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EMPIRICAL RESEARCH

Parental Knowledge is a Contextual Amplifier of Associations of Pubertal Maturation and Substance Use

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Abstract Earlier pubertal development and less parental knowledge have been linked to more substance use during adolescence. The present study examines interactions between pubertal timing and tempo and parental knowledge (children's disclosure, parental control, and parental solicitation) for adolescent substance initiation. Data are from a northeastern US-based cohort-sequential study examining 1023 youth (52 % female) semiannually for up to 6 assessments (ages 10.5–19 years). The findings supported the hypothesis that lower knowledge is a contextual amplifier of early timing-substance use associations in girls and later timing/slower tempo-substance use associations in boys, though results varied based on source of knowledge. The findings suggest that prevention efforts may have the greatest impact when targeting families of early developing girls, and later developing boys, and that incorporating a focus on specific sources of knowledge depending on the pubertal maturation profile of the adolescent may prove valuable in prevention/intervention efforts.

Keywords Pubertal timing · Pubertal tempo · Parental knowledge · Adolescence · Substance use

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Introduction

Adolescents who initiate substance use early are at heightened risk for lifelong problems with addiction and mental health, including alcohol-related problems and dependence (Grant et al. 2001; Pedersen and Skrondal 1998), tobacco and illicit drug use, abuse, and dependence (McGue et al. 2001). Multiple biological (e.g., genetic, pubertal maturation, endocrine) and environmental (e.g., parenting, peer characteristics) influences have been linked to a higher likelihood of adolescent substance use (e.g., Hopfer et al. 2003; Windle et al. 2008). The focus of this study is the combined roles of pubertal maturation and parental knowledge of adolescents' whereabouts and activities for adolescent substance use initiation. Pubertal maturation is arguably one of the most salient biosocial factors for adolescent substance use, as it encompasses both biological changes and social responses to those changes, and occurs in the same developmental period as early substance use. The social context is highly influential on youth substance use, with parental knowledge in particular being linked to use (Lac and Crano 2009; Ryan et al. 2010). However, despite the importance of considering person-environment interactions for understanding adolescent behavior, few studies have examined interactions of pubertal timing and parenting for substance use. There is some evidence for a combined role of pubertal timing and a variety of specific parenting behaviors for identifying risk for adolescent substance use (see Hummel et al. 2013 for a review). The relatively small body of research on pubertal maturation and parenting is due in part to a larger focus on peers as a social contextual influence during adolescence, as puberty begins a stage of increasing peer influence. Nevertheless, a solid body of research supports the continued importance of specific parenting behaviors (e.g., knowledge, monitoring, parent–child relationship quality) for child behavior, including substance use, particularly in early adolescence (e.g., Van Ryzin et al. 2012; Steinberg et al. 1994). Thus, parenting characteristics, specifically parental knowledge of adolescents' whereabouts and activities, should be addressed when investigating the associations between pubertal development and substance use in adolescence.

Pubertal Maturation and Substance Use

A plethora of studies has linked early pubertal timing (e.g., onset of puberty) with substance use (e.g., Cance et al. 2013; Castellanos-Ryan et al. 2013). The developmental readiness (Ge and Natsuaki 2009) or maturational disparity (Mendle et al. 2010) hypothesis states that early pubertal timing is expected to lead to detrimental outcomes because youth are not cognitively or emotionally ready for the changes of puberty (e.g., increased responsibility, being treated as a grown-up, hormonally-influenced mood changes). In the case of substance use, early developing youth may seek to initiate substance use early in order to appear more mature to their broader peer group. This theory has been extended to hypothesize about the role of pubertal tempo, which refers to the speed, or rate of change, of pubertal maturation over time. The maturational compression hypothesis (Mendle et al. 2010) states that more rapid tempo of development compresses the timeframe of puberty, so that developmental milestones are reached earlier and earlier, and this compressed timeframe puts youth at risk for behavior problems. That is, if faster developing youth perceive themselves (and others perceive them) as more mature because of the visible physical manifestations of puberty, they may act in ways they view as more mature at a younger age (e.g., trying alcohol or other drugs). Children who perceive themselves as more mature may act differently than children who think they are less mature. This may, in turn, lead to differences in the independence accorded by parents to children of varying perceived development (e.g., Moore et al. 2014).

There is generally support for the developmental readiness hypothesis in regard to substance use (Mendle and Ferrero 2012; Mendle et al. 2007; Skoog and Stattin 2014; Lee et al. 2014). For boys and girls, earlier timing is associated with substance use and problems for both self-reported (e.g., Cance et al. 2013; Costello et al. 2007) and more objective measures of timing (e.g., Dawes et al. 1999; de Water et al. 2013), though the evidence is less consistent for boys. However, very few studies have investigated the role of tempo for substance use. A related construct, pubertal change (assessed linearly over 2-year spans in mid-adolescence) is associated with greater substance use in boys and girls (Castellanos-Ryan et al. 2013; Dick et al. 2001) with faster change associated with more use. In contrast, Beltz et al. (2014) failed to find an association between drug use symptoms and tempo derived from comprehensive linear and nonlinear models of pubertal development, or with pubertal change measured as the length of time between two milestones (Beltz et al. 2014). Because these null findings were for a different (though related) substance use phenotype (symptoms rather than use), we might still expect that earlier timing and faster tempo will be linked with adolescent substance use initiation.

Parental Knowledge

In seminal theoretical work, Dishion and McMahon (1998, pp. 61) defined parental monitoring as "a set of correlated parenting behaviors involving attention to and tracking of the child's whereabouts, activities, and adaptations". Parents are conceptualized as intentionally and actively seeking out information regarding the children's behaviors in order to identify inappropriate behavior or potential negative influences on their children (Crouter and Head 2002). Should maladaptive behaviors or influences be identified, parents can then seek to limit or prevent age inappropriate risk. Parental knowledge, as a construct, represents the *results* of these tracking behaviors, as it is primarily operationalized as the extent to which parents have knowledge of youth activities (Kerr and Stattin 2000; Stattin and Kerr 2000).

Work by Stattin and Kerr has redirected the conceptualization of parental knowledge toward a multidimensional, second-order construct consisting of both parent and youth behaviors (Kerr and Stattin 2000; Stattin and Kerr 2000). In this work, parental knowledge is defined as the result of parental solicitation (i.e., parental asking for information from children), child disclosure (i.e., voluntary provision of information to parents from children), and parental control of their child's activities (i.e., parental efforts to limit opportunities for maladaptive behaviors of children). The current study follows the Stattin and Kerr (2000) framework by examining each of these specific sources of parental knowledge.

