

Puberty and the Onset of Substance Use and Abuse

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ABSTRACT. *Objective.* Substance abuse remains one of the major threats to adolescent health in Western cultures. The study aim was to ascertain the extent of association between pubertal development and early adolescent substance use.

Methods. The design was a cross-sectional survey of 10- to 15-year-old subjects in the states of Washington, United States, and Victoria, Australia. Participants were 5769 students in grades 5, 7, and 9, drawn as a 2-stage cluster sample in each state, and the questionnaire was completed in the school classrooms. The main outcomes of the study were lifetime substance use (tobacco use, having been drunk, or cannabis use), recent substance use (tobacco, alcohol, or cannabis use in the previous month), and substance abuse (daily smoking, any binge drinking, drinking at least weekly, or cannabis use at least weekly).

Results. The odds of lifetime substance use were almost twofold higher (odds ratio [OR]: 1.7; 95% confidence interval [CI]: 1.4–2.1) in midpuberty (Tanner stage III) and were threefold higher (OR: 3.1; 95% CI: 2.4–4.2) in late puberty (Tanner stage IV/V), after adjustment for age and school grade level. Recent substance use was moderately higher (OR: 1.4; 95% CI: 1.0–1.9) in midpuberty and more than twofold higher (OR: 2.3; 95% CI: 1.7–3.3) in late puberty. The odds of substance abuse were twofold higher (OR: 2.0; 95% CI: 1.2–3.2) in midpuberty and more than threefold higher (OR: 3.5; 95% CI: 2.2–5.4) in late puberty. Reporting most friends as substance users was more likely in the later stages of pubertal development, a relationship that accounted in part for the association found between later pubertal stage and substance abuse.

Conclusions. Pubertal stage was associated with higher rates of substance use and abuse independent of age and school grade level. Early maturers had higher levels of substance use because they entered the risk period at an earlier point than did late maturers. The study findings support prevention strategies and policies that decrease recreational substance use within the peer social group in the early teens. *Pediatrics* 2004; 114:e300–e306. URL: <http://www.pediatrics.org/cgi/content/full/114/3/e300>; *puberty, substance abuse, smoking, alcohol consumption, cannabis, adolescence.*

ABBREVIATIONS. PDS, Pubertal Development Scale; OR, odds ratio; CI, confidence interval.

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Profound changes in patterns of health risk occur during adolescence. The major determinants of later adult health arise in patterns of mental health, behavior, and lifestyles that develop in the early teens.¹ Early adolescent increases in depression and anxiety,^{2,3} eating disorders,⁴ risky sexual activity,⁵ and aggressive and antisocial behavior⁶ have been well documented, as have their consequences in later life.

The early teens also commonly herald the onset of substance use and abuse.^{7–9} Early adolescent substance abuse is relevant to health not only because it is associated with risky sexual behavior and intentional and unintentional injuries during the teens but also because it strongly predicts later adult abuse and dependence.¹⁰ Much earlier work emphasized changes in school, family, and peer contexts in the early teens as determinants of adolescent recreational drug use. Such social changes have been commonly presumed to be a normal consequence of becoming older and progressing through school, with puberty having an indirect influence on patterns of substance use.¹¹ However, a suspicion has grown that pubertal changes may play a more specific role. Pubertal timing among girls has been shown to predict patterns of substance use, with early maturers reporting higher use of tobacco and alcohol in the early teens.^{12,13} A common interpretation has been that early maturers are disadvantaged as a result of peer rejection and so experience low self-esteem. For these reasons, they may be more likely to turn to substance use.⁸

An alternative explanation is that puberty ushers in a phase of heightened risk for substance use. According to this hypothesis, early maturers report higher rates of substance use as a result of their early entry into a high-risk life phase. This explanation of puberty initiating a phase of higher risk has gained support in relation to the well-established early adolescent increase in depression.² Pubertal stage predicts depressive symptoms for each age level in early adolescence, with higher rates among early maturers arising from a 0-time shift in the onset of risk, relative to late maturers.

