THE MEANING OF PUBERTAL TIMING AND THE IMPLICATIONS FOR SUBSTANCE USE ACROSS ADOLESCENCE

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ABSTRACT

JESSICA DUNCAN CANCE: The Meaning of Pubertal Timing and the Implications for Substance Use across Adolescence
(Under the direction of Susan Ennett)

The purpose of this dissertation was to disentangle the measurement of self-report pubertal timing – the comparative development of an adolescent in relation to peers – in order to determine the longitudinal impact of pubertal timing on substance use across adolescence. Data are from the Context of Adolescent Substance Use study, a school-based longitudinal study of three cohorts, beginning in the 6^{th} to 8^{th} grades (aged 11 to 17, 50% male, 53% White).

Study 1 examined the concordance between two self-report measures, stage-normative (based on the PDS) and peer-normative pubertal timing. Kappa statistics were calculated, both as a whole and by demographic subgroup at each age (N=6,425). Most Kappa statistics ranged from poor to modest concordance, indicating that the pubertal timing measures should not be used interchangeably.

Study 2 used two longitudinal methods to examine the stability of pubertal timing (N=6,425). When calculating intraclass correlation coefficients (ICC) using one-way ANOVA random effects models, both measures had similar, but poor, stability (stage-normative ICC=.40 and peer-normative ICC=.39). In contrast, latent class analysis (LCA), which determines stability via the underlying response patterns of each measure, showed three stable and distinct response patterns for both measures: always early, always on-time, and always late.

Study 3 used latent class growth modeling to test the impact of pubertal timing on current cigarette, alcohol, and marijuana use (N=5,846). Contrasts tested for significant substance use growth model parameter differences between the Study 2 pubertal timing latent classes. For both measures, a higher proportion of early developing adolescents were using substances compared with on-time and, in general, late developers. But using the peer-normative measure, there also was a higher proportion of late developers using cigarettes compared with their on-time peers. The influence on substance use was greatest in early adolescence for both pubertal timing measures and the strength of the relationship was generally stronger using the peer-normative measure.

Stage-normative and peer-normative pubertal timing are not synonymous but both are stable throughout adolescence. Early developing adolescents are at greatest risk for substance use and results suggest the social aspects of pubertal development are more influential than the biological aspects.

To my family, who have always supported my dreams.

To Paul, my rock, who makes my success possible.

And to Jack, for whom I want to make the world a better place.

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CHAPTER 1: INTRODUCTION

Overview

Pubertal timing – the comparative pubertal development of an adolescent in relation to peers – has been linked to a number of deleterious health behaviors among adolescents, including sexual risk taking,[6, 19, 20] delinquency,[21] and substance use.[3-5, 7-10, 13, 15-18, 22-26] But issues with the measurement of pubertal timing preclude a thorough understanding of the relationship between pubertal timing and health risk behavior. The purpose of this dissertation was to better understand pubertal timing through the construction of three studies. The first study examined the concordance between two commonly used measures of self-report pubertal timing, what I'm referring to as *stage-normative pubertal timing* and *peer-normative pubertal timing*. The second study examined the stability of the two pubertal timing measures using two longitudinal methods, random effects ANOVA modeling and latent class analysis. The third study determined the relationship between each of the pubertal timing measures and the development of substance use (cigarettes, alcohol, and marijuana) from ages 11 through 17, using latent class growth analysis.

The three studies were conducted through the secondary analysis of data from the Context of Adolescent Substance Use study (The Context Study). The Context Study, funded by the National Institute on Drug Abuse (R01 DA13459), is a longitudinal school-based study of adolescents from public schools in three North Carolina counties. Data collection began in April of 2002 and continued every school semester until April of 2004, for a total of five waves of data. The final sample for this dissertation included 6,425 adolescents between the ages of 11 and 17 who participated in at least one wave of data collection.

This dissertation is organized in five chapters. Chapter 1 provides an introduction to pubertal development and describes the empirical and theoretical literature that informed the three studies. Chapters 2-4 are manuscripts describing the three studies in detail. The dissertation ends with Chapter 5, a discussion of the key findings, limitations, and implications for future research and public health practice.

The Biological and Social Processes of Pubertal Development

The most significant biological change that occurs during adolescence is the onset and completion of puberty. The result is pubertal maturation – the maturation of the gonads, or sexual organs. Puberty is not a one-time distinct event, but is a process of sequential events that has variable onset and progression (or tempo).[50] There are gender and racial/ethnic differences in the onset and tempo of puberty, as well as individual differences within groups.

Puberty is a process of the central nervous system, and specifically, the hypothalamus, the pituitary gland, the gonads, and the adrenal glands. The onset of puberty occurs when the hypothalamus-pituitary-adrenal axis (HPA) and hypothalamus-pituitary-gonadal (HPG) axis are activated.[51-53] The primary hormone implicated in the onset and progression of pubertal development is gonadotropin releasing hormone (GnRH). GnRH levels are very active during late prenatal and eary postnatal development but then decline to very low levels during childhood. Puberty begins when GnRH secretion levels begin to rise, generated by signals from the hypothalamus. This rise in GnRH signals the production of luteinizing hormone (LH) and follicle stimulating hormone (FSH) in the pituitary gland. LH and FSH send signals to the gonads, the testes and ovaries, to begin the production of sperm and eggs, as well as to produce gonadal steroid hormones (estradiol and testosterone). In the process known as gonadarche, the gonadal steroid hormones cause gonadal maturation as well as continued secretion of GnRH in the brain. The adrenal glands also begin to produce steroid hormones in a process known as adrenarche.

Throughout the pubertal process a number of physical changes occur.[52, 53] Skeletal growth is increased and the circulatory and respiratory systems experience further development. The nervous and endocrine systems also develop during this process. Specifically, adolescents experience growth in the amygdala, which is responsible for emotions, and the hippocampus, responsible for learning and memory. This results in an increase in emotional responses as well as an increase in cognitive functioning. The fat-to-muscle ratio also changes due to the increase in steroid hormones. For males, the fat-to-muscle ratio decreases while in females this ratio increases. Prior to entering puberty, the fat-to-muscle ratio is similar in males and females, but after puberty is complete males have 1.5 times the lean body mass of females and females have twice the amount of fat body mass as males.

The most recognized physical changes that occur during puberty are those changes that occur to the reproductive organs and secondary sexual characteristics. In females, pubertal onset typically manifests first as breast budding, followed by pubic hair growth, height growth spurts, and finally, the onset of menarche. In males, the typical manifestation of pubertal development begins with the growth of the testicles and scrotum and is followed by height growth spurts, pubic hair growth, and finally voice change and facial hair growth. These manifestations of pubertal development occur over a period of time, overlap with one another, and can vary dramatically by individual. Most of the current knowledge of the stages of pubertal development is based in the work conducted by Tanner and his colleagues in the 1950s with white youth from Great Britain. Based on this work, breast and pubic hair development in females and penile and pubic hair development in males has been divided into five stages, known as

Tanner stages.[2] Adolescents at Stage 1 have had no development in the characteristic of interest, whereas adolescents at Stage 5 have completed development. Table 1.1 shows the general development of males and females by age, according to the research conducted by Tanner.[54]

Table 1.1. Age range of initial development of secondary sexual characteristics, based on Tanner stages

	Age range of development	
Characteristic	**Males**	**Females**
Breasts	--	8.9 – 12.9 years
Testes and penis	9.5 – 16.5 years	--
Height	10.5 – 16.0 years	9.5 – 14.5 years
Pubic hair	12.0 – 14.5 years	9.0 – 13.4 years
Menarche	--	10.5 – 15.5 years
Voice/ Facial hair	14.0 – 15.0 years	--

The exact causes of the activation of increased GnRH secretion, and therefore the onset of puberty, are still unknown.[51] As demonstrated in Table 1.1, there is not an exact point in time considered "normal" for development. Rather, onset that occurs within the age ranges cited in the table is considered normal.[52, 53] However, there are studies that suggest gender and racial differences in the onset of puberty in adolescents. In general, females and males begin gonadarche at relatively similar times but the outward physical characteristics associated with pubertal onset occur earlier in females.[51, 53, 55] There has also been research that indicates Black males and females may be entering puberty slightly earlier than their White counterparts, but this research has not been conclusive.[53, 55]

There has been a debate in the literature as to whether the onset of puberty in adolescents has been decreasing in recent years, and what the causes of this downward trend may be.[52, 53, 55-57] Despite the variability in sampling strategies and methodologies of the studies, it appears that both males and females are starting puberty at an earlier age, regardless of race/ethnicity. However, the average age of completion of puberty has not decreased, suggesting that the tempo of pubertal development has slowed. There have been many explanations hypothesized for the earlier age of pubertal onset, including genetic factors, prenatal influences, exposure to environmental toxins, increasing rates of body fat, increasing hyperinsulinaemia and insulin resistance, and exposure to social stressors. However, none of these hypotheses is considered to be a conclusive explanation of the trend. What is known is that for the first time in recent history, perhaps ever in the history of humans, there is discordance between the age of physical maturation and the age of social maturation.[52, 56]