Parental knowledge has been related in observational/survey research to onset of substance use in a variety of settings (e.g., Dodge et al. 2009; Cohen et al. 1994). Experimental work has also shown that parental knowledge can be manipulated, and greater knowledge results in decreased likelihood of alcohol use (Dishion et al. 2003). To date, however, little work has examined the extent to which parental knowledge may modify the observed relationships between pubertal measures (timing and tempo) and age of onset of alcohol use, and none has considered the unique role of the different sources of parental knowledge (child disclosure, parental control, and parental solicitation).

Pubertal Maturation and Parental Knowledge

The contextual amplification theory (Ge et al. 2002) was espoused in order to explain how social processes are likely to interact with effects of pubertal maturation to predict increased risk for externalizing problems. Although the primary social process considered by Ge et al. (2002) was deviant peer affiliation, the theory extends to other social processes, including parenting. In extending this theory to parental knowledge, it is expected that the effects of early timing and fast tempo of puberty may be exacerbated when parents are less knowledgeable of their child's activities, including who they are with (e.g., older peers, boyfriends) and where they are (e.g., locations where alcohol is easily accessed or with reduced social control), and, in turn, parents' ability to limit or prevent risky behavior such as substance use is lessened. Conversely, higher levels of parental knowledge may buffer the effects of pubertal maturation on risk for substance use by reducing the opportunity to initiate.

To date, few studies have examined interactions of pubertal timing and parenting (e.g., harsh parenting, household characteristics, parent–child relationship quality) for externalizing behavior (e.g., Deardorff et al. 2013) and substance use in adolescence (e.g., Hummel et al. 2013; Li et al. 2014). Among the studies specifically focusing on parental knowledge, one showed that pubertal timing predicted adolescent substance use even controlling on parental knowledge (Kaltiala-Heino et al. 2011), but the study did not examine interactions of pubertal timing and parental knowledge. The only study examining interactions between these two factors demonstrated that the combination of low knowledge and early pubertal timing (relative to the sample) predicted the highest rates of adolescent substance use, although results varied slightly by substance with effects observed for alcohol but not cigarette use (Westling et al. 2008). Thus, it is likely that (low) parental knowledge may be a contextual amplifier of the effects of pubertal timing. No studies to date, however, have examined the moderating role of parental knowledge (and specific sources) for potential pubertal tempo-substance use associations.

A Note on Measurement of Pubertal Maturation

There is a long history of examining pubertal maturation in studies of the development of behavior and behavior problems. Pubertal maturation is generally assessed using one of several methods, including Tanner Stages (ideally clinician or nurse-reported, Marshall and Tanner 1969, 1970), the Pubertal Development Scale (PDS, Petersen et al. 1988), age at menarche/spermarche, or via levels and changes in puberty-related hormones (see Dorn and Biro 2011; Shirtcliff et al. 2009). Nurse-reported Tanner stages are considered the gold-standard for objective assessment of pubertal maturation. However, the utility of self-reported pubertal maturation assessed either by the PDS or using Tanner pictures has been increasingly highlighted in the literature (Shirtcliff et al. 2009; Beltz et al. 2014). Specifically, self-reported pubertal maturation is likely to index both physiological changes and the adolescents' perceptions of their changes within the context of the level of development of their peers. The means by which pubertal maturation influences behavior likely encompass both physiological and social mechanisms. Theory and evidence support the role of physiological mechanisms, including the influence of changing hormone levels on the brain and related brain development (Dawes et al. 1999; Paikoff and Brooks-Gunn 1991). However, there is also evidence that socially relevant appraisals of the level of maturation, and therefore abilities and responsibilities, of the developing child play an important role for how puberty influences adolescent behavior (Mendle et al. 2007). When assessing pubertal maturation using youth self-reports, associations with behavior may be due to either, or both, types of mechanisms.

Pubertal Timing and Tempo

Pubertal timing reflects the onset of puberty, and is generally assessed in two of several ways. First, timing relative to peers can be calculated from cross-sectional data by standardizing pubertal maturation within age and sex (e.g., Ge and Natsuaki 2009). Alternatively, pubertal timing can be calculated as the age at a pubertal milestone, for example menarche or spermarche, retrospectively, or the age of entry into a given stage of puberty derived from longitudinal data. The former method assesses pubertal timing relative to the sample, whereas the latter options assess a more objective measure of pubertal timing related to actual age at particular developmental milestones (e.g., menarche, spermarche, the mid-point of breast, genital, and/or pubic hair development) for each individual. Here, we conceptualize timing as the age at reaching the mid-point of puberty (e.g., Marceau et al. 2011).

Pubertal tempo reflects the speed, or rate of change, of pubertal maturation over time. Longitudinal data is required to assess pubertal tempo. Pubertal tempo has been assessed using difference scores for maturational stage measured at two arbitrary ages, although this method actually reflects status change rather than pubertal tempo (e.g., Dick et al. 2001), using linear growth models of repeated assessments of pubertal maturation (Mendle et al.

2010), or even piece-wise growth curves (Ellis et al. 2011). However, pubertal maturation theoretically follows a nonlinear, logistic (elongated S-shaped) shape of development (Marshall and Tanner 1970, 1969), as all individuals spend years in a completely undeveloped state, followed by pubertal development, and ending at a fully matured state without regression. This nonlinear pattern has been shown to better fit repeated measures of nurse-reported Tanner stage data (Marceau et al. 2011; 2014; Susman et al. 2010) and recently using seven annually repeated measures of self-report data on the PDS (Beltz et al. 2014) than linear models. In contrast to quadratic or other polynomial models of growth, these nonlinear models have the benefits of mapping onto the theoretical shape of puberty, and estimating a single theoretically-based measure of pubertal timing and of pubertal tempo (rather than a linear rate and quadratic acceleration term, for example).

The modeling of self-reported data is arguably affected by measurement error to a greater degree as compared to the modeling of nurse-reported data. For example, youth often report regression in stage as they learn more about pubertal maturation (Shirtcliff et al. 2009). Thus, replication of the utility of nonlinear models over linear models for self-reported data is particularly important. The present study assesses both linear and nonlinear models of pubertal maturation for longitudinal self-reported pubertal maturation data assessed via the PDS on a different assessment schedule (e.g., every 6 months, rather than every year).