There has been growing speculation about the effects of puberty on neurobiologic processes implicated in substance abuse.¹⁴ Puberty also ushers in profound changes in cognitive and emotional styles, with an increasing orientation to adult environmental cues.¹⁵ Animal studies have shown heightened exploration and novelty-seeking, changes linked to the mesolimbic system so commonly implicated in

substance abuse.¹⁶ However, the evidence that puberty is associated with substance abuse independent of age and school grade level is uncertain. Available reports were derived from small clinical samples or are limited in the age range of subjects and are therefore unable to address the issue of an association with pubertal stage independent of age.

The current report is derived from a large binational study of adolescent development in community samples in the United States and Australia, recording variations in pubertal status, age, and school grade level. It addresses the relationships of pubertal stage and timing to substance (tobacco, alcohol, and cannabis) use and abuse among >5000 subjects 10 to 15 years of age. It also tests the mediating role of 3 well-established risk factors for substance use that might be affected by pubertal development, age, and school grade level, namely, exposure to substance use among friends, family and school connections, and sensation-seeking.^{1,7}

METHODS

Procedure and Sample

Data were collected as part of a binational study of youth development in Washington State, United States, and Victoria, Australia. Each state used a 2-stage cluster sampling procedure. In the first stage, schools at each study year level were selected at random from a stratified sampling frame of all schools in Victoria (Catholic, independent, and government-run) and Washington (public, private, and alternative). In the second stage, single intact classes from each school for the selected year level were chosen at random; in a few cases, 2 classes from different year levels were randomly chosen at a school. In Victoria, 165 classes in 152 schools (65% of eligible schools, $N = 233$) agreed to participate. In Washington, 155 classes in 153 schools (73% of those approached, $N = 212$) participated. In Victoria, 55 classes participated at grade 5 (10–11-year-olds), 54 at grade 7 (12–13-year-olds), and 56 at grade 9 (14–15-year-olds). In Washington, 54 classes participated at grade 5, 51 classes at grade 7, and 50 classes at grade 9.

The study was presented to participants as the first part of a longitudinal study investigating important influences on adolescent development. Each state sought active parental consent for student participation. Standard data collection protocols, approved by the internal review board of the University of Washington and Victoria's Royal Children's Hospital Ethics in Human Research Committee, were followed in each state. The student survey protocol consisted of a self-report instrument that was adapted and expanded from the Communities That Care Youth Survey, which has shown good reliability and validity in large samples.^{17,18} The instrument included instructions on how to answer the questions and assurances of confidentiality, which were presented before survey administration by trained study staff members. Surveys were administered in classrooms during a 45-minute to 1-hour period. Students who were absent from school on the day of survey administration were administered surveys later by school personnel or, in a small percentage of cases, over the telephone by study staff members. After completion of the survey, students in Washington received \$10 and students in Victoria received a small pocket calculator.

Student participation rates in Washington were 69.2% ($n = 943$) in grade 5, 78.3% ($n = 961$) in grade 7, and 77.5% ($n = 981$) in grade 9, for an overall participation rate of 74.8%. Reasons for nonparticipation included failure to return the consent form (11%) and refusal (14%). Participation rates in Victoria were 69.0% ($n = 927$) in grade 5, 75.2% ($n = 984$) in grade 7, and 75.0% ($n = 973$) in grade 9, for an overall participation rate of 73.0%. Reasons for nonparticipation included failure to return the consent form (5%) and refusal (21.2%) by parents or students themselves. Therefore, the total sample sizes available for analysis were 2884 students in Victoria and 2885 students in Washington, for a combined sample of 5769.

Measures

Substance use was assessed with self-report items derived from the Monitoring the Future surveys.¹⁹ Tobacco use in the previous 30 days was classified as none, experimental (less than daily), or daily. Alcohol use in the previous 30 days was classified as none, less than weekly, or at least weekly. Binge drinking was defined on the basis of 1 episode of drinking ≥ 5 drinks in a row in the previous 2 weeks. Cannabis use in the previous 30 days was classified as none, less than weekly, or at least weekly. The primary aim of the study was to address the association of puberty with recreational substance use, rather than with a specific substance. For this reason and to ensure adequately powered analyses, aggregate measures of substance use were derived as follows. Recent substance use was defined at 2 levels, ie, no use versus any use of 1 substance in the previous 30 days. Substance abuse was similarly defined at 2 levels, ie, no use or lower-level use versus any of the following: daily smoking, drinking at least weekly, any binge drinking in the previous 2 weeks, or weekly cannabis use. Lifetime substance use was defined as any use of tobacco or cannabis or having ever been drunk. Multiple-substance abuse was defined as abuse of ≥ 2 substances, compared with abuse of a single substance.

