavioral disinhibition	.19***	.11*	.24***	.14	.19***	.02	.04	.02	.18***	.01	.22**	.23*
Social functioning												
Antisocial peers	.36***	.14**	.30***	.16*	.36***	.05	.12*	.08	.42***	.17***	.22**	.05
Prosocial peer disaffiliation	.17***	-.03	.20**	.22**	.18***	.06	.03	-.02	.23***	.10	.09	-.01
Recent sexual partners	.23***	.11	.25***	.14	.18***	-.02	.05	.07	.15***	-.03	.11	.14
Partner's alcohol misuse	.26***	.09	.13	.05	.15***	.09	.05	-.04	.17***	.11	-.07	-.17
Partner's permissiveness												
Toward substance use	.37***	.17*	.24**	.07	.30***	.06	.17*	.10	.41***	.10	.21*	.11

Notes: Btwn = between; MZ = monozygotic; DZ = dizygotic; zyg = zygosity; no. = number; avg. = average; sx = symptoms. ^aIn co-twin analyses, measures of adult functioning were separately regressed on each of the adolescent drinking phenotypes. For each adult outcome, the “between-pair” coefficient reflects the effects that are common to a twin pair. A positive “within-pair” coefficient reflects that the twin with higher drinking had more problematic functioning on the adult outcome compared with their co-twin. The zygosity by within-twin pair interaction term (abbreviated as “Zyg×Within-Pair”) indicates whether the within-twin pair effect differed significantly across MZ and DZ twins. A positive within-twin pair zygosity interaction term reflects that the within-pair effect was stronger within DZ twins compared with MZ twins, consistent with some influence of genetic confounding. (To obtain the within-pair estimates for both MZ and DZ twins, each analysis was run twice, first with the MZ twins as the reference group and then as the DZ twins as the reference group.) All variables were standardized. All analyses adjusted for gender, cohort, zygosity, and ages at the adolescent and adult assessments. *Ns* range from 1,731 (for age 29 outcomes relating to participant's romantic partner) to 2,390.

p* < .01; *p* < .01; ****p* < .001.

the co-twin control analyses are reported in Table 3. For the three adolescent drinking measures, there was a significant between-pair effect of adolescent drinking on nearly all of the adult adjustment variables (Table 3). These family-level findings were expected given the results recorded for individuals in Table 1.

For the ACI, there were significant within-twin pair effects for both MZ and DZ twins on most of the substance use measures, adult antisocial behavior symptoms, legal problems, educational stagnation, behavioral disinhibition, partner's permissiveness toward substance use, and antisocial peers (Table 3), indicating that the twin with higher levels of adolescent alcohol consumption had more problematic functioning on these outcomes compared with their co-twin; this pattern of results was consistent with a causal process. The within-twin pair by zygosity interaction term was significant for largest number of drinks consumed, recent marijuana uses, nicotine dependence symptoms, drug

classes tried, adult antisocial behavior symptoms, prosocial peer disaffiliation, and antisocial peers, demonstrating that the within-pair effect of adolescent drinking on later functioning was stronger when there was less control for genetic influences.

For early first drink, there was a significant MZ and DZ within-twin pair effect and significant zygosity interaction term for the number of drug classes tried. For early first intoxication, within-twin pair associations were also present for both DZ and MZ pairs for average number of drinks consumed, drug classes tried, and antisocial peers, consistent with a causal effect of early intoxication on both of these indicators. However, there was a significant zygosity interaction for number of drug classes, suggestive of partial genetic confounding, as well as for largest number of drinks consumed, recent marijuana uses, marijuana use disorder symptoms, adult antisocial behavior symptoms, and behavioral disinhibition.

Of the 20 adult outcome variables that were included, 12 measures (spanning each of the categories of adult adjustment) displayed a pattern where there were significant within-pair effects for both MZ and DZ twins (the pattern of results consistent with a causal process) for at least one of the three adolescent drinking indicators. However, for 6 of these 12 measures, the significant MZ and DZ within-pair findings were also accompanied by a significant zygosity interaction term, which is consistent with an influence of partial genetic confounding on the relationship. Moreover, for 7 of the 20 adult outcomes measures (spanning each of the adult adjustment categories except for antisocial behavior), no within-pair MZ effects were significant. Although not all of these adult measures showed clear evidence of genetic confounding (e.g., there was not a significant zygosity interaction term), MZ coefficients tended to be smaller than DZ coefficients. There were two variables (occupational and educational stagnation) in which the MZ within-pair effect was significant, whereas the DZ within-pair effect was not for two different drinking measures. Given the lack of DZ effect, this pattern should be interpreted cautiously.

Discussion

This study examined the impact of adolescent drinking on a wide range of adult adjustment measures. Pointing to the construct validity of the adolescent drinking measures, each of the three adolescent drinking indices predicted all of the adult outcomes. Given some of the limitations in the literature that have prevented conclusions about adult consequences of adolescent drinking, the co-twin control design was used to control for familial influences that could act as confounders.