Present Study

In the present study, we aimed to examine whether perceived pubertal maturation (e.g., timing and tempo), parental knowledge, and their interaction predicted substance initiation (e.g., experimentation: an early stage on the substance use developmental trajectory) during early adolescence. We addressed this aim by estimating perceived timing and tempo of puberty using nonlinear growth models of repeated measures of self-reported data, which we expected would better characterize the repeated measures of puberty than would linear growth models. We hypothesized that (a) there would be main effects of perceived earlier timing, faster tempo, and lower parental knowledge predicting higher likelihood of substance initiation, and (b) that the combinations (i.e., interactions) of perceived earlier timing, faster tempo, and lower parental knowledge would identify youth at the highest risk for substance initiation. Because of the gender differences in pubertal maturation, we follow the tradition of modeling pubertal maturation and the associations of pubertal maturation with outcomes separately for boys and girls (e.g., Susman et al. 2010; Costello et al. 2007; Granger et al. 2003). Further, because of known differences in pubertal maturation and parenting, including knowledge/child disclosure, for different ethnicities (e.g., Susman et al. 2010; Bumpus and Rodgers 2009) we examined racial/ethnic differences in our estimates of pubertal timing and tempo, and included race/ethnicity as a covariate in the tests of our hypotheses about contextual amplification.

Methods

Participants

Data were taken from an ongoing three-year study on adolescent alcohol use and progression (see Jackson et al. 2014). Participants included N = 1023 youth (52 % female; 12 % Hispanic; 76 % Caucasian, 5 % Black, 8 % mixed race; 12 % Other race/ethnicity) from six middle schools (two rural, three suburban, and one urban), with data collected in five cohorts enrolled roughly 6 months apart (Cohort 1 was comprised of two schools). Participants were roughly equally divided across the three grades (33 % in 6th grade, 32 % in 7th grade, and 35 % in 8th grade), and had a mean Wave 1 age of 12.22 years (SD = 0.98, range 10–15). As compared to data from the Rhode Island Department of Education (http://infoworks.ride.ri.gov/), the sample was largely representative of the schools from which they were drawn in terms of gender and grade, but was more racially diverse and less disadvantaged than the school populations.

Procedure

Participants were recruited directly from schools, with study information mailed and also provided in classrooms (see Jackson et al. 2014 for additional details). Completed consent forms were returned to schools with classroom incentives for returned forms (regardless of whether consent to participate in the study was granted). Participants completed a 2-h in-person group orientation session held in a classroom after school. During the orientation sessions, participants completed the baseline survey on laptops provided by study staff. Students were compensated at baseline with a $25 gift card. During the orientation session, the definition of a standard drink was given and an emphasis was placed on confidentiality.

Following baseline, participants completed five web-based semi-annual follow-up surveys. Follow-up assessments were spaced 6 months apart, with exception that Wave 6 was administered 12 months after Wave 5. Surveys were self-initiated by the student, using any location with Internet access, and took approximately 45-min to complete. For each follow-up survey completed, students were compensated with a \$20 gift card. The Brown University Institutional Review Board approved all study procedures.

Retention rates were high (Wave 2: $n = 937$, 92 %; Wave 3: $n = 901$, 88 %; Wave 4: $n = 873$, 85 %; Wave 5: $n = 846$, 83 %; Wave 6: $n = 850$, 83 %). Over 80 % of the sample had valid data on substance use at Wave 6 ($n = 845$). Kruskal–Wallace tests showed that youth with and without valid substance use data did not differ on most demographic (e.g., parent age, marital status) and study (e.g., parental knowledge and PDS scores at T1) variables, p's > .05. Exceptions were that youth who qualified for free/reduced school lunches and whose parents had lower education and income were somewhat less likely to have substance use data ($\chi^2 = 5.29$–10.55, p's < .05).

Measures

Parental Knowledge

Parental knowledge was assessed at the final assessment, when children were on average 15.5 years of age ($n = 845$). Specific sources of parental knowledge were assessed using youth self-report on the Parental Knowledge scale from Kerr and Stattin (2000). This measure consists of scales corresponding to specific sources of knowledge: child disclosure (e.g., how much the adolescent tells parents of his/her activities; 5 items), parental solicitation (e.g., how much parents ask about adolescent's activities; 5 items), and parental control (e.g., how much parents control adolescent's activities; 5 items; α range across scales = .74–.93). Response options ranged from "No, never (0 %)" [1] to "Yes, always (100 %)" [5]. See Table 1 for descriptive statistics.

Pubertal Status

Children's perceived pubertal development was assessed at each time point using the Pubertal Development Scale (PDS, Peterson et al. 1988). The PDS consists of a set of 3 standard items plus 3–4 sex-specific items assessing pubertal development. Response options ranged from No (1) to Development completed (4). As per standard scoring procedures, the average scores across 5 items for boys and for girls were used in data analysis (α range across Waves = .79–.55 for girls; .81–.49 for boys, generally decreasing over time). Retention was good; 80 % of the sample had at least 5 assessments of the PDS ($n = 815$), whereas only 11 % of the sample was missing 3 of the assessments or more ($n = 113$). Pubertal data was not used for two children who only had data at one assessment. Thus, timing and tempo were calculated for $n = 1021$ youth.

Substance Initiation

Substance initiation was assessed by a binary variable indicating whether the adolescent had initiated any of the following: alcohol (ever had a full drink of alcohol?), tobacco (ever smoked a whole cigarette?), marijuana (ever used marijuana (pot, hash, hash oil, etc.)?), or other drugs (ever used illegal drugs other than marijuana or used prescription drugs without a doctor's orders or to get high?) by the time of the last assessment. We scored initiation such that if initiation was reported at any wave, lifetime initiation was coded as "1". Thus, we used all waves of data, maximizing sample size; substance use initiation data was available for the full sample of 1023 youth. By Wave 6, 40 % of youth had initiated any substance use (of alcohol,

Table 1 Sample descriptive statistics and associations among study variables

	Boys		Girls		Associations among study variables					
	M	(SD)	M	(SD)	Child disclosure	Parental solicitation	Parental control	Pubertal tempo	Pubertal timing	Substance initiation
Child disclosure	3.64	0.85	3.63	0.93		67*	.46*	.16*	.07	−.29*
Parental solicitation	3.00	1.07	3.14	1.13	.52*		.47*	.12*	.04	−.13*
Parental control	3.89	1.18	4.13	1.05	.54*	.54*		.15*	.04	−.26*
Pubertal tempo	0.47	0.19	0.50	0.21	.13*	.09+	.11*		.44*	−.11*
Pubertal timing	13.68	0.78	12.55	1.27	−.14*	−.07	−.19*	−.02		−.11*
Substance initiation	% Initiated 36 %		% Initiated 44 %		−.26*	−.14*	−.25*	−.22*	.10*	

For associations, boys are presented below the diagonal and girls above. *M* Mean, *SD* Standard deviation. Tempo is assessed in PDS stages per year, so positive associations of tempo and other variables indicate that faster tempo is associated with higher levels of the other variables. Pubertal timing is assessed in age in years at the mid-point of puberty, so negative associations of pubertal timing and other variables indicate that earlier timing is associated with higher levels of the other variable

+ $p < .10$; * $p < .05$

marijuana, cigarettes, and other drugs); 28 % had initiated alcohol, 25 % had initiated marijuana, 12 % had initiated cigarettes, and 3 % had initiated other drugs. We examined initiation of any substance to maximize variability in the sample, as few youth had reached later milestones on the developmental trajectory for substance use for any individual substance (Jackson et al. 2015).