Pubertal development is not only a biological process but a social process as well. While in Western societies puberty is often treated as a personal experience, the profound biological transition from a prepubertal child's body into a postpubertal sexually mature body and the outward changes that occur are evident not only to the adolescent but also to adults and peers. Pubertal changes signify advancement towards adulthood, but a postpubescent adolescent is not likely to be considered an adult but rather someone in between the roles of a child and an adult. For instance, in recent decades the average age of first menarche has decreased as the average age of first pregnancy has increased. As such, the role of pubertal development in determining the readiness for adult roles would seem to be diminished. However, pubertal timing does appear to influence demands on adolescents: adolescents who mature earlier compared with their peers, and therefore look older than their chronological age, are expected to have greater social maturity and are granted more social autonomy by parents and teachers, whereas the opposite is true for less developed adolescents.[88]

During adolescence peer relationships become increasingly important (see Giordano 2003 for a review). It is not surprising then that peers play an important role in shaping an adolescent's pubertal experience. More specifically, an adolescent's understanding of their pubertal process is shaped in part by comparisons to and reactions from peers. Breast development, one of the first outward signs of pubertal development, and the initiation of menarche have been shown to cause both embarrassment and empowerment among females, in part because of the changing relationships with peers.[89,90] Females reflecting on their first menstrual experiences reported embarrassment and teasing from males when menstrual education was conducted in school, and many turned to their peers when they couldn't speak with their mothers about the menstrual experience.[91]

Less is known about the pubertal experience of males, but one qualitative study found that males compared their personal pubertal development to those of peers and older males with increasing frequency as pubertal changes began and then decreasing frequency as the pubertal changes ceased.[92] Males were less concerned about the pubertal changes occurring and more about the reactions these changes, or lack of changes, would produce among peers. The dominant feeling during puberty was being abnormal and as such a great deal of effort was spent attempting to decrease embarrassing moments.

The Measurement of Pubertal Status and Pubertal Timing

There are two important aspects of pubertal development: pubertal status and pubertal timing. Pubertal status, also known as pubertal stage, is a measure of how developed an adolescent is in relation to the pubertal development process. Most of the current knowledge of the stages of pubertal development is based in the work conducted by Tanner (see above for more detail). Pubertal timing is a measure of how developed an adolescent is in relation to her or his peers. Adolescents are classified as developing early, on-time, or late. Those who develop early or late compared with their peers are determined to be developing "off-time."

Pubertal status can be assessed using a number of different indicators. An adolescent's pubertal stage can be assessed clinically by trained professionals (e.g., physicians, nurse practitioners). Clinical measures include staging using recommendations based on the work of Tanner, determining hormone concentrations using blood spot, urine, or saliva data collection, and gonadal ultrasound to examine ovarian or testicular volume.[11]

Self-report of pubertal development has been used in a number of studies[3-10] and has been shown be a valid assessment of pubertal stage.[1, 11] Adolescents report their perceived Tanner stage based on drawings of adolescents. It is also possible to estimate pubertal development based on self-report of age of first menarche or age of first spermarche. However, because menarche and spermarche occur later in pubertal development, it is inappropriate to consider an adolescent prepubertal if they have not experienced menarche or spermarche. One commonly used self-report measure of pubertal stage is the Pubertal Development Scale (PDS), a five-item scale that assesses secondary sexual characteristics.[58] Even though adolescents tend to overestimate their development at early pubertal stages and underestimate at later pubertal stages, it has been argued that self-report is acceptable when approximation is acceptable.[11, 12] This would include studies such as the third study of this dissertation, where the outcome of substance use is not reliant on adolescents reaching a specific stage in development, but rather a general perception of where the adolescent is in the development process.

There are two common ways to establish pubertal timing. In the first, *stage-normative pubertal timing,* the adolescent's pubertal status is compared with the average pubertal status of the sample. Because pubertal development has been shown to vary by age, gender, and race/ethnicity, pubertal status is usually normed within these subgroups. In the second method, *peer-normative pubertal timing*, adolescents are asked how they perceive their timing to be compared with their peers.

Study 1: Pubertal Timing throughout Adolescence: A Comparison of Two Measures

The two measures of pubertal timing, stage-normative and peer-normative, are often used interchangeably in the literature as predictors of adolescent risk behavior. However, this may be inappropriate because stage-normative pubertal timing is based on biological referents while peer-normative pubertal timing presumably reflects an adolescent's social experience of pubertal development. The concordance of the two measures has implications for understanding the role of pubertal timing in adolescence; discordance between the two measures would imply that the social experience of puberty is different than the biological experience. No studies have empirically tested whether the measures are synonymous.

The primary purpose of Study 1 (Chapter 2) was to determine the concordance between peer-normative and stage-normative pubertal timing. Because stage-normative pubertal timing is based on pubertal status, descriptive analyses of pubertal status were conducted first. In addition, because of known variation in pubertal development by age, sex, and race/ethnicity, I also conducted analyses of pubertal status and the two pubertal timing measures within demographic subgroups.

This study was guided by person-in-context theory, which is based on the premise that in order to successfully establish a personal identity one must balance the competing demands to differentiate from others while integrating into society.[86] Personal identity is formed based on an understanding of the contexts into which an adolescent is embedded. Furthermore, while these contexts shape the adolescent, the adolescent also shapes the contexts.

Person-in-context theory supports the belief that puberty is not only a biological process, but a dynamic interplay of biological, psychological, and social processes.[52, 87, 94, 95] Individual perception of pubertal development is not based solely on biological development, but also on an understanding of how this development matches with norms established by distal and proximal contexts. However, because pubertal onset and progression vary dramatically across individuals, the meaning of what is normative for an adolescent changes depending on age and context.

Based on person-in-context theory, I hypothesized that stage-normative and peer-normative pubertal timing would have good but not excellent concordance (Kappa values between .40 and .75). The stage-normative measure is based on an adolescent's perception of where she or he is in the pubertal development process, as determined by self-assessment of numerous biological indicators. In contrast, the peer-normative measure is more subjective because it takes into account both biological and social assessment, by asking adolescents to directly compare their development not to the biological process but to the development of peers. For an adolescent to determine her or his peer-normative pubertal timing, the adolescent must first analyze her or his personal pubertal development (presumably in a process similar to that of answering the pubertal status questions used to develop the stage-normative pubertal timing measure) and then engage in social comparison to determine how her or his pubertal status compares with peers. It is possible that this second step of social comparison introduces a psychosocial component to the peer-normative pubertal timing measure that is missing from the stage-normative pubertal timing measure.

Study 2: The Stability of Perceived Pubertal Timing across Adolescence

One challenge with self-report measures of pubertal status and pubertal timing in adolescence is that pubertal development for most adolescents is ongoing. Not only is the adolescent changing but their referent peer group is also changing. Therefore, self-perception of where an adolescent is in the pubertal development process could be changing as well as self-perception of how developed they are in relation to their peers.

For example, an adolescent may begin their pubertal development early compared to their peers (and therefore be classified as early developing) but may progress through puberty at a slower rate than their peers, resulting in a classification of on-time a couple of years later.

Studies assessing the relationship between pubertal timing and behavior have been conducted with adolescents of varying ages. Uncertainty as to whether perceived pubertal timing is stable across adolescence presents a challenge for researchers interested in the impact of pubertal timing across the span of adolescence. If the construct is unstable, any relationships involving pubertal timing could be transitory, with perhaps limited impact on adolescent development. Accordingly, relationships detected at one age could not be expected to persist at other ages. On the other hand, if the construct is stable, assessment of the impact of pubertal timing at any one age could have implications for other ages. How pubertal timing is measured may have implications for the likely stability or instability of the construct.

Few studies have examined the stability of perceived pubertal timing across adolescence. And assessment of the stability of pubertal timing has thus far been based on crude correlation analyses that are based on limited longitudinal samples. Longitudinal data analysis is important because it allows for the assessment of dynamic relationships and provides the ability to understand the heterogeneity among subjects.[65]

Furthermore, most research on the stability of pubertal timing has been based on stage-normative measures. Perceived pubertal timing based on a stage-normative measure could be expected to change over time. In early adolescence, when pubertal development typically is just beginning, an early-developing adolescent is non-normative while on-time and late developers are normative. In contrast, in late adolescence, when pubertal development is typically concluding, early and on-time developers are normative and a late-developing adolescent is non-normative. Stage-normative measures of pubertal timing thus may lack stability and be dependent on adolescent age. However, empirical evidence only partially supports the hypothesis that stage-normative measures of pubertal timing lack stability. This could be because the studies, with one exception, have only used two waves of data to assess stability, and the analyses have not been stratified by age, despite a wide age range in the sample.

Unlike stage-normative pubertal timing, there is theoretical reason to believe peer-normative pubertal timing would be stable throughout adolescence. According to Erikson's theory of psychosocial development, adolescence is a developmental stage focused on the formation of personal identity, of which puberty plays an important role.[106] In order to establish ego identity – knowledge of who you are and how you fit into the broader society – the adolescent interacts and compares himself or herself to significant others, a process known as *psychosocial reciprocity*.[93,107] Pubertal onset and timing are highly salient in early adolescence and are associated with emotions ranging from embarrassment to empowerment.[89-92] Pubertal timing has also been shown to impact relationships with parents, teachers, and peers.[88] According to the theory, these interactions influence the adolescent's identity formation such that the perception of pubertal timing during this formative time is internalized and considered constant, regardless of actual pubertal development. These early experiences of pubertal development thus become a part of adolescent identity, such that peer-normative pubertal timing should remain stable throughout adolescence. However, two studies that used a peer-normative measure of perceived pubertal timing found lower stability than reported for stage-normative measures.[13,14]

Whether pubertal timing is stable has implications not only for the measurement of pubertal timing but also for the prevention of adolescent risk behavior. If pubertal timing is stable, then interventions designed to buffer the risk of off-timing could be implemented in early adolescence and have long-term benefit. However, if pubertal timing is unstable, interventions would need to be implemented throughout adolescence because self-perceptions in early adolescence would be different than perceptions in middle or late adolescence.