Pubertal status was assessed in both Victoria and Washington with a modified self-report version of the Pubertal Development Scale (PDS).^{20,21} In addition, participants in Victoria completed pictorial displays of the 5 Tanner stages. School authorities did not permit the use of the Tanner scale in Washington. Male subjects were asked to rate their current development on 5 pictures, corresponding to Tanner stages I to V. Female subjects rated their development on 2 sets of 5 pictures, corresponding to breast and axillary/pubertal hair development. The PDS demonstrated internal consistency coefficients of 0.79 among male subjects and 0.69 among female subjects. The overall intraclass correlation between the PDS and Tanner scales was 0.54 (95% confidence interval [CI]: 0.26–0.82). The intraclass correlation tended to be lower among male subjects (0.50; 95% CI: 0.14–0.86) than among female subjects (0.67; 95% CI: 0.43–0.90). For all students, the PDS was used as the primary pubertal index. Supplementary analyses for the Victoria sample used only the ratings on the Tanner charts, to provide an additional test of associations with pubertal stage.

Psychosocial Risk Factors

Family connections were estimated as the mean of 3 scales, reflecting parental attachment ($\alpha = .75$), opportunities for prosocial involvement ($\alpha = .75$), and rewards for prosocial involvement in the home ($\alpha = .74$), with total scores ranging from 1 to 4. School connections were estimated as the mean of 3 scales, reflecting commitment to school ($\alpha = .78$), opportunities for prosocial involvement ($\alpha = .57$), and rewards for prosocial involvement ($\alpha = .69$), with total scores ranging from 1 to 4.

Peer substance use was determined from items relating to the number of best friends reporting tobacco, alcohol, or cannabis use in the previous 12 months, with total scores ranging from 0 to 4 and an internal consistency of .84.¹⁸ Sensation-seeking was measured with a single 3-item scale, giving scores ranging from 1 to 6 ($\alpha = .72$).²²

Analysis

Data analysis was performed with the Stata program.²³ Models are presented with robust SEs, to adjust for the effects of clustering. All prevalence estimates and measures of association used robust "information-sandwich" estimates of SEs, with adjustment for clustering within schools. Multivariate models were constructed with logistic regression; this allowed testing of associations with puberty at lower levels of substance use, as well as levels of abuse relevant to clinicians.

RESULTS

Study Sample

The sample characteristics are shown in Table 1. The mean ages of the US sample were 12.7 years (95% CI: 12.4–13 years) for male subjects and 12.6 years (95% CI: 12.3–12.8 years) for female subjects. The mean ages of the Australian sample were 12.5

TABLE 1. Profiles of Puberty, Age, and Substance Use Among 5721 Male and Female Survey Participants in Washington, United States, and Victoria, Australia

	Washington		Victoria	
	Male, % (n = 1432)	Female, % (n = 1453)	Male, % (n = 1395)	Female, % (n = 1489)
Pubertal indices (PDS)				
I	8	5	9	5
II	26	7	28	10
III	43	26	44	35
IV	20	56	17	46
V	3	7	2	4
Age, y				
10	12	15	15	18
11	20	17	16	14
12	15	17	19	21
13	19	17	15	13
14	16	17	20	23
15	19	17	14	11
Tobacco use*				
In past month	6	9	13	16
Daily	3	4	7	8
Alcohol use*				
In past month	18	20	46	40
Weekly	7	6	19	12
Cannabis use*				
In past month	9	10	5	4
Weekly	5	5	2	2
Substance use				
Lifetime	25	25	39	34
Recent*	22	24	48	43
Abuse*	12	14	30	25

* Grades 7 and 9 only.

years (95% CI: 12.2–12.8 years) for male subjects and 12.4 years (95% CI: 12.1–12.7 years) for female subjects. Two subjects 9 years of age, 41 subjects 16 years of age, and 1 subject 17 years of age were excluded from the analyses, giving a total sample size of 5725.