Analytic Strategy

Pubertal Development

Perceived pubertal timing and tempo scores were obtained from the repeated measures of the PDS using nonlinear growth curves (Grimm et al. 2011). The logistic function below was constructed to closely match previous studies applying this methodology to repeated assessments of nurse reported Tanner Stages (Marceau et al. 2011, 2014) and self-reported data (Beltz et al. 2014).

$$\text{Pubertal Development Stage}_{ti} = \beta_0 + (\beta_1 - \beta_0)\left[\frac{1}{1+\exp(-\alpha_i(Age_{ti}-\lambda_i))}\right] + r_{ti} \quad (1)$$

where *Pubertal Development Stage*$_{ti}$, the observed level of development at assessment t for individual i, is a function of a lower asymptote β_0 = PDS minimum score of 1, upper asymptote β_1 = PDS maximum score of 4, growth rate α_i, = *tempo* of development, centering term λ_i = *timing* of development, and time-specific residual, r_{ti}. Age is assessed continuously. Perceived timing and tempo coefficients (evaluated at the midpoint of development, between PDS scores of 2 and 3) were in turn modeled as sample-level means and individual deviations from those means. The Bayes empirical estimates for individuals' perceived timing (λ), and tempo (α) of puberty were extracted from the models to be used in hypothesis testing for the main study aims. Descriptive statistics for are presented in Table 1. Incomplete data were treated using standard missing at random assumptions (Little and Rubin 1987) and modeled using Reduced Error Maximum Likelihood (REML) estimation. In order to test the hypothesis that this nonlinear growth model would fit the data better than a linear model we also fit the linear model and compared the fit statistics. The model with the lowest AIC and BIC was judged to be the best-fitting.

Interactions of Puberty and Knowledge for Substance Initiation

Logistic regressions were performed using SAS PROC LOGISTIC in order to test hypotheses, separately for boys and girls. Each analysis included the main effects of perceived timing, tempo (the estimates from the models of pubertal maturation above, saved and used as predictors here), and knowledge, and the interactions of timing × tempo, timing × knowledge, tempo × knowledge, and the three-way interaction of timing × tempo × knowledge. Race/ethnicity was entered as a covariate (using dummy codes for Black, Hispanic, and Other) and cohort was also controlled,[1] given that data were collected across five study cohorts. Regressions of this form were repeated for each of the source of parental knowledge to determine whether particular sources of parental knowledge drove associations and interactions with perceived pubertal development to predict substance initiation. Because missing data were deleted listwise, each regression included 450–452 girls or 386–388 boys (n's presented with results in Tables 2 and 3).

Results

Perceived Pubertal Development

Comparisons of the AIC (linear: 3575.7, nonlinear: 3445.5) and BIC (linear: 3592.8, nonlinear: 3471.2) suggested that the nonlinear model fit the data better than the linear model for girls, as the linear model had a lower AIC and BIC than the nonlinear model, indicating better fit. For boys, comparisons of the AIC (linear: 3711.3, nonlinear: 3676.7) and BIC (linear: 3728.0, nonlinear: 3701.8) also suggested that the nonlinear model fit the data better than the linear model, as expected.

The mid-point of puberty occurred at age 13.68 years (SD = .78) for boys and pubertal development at this age was to progress at a rate of 0.47 PDS units per year (SD = .19). Girls' that their pubertal development progressed at 0.50 PDS units per year (SD = .21), reaching the mid-point of puberty at 12.55 years (SD = 1.27). Later timing was associated with faster tempo among girls ($r_{\lambda\alpha} = .44$, $p < .05$), but not boys ($r_{\lambda\alpha} = -.02$, $p > .05$).

There were no significant ethnicity-related differences in timing (F's < 1.97, $p > .05$). Significant ethnicity-related differences were apparent in tempo, F's > 3.13, $p < .05$. Contrasts revealed that White youth had a faster tempo (0.52 PDS units per year, SD = .20 for boys, 0.49 PDS units per year, SD = .18 for girls) than the other non-White racial/ethnic groups (0.46 PDS units per year, SD = .23 for boys, 0.44 PDS units per year, SD = .23 for girls), for both boys and girls. Hispanic boys also reported developing faster than Black boys (0.48 PDS units per

[1] We also ran the analyses including age as an additional covariate and results did not change substantively.

Table 2 Logistic regression results for girls

	Girls					
	Child disclosure		Parental solicitation		Parental control	
Model fit						
R^2	.14		.07		.13	
Wald	57.50*		28.78*		53.50*	
	Est.	SE	Est.	SE	Est.	SE
Parameter estimates						
Intercept	−0.11	0.14	−0.14	0.14	−0.10	0.14
Timing	−0.14*	0.06	-0.10^{+}	0.05	−0.12*	0.06
Tempo	0.05	0.33	−0.10	0.32	0.03	0.33
Knowledge	−0.43*	0.08	−0.13*	0.06	−0.38*	0.07
Timing × tempo	−0.37	0.23	−0.33	0.22	−0.34	0.23
Timing × knowledge	0.17*	0.06	0.04	0.04	0.15*	0.05
Tempo × knowledge	−0.23	0.37	−0.26	0.26	-0.56^{+}	0.30
Timing × tempo × knowledge	0.31	0.30	0.02	0.17	0.12	0.16
Covariates						
Race/ethnicity (Black)	0.11	0.30	0.17	0.29	0.13	0.29
Race/ethnicity (Hispanic)	−0.24	0.23	−0.27	0.22	−0.26	0.22
Race/ethnicity (other)	0.12	0.19	0.14	0.19	0.05	0.20
Cohort (2)	0.13	0.20	0.07	0.19	−0.02	0.20
Cohort (3)	0.01	0.21	0.10	0.20	0.15	0.20
Cohort (4)	0.60	0.27	0.61	0.26	0.67	0.26
Cohort (5)	−0.12	0.19	−0.14	0.18	−0.21	0.19

Race/ethnicity reference group = White. Cohort reference group = 1

$^{+}$ $p < .10$; * $p < .05$

year, SD = .22, and 0.42 PDS units per year, SD = .25, respectively).