The purpose of Study 2 (Chapter 3) was to examine the stability of stage-normative and peer-normative pubertal timing using two different longitudinal methods (N=6,425). First, I examined the stability of the two pubertal timing measures using random effects ANOVA modeling. I then looked at whether there were underlying and stable response patterns in either of the two measures using latent class analysis.

Study 3: Perceived Pubertal Timing and Substance Use among Adolescents: A Longitudinal Perspective

Substance use among adolescents has declined over the past decade, but in 2006, researchers found that by the 12th grade, almost 75 percent of adolescents have had a drink of alcohol, close to 50 percent have smoked a cigarette, and over 40 percent have tried marijuana.[30] Alcohol use among adolescents peaked in the late 1970s and decreased until the mid-1990s when another peak in use occurred. Over the past few years alcohol use has remained relatively stable. The pattern of cigarette use has been slightly different; cigarette use declined dramatically between the mid-1990s and the early 2000s, and while cigarette use is still on the decline, the decrease has slowed in the past few years. Marijuana use has followed a similar trend to alcohol use over the past 30 years.

Male adolescents typically initiate substance use earlier and use more frequently than female adolescents. However, in recent years the gap between male and female adolescent substance use has decreased.[31] White adolescents are more likely to smoke cigarettes and drink alcohol compared with African-American adolescents, with Hispanic/Latino youth falling in the middle, but rates of marijuana use are similar for all three groups.[30, 32] While rates of marijuana use are higher among urban adolescents, rates of alcohol and cigarette use are higher among adolescents from rural areas compared with those from nonrural areas.[30, 32, 33]

Adolescent substance use is associated with a number of physical consequences, including brain damage and impaired memory [34-37] and respiratory issues. [38] Social consequences associated with adolescent substance use include delinquency and risky sexual activity.[39-44] Furthermore, the likelihood of substance dependence and abuse increases as the age of substance use initiation decreases.[45-49] It is imperative to determine the precursors of substance use in order to develop strategies to prevent substance use onset in adolescence.

There are two competing hypotheses regarding the relationship between pubertal timing and adolescent substance use – the maturational deviance hypothesis and the early maturation hypothesis.[24, 27] According to the maturational deviance hypothesis, adolescents whose pubertal development is non-normative (either early or late compared with their peers) are more likely to engage in substance use, due to an increase in psychological distress. In contrast, the early maturation hypothesis states that early maturing adolescents are the only group at risk for substance use because others may view them as more mature and thus they are more likely to associate with older peers who provide exposure to substance use and other deviant behaviors.

Most of the research conducted on pubertal timing and substance use has supported the early maturation hypothesis, regardless of the measure of pubertal timing used. In particular, female adolescents who develop earlier than their peers appear to be at the highest risk for substance use.[3-5, 7,8,10, 13, 16-18, 23,24,26,116,117-121] However, a number of these studies have grouped together on-time and later developing females which prevents a test of the maturational deviance hypothesis.

The maturational deviance hypothesis postulates off-time adolescents, both early and late, are at higher risk for substance use due to the psychological stress associated with being different from others. This theoretically suggests late developing adolescents would be at higher risk for substance use using the peer-normative pubertal timing measure, which takes into account the psychosocial process of pubertal development, compared with the stage-normative pubertal timing measure. However, the few studies that have used a peer-normative measure so far have supported the early maturation hypothesis.[3,5,8,13,116]

Few studies on the links between pubertal timing and substance use have included males in their sample and the results have been mixed. As with female adolescents, most of the research with males supports the early maturation hypothesis,[3, 4, 8, 9, 16-18, 23, 24,116,118] but there is also limited support for the maturational deviance hypothesis.[25] The few studies that have looked at whether adolescent sex moderates the relationship between pubertal timing and substance use have also been mixed, with some suggesting the relationship may either be nonexistent or weaker for males,[119,120] and others finding the relationship to be stronger for males.[17,121]

Few studies have examined whether the relationship between pubertal timing and substance use varies depending on the substance of interest, and almost no studies have included illicit drugs, such as marijuana use, as the outcome of interest. While some studies have found no difference in the relationship between pubertal timing and various substance use outcomes,[18,23] there is some evidence to suggest differential relationships.[3,16,115]

While the two measures of pubertal timing, stage-normative and peer-normative, are often used interchangeably in the literature, this may be inappropriate. However there has been very little research comparing the impact of the two measures on adolescent risk behavior. Furthermore, few studies have considered the longitudinal associations between pubertal timing and substance use. Both pubertal development and substance use are processes that develop over time and thus previous studies limit the ability to understand the longitudinal relationship between pubertal timing and substance use.

The purpose of Study 3 (Chapter 4) was to examine the relationship between pubertal timing and substance use by testing relationships suggested by the maturational-deviance and early maturation hypotheses. In addition, the potential moderating role of gender was explored. Latent class growth modeling was used to determine the relationship between stage-normative and peer-normative pubertal timing and the development of substance use (cigarettes, alcohol, and marijuana) over time (N=5,836).

Significance of Research

There is a growing body of literature that suggests adolescents who develop early or late compared with their peers are more likely to engage in health risk behaviors. However there are inconsistencies in the measurement of self-report pubertal timing that prevent a thorough understanding of the relationship between pubertal timing and substance use. There has been extensive research comparing self-report and clinical measures of pubertal timing, but no studies have determined whether stage-normative and peer-normative pubertal timing are synonymous. Person-in-context theory would suggest that the two measures are not the same and, if not, the peer-normative measure is likely to be more predictive of adolescent risk behavior because it takes into account the adolescent’s social experience of puberty. Both pubertal timing and substance use are developmental processes but most research on the relationship between pubertal timing and substance use has been cross-sectional or measure pubertal timing at one point in time as a predictor of the development of substance use.

The theory of psychosocial development suggests peer-normative pubertal timing would be a stable construct but previous studies have not supported this hypothesis.

This dissertation adds to the literature by disentangling the measurement of pubertal timing and the relationship between pubertal timing and substance use. All three studies of this dissertation used both stage-normative and peer-normative pubertal timing. While these two measures are often used interchangeably, person-in-context theory suggests the two measures are not synonymous. Furthermore, the potential differential impact of these two measures on substance use would provide insight into the reasons why pubertal timing is linked to substance use. There is evidence that the relationship between pubertal timing and substance use could vary depending on the substance examined, and as such the third study of this dissertation looks at the relationship between pubertal timing and cigarette, alcohol, and marijuana use separately.

Secondary analysis of The Context of Adolescent Substance Use study data also allows for a longitudinal examination of stability of pubertal timing and the relationship between pubertal timing and substance use. Most of the research thus far on pubertal timing and substance use has been cross-sectional in design or based only on two waves of data collection.[4, 5, 7-10, 23, 24] This has prevented researchers from being able to determine the stability of pubertal timing across a wide range of ages in adolescence, which was accomplished in the second study (Chapter 3). While the literature has established a correlation between pubertal timing and substance use among adolescents, analysis of longitudinal data furthers this research by enabling a test of the temporal ordering between pubertal timing and substance use (Chapter 4). Using latent class growth analysis in the third study allowed for a determination of how pubertal timing impacts adolescent substance use; I was able to test whether early or late pubertal timing predicted either a higher initial level of substance use and/or increased the development of substance use from early to middle adolescence. Growth modeling is an improvement over traditional longitudinal analyses because it allows for better statistical modeling of change over time and also fits more accurately with the belief of developmental theory that change is “a continuous growth process over time.”[29]

This sample chosen for this dissertation also builds on current research on pubertal timing and adolescent substance use. All three studies include a racially diverse sample of adolescents from the rural Southeast, an understudied area that has been shown to have high rates of substance use. With this diverse sample it is possible to test not only for potential gender differences in the proposed relationships, but also extend the current literature on pubertal timing and substance use beyond the study of White adolescents to include Black and Latino adolescents.

Substance use remains a pervasive issue in adolescence with physical and social consequences that could be prevented. The fundamental purpose of this dissertation is to determine whether pubertal timing predicts substance use throughout adolescence. In order to discern this relationship, I first had to disentangle the complicated measurement of pubertal timing. The first two studies of this dissertation will help to inform future research on pubertal timing and other health risk behaviors by determining the concordance between the two self-report measures and the stability of pubertal timing. The final study incorporates the lessons learned from these measurement studies and provides further insight into the relationship between pubertal timing and substance use.