Differences in patterns of substance use between the 2 state samples were apparent. Overall rates of lifetime substance use were 36% (95% CI: 32–40%) among students in Victoria, compared with 25% (95% CI: 22–28%) among students in Washington. Recent substance use was higher in Victoria (46%; 95% CI: 42–49%), compared with Washington (23%; 95% CI: 20–26%). Substance abuse was also higher in the Australian sample (27%; 95% CI: 23–31%) than the US sample (13%; 95% CI: 11–15%).

The distribution of pubertal stages is shown in Table 1. The majority of students reported pubertal stages between stage II and stage IV, with 7% stage I

and 4% stage V. For this reason, pubertal stages were categorized in 3 levels, ie, early (stages I and II), middle (stage III), and late (stages IV and V). Regression analysis suggested that the distribution of pubertal stages after adjustment for age in Washington was similar to that in Victoria for male subjects ($\beta = .047$; 95% CI: $-.01$ to $.10$; $P = .1$) but female subjects in Washington tended to report later pubertal stages ($\beta = .1$; 95% CI: $.05$ – $.15$; $P < .001$) than did female subjects in Victoria.

Associations of Pubertal Stage With Substance Use

These associations were examined in 4 logistic regression models, reflecting different levels of substance use (Table 2). Lifetime substance use was ascertained for all grade levels. Midpuberty was associated with an almost twofold increase (odds ratio [OR]: 1.7; 95% CI: 1.4–2.1) in lifetime substance

TABLE 2. Associations Between Substance Use and Abuse and Pubertal Stage, Controlling for Age, School Grade Level, Gender, and Country, Among Grade 5, 7, and 9 Students in the United States and Australia

	OR (95% CI)			
	Lifetime Substance Use (n = 5425)	Recent Substance Use (n = 3824)*	Substance Abuse (n = 3824)*	Multisubstance Abuse (n = 767)*†
Pubertal stage				
I/II	1.0	1.0	1.0	1.0
III	1.7 (1.4–2.1)	1.4 (1.0–1.9)	2.0 (1.3–3.2)	1.5 (0.5–4.5)
IV/V	3.1 (2.4–4.2)	2.3 (1.7–3.3)	3.5 (2.2–5.4)	2.0 (0.7–6.1)
Age	1.1 (1.0–1.3)	1.1 (1.0–1.3)	1.2 (1.0–1.5)	1.5 (1.0–2.1)
School grade level	1.5 (1.2–2.0)	1.7 (1.2–2.4)	1.5 (0.9–2.3)	0.7 (0.3–1.4)
US sample	0.5 (0.4–0.6)	0.3 (0.2–0.4)	0.3 (0.2–0.4)	1.4 (0.9–2.2)
Female gender	0.6 (0.5–0.7)	0.7 (0.6–0.8)	0.6 (0.5–0.8)	1.0 (0.7–1.5)

* Comparison involving grade 7 and 9 students only.

† Comparison of those using ≥ 2 substances (n = 209) with single-substance abusers (n = 558).

use and late puberty was associated with a threefold increase (OR: 3.1; 95% CI: 2.4–4.2) in lifetime substance use, compared with stage I/II. Both age and school grade level exhibited modest independent associations with lifetime substance use. No second-order interactions were found. Using Tanner self-reporting (Victoria sample) for classifying pubertal stage yielded similar associations with midpuberty (OR: 1.8; 95% CI: 1.3–2.4) and late puberty (OR: 3.0; 95% CI: 2.2–4.2).

Midpuberty was associated with a modest increase (OR: 1.4; 95% CI: 1.0–1.9) in recent substance use, and late puberty was associated with a more than twofold increase (OR: 2.3; 95% CI: 1.7–3.3). School grade level demonstrated a modest independent association with recent substance use, but no association with age was found. No second-order interactions were found. Using Tanner self-reporting yielded similar associations with midpuberty (OR: 1.6; 95% CI: 1.1–2.2) and late puberty (OR: 2.6; 95% CI: 1.8–3.7).