Interactions of Puberty and Knowledge for Substance Initiation

Girls

Parameter estimates for nonlinear models predicting substance use from perceived puberty (timing, tempo) and knowledge variables (child disclosure, parental solicitation, and parental control) for girls are presented in Table 2. Across models, there was a main effect of timing such that earlier timing was associated with an increased probability of substance initiation. There was no evidence of a main effect of pubertal tempo, despite a zero-order association (Table 1). There was no evidence of a pubertal timing*tempo interaction. As expected, there were main effects of each source of parental knowledge such that less child disclosure, parental solicitation, and parental control were each associated with an increased probability of substance initiation.

Importantly, there were timing-by-knowledge interactions for child disclosure and parental control, such that girls who reported early timing and low parental knowledge had the highest probability of substance initiation, whereas girls who reported later timing and high parental knowledge had the lowest probability of substance initiation (see Fig. 1). This interaction was not significant for parental solicitation. We found no evidence of interactions of tempo × knowledge or timing × tempo × knowledge in predicting substance initiation for girls.

Boys

Parameter estimates for boys are presented in Table 3. Across models, there was no main effect of pubertal timing on substance initiation. However, there was a consistent main effect of pubertal tempo, such that boys who reported a slower tempo were more likely to initiate substance use. There was no evidence of a pubertal timing × tempo interaction. As expected, there were main effects of each source of parental knowledge, such that less child disclosure, parental solicitation, and parental control were each

Table 3 Logistic regression results for boys

	Boys					
	Child disclosure		Parental solicitation		Parental control	
Model fit						
R^2	.15		.11		.12	
Wald	52.77*		39.98*		47.28*	
	Est.	SE	Est.	SE	Est.	SE
Parameter estimates						
Intercept	−0.26*	0.13	−0.24⁺	0.13	−0.25*	0.13
Timing	0.15	0.09	0.20*	0.09	0.11	0.09
Tempo	−1.18*	0.40	−1.38*	0.37	−1.37*	0.38
Knowledge	−0.36*	0.09	−0.13*	0.07	−0.24*	0.06
Timing × tempo	−0.17	0.52	−0.56	0.49	−0.52	0.49
Timing × knowledge	0.05	0.11	0.18*	0.09	0.01	0.08
Tempo × knowledge	−0.02	0.49	−0.12	0.34	−0.14	0.30
Timing × tempo × knowledge	1.76*	0.61	0.06	0.42	0.10	0.40
Covariates						
Race/ethnicity (Black)	0.20	0.54	0.05	0.53	−0.06	0.52
Race/ethnicity (Hispanic)	0.41	0.23	0.33	0.23	0.34	0.23
Race/ethnicity (other)	−0.04	0.25	0.00	0.25	−0.02	0.25
Cohort (2)	−0.16	0.22	−0.09	0.21	−0.09	0.21
Cohort (3)	−0.14	0.20	−0.07	0.20	−0.05	0.20
Cohort (4)	0.00	0.27	−0.04	0.27	−0.05	0.27
Cohort (5)	−0.32	0.20	−0.35	0.20	−0.33	0.20

Race/Ethnicity reference group = White. Cohort reference group = 1

⁺ $p < .10$; * $p < .05$

associated with an increased probability of substance initiation.

There was an interaction of parental solicitation with pubertal timing, such that boys who reported later timing and low parental solicitation had the highest probability of substance use and boys reporting earlier timing and high parental solicitation had the lowest probability of substance use (see Fig. 2). Finally, there was a three-way interaction of timing, tempo, and child disclosure (see Table 3). Boys who disclosed less, and who also reported later and slower development had the highest probability of initiating substances whereas boys who disclosed more and also reported earlier and faster development had the lowest probability of initiation (see Fig. 3).

Discussion

The present study built on several observations in the literature. First, parental knowledge is a particularly influential contextual influence serving to reduce substance use (e.g., Lac and Crano 2009; Ryan et al. 2010; Dodge et al. 2009). Second, pubertal maturation is a key biosocial factor influencing adolescent substance use (e.g., Cance et al. 2013; Castellanos-Ryan et al. 2013). Third, the contextual amplification hypothesis states that influential contexts may magnify the influence of pubertal maturation on adolescent externalizing behavior (e.g., Ge et al. 2002), but to date, the literature has been limited to questions of pubertal timing and has not comprehensively examined different domains of parental knowledge. This study sought to fill a gap in the literature to understand whether parental knowledge of youth whereabouts and activities may serve as a contextual amplifier of associations of both the timing and tempo of puberty and adolescent substance use initiation.

Our study first replicated that logistic growth curves more accurately model pubertal timing and tempo than linear curves for repeated measures of self-reported pubertal maturation (Marceau et al. 2011; Beltz et al. 2014). We corroborated existing evidence that perceived early timing of puberty for girls (Mendle et al. 2007; Skoog and Stattin 2014) and lower levels of parental knowledge (e.g., Dishion et al. 2003; Dodge et al. 2009) are associated

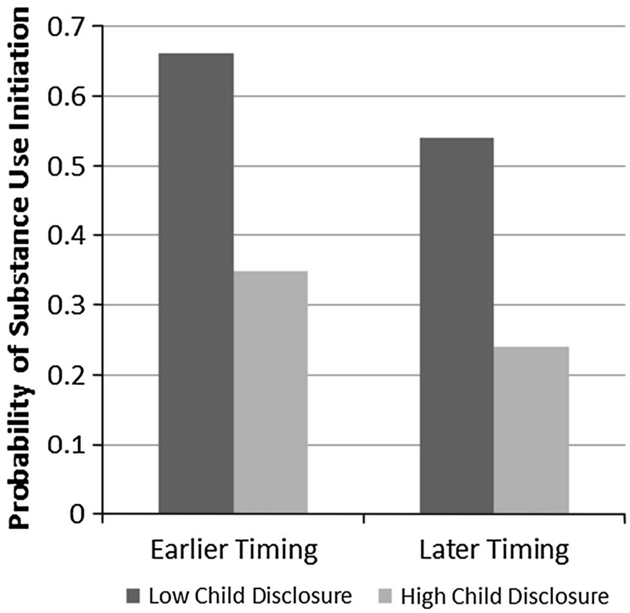

Fig. 1 The interaction of perceived pubertal timing and child disclosure predict the probability of substance initiation in girls. *Note*: *Bars* represent the probability of substance initiation in girls. Earlier timing reflects the model estimated probabilities when timing of mid-puberty was 1 SD below the sample mean, and later timing reflects the model estimated probabilities when timing of mid-puberty was 1 SD above the sample mean. Lower child disclosure reflects the model estimated probabilities at child disclosure scores at 1 SD below the sample mean, and higher child disclosure reflects the model estimated probabilities at child disclosure scores at 1 SD above the sample mean. This pattern of effects also characterizes the parallel interaction of pubertal timing with parental control, for girls