CHAPTER 2: PUBERTAL TIMING THROUGHOUT ADOLESCENCE: A COMPARISON OF TWO MEASURES

Introduction

Puberty is the most significant biological change that occurs during adolescence. Puberty has profound social implications as well because of the outward changes that occur during this process of sexual maturation, making it visible to others. Individual onset and progression through puberty can vary dramatically, leading to a large body of research dedicated to the study of pubertal timing; that is, an adolescent's pubertal development compared with their peers. Pubertal timing can be measured objectively based on biological referents by comparing the adolescent's pubertal status to the average pubertal status of their peers. It also can be measured subjectively based on the adolescent's self-assessment of pubertal development relative to peers. The two measures are often used interchangeably in the literature but this may be inappropriate because the subjective measure, which presumably reflects biological referents, also includes the adolescent's social experience of pubertal development. Person-in-context theory suggests that because of the inclusion of the social experience the two measures should differ.[86] Yet, the relationship between objective and subjective measures of pubertal timing has not been empirically examined.

The primary purpose of this study is to describe pubertal timing in a sample of youth aged 11 to 17 using objective and subjective measures and to determine the extent to which the two measures are correlated. Because the objective measure of pubertal timing is based on pubertal status, descriptive analyses of pubertal status are presented first. In addition, because of known variation in pubertal development by age, sex, and race/ethnicity, analyses of pubertal status and the two pubertal timing measures within demographic subgroups are presented and compared. Findings from this study may have important measurement implications for researchers assessing relationships between pubertal timing and health behavior.

Puberty as a biological process

Puberty should be thought of not as a one-time distinct event, but as a process of sequential events that has variable onset and progression (or tempo) that results in pubertal maturation – the maturation of the gonads, or sexual organs.[50] It is a process of the central nervous system, and specifically, the hypothalamus, the pituitary gland, the gonads, and the adrenal glands. The onset of puberty occurs when the hypothalamus-pituitary-adrenal axis (HPA) and hypothalamus-pituitary-gonadal (HPG) axis are activated.[51-53] The primary hormone implicated in the onset and progression of pubertal development is gonadotropin releasing hormone (GnRH). In the process known as gonadarche, the gonadal steroid hormones cause gonadal maturation as well as continued secretion of GnRH in the brain. The adrenal glands also begin to produce steroid hormones in a process known as adrenarche. The exact causes of the activation of increased GnRH secretion, and therefore the onset of puberty, are still unknown.[51] There is not an exact moment in time considered "normal" for development. Rather, onset that occurs within specific age ranges is considered normal.[52, 53]

Throughout the pubertal process a number of physical changes occur. [52, 53] Skeletal growth is increased and the circulatory and respiratory systems experience further development. The nervous and endocrine systems also develop during this process. Specifically, adolescents experience growth in the amygdala, which is responsible for emotions, and the hippocampus, responsible for learning and memory. This results in an increase in emotional responses as well as an increase in cognitive functioning. The fat-to-muscle ratio also changes due to the increase in steroid hormones. For males, the fat-to-muscle ratio decreases while in females this ratio increases. Prior to entering puberty, the fat-to-muscle ratio is similar in males and females, but after puberty is complete males have 1.5 times the lean body mass of females and females have twice the amount of fat body mass as males.

The most recognized physical changes that occur during puberty are those changes that occur to the reproductive organs and secondary sexual characteristics. Most of the current knowledge of development of the secondary sexual characteristics during puberty is based in the work conducted by Tanner and his colleagues in the 1950s with white youth from Great Britain.[2, 54] In females, pubertal onset typically manifests first as breast budding, followed by pubic hair growth, height growth spurts, and finally, the onset of menarche. In males, the typical manifestation of pubertal development begins with the growth of the testicles and scrotum and is followed by height growth spurts, pubic hair growth, and finally voice change and facial hair growth. These manifestations of pubertal development occur over a period of time, overlap with one another, can vary dramatically by individual, and form the basis for measures of pubertal status.

Puberty as a social process

While in Western societies puberty is often treated as a personal experience, the profound biological transition from a prepubertal child's body into a postpubertal sexually mature body and the outward changes that occur are evident not only to the adolescent but also to adults and peers. For the first time in recent history, perhaps ever in the history of humans, there is discordance between the age of physical maturation and the age of social maturation.[52, 56,87] While pubertal changes signify advancement towards adulthood, a postpubescent adolescent is not likely to be considered an adult but rather someone in between the roles of a child and an adult. For instance, in recent decades the average age of first menarche has decreased as the average age of first pregnancy has increased. As such, the role of pubertal development in determining the readiness for adult roles would seem to be diminished. However, pubertal timing does appear to influence demands on adolescents: adolescents who mature earlier compared with their peers, and therefore look older than their chronological age, are expected to have greater social maturity and are granted more social autonomy by parents and teachers, whereas the opposite is true for less developed adolescents.[88]

During adolescence peer relationships become increasingly important (see Giordano 2003 for a review). It is not surprising then that peers play an important role in shaping an adolescent's pubertal experience. More specifically, an adolescent's understanding of their pubertal process is shaped in part by comparisons to and reactions from peers. Breast development, one of the first outward signs of pubertal development, and the initiation of menarche have been shown to cause both embarrassment and empowerment among females, in part because of the changing relationships with peers.[89,90] Females reflecting on their first menstrual experiences reported embarrassment and teasing from males when menstrual education was conducted in school, and many turned to their peers when they couldn't speak with their mothers about the menstrual experience.[91]

Less is known about the pubertal experience of males, but one qualitative study found that males compared their personal pubertal development to those of peers and older males with increasing frequency as pubertal changes began and then decreasing frequency as the pubertal changes ceased.[92] Males were less concerned about the pubertal changes occurring and more about the reactions these changes, or lack of changes, would produce among peers. The dominant feeling during puberty was being abnormal and as such a great deal of effort was spent attempting to decrease embarrassing moments.

Theoretical considerations of pubertal development

A major task of adolescence is developing a personal identity. As part of identity development, adolescents engage in social comparison to better understand their place in both proximal (e.g., peer, family, school) and distal (e.g., media and culture) contexts.[93] Person-in-context theory is based on the premise that in order to successfully establish a personal identity one must balance the competing demands to differentiate from others while integrating into society.[86] Personal identity is formed based on an understanding of the contexts into which an adolescent is embedded. Furthermore, while these contexts shape the adolescent, the adolescent also shapes the contexts.

Person-in-context theory supports the belief that puberty is not only a biological process, but a dynamic interplay of biological, psychological, and social processes.[52, 87, 94, 95] Individual perception of pubertal development is not based solely on biological development, but also on an understanding of how this development matches with norms established by distal and proximal contexts. However, because pubertal onset and progression vary dramatically across individuals, the meaning of what is normative for an adolescent changes depending on age and context.

Measuring puberty: Pubertal status and pubertal timing

Given widespread recognition of the importance of puberty as a biological and social process, two dimensions of puberty, pubertal status and pubertal timing, have been the focus of research on pubertal development.[96] Pubertal status, also known as pubertal stage, is a measure of how developed an adolescent is in relation to the pubertal development process. Pubertal timing is a measure of how developed an adolescent is in relation to her or his peers. For the latter measure, adolescents are classified as developing early, on-time, or late, relative to the average development of peers or relative to the adolescent's comparison to peers; those who develop early or late compared with their peers are determined to be developing "off-time."

Pubertal status can be assessed using a number of different indicators. An adolescent's pubertal stage can be assessed clinically by trained professionals (e.g., physicians, nurse practitioners). Clinical measures include staging using recommendations based on the work of Tanner; determining hormone concentrations using blood spot, urine, or saliva data collection; and gonadal ultrasound to examine ovarian or testicular volume.[11] Self-report of pubertal status has been used in a number of studies[3-10] and has been shown to be a valid assessment of pubertal status.[1, 11] Some studies have estimated pubertal development based on self-report of age of first menarche or age of first spermarche. Because menarche and spermarche occur later in pubertal development, however, adolescents who have not experienced menarche or spermarche should not necessarily be considered prepubertal. One commonly used self-report measure of pubertal status that can differentiate between prepubertal, pubertal, and postpubertal adolescents is the Pubertal Development Scale (PDS), a five-item scale that assesses pubertal status based on the presence of secondary sexual characteristics.[58] Adolescents report on how complete their development of secondary sexual characteristics is, typically from "not yet started" to "complete."

There are two common ways of establishing pubertal timing. In the first, stage-normative pubertal timing, the adolescent's pubertal status is compared with the average pubertal status of the sample. Because pubertal development has been shown to vary by age, gender, and race/ethnicity, timing based on pubertal status is usually normed within these subgroups. The second method, peer-normative pubertal timing, is not based on pubertal status or group averages; instead adolescents are asked how they perceive their timing to be compared with their peers. Even though stage-normative pubertal timing may be based on adolescent self-report, it is considered more objective because it is primarily biologically (physically) based and because it does not involve the adolescent's direct comparison with peers. Peer-normative pubertal timing is more subjective because it takes into account both biological and social assessment, by asking adolescents to directly compare their development not to the biological process but to the development of peers. For an adolescent to determine her or his peer-normative pubertal timing, the adolescent must first analyze her or his personal pubertal development (presumably in a process similar to that of answering the pubertal status questions used to develop the stage-normative pubertal timing measure) and then engage in social comparison to determine how her or his pubertal status compares with peers. It is possible that this second step of social comparison introduces a psychosocial component to the peer-normative pubertal timing measure that is missing from the stage-normative pubertal timing measure. But there are fewer studies using measures of pubertal timing based on peer norms than those based on stage norms, and little research on whether the two types of measures of pubertal timing are comparable.