Midpuberty was associated with a twofold increase (OR: 2.0; 95% CI: 1.2–3.2) in substance abuse, and late puberty was associated with a more than threefold increase (OR: 3.5; 95% CI: 2.2–5.4). Age and school grade level were independently but more weakly associated with substance abuse. No second-order interactions were found. Using Tanner self-reporting yielded similar associations with midpuberty (OR: 2.0; 95% CI: 1.2–3.5) and late puberty (OR: 3.1; 95% CI: 1.9–5.2).

Multiple-substance abusers ($n = 209$) were compared with subjects who reported single-substance abuse ($n = 558$). A trend for later stages of puberty to be associated with higher rates of multiple-substance abuse was found. Age carried a more substantial independent risk for multiple-substance abuse than for single-substance abuse.

Associations of Pubertal Stage Versus Timing With Substance Use

The sample was stratified according to age, to examine whether there was a tendency for earlier maturers to have higher rates of substance use or abuse (Table 3). Lifetime substance use tended to be higher in later puberty at each of the 6 age levels, with the possible exception of students already reporting a late pubertal stage at 10 years. Tests for

interaction found no clear trend for the association between lifetime experimentation and pubertal stage to differ with age, at either midpuberty ($\chi^2_1 = 0.71$, $P = .4$) or late puberty ($\chi^2_1 = 2.5$, $P = .1$). Using Tanner self-reports as the index of pubertal stage yielded similar overall associations with midpuberty (OR: 1.9; 95% CI: 1.4–2.5) and late puberty (OR: 3.3; 95% CI: 2.4–4.4).

Recent substance use also tended to be higher in later puberty at each of the 4 age levels. Tests for interaction again found no clear trend for the association with pubertal stage to differ with age, at either midpuberty ($\chi^2_1 = 0.55$, $P = .5$) or late puberty ($\chi^2_1 = 0.7$, $P = .4$). Using Tanner self-reports as the index of pubertal stage yielded slightly stronger associations with midpuberty (OR: 1.6; 95% CI: 1.1–2.2) and late puberty (OR: 2.7; 95% CI: 1.9–3.8).

Substance abuse was consistently higher for students reporting later puberty, at each age level. Tests for interaction found no linear trend for the association with pubertal stage to differ with age, at either midpuberty ($\chi^2_1 = 0.01$, $P = .9$) or late puberty ($\chi^2_1 = 0.00$, $P = .98$). Associations with midpuberty (OR: 2.1; 95% CI: 1.2–3.5) and late puberty (OR: 3.3; 95% CI: 2.1–5.4) determined with Tanner stage self-reporting were similar to those determined with the PDS.

Testing of Putative Mediators

Four additional logistic regression models examined the roles of established psychosocial risk factors as mediators of associations between pubertal stage, age and grade levels, and substance abuse (Table 4). Social connections were assessed with a combined measure of family and school connections. Both school and family connections exhibited significant cross-sectional protective associations with substance abuse. Adjustment for school and family connections in the multivariate model substantially reduced the association with school grade level and slightly reduced the association with pubertal stage; it had little effect on the association with age.

Peer substance use held a strong association with substance abuse. Controlling for peer substance use, more than any other social factor, reduced the association between pubertal stage and substance abuse. Controlling for peer substance use also diminished the association with school grade level but had little

TABLE 3. Association Between Pubertal Stage and Substance Use Among 5725 School Students, 10 to 15 Years of Age, Stratified According to Age