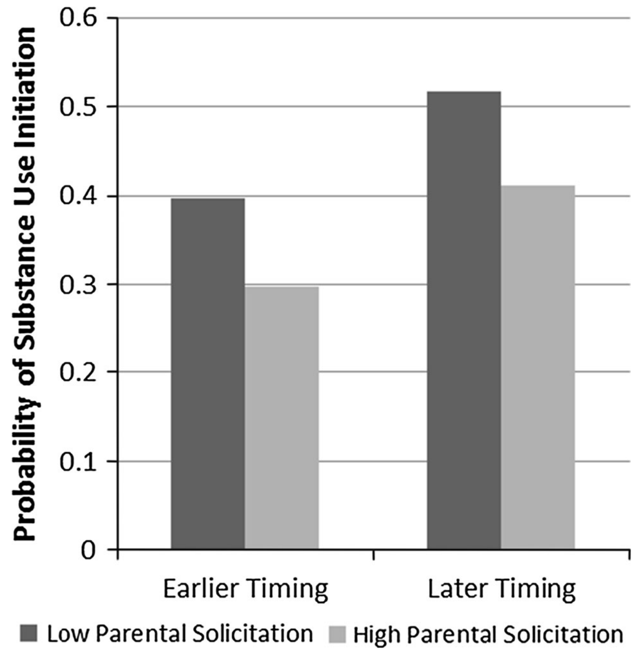

Fig. 2 The interaction of perceived pubertal timing and parental solicitation predict the probability of substance initiation in boys. *Note*: *Bars* represent the probability of substance initiation in boys. Earlier timing reflects the model estimated probabilities when timing of mid-puberty was 1 SD below the sample mean, and later timing reflects the model estimated probabilities when timing of mid-puberty was 1 SD above the sample mean. Lower parental solicitation reflects the model estimated probabilities at parental solicitation scores at 1 SD below the sample mean, and higher parental solicitation reflects the model estimated probabilities at 1 SD above the sample mean

with adolescent substance initiation. Further, we replicated the finding that earlier perceived pubertal timing in combination with lower parental monitoring/supervision is associated with higher likelihood of use, at least in girls (Westling et al. 2008). In contrast, for boys, the combination of perceived later timing and lower parental solicitation of boys' whereabouts and activities, and profiles of puberty characterized by slower and later development in conjunction with less disclosure characterized the highest risk for substance use. For boys and for girls, the 'risky' pubertal maturation profiles (demonstrated in zero-order associations with substance use initiation) was amplified by lower parental knowledge, consistent with hypotheses.

Perceived Pubertal Maturation and Substance Use

Perceived early timing was associated with a higher likelihood of substance use in girls, supporting the developmental readiness hypothesis. There was no association of faster tempo with substance initiation. Thus, the maturational compression hypothesis, which posits that faster tempo should exacerbate the risk associated with earlier puberty because multiple visible milestones (menarche, breast development) would occur earlier relative to peers, appears to not play a large role in substance use initiation for girls (consistent with Beltz et al. 2014). In contrast to girls, the pattern of greatest risk for boys was the combination of later timing and slower tempo. Although not hypothesized a priori, this finding is not unsupported in the literature (Mendle and Ferrero 2012), given the independent risks associated with later timing (e.g., Graber et al. 1997) and slower tempo (e.g., Laitinen-Krispijn et al. 1999). It may be that some boys engage in mature behavior to compensate for the perception that they are lagging behind their peers, as we found that slower tempo was associated with increased risk of substance use in boys (although there was no interaction with timing for boys), consistent with other work (e.g., Laitinen-Krispijn et al. 1999).

Contextual Amplification

The present study uniformly supported the contextual amplification hypothesis, where high parental knowledge

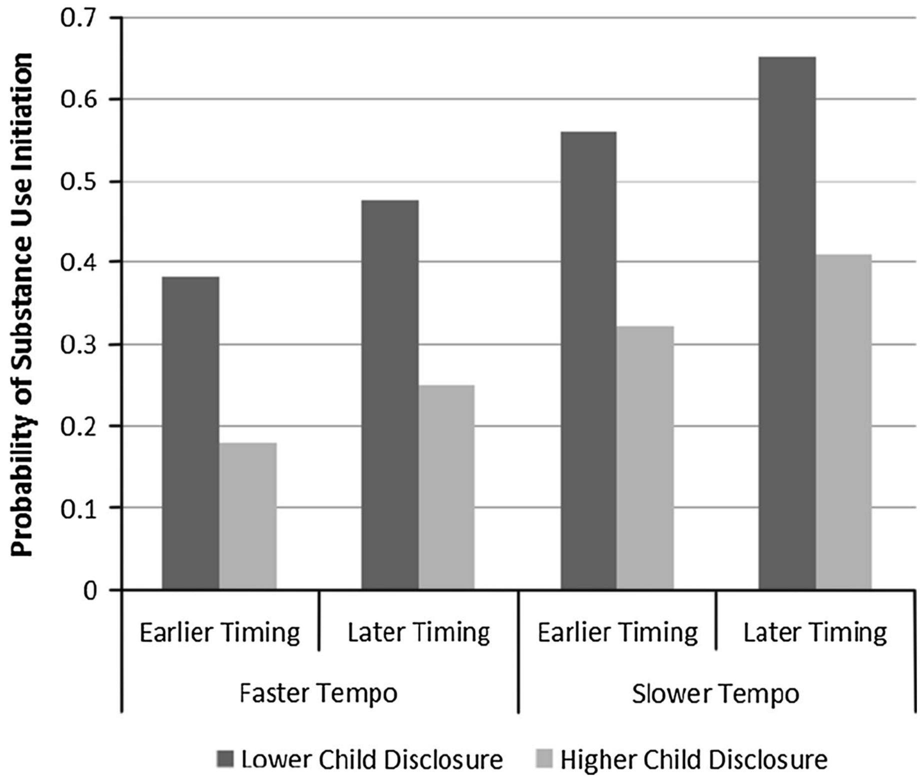

Fig. 3 The interaction of perceived pubertal timing, tempo and child disclosure predict the probability of substance initiation in boys. *Note*: *Bars* represent the probability of substance initiation in boys. Slower tempo reflects the model estimated probability when tempo was 1 SD below the sample mean, and faster tempo reflects the estimated probability when tempo was 1 SD above the sample mean. Earlier timing reflects the model estimated probabilities when timing of mid-puberty was 1 SD below the sample mean, and later timing reflects the model estimated probabilities when timing of mid-puberty was 1 SD above the sample mean. Lower child disclosure reflects the model estimated probabilities at parental control scores at 1 SD below the sample mean, and higher parental control reflects the model estimated probabilities at child disclosure scores at 1 SD above the sample mean