Demographic differences in pubertal status and pubertal timing

Most of the research on pubertal development has been conducted using measures of pubertal status and cross-section designs. While most have lacked gender or racial/ethnic heterogeneity, some demographic differences have been noted. Based on the work of Tanner, development of secondary sexual characteristics has been shown typically to begin around age 9 and be complete by age 16.[54] Females have been shown to begin and complete puberty earlier than males,[51,53,55] and Black adolescents have been shown to begin puberty earlier than White adolescents.[53,55,97-100] National studies have found that rates of pubertal maturation are similar among Latino and White adolescents.[99, 100]

In contrast to research on pubertal status, less is known about potential demographic differences in pubertal timing. Stage-normative pubertal timing is normed by demographic subgroup (i.e., comparative average values are computed within demographic subgroups), so the resulting measure has a mean close to zero for all groups at all ages. Therefore, stage-normative pubertal timing should have few demographic differences. Most of the research on peer-normative pubertal timing has been conducted with study samples that have limited demographic diversity, which could explain why the results of demographic differences in peer-normative pubertal timing have been mixed. One study of peer-normative pubertal timing across three grades (grades 7, 8 and 12) found that it varied by school grade but not in a consistent pattern.[13] Studies have found that it is socially desirable for males to be more developed than their peers but none have examined whether this social desirability results in gender differences in self-reported pubertal timing.[102, 103] One study found that girls who considered themselves to be on-time had a higher body image than girls who were early or late, whereas late developing boys had lower body image compared with on-time or early developing boys.[98] Siegel and her colleagues found that Black adolescents who were late developing had lower body image compared with those who were early or on-time, regardless of gender.[98] Again, however, the possibility that body image concerns lead to gender or racial/ethnic differences in self-reported pubertal timing has not been established even if it may be plausible.

Research Questions and Hypotheses

The purpose of the current study is to examine measures of pubertal status, stage-normative pubertal timing, and peer-normative pubertal timing in a diverse sample of rural adolescents ages 11 to 17. Specifically, the following research questions will be addressed:

1) What is the mean *pubertal status* by age for the total sample from age 11 through 17? Does mean pubertal status vary by sex or race/ethnicity, assessed separately and in combination with each other? The results from this first series of research questions will be used to develop the stage-normative measure of pubertal timing.

I expect the self-reported pubertal status measure used in this study to perform similarly to other studies, with the average score increasing until later adolescence (around age 15) when it will plateau. Based on the prior research, I expect there to be age, sex, and racial/ethnic differences in pubertal status, such that pubertal status will increase with increasing age, females will be more mature than males at all ages, Black adolescents will be more mature at all ages than White adolescents, and White and Latino adolescents will be similar in their pubertal development at all ages.

2) What are the mean values by age for *stage-normative pubertal timing* and *peer-normative pubertal timing* from age 11 through 17? Do the mean values vary by sex or race/ethnicity, assessed separately and in combination with each other?

I expect the mean values at each age for stage-normative pubertal timing to be close to zero and there to be few demographic differences in stage-normative pubertal timing because the measure is normed by demographic subgroup. However, based on evidence of social desirability differences regarding pubertal timing by sex and race/ethnicity, I expect demographic differences in the values of peer-normative pubertal timing, such that males will perceive themselves as more mature compared with their peers than females perceive themselves compared with their peers, and Black adolescents will perceive themselves as more mature compared with their peers than non-Black adolescents perceive themselves compared with their peers.

3) How strongly does stage-normative pubertal timing correlate with peer-normative pubertal timing at each age from 11 through 17? Does the correlation vary by sex or race/ethnicity, assessed separately and in combination with each other?

Other studies have compared self-report measures of pubertal timing with measures based on clinical assessment or other referents (such as parents or teachers), but no studies have compared two self-report measures.[11] Based on person-in-context theory, I expect that the two pubertal timing measures to be related but not synonymous. I hypothesize the two timing measures will have good concordance (Kappa values between .40 and .75), but not excellent concordance (Kappa values above .75) because of the expected greater variation in the peer-normative measure relative to the stage-normative measure due to psychosocial factors. I also predict there will be demographic differences in the concordance between the two measures. With increasing age, adolescents are less likely to be classified as early developing using the stage-normative measure because the entire sample is becoming more developed, creating a ceiling effect. The peer-normative measure has been shown to vary randomly over time. Therefore I would expect the concordance between the two measures to decrease with increasing age. Males will have lower concordance between the two measures compared with females because they will be more likely to consider themselves as early on the peer-normative measure than would be expected with the stage-normative measure. Black adolescents will be more likely to perceive themselves as early on the peer-normative measure than would be expected with the stage-normative measure, resulting in lower congruency between the two measures compared with Non-Black adolescents.

Method

The Context Study

This study was conducted through the secondary analysis of five waves of data from the Context of Adolescent Substance Use study (Context Study), a school-based longitudinal study of three cohorts of adolescents from three North Carolina counties.[132] Wave 1 began in the Spring of 2002 when adolescents were enrolled in the 6th to 8th grades and data collection occurred every semester until the Spring of 2004 (Wave 5). At each wave, all adolescents in the grades of interest in the sampled schools (eight middle schools, two K-8 schools, six high schools, and three alternative schools) were considered eligible for participation. Adolescents in self-contained special education classes and adolescents who had English as a second language and had insufficient reading skills to complete the questionnaire in English were excluded from the study. Response rates ranged from 88 percent at Wave 1 to 76 percent at Wave 5.

The Context Study was approved by UNC's School of Public Health IRB in the Office of Human Research Ethics. The study received a waiver of written parental consent; written adolescent assent was obtained. Parents received a letter by mail describing the study approximately four weeks before each wave of data collection. This information was also sent home with each eligible adolescent from school. Consent materials were distributed in Spanish as needed. Parents were asked to telephone the research office (toll-free) or to return a signed form (postage-paid) if they did not want their child to participate in the particular wave of the study. Written adolescent assent was obtained on the day of data collection by trained data collectors. Data were collected in the schools in a group setting using self-administered questionnaires designed for optical-mark reader scanning. Each classroom had at least one data collector from the research team and larger classrooms were assigned two data collectors. Data collectors returned to the school on as many as four additional days after primary data collection to attempt to reach absent adolescents.

Adolescents whose parents refused permission for participation were excused from the classroom and sent to a pre-designated location in the school. Remaining adolescents were given two assent forms (one copy for the researchers and one for the adolescent to keep) and the questionnaire in a manila envelope with a label on front with the adolescent's name and predetermined subject ID number which was peeled off as it was handed to the adolescent. After the questionnaire distribution the data collector followed a scripted protocol to describe the study and to obtain adolescent assent. Adolescents who did not assent were excused from participating. The data collector then read the instructions for completing the questionnaire.

Teachers remained in the classroom to maintain order among the students but, to protect confidentiality, teachers were requested not to walk around the classroom during the data collection or answer student questions about the study. Adolescents were asked to enclose their completed questionnaire in the same manila envelope and seal the envelope before turning it back in to the data collector. The completion time for the questionnaire was approximately one hour and there was no monetary compensation for participation in the study.

Study Sample

The current study is based on data from adolescents who participated in at least one wave of data collection (N=6,892). Approximately 13 percent of adolescents participated in one wave, 13 percent participated in two waves, 15 percent participated in three waves, 17 percent participated in four waves, and the majority, 42 percent, participated in all five waves of data collection. Participants missing information on age, gender, or race/ethnicity were excluded from analyses (N=295 excluded) and the sample was limited to adolescents aged 11 to 17 (N=172 excluded). Excluded adolescents were less likely to be White (p<.001), less likely to be in the other racial/ethnic category (p<.05), and more likely to be male (p<.001). Excluded adolescents were also less likely to have participated in all five waves of data collection (p<.001). The final sample included 6,425 respondents (50 percent male, 53 percent White, 36 percent African-American, 4 percent Latino, and 7 percent indicating another racial/ethnic category). The mean ages at each wave were 13.1 (SD=0.97), 13.5 (SD=0.96), 14.0 (SD=0.95), 14.5 (SD=0.94) and 15.0 (SD=0.92).

Measures

Pubertal status

Pubertal stage was assessed using a revised version of the Pubertal Development Scale (PDS).[58] The PDS consists of five questions assessing development of body hair growth, skin changes, height, and either voice and facial hair growth for males or breast development for females. The range of the items is 1=not yet started to 4=seems complete. Females were also asked if they started menstruating (1=no, 4=yes), and at what age. The items were averaged to obtain a mean PDS score (alphas by wave ranged from 0.68 to 0.73 for females and 0.76 to 0.81 for males).

Pubertal timing

To measure *stage-normative pubertal timing*, I first calculated the mean pubertal stage among adolescents in the sample by age, and at each age by gender, race/ethnicity, and gender by race/ethnicity. I then compared each adolescent's pubertal status to the mean for the demographic subgroup. Adolescents were classified as "early" (1=more than one standard deviation above the mean pubertal stage), "on-time" (0), or “late” (-1=more than one standard deviation below the mean pubertal stage) based on the norm for their demographic subgroup.