Age, y	OR (95% CI)					
	Lifetime Substance Use		Recent Substance Use		Substance Abuse	
	Midpuberty	Late Puberty	Midpuberty	Late Puberty	Midpuberty	Late Puberty
10	2.1 (1.2–3.5)	2.0 (0.6–6.4)				
11	2.8 (1.7–4.5)	7.3 (2.8–19)				
12	1.2 (0.8–1.9)	2.9 (1.7–4.9)	1.3 (0.8–2.1)	2.2 (1.3–3.6)	1.8 (0.9–3.8)	3.2 (1.4–7.3)
13	2.0 (1.2–3.2)	2.9 (1.6–5.3)	1.2 (0.7–2.1)	1.4 (0.8–2.5)	2.3 (1.0–5.2)	2.8 (1.2–6.7)
14	1.3 (0.6–2.6)	1.6 (0.8–3.3)	1.9 (0.8–4.4)	2.7 (1.1–6.4)	3.2 (1.0–10)	5.5 (1.7–17)
15	2.3 (0.6–8.8)	3.7 (1.9–15)	1.7 (0.5–6.0)	2.5 (0.7–9.4)	1.0 (0.2–4.0)	1.3 (0.2–4.8)
Overall	1.7 (1.4–2.1)	3.0 (2.3–4.0)	1.3 (1.0–1.8)	1.9 (1.4–2.7)	2.0 (1.3–3.1)	3.0 (2.0–4.6)

TABLE 4. Association of Puberty With Substance Abuse, After Adjustment for Putative Mediators of Social Connection, Peer Substance Use, and Sensation-Seeking, Among 3824 Grade 7 and 9 Secondary School Students

	OR (95% CI)*				
	Unadjusted Associations	Multivariate Models Incorporating Putative Mediators			
		Social Connection	Friends' Substance Use	Sensation-Seeking	All Mediators
Pubertal stage					
Early	1.0	1.0	1.0	1.0	1.0
Mid	2.0 (1.3–3.2)	1.8 (1.2–2.9)	1.6 (1.0–2.5)	1.8 (1.1–2.9)	1.5 (0.9–2.4)
Late	3.5 (2.2–5.4)	2.9 (1.8–4.7)	2.3 (1.5–3.0)	2.8 (1.7–4.5)	2.0 (1.3–3.2)
Age	1.2 (1.0–1.5)	1.3 (1.1–1.5)	1.2 (1.0–1.5)	1.2 (1.0–1.5)	1.3 (1.0–1.6)
School grade level	1.4 (1.0–2.1)	1.2 (0.8–1.8)	0.7 (0.5–1.1)	1.3 (0.8–2.0)	0.7 (0.4–1.1)
Family connection	0.45 (0.39–0.51)	0.60 (0.50–0.71)			0.80 (0.68–0.97)
School connection	0.25 (0.20–0.31)	0.37 (0.28–0.48)			0.76 (0.56–1.02)
Friends' substance use	3.6 (3.2–4.0)		3.5 (3.2–3.9)		2.8 (2.5–3.2)
Sensation-seeking	2.1 (1.9–2.3)			2.0 (1.9–2.2)	1.6 (1.5–1.7)

* All models were adjusted for country and gender as well as age and grade level.

effect on the association with age. No second-order interactions were found.

The mediating role of most friends as substance users reflected a higher prevalence of peer substance use with increasing pubertal stage. The prevalence of most friends reporting use in early puberty (stages I and II) was 6.4% (95% CI: 4.1–8.9%), in midpuberty (stage III) was 14.0% (95% CI: 12.1–15.9%), and in late puberty (stages IV and V) was 24.1% (95% CI: 22.2–26.0%).

Sensation-seeking was associated with a twofold increased risk of substance abuse for each step on the 4-point scale. Controlling for sensation-seeking did not change the association with age but brought a small reduction in the risk associated with pubertal stage. After controlling for all 3 putative mediators, positive independent associations with substance abuse remained for both pubertal stage and age.

DISCUSSION

Pubertal stage and chronologic age were independently associated with early adolescent substance use and abuse. Pubertal stage, however, demonstrated the clearest and strongest associations. Controlling for age and year level, adolescents in late puberty were 2 to 3 times more likely to report lifetime and recent recreational substance use than were those at an early pubertal stage. The link with substance abuse was even stronger, with late puberty being associated with a threefold higher rate of substance abuse. Within the group of substance abusers, late puberty was associated with an additional, almost threefold higher rate of multiple-substance abuse. Although both school grade level and chronologic age exhibited associations with substance use and abuse, the association with grade disappeared after adjustment for pubertal stage and the association with age decreased substantially.