For the ACI, there were significant within-twin pair coefficients for both MZ and DZ twin pairs on 12 of the 20 adult measures, supportive of an effect of alcohol exposure. Propensity score analyses of the younger cohort revealed that twin pairs tended not to differ from each other on childhood factors that might increase the risk of adolescent drinking, suggesting that differences in risk before drinking did not explain the significant co-twin results. Of note, for the substance use measures, antisocial peers, and adult antisocial behavior symptoms, the MZ coefficient was significantly smaller than the DZ coefficient, reflecting that the relationship between adolescent drinking and these adult variables is at least partially attributable to genetic influences. This result is not surprising given that these adult measures have all been used as indicators of the genetically influenced externalizing dimension. In summary, findings support that the relationship between adolescent drinking and later functioning is explained by common genetic influences and the impact of alcohol exposure, suggesting that reducing the intake of alcohol during adolescence may have an impact on later-life functioning.

The pattern of results was markedly different for the measure of early first drink, where there was minimal evidence for a causal impact of early exposure. There was only one measure (drug classes tried) where MZ and DZ within-pair coefficients were significant. Unlike the ACI, the findings suggest that the relationship between early first drink and later functioning is largely explained by familial influences (genes or shared environment) rather than an impact of actual exposure.

Similar to the ACI results, the findings for early first intoxication reflected that the relationship with adult externalizing problems was attributable to genetic influences, as evidenced by the significant difference between the MZ and DZ coefficients. Compared with early first drink, there was more evidence for an impact of alcohol exposure, as both MZ and DZ coefficients were significant for multiple substance use measures and antisocial peer engagement; however, the general pattern across all of the adult measures showed limited support for a broad impact of delaying first intoxication on later functioning.

This study is the first of its kind to use a prospective co-twin control design to investigate adolescent alcohol consumption and a range of measures of functioning beyond emerging adulthood. Importantly, these results provide empirical justification for policies designed to alleviate long-term consequences associated with adolescent drinking by reducing the level of adolescent alcohol consumption. The evidence in this investigation was less clear that delaying the onset of drinking or early intoxication would improve later-life adjustment.

Given the evidence for genetic confounding observed in the co-twin analyses, as well as the results from the propensity score analyses demonstrating that adolescent drinkers are different on childhood risk factors that predate the onset of drinking, the findings speak to the potential importance of interventions aimed at identifying children or adolescents with family risk for subsequent behavioral issues and adjustment problems, rather than focusing solely on large-scale efforts to reduce or delay drinking. The study further demonstrates the potential importance of methodological approaches that account for and control for familial influences, as evidenced by the different pattern of results in the co-twin analyses compared with the individual-level analyses.

Because this is the first prospective co-twin control study of adolescent drinking's impact beyond emerging adulthood, it is important to interpret these results with caution. First, considering the wide sweeping public health implications, even a very small causal relationship between adolescent drinking and later functioning could have an important impact, which is particularly relevant for the measures of initiation where within-twin pair effects tended to be nonsignificant. Given the high prevalence of early drinking initiation, there could be a significant public health impact with even very subtle causal effects, and fu-

ture studies with greater power should continue to investigate this possibility.

In addition, for some outcomes where the MZ within-twin pair effect was not significant but the DZ within-twin pair effect was, which would be consistent with genetic confounding, the interaction term was not significant, which made it difficult to determine whether shared environmental influences or genetic influences explained the link with adolescent drinking. It is also noted that findings from this study have limited generalizability, as the sample largely comprised White twins.

In sum, it would be useful for future studies of adolescent drinking and adult functioning to replicate the findings identified in the current study, to make use of an ethnically diverse sample, and (for those measures where the source of familial confounding was not clear) to focus on whether these influences are more consistent with shared environmental or genetic effects. Further, considering that this study does provide an empirical basis for stronger conclusions about a causal relationship between adolescent drinking and adult adjustment but does not provide evidence of specific mechanisms involved in how adolescent drinking could exert its effect, future studies should test explanatory mechanisms and mediating variables that could causally link adolescent drinking with later functioning. Finally, given that adolescent drinkers demonstrated vulnerabilities in childhood that predated adolescent drinking, future research should examine how adolescent drinking may differentially affect those who are on “at-risk” developmental trajectories compared with those who are not.

Important strengths of this study include the genetically informed population-based sample, prospective design, minimal attrition rate, co-twin control analysis to address unmeasured confounding influences, and the range of domains of adult functioning that were included. In summary, the present study extends the previous literature by demonstrating that adolescent drinking indexes risk for a wide range of domains in the later–young adult period. The findings reveal that genetic confounders play a role in the relationship between adolescent drinking and later functioning, but there is still evidence consistent with a causal relationship between adolescent alcohol consumption and a range of indicators of adult functioning. In contrast, the findings did not suggest that efforts to delay early drinking or intoxication would have a broad impact on the areas of adult functioning assessed in this investigation.

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