Peer-normative pubertal timing was based on adolescent perceptions of their pubertal development relative to their peers. Adolescents were asked one item about how they believed their physical development compared with others their own age and sex (1=much earlier to 5=much later). Adolescents indicating their development was much or somewhat earlier than their peers were classified as “early” (1), about the same as their peers as “on-time” (0), and somewhat or much later than their peers as “late” (-1) developers.

Age

Age was calculated using adolescent date of birth and the date of the interview. Age was recoded into twelve half-year categories, ranging from 11 to 16.5.

Analyses

The sample was reconfigured to use age as the unit of time instead of wave of data collection. Because the Context Study was a longitudinal study of cohorts in three different grades at baseline, there is wide variation in age at each wave, which would be ignored in analyses based on data collection wave. It is also appropriate to look at a biological process such as puberty by age rather than wave of data collection or school grade.

The average perceived pubertal status, average stage-normative perceived pubertal timing, and average peer-normative perceived pubertal timing were calculated at each age. The sample was divided by gender (two groups), race/ethnicity (four groups), and by both gender and race/ethnicity (eight groups) to assess subgroup differences in each of the three measures. A one-way analysis of variance (ANOVA) model was conducted for each comparison of means. For the models including racial/ethnic groups, *t*-test comparisons were conducted when the overall *F*-statistic was significant. All analyses were conducted using SAS Version 9.1.

To determine how strongly the stage-normative and peer-normative measures of perceived pubertal timing were correlated, a Kappa statistic, which is designed to quantify the degree of association between categorical variables, was calculated at each age. A Kappa statistic of less than .40 indicates marginal concordance, between .40 and .75 is good, and greater than 0.75 indicates excellent concordance.[73] The correlation between the two timing measures was examined for the sample as a whole at each age and then at each age by gender, race/ethnicity, and both gender and race/ethnicity.

Results

Pubertal status. Average pubertal status increased with increasing age (from 2.03, SD=0.61 at age 11 to 3.18, SD=0.59 at age 16.5, F=469.67, $p<0.001$). At all ages, females reported higher pubertal development than males (Table 2.1). From ages 11.5 to 16, racial/ethnic differences in pubertal status were evident (Table 2.2). White and Black youth tended to have higher pubertal development compared with Latino youth, but most of the significant differences were between White and Black youth. From ages 11.5 to 13, Black participants reported more developed pubertal status than White participants, but the difference reversed around age 14.5 with White participants reporting more developed pubertal status than Black participants. The same pattern of reversal was evident for Black and White males (Table 2.3). Among females, Blacks reported more advanced pubertal development from ages 11.5 through 13, but the reverse pattern was only evident at age 15 (Table 2.4). While there were no differences in pubertal stage by age between Latino males and those of other race/ethnicities, Latino females tended to be less developed at most ages than White or Black females.

Pubertal timing. As seen in Table 2.5, and as expected, the average means for stage-normative pubertal timing were close to zero at all ages in the total sample and showed a slight increase with age. The average means for peer-normative pubertal timing were larger than zero at all ages except age 11 and the means increased with increasing age, indicating that as adolescents aged they were more likely to perceive their timing as early compared with their peers (Table 2.5).

As expected, because the stage-normative measure was normed within age, gender, and racial/ethnic group, there were very few differences in stage-normative pubertal timing in the demographic comparisons (Tables 2.6-2.9). Contrary to the pubertal status analyses, where differences between males and females were significant, males were more likely than females to be classified as more advanced compared to their peers on stage-normative pubertal timing and were more likely than females to perceive themselves as more advanced on peer-normative pubertal timing, although there were relatively few significant differences overall (Table 2.6).

There were significant racial differences in the peer-normative measure of perceived pubertal timing from the ages of 12.5 to 15, with Black participants being more likely to perceive themselves as more advanced compared to their peers than White participants (Table 2.7). The same pattern between White and Black participants was true across gender, although for more constricted age ranges (Tables 2.8 and 2.9).

Relationship between stage-normative pubertal timing and peer-normative pubertal timing. While many of the correlations between the stage-normative and peer-normative pubertal timing measures were statistically significant, the strength of the correlations was less than marginal based on established standards of the Kappa statistic, with most correlations less than .30 (Table 2.10). The highest concordance for the full sample and demographic subgroups occurred between the ages of 12 and 14. In general, the two measures were more highly correlated among females than males and among White participants compared with participants from other racial/ethnic groups.

Discussion

The primary purpose of this study was to investigate the relationship between two self-report measures of pubertal timing: an objective measure based on comparing the adolescent's pubertal status to the average pubertal status of their demographic subgroup (stage-normative) and a subjective measure based on direct comparison with peers that presumably reflected biological and social perspectives (peer-normative). A secondary purpose was to examine demographic differences in pubertal status, which was the basis for stage-normative pubertal timing. The primary purpose was accomplished by examining associations between these two pubertal timing measures by age, gender, and race/ethnicity in a diverse sample that encompassed ages 11 to 16.5. The weak associations between the two measures suggest that stage-normative pubertal timing and peer-normative pubertal timing are assessing different aspects of the pubertal development process. The discordance between these measures has important implications for research concerned with phenomenon thought to be impacted by pubertal timing. In the following sections I review and discuss my findings relevant to the three research questions and associated hypotheses that guided this study.

Demographic differences in pubertal status

As hypothesized, self-reported pubertal status scores increased with increasing age and eventually evened out in later adolescence. Overall, and as expected, females were more developed than males at each age (11 to 16.5 years of age), which has also been supported in past research.[51, 53, 55] An unusual pattern in pubertal status emerged when comparing Black and White participants. Consistent with other studies, Black participants were more developed than White participants at the earlier ages of 11.5 to 13 but, unexpectedly, the differences reversed later in adolescence, after age 14. This pattern was evident for both males and females. This reversal has not been reported elsewhere, but this is one of the few studies to examine pubertal status in a sample diverse enough to allow for comparisons by age, gender, and race/ethnicity. Previous research has suggested that Black adolescents begin puberty earlier than White adolescents, but that pubertal maturation completes close to the same time.[53, 100] This study suggests that in later adolescence White adolescents may "catch up" in their development and, at the oldest age examined of 16.5 years are actually more biologically mature than Black adolescents.

I had hypothesized that White and Latino adolescents would be similar in their pubertal status. However, Latino adolescents generally had the lowest pubertal status scores compared with other racial/ethnic groups, and this finding was more prominent among females than males. These results are slightly different from other studies of urban adolescents, which found that Latino adolescents had similar rates of pubertal maturation compared with White adolescents.[97, 98] Adolescents who indicated a racial or ethnic group other than White, Black, or Latino did not have a consistent pattern of comparison with other racial/ethnic groups. This could be because of the smaller sample size of adolescents who were categorized into this group, or because of the varying racial/ethnic identities (American Indian/Native American, Asian or Pacific Islander, multiracial, other, or don't know) that were grouped into this category. Larger samples of adolescents from these groups are needed to describe the patterns of pubertal status in these subgroups.

Demographic differences in stage-normative and peer-normative pubertal timing

As anticipated, there were few demographic differences in the stage-normative measure of pubertal timing. This was expected because this measure was normed by age, sex, and race/ethnicity. However, the average value of stage-normative pubertal timing was higher for males compared with females between the ages of 12 and 13 (suggesting that males had relatively earlier development relative to their peers of the same sex, age, and race/ethnicity compared with females), and at age 13.5 females had a higher mean value of stage-normative pubertal timing than males. This finding was in contrast with the pubertal status analyses, where females were more developed than males at every age. It appears that the differences were not due to male development but rather female development; between the ages of 12 and 13 the mean values of stage-normative pubertal timing became negative for females, suggesting that at these ages the distribution of pubertal development is skewed such that more females are late developing than early developing. More research needs to be conducted at these ages to validate this skewness.

Different demographic patterns of significance were apparent for the peer-normative pubertal timing measure compared with the stage-normative pubertal timing measure. I had hypothesized there would be no age-related pattern to peer-normative pubertal timing. However, as adolescents aged, and therefore became more developed, their perception of their development compared to their peers also changed, such that they believed they were more developed compared with their peers. This indicates a need to measure and examine the role of pubertal timing across adolescence rather than at one point in time.

My hypothesis of sex differences in peer-normative pubertal timing was partially supported. Males were more likely than females to perceive themselves as early compared with their peers, except at the ages of 15 and 15.5, but the differences were only statistically significant in younger adolescence (from age 11.5 through age 13). The sex differences at ages 12.5 and 13 correspond with statistically significant sex differences in stage-normative pubertal timing, which supports the contention that adolescent perception of pubertal timing is based in part on biological referents.

As hypothesized, in general, Black adolescents were more likely than White adolescents to perceive their timing to be early, independent of age or sex, using the peer-normative measure. I had not developed hypotheses related to pubertal timing differences among Latino adolescents compared with other adolescents, but opposite of what was found in the pubertal status analyses, Latino adolescents trended towards higher means of peer-normative pubertal timing (i.e., early development) compared with White adolescents but the differences were not significant.

The demographic differences in the peer-normative pubertal timing measure point to the need for more detailed research to explore the nature of the comparisons adolescents make when they compare their pubertal development to their peers. For example, what physical characteristics are adolescents looking at in making their comparisons with their peers? Also, while the peer-normative measure used in this study asked adolescents to compare within their own age and gender, they also may have made comparisons with peers within their same racial/ethnic group. Focus groups with adolescents could help explain some of the cognitive processes occurring during such social comparisons of puberty and help with development of additional measures of peer-normative pubertal timing.