In contrast to the clear links with pubertal stage, there was little evidence to suggest that pubertal timing itself was associated with substance use or abuse. No trend was apparent, after adjustment for pubertal stage, for early maturers (either male or female) to report higher rates of substance use. Instead, early maturers demonstrated higher levels of

substance use and abuse because they entered a risk period, initiated by puberty, at an earlier point.

The large sample size and coverage of an age range relevant to puberty allowed the testing of whether associations with pubertal stage occurred independent of age and school grade level. Some study limitations should be noted. This study addressed associations between puberty and substance use among children 10 to 15 years of age, and inferences cannot be drawn regarding children entering puberty far out of synchrony with their peers. Response rates were high, but nonresponders in the older sample might have been more likely to report substance abuse.²⁴ It is also possible that nonresponders might differ in their pubertal profiles. Although such factors might affect the estimations of the associations, they are unlikely to provide a sufficient explanation, given the strength of associations found.

The pubertal measures were based on self-reporting, rather than direct observation, to minimize intrusion. Comparisons with physician assessments support the validity of self-reporting with Tanner charts.^{25,26} The PDS has similarly received support in validation studies, although the evidence was clearer among girls than boys.²⁷ The level of agreement between measures was strong for both male and female subjects in this study, but the higher levels of agreement for female subjects are perhaps consistent with previous evidence that female subjects more accurately rate pubertal stages. Because students in Washington did not report Tanner levels, whereas both Tanner charts and the PDS were used in Victoria, it is possible that puberty might have been less precisely measured in the US sample. The finding that the associations between substance use and pubertal stage were similar with self-reports on Tanner charts is reassuring.

The independent associations with pubertal stage raise a question of how the biologically driven process of puberty might trigger a phase of higher risk for substance use and abuse. Earlier biosocial hypotheses emphasized changes in family, school, and peer contexts as determinants of postpubertal changes in behavior, including an increase in delin-

quency.²⁸ Consistent with such work, this study illustrates the effects of social context on adolescent substance abuse. It confirmed the protective effects of family and school connections, associations that were noted independent of pubertal stage, age, and school grade level.¹ However, change in patterns of school and family connections did not markedly decrease associations with pubertal stage.

The strongest social factor associated with substance abuse was the report of best friends being substance users.²⁹ Associations with this risk factor differed across pubertal stages, with almost threefold higher odds of most friends being substance users for those in late puberty, compared with those in early puberty. The changes in friends being substance users explained in part the increase in substance abuse that occurred with advancing pubertal stage. This pattern of association suggests that advancing pubertal stage may bring a tendency toward greater affiliation with substance-using friends, which promotes substance use and abuse by the maturing adolescent. Puberty has long been noted as a time of greater emphasis on relationships with peers and greater distances from parents, a pattern consistent with the current findings. Receiving less attention, however, is the possibility that puberty spurs the development of new patterns of friendship, which then affect health-related attitudes and behavior. Such a view is consistent with observations of different patterns of socialization and novelty-seeking among periadolescent animals and a greater orientation to adult stimuli among humans during adolescence.^{15,16} Whether such changes in social orientation are hormonally mediated falls beyond the scope of this article, but sex hormones do act at receptors in the hippocampus and hypothalamus, areas of the brain implicated in novelty-seeking and social interaction.³⁰

Puberty is also a time of psychologic changes, with shifts to higher levels of risk-taking and sensation-seeking, which is a possible alternative explanation for changes in substance abuse with pubertal stage.^{31,32} The study confirmed that sensation-seeking carries risks for teenage substance abuse independent of social context.^{7,33} However, in contrast to the shifts in substance use among best friends, changes in sensation-seeking did not substantially decrease the association between substance abuse and pubertal stage.

This study suggests that pubertal changes are more directly implicated in the development of substance abuse than previously understood. Changes in patterns of affiliation, with increasing numbers of friends who are substance users in later puberty, seem to represent an important mediating pathway, one that has implications for the prevention of substance abuse. Social contexts in which early adolescent substance use is common may well be the settings in which pubertal development brings scope for affiliation with substance users and triggers high rates of initiation into substance use and abuse. If so, strategies and policies that delay the onset of recreational substance use within the peer social group well beyond the phase of pubertal development may

be effective in the primary prevention of substance abuse.

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