buffered and low parental knowledge exacerbated the risks associated with pubertal timing and tempo. This corroborates evidence (Westling et al. 2008) that parental monitoring/supervision is a contextual amplifier in adolescence. Notably, more child disclosure was a protective factor against the risks associated with perceived pubertal maturation for boys and girls. Statin and Kerr (2000) indicated disclosure to be the most relevant source of knowledge, and our findings confirm the importance of child disclosure for boys and girls. The interactions of perceived pubertal maturation and child disclosure highlight that adolescents have a great influence on how they are parented, and in the amount of knowledge that parents have. Adolescent-specific factors can and do buffer their own risk from how they perceive their maturation (e.g., early maturation for girls, slow/late maturation for boys).

Importantly, contextual amplification by parental knowledge was not only seen for child-driven knowledge. This is generally consistent with the broader parenting literature, which suggests that lower parent–child or family relationship quality exacerbates the risk associated with early maturation, particularly for girls (Li et al. 2014; Hummel et al. 2013; Costello et al. 2007). Parent–child relationship quality tends to be related to parental monitoring, such that families characterized by closer mother–child and/or father–child relationships are also characterized by higher levels of parental knowledge (Fosco et al. 2012). Further, lower parent–child relationship quality has been found to exacerbate associations between risk-related profiles of puberty-related hormones (e.g., high testosterone for boys) and behavior problems in adolescents (Booth et al. 2003).

In the future, studies are needed to test the moderating role of specific and general indexes of parenting in order to establish whether particular parenting behaviors play an important moderating role for puberty-behavior associations above the global family environment, or whether the findings here simply reflect the larger family environment. We believe that there is likely a stronger role for some parenting behaviors than others, given present study findings supporting different effects for different sources of knowledge. For example, more control by the parent buffered the risk conferred by early timing for girls, but there was no such effect for parental solicitation. This may mean that parents' simply asking about early developing girls' whereabouts is not enough. Instead, parents' overt control of girls' whereabouts is the more salient protective parenting behavior. Although speculative, it may be that girls are less likely to transgress parental control efforts than boys, making control more relevant for girls than boys. But, this speculation is in need of further inquiry before weight is given to this explanation. In contrast, parental solicitation was the best buffer for boys, as parental solicitation mitigated the risk associated with (later) pubertal timing but parental control did not. It is possible that solicitation may only be relevant for boys due to potential differences in disclosure. That is, among girls who are willing to let their parents know their whereabouts and activities, girls may disclose at higher levels and so there might be less to be learned from soliciting them, whereas boys may be willing to let their parents know their whereabouts and activities but require solicitation. Together, these findings suggest that the importance of a given facet of parenting may differ by child gender. Elucidating the parenting behaviors that exert the strongest influences relative to other parenting behaviors, and for whom, is important for future research because it will help to identify the most relevant targets for intervention.

There is recent evidence that an integrative approach can help us to better understand how social contextual factors are implicated in associations of pubertal maturation and mental health and substance use problems (Skoog and Stattin 2014). There is evidence of associations between pubertal maturation and several parenting behaviors and aspects of the parent–child relationship both here and in the literature (Hummel et al. 2013; Li et al. 2014). Given the inter-relationships of parenting, puberty, and behavioral outcomes in the literature, it is also likely that parenting serves to mediate associations of pubertal maturation and behavior problems, perhaps in addition to being a contextual amplifier of the association—that is, youth who attain puberty early are seen as more mature by their parents and parents might grant a mature-looking adolescent more freedom and less scrutiny (Moore et al. 2014), which in turns elevates risk for engaging in problem behavior.

Further, combinations of the two most prominent contextual influences implicated in puberty-behavior associations, parents and peers, is likely to lead to further advances in our understanding of when and why atypical pubertal maturation is a risk factor for substance use. This is a future direction for our research. There is already evidence that parental knowledge and peer context may work in tandem in promoting risky behavior in adolescence (Ge et al. 2002). For example, affiliation with deviant peers partially mediated associations between pubertal timing and alcohol use, and further that low parental knowledge was a contextual amplifier of this pathway, at least for girls (Westling et al. 2008). These findings are in need of replication and extension, for example, to expand our understanding of the role of parental knowledge and peer context for associations of substance use and other mental health outcomes including pubertal tempo as well. Given the findings from the present study, we might expect that the combined role of pubertal timing and tempo may be particularly important for boys. We hypothesize, for example, that for boys, peer deviance would mediate associations of pubertal development profiles of later timing and slower tempo and substance use, and that these mediation pathways would be strengthened in the context of low parental knowledge. These pathways through deviant peers also may be differentially moderated by the different sources of knowledge; one might predict that parental control would be a stronger moderator as it involves actively keeping track of the child's whereabouts and surroundings, including the social context.

Pubertal Timing and Tempo

The present study successfully replicated recent work suggesting that nonlinear models fit repeated measures of self-reported PDS data better than linear models (Beltz et al. 2014). Although puberty is generally conceptualized as a non-linear state-based progressive process, few studies have modeled it as such (Marceau et al. 2011, 2014; Susman et al. 2010; Beltz et al. 2014), and this is the first study to use a semi-annual assessment schedule to investigate nonlinear trajectories of puberty, and relations of timing and tempo estimates with substance use. Thus, although the gold-standard for pubertal assessment is nurse-reported/Tanner stage (Dorn and Biro 2011), modeling self-reported data is a reasonable approach, as long as the data are interpreted as perceived pubertal timing and tempo, as we do here. Despite several differences in measurement and in the timing of assessments for this study versus others using the same model (Marceau et al. 2011, 2014; Beltz et al. 2014), we still found nonlinear model exhibited the best fit.