Associations between stage-normative and peer-normative pubertal timing

I hypothesized that the two measures of pubertal timing would have good concordance in the overall sample. However, while many of the Kappa statistics were statistically significant, the values did not meet the Kappa range for good concordance of

.40 to .75 and indeed most values were considerably lower than the criterion for marginal concordance (.40) set forth by Rosner.[73] Both pubertal timing measures were based on self-report, but adolescents perceived their pubertal timing (as measured by the peer-normative measure) to be less similar to their peers than was suggested by actual stage differences between adolescents and their peers. While some discrepancy between the two measures was expected based on empirical evidence and person-in-context theory, the magnitude of the discordance between the two pubertal timing measures was surprising.

As hypothesized, the extent of the discordance between the two pubertal timing measures varied by demographic characteristics. However, contrary to my hypothesis that the discordance would increase with increasing age, there appeared to be no pattern in the Kappa statistics by adolescent age. In addition, contrary to the hypothesis that the measures would be more strongly correlated for females compared with males at all ages, the two measures were more strongly correlated for females at younger ages (11.5 to 13) and more strongly correlated for males in later adolescence (13.5 to 15.5). In general, as hypothesized, the two pubertal timing measures were more strongly correlated for White adolescents compared with adolescents from other racial/ethnic groups. But, again, it should be noted that most of the Kappa statistics were below the cutoff of marginal (<.40). While the demographic differences are only descriptive and not statistically tested, these results suggest that the differences between the social and biological constructions of puberty vary based on age, sex, and race/ethnicity. Furthermore, these differences highlight the need for diverse samples when examining pubertal development among adolescents.

The results from this study suggest that how adolescents construct their understanding of puberty is based on more than biological referents, and indeed may only minimally reflect biological construction. The stage-normative measure of pubertal timing was based on each adolescent's assessment of how complete the pubertal process was for various secondary sexual characteristics and objective comparison of their individual assessment to the group average. In contrast, for the peer-normative measure, each adolescent directly compared their physical development to their peers. Thus only the latter measure specifically involved social comparison.

It is well established that identity development is an important task in adolescence and that part of this development occurs through the process of social comparison.[93] The inclusion of social comparison led to the peer-normative measure being a very different measure of pubertal timing than the stage-normative measure which was based on the biological pubertal process. The importance of the social comparison process is supported by person-in-context theory, which postulates that adolescents develop personal identity through an understanding of their surrounding contexts. This study suggests that while the biological changes that occur during puberty are an important part of an adolescent's developing personal identity, the differences between the stage-normative and peer-normative pubertal timing measures are likely due in part to the social comparison process and adolescents' subjective perceptions of their pubertal development relative to peers. Discussion of the changes that occur during puberty is not encouraged in our society, so adolescents have to rely on their understanding of how they compare with their peers in order to determine where they are in the pubertal process.

The extreme discordance between the two measures suggests that many attributes may have factored into the social comparisons and discrepancies. As discussed earlier, it is possible that the peer-normative measure showed different results by race and ethnicity than what is observed in the more objective pubertal status and stage-normative pubertal timing measures because the peer-normative measure only asked adolescents to compare their development to peers of the same age and gender and did not mention race or ethnicity. While this could explain the findings among younger White and Black adolescents (before age 14 Black adolescents were more developed than White adolescents), it does not explain the findings for older Black adolescents, because in this study older Black adolescents were actually less developed than their White peers.

Another possibility is that the peer-normative measure of pubertal timing was confounded by body mass index, which was not measured in this study. Other studies have found that Black and Latino adolescents on average have a higher BMI than White adolescents,[104] and that BMI can influence the perception of pubertal development, such that heavier children overestimate their pubertal development.[105] More research is needed to determine if some of the differences found between the two pubertal timing measures could be explained by confounding variables such as BMI.

The differences between the stage-normative and peer-normative pubertal timing measures could also be due in part to social desirability. For example, the differences in pubertal timing between males and females are contrary to previous research examining gender differences in stage-normative pubertal timing, but supports previous research that has suggested that it is more socially desirable for males than females to be more developed than their peers.[98, 101-103] There are few studies regarding racial or ethnic differences in the social desirability of perceived pubertal timing. Siegel and her colleagues found that African American adolescents who were late developing had lower body image compared with those who were early or on-time, regardless of gender, which suggests a social desirability to be more developed.[98]

Most studies use only one measure of self-report pubertal timing and do not differentiate stage-normative from peer-normative measures of timing. Dorn and her colleagues suggest selecting measures of pubertal development based on research questions of interest, but there is no distinction made between measures based on self-perception.[11] The current study findings further this team's work by suggesting a potential for different research findings depending on the measure of self-perceived pubertal timing. Because the stage-normative measure is based on numerous physical characteristics it may be more appropriate for studies seeking to understand whether differences in pubertal development impact biological health outcomes, such as obesity. But the peer-normative measure could be more important in predicting behavioral outcomes such as substance use or sexual activity where interpersonal processes are relevant. This hypothesis is supported by person-in-context theory; it is not the adolescent's actual pubertal development that makes her or him more likely to engage in risky behavior, but rather the adolescent's interpretation of how that pubertal development compares to peers. Additional research using both measures of pubertal timing is needed to determine whether they differentially predict various behavioral and health outcomes.

Study limitations and strengths

There are limitations to this study due to the study sample. In particular, the youngest adolescents in the study sample were 11 years of age. The first stages of pubertal development typically begin by age 9 or 10, and early developing adolescents could show signs of maturation as early as age 7 or 8. [54] Therefore, differences in pubertal status or pubertal timing that could be occurring early on in the development process could not be assessed. There also were not enough adolescents in the rarely reported racial groups to be able to separate each racial/ethnic group in the analyses, but I was able to examine differences between White, Black, and Latino adolescents. The adolescents in this study are from a longitudinal sample, so the time points are not independent; the greatest impact of this nonindependence would be in the middle ages of the sample, where there was the most overlap in the ages of the three cohorts. The analyses did not control for potential clustering by school because I did not hypothesize that school-level factors would influence pubertal timing beyond the influence of adolescent sex or race/ethnicity.

This study did not collect clinical measures of pubertal development so it is not possible to assess the validity of the self-reported measure of pubertal status. Numerous studies, however, have suggested that self-reports of pubertal development correlate strongly with clinical measures.[1,11] As another measurement consideration, both measures of pubertal timing were trichotomized into the classes of early, on-time, and late. The results may have differed if the categorization had used all five categories (very early, early, on-time, late, very late). The stage-normative pubertal timing measure used one standard deviation as the cutoff for off-timing. Using a different cut-off, such as two standard deviations from the mean, would likely have produced different results. One standard deviation difference was chosen as the cutoff because a majority of the studies using stage-normative pubertal timing have used this cutoff and I was interested in determining how this classification was correlated with the similarly categorized peer-normative pubertal timing measure. The peer-normative measure was based on one item assessing how adolescents perceived their overall development to be compared with peers. This is a common way of assessing peer-normative pubertal timing,[13,14,98,101] but it is possible that a scale of items assessing how adolescents perceived their development of specific characteristics (e.g., body hair, breast development) may have resulted in a more comparable measure to stage-normative pubertal timing.

Despite the limitations, this study is one of the first to examine pubertal status and timing differences among a diverse sample of adolescents, as well as to compare an objective and subjective measure of self-reported pubertal timing. The large sample size allowed for comparisons of pubertal status and the two measures of pubertal timing by age, gender, and race/ethnicity. I found very low concordance between the two measures of pubertal timing as well as varying age, gender, and racial/ethnic differences between the two measures. The findings suggest that the measures are tapping different aspects of puberty. Inconclusive results found across previous studies of pubertal timing and adolescent health behavior may be due to measurement differences. It is critical that researchers assessing the impact of pubertal development on health behavior carefully consider the implications of the measure they choose.