We sought to compare the estimates of timing, tempo, and their associations obtained in the present study from the two other studies in which they have been modeled non-linearly: the National Institute of Child Health and Human Development Study of Early Child Care and Youth Development (SECCYD; using estimates reported in Marceau et al. 2014) and the Colorado Twin Study/Colorado Adoption Project (CTS/CAP; using estimates reported in Beltz et al. 2014). The present study and the CTS/CAP are similar in that they both use self-reported data from the PDS, whereas the NICHD used nurse-reported Tanner stages. The CTS/CAP and SECCYD are similar in assessment schedule, where each child was assessed yearly from age 9.5 to 15.5, whereas in the present study each child was assessed every 6 months spanning about a 3.5 year period (although the entire sample, and therefore the sample average, represents ages 10–19). In order to more directly compare the perceived timing and tempo scores for boys and girls previously obtained using SECCYD data, raw PDS scores were converted into Tanner stages using the methodology described in Shirtcliff et al. (2009) and the models of puberty were re-estimated (estimates available upon author request).

In all studies, girls attained the mid-point of puberty earlier than boys, as frequently shown in the literature. As in the SECCYD, we found that tempo was somewhat similar for girls and boys. The estimates for timing recovered here fall between those reported from the SECCYD and the CTS/CAP, whereas the estimates for tempo match better with the CTS/CAP. The associations of timing and tempo diverged somewhat across the three studies; timing and tempo were uncorrelated for boys and positively correlated for girls here, but negatively correlated for boys and positively correlated for girls in the CTS/CAP, and negatively correlated for boys but uncorrelated for girls in the SECCYD. Thus, it appears that when significant associations between timing and tempo are found, they are negative for boys (i.e., boys who start puberty early have a more rapid progression) and positive for girls (i.e., girls who start puberty early have a slower progression). Non-significant associations were in the same direction as significant associations in the other studies, suggesting some consistency across studies. Given the many differences between these three studies (e.g., perceived vs. nurse-reported development, general vs. adrenal and gonadal development, assessment interval, multi- vs. single-cohort design, ages), the similarity of the estimates of timing and tempo with previous studies are remarkable. Because the estimates of timing and tempo recovered here are likely sensitive to the types of measurement issues noted above (and below), we encourage replication in order to draw comparisons across samples. Replication efforts in a variety of samples, with assessments using self- and nurse-report and on a number of time-scales are needed.

Limitations

There are several limitations important to consider when interpreting results. First, the present study relied on self-reported data from the adolescent. This may have inflated results due to shared method variance. Other analyses using these data have indicated that although there were discrepancies between youth and parent report of knowledge, the knowledge effects on alcohol use were consistent (although weaker for parent report; Abar et al. 2014). Further, this is a purely associational analysis: the measures of parental knowledge and substance use were both assessed at the end of the study and so causation cannot be established. Because pubertal timing and tempo were assessed via self-reported data, it is difficult to understand the mechanism of action of puberty in this study—findings may be driven by perceptions and/or by actual physiological mechanisms. Further, because of the compressed assessment schedule, a significant proportion of youth did not complete puberty by the end of the study, though most were at least in later stages in development. Although nonlinear models have been shown to perform better than linear models particularly when development is not completed (Beltz et al. 2014), the timing and tempo of puberty may not reflect the timing and tempo of the entire pubertal transition for those youth who have not completed development. Our measure of substance use is somewhat crude, and only assesses the beginning stages of the substance use trajectory (e.g., initiation or experimentation). It will be important in the future to also examine the contextual amplification hypothesis with more nuanced measures of regular, heavy, or problematic substance use to determine whether the results extend to other parts of the developmental trajectory of substance use and substance use problems. Finally, although missing data were accommodated in the modeling of pubertal timing and tempo, in the logistic regressions missing data were deleted listwise. Thus, the findings may not generalize to the entire sample, as there were SES differences in families with and without substance use data.

Implications

Our findings have implications for targeting parenting interventions at both the universal (primary prevention) and selective (secondary prevention) levels. For example, existing substance use interventions such as Family Check-Up and related interventions (e.g., Dishion et al. 2003; Spirito et al. 2011) may have the greatest impact when targeting families of early developing girls, and later developing boys. Further, our results point to incorporating a focus on specific sources of knowledge depending on the pubertal maturation profile of the adolescent. For example, for girls, improving parents' control of the whereabouts and activities of the girls may disrupt the mechanism by which perceived early pubertal maturation puts girls at risk for substance use. For boys, improving parents' knowledge acquisition skills in terms of solicitation of boys' whereabouts and activities would be important for disrupting the mechanism by which perceived later pubertal maturation puts boys at risk for substance use. However, for boys that perceive (accurately or not) that they are maturing both slowly and later than their peers, and for girls that perceive that they are early-maturing, interventions that teach adolescents to disclose their whereabouts and activities to their parents may also be successful. These implications are potentially specific to early stages of substance use involvement, and therefore our findings may be most applicable to primary prevention efforts. If findings are replicated when examining later milestones on the substance use trajectory (e.g., heavy use, substance use problems), then these implications may also apply to more selective and indicated substance use interventions either in prevention efforts or for interventions after substance use has progressed. These implications remain hypotheses and empirical questions that should be tested in future parenting interventions of substance use.

Conclusions

We found support for the notion that low parental knowledge of youth activities can operate as a contextual amplifier for associations between perceived pubertal timing and tempo and substance initiation. Our overall findings confirmed the importance of different sources of parental knowledge as a contextual influence on substance initiation (Bumpus and Rodgers 2009; Steinberg et al. 1994; Van Ryzin et al. 2012). In addition, the nature of the interactions between knowledge and puberty differed across adolescent sex. For girls, low parental knowledge, specifically less child disclosure and parental control, strengthened associations of earlier timing and substance initiation. For boys, low levels of parental solicitation amplified associations of later timing and substance initiation, whereas low levels of child disclosure amplified associations of profiles of later timing and slower tempo with substance initiation. Our joint analysis of both timing and tempo of puberty provide novel insights into how pubertal maturation operates in relation to behavioral development. Specifically, although early timing remains the strongest predictor of behavior for girls, the mixed effects observed in the literature for boys may be explained in part by the pattern of findings in the current study. That is, tempo of development played a stronger role than timing, and in some cases, it was the combination of timing and tempo in conjunction with specific parenting behaviors that revealed the highest risk for substance use. Thus, for boys, the influence of puberty is not specific to timing, but rather the entire profile of pubertal maturation is important to consider. Future research should continue to examine the full pubertal profile, especially for boys, and continue to consider person-environment interactions in order to expand our understanding of adolescent biosocial development.

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Authors' Contributions KM analyzed the data and drafted the manuscript. CA helped draft and edit the manuscript. KJ conceived and executed the larger study, and helped draft and edit the manuscript. All authors read and approved the final manuscript.

Compliance with Ethical Standards

Conflicts of interest The authors report no conflicts of interest.

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