Table 2.1. Mean pubertal stage for full sample, males, and females, by age

Age	N	Total	Male	Female	F-value
11.0	167	2.03	1.86	2.15	9.82**
11.5	843	2.20	2.01	2.37	78.76***
12.0	1555	2.37	2.13	2.58	225.25***
12.5	2315	2.53	2.30	2.72	307.72***
13.0	3069	2.69	2.44	2.90	523.57***
13.5	3458	2.83	2.60	3.04	622.63***
14.0	3432	2.93	2.72	3.13	592.75***
14.5	2825	3.03	2.84	3.23	420.93***
15.0	2133	3.11	2.92	3.31	323.19***
15.5	1410	3.17	2.94	3.38	192.22***
16.0	762	3.21	3.02	3.45	124.61***
16.5	176	3.18	3.07	3.40	13.05***

Range of pubertal stage is 1-4, with higher values indicating more advanced pubertal development
*p<.05, ** p <.01, *** p <.001

Table 2.2. Mean pubertal stage by age and race/ethnicity

Age	White	Black	Latino	Other	F-value
11.0	2.02	2.10	1.79	2.09	1.04
11.5	2.12	2.35	2.10	2.16	8.74*** [a]
12.0	2.28	2.52	2.19	2.45	18.43*** [acdf]
12.5	2.47	2.61	2.44	2.61	9.83*** [ad]
13.0	2.65	2.74	2.65	2.68	4.60** [a]
13.5	2.83	2.85	2.65	2.81	4.55** [bdf]
14.0	2.95	2.92	2.81	2.99	3.85** [bf]
14.5	3.07	2.99	2.89	3.05	7.04*** [ab]
15.0	3.16	3.03	3.05	3.16	9.12*** [ae]
15.5	3.23	3.11	3.05	3.19	5.42*** [a]
16.0	3.31	3.12	2.98	3.15	8.55*** [ab]
16.5	3.31	3.10	2.94	3.29	2.65

Range of pubertal stage is 1-4, with higher values indicating more advanced pubertal development
[a-f]Different superscripts indicate significant difference in means: a=White vs. Black, b=White vs. Latino, c=White vs. Other, d=Black vs. Latino, e=Black vs. Other, f=Latino vs. Other
* p <.05, ** p <.01, *** p <.001

Table 2.3. Mean pubertal stage by age and race/ethnicity among males

Age	N	White	Black	Latino	Other	F-value
11.0	69	1.77	1.95	1.66	2.15	1.61
11.5	392	1.92	2.15	1.98	2.04	5.91*** [a]
12.0	724	2.06	2.27	2.09	2.13	8.56*** [a]
12.5	1075	2.26	2.37	2.33	2.33	3.70* [a]
13.0	1435	2.43	2.46	2.55	2.35	1.88
13.5	1652	2.62	2.57	2.53	2.59	1.24
14.0	1652	2.75	2.66	2.74	2.80	3.95** [a]
14.5	1407	2.88	2.76	2.88	2.85	5.11* [a]
15.0	1092	2.99	2.79	3.00	2.93	11.56*** [a]
15.5	742	3.08	2.83	2.92	2.99	10.58*** [a]
16.0	416	3.15	2.85	2.91	2.80	11.55*** [ac]
16.5	117	3.24	2.95	2.85	3.16	2.77*

Range of pubertal stage is 1-4, with higher values indicating more advanced pubertal development

[a-f]Different superscripts indicate significant difference in means: a=White vs. Black, b=White vs. Latino, c=White vs. Other, d=Black vs. Latino, e=Black vs. Other, f=Latino vs. Other

* p <.05, ** p <.01, *** p <.001

Table 2.4. Mean pubertal stage by age and race/ethnicity among females

Age	N	White	Black	Latino	Other	F-value
11.0	98	2.13	2.28	1.91	2.06	0.65
11.5	451	2.29	2.53	2.20	2.28	4.92** [a]
12.0	831	2.49	2.73	2.31	2.65	11.16*** [ad]
12.5	1240	2.67	2.79	2.57	2.81	5.49*** [a]
13.0	1634	2.87	2.96	2.80	2.89	3.77** [a]
13.5	1806	3.03	3.06	2.81	3.01	4.09** [bd]
14.0	1780	3.15	3.13	2.88	3.13	6.01*** [bdf]
14.5	1418	3.26	3.20	2.91	3.22	8.13*** [bdf]
15.0	1041	3.35	3.26	3.11	3.33	4.74** [ab]
15.5	668	3.41	3.36	3.22	3.37	1.38
16.0	346	3.52	3.38	3.12	3.47	3.78* [b]
16.5	59	3.47	3.37	3.16	3.52	0.50

Range of pubertal stage is 1-4, with higher values indicating more advanced pubertal development

[a-f]Different superscripts indicate significant difference in means: a=White vs. Black, b=White vs. Latino, c=White vs. Other, d=Black vs. Latino, e=Black vs. Other, f=Latino vs. Other

* p <.05, ** p <.01, *** p <.001

Table 2.5. Means and standard deviations for stage-normative and peer-normative pubertal timing by age

	Stage-normative pubertal timing			Peer-normative pubertal timing		
Age	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
11.0	167	-.006	.565	152	-.046	.703
11.5	843	.027	.617	785	.050	.681
12.0	1555	.021	.583	1471	.094	.679
12.5	2315	-.025	.578	2174	.093	.690
13.0	3069	-.016	.554	2893	.122	.678
13.5	3458	-.001	.525	3269	.128	.686
14.0	3432	-.030	.516	3230	.145	.673
14.5	2825	.034	.524	2631	.166	.680
15.0	2133	.019	.522	2021	.186	.678
15.5	1410	.042	.544	1323	.193	.659
16.0	762	.028	.567	707	.197	.656
16.5	176	-.011	.513	159	.208	.657

Range is -1 to 1 (-1=late, 0=on-time, 1=early)

Table 2.6. Mean stage-normative and peer-normative pubertal timing by age and sex

	Stage-normative pubertal timing				Peer-normative pubertal timing			
Age	**N**	**Male**	**Female**	**F-value**	**N**	**Male**	**Female**	**F-value**
11.0	167	-.029	.010	.19	152	.063	-.125	2.66
11.5	843	.008	.044	.74	785	.104	.002	4.41*
12.0	1555	.061	-.014	6.47*	1471	.118	.074	1.59
12.5	2315	.020	-.065	12.23***	2174	.135	.057	6.90**
13.0	3069	.037	-.063	25.03***	2893	.163	.087	9.09**
13.5	3458	-.025	.020	6.28*	3269	.135	.122	.33
14.0	3432	-.032	-.028	.07	3230	.159	.131	1.40
14.5	2825	.028	.040	.36	2631	.184	.148	1.85
15.0	2133	.002	.037	2.23	2021	.168	.203	1.35
15.5	1410	.045	.039	.04	1323	.172	.215	1.45
16.0	762	.002	.058	1.81	707	.198	.195	.00
16.5	176	.034	-.102	2.78	159	.243	.143	.84

Range is -1 to 1 (-1=late, 0=on-time, 1=early)
* *p* <.05, ** *p* <.01, *** *p* <.001

Table 2.7. Mean stage-normative and peer-normative pubertal timing by age and race/ethnicity

	Stage-normative pubertal timing				**Peer-normative pubertal timing**			
Age	**Black**	**Latino**	**Other**	**F-value**	**White**	**Black**	**Other**	**F-value**
11.0	-0.02	-0.14	-0.11	0.53	-0.12	0.09	-0.14	0.90
11.5	0.00	0.08	0.04	0.34	0.02	0.09	0.09	0.90
12.0	0.02	0.04	-0.07	0.93	0.06	0.13	0.16	1.69
12.5	-0.04	0.03	0.01	0.64	0.05	0.16	0.08	4.26** [a]
13.0	0.00	0.00	-0.01	0.39	0.07	0.22	0.07	10.66*** [ae]
13.5	0.00	0.01	0.02	0.30	0.08	0.21	0.17	9.82*** [a]
14.0	-0.01	-0.03	0.01	2.02	0.09	0.23	0.19	10.05*** [a]
14.5	-0.01	0.01	0.01	4.87** [a]	0.14	0.22	0.09	3.60* [a]
15.0	0.05	0.04	-0.01	1.63	0.17	0.24	0.12	2.62*
15.5	-0.01	-0.06	0.04	3.95** [a]	0.16	0.24	0.15	2.38
16.0	0.01	-0.06	-0.04	0.81	0.18	0.18	0.23	1.47
16.5	-0.05	0.06	-0.14	0.84	0.17	0.15	0.50	1.28

Range is -1 to 1 (-1=late, 0=on-time, 1=early)

[a-f]Different superscripts indicate significant difference in means: a=White vs. Black, b=White vs. Latino, c=White vs. Other, d=Black vs. Latino, e=Black vs. Other, f=Latino vs. Other

* p <.05, ** p <.01, *** p <.001

Table 2.8. Mean stage-normative and peer-normative pubertal timing by age and race/ethnicity among males

	Stage-normative pubertal timing						Peer-normative pubertal timing					
Age	**N**	**White**	**Black**	**Latino**	**Other**	**F-value**	**N**	**White**	**Black**	**Latino**	**Other**	**F-value**
11.0	69	0.00	0.00	-0.14	-0.33	0.58	69	-0.17	0.19	0.50	0.50	2.51
11.5	392	0.03	-0.04	0.06	0.00	0.39	364	0.06	0.17	0.13	0.17	0.83
12.0	724	0.06	0.07	0.05	0.05	0.04	684	0.10	0.14	0.20	0.08	0.35
12.5	1075	0.05	-0.05	0.09	0.03	2.88* [a]	1006	0.10	0.19	0.13	0.22	1.81
13.0	1435	0.03	0.05	0.05	0.06	0.25	1346	0.12	0.27	0.16	0.05	5.54*** [a]
13.5	1652	-0.02	-0.05	0.01	0.04	1.13	1558	0.09	0.22	0.06	0.18	3.83** [a]
14.0	1652	-0.06	0.02	0.02	-0.02	2.94* [a]	1545	0.10	0.27	0.16	0.19	6.50*** [a]
14.5	1407	0.06	-0.03	0.00	0.01	3.06* [a]	1308	0.16	0.24	0.17	0.14	1.50
15.0	1092	0.01	-0.01	0.05	-0.02	0.25	1033	0.15	0.23	0.00	0.16	1.87
15.5	742	0.10	-0.02	-0.07	-0.02	3.40* [a]	687	0.14	0.23	0.37	0.13	1.71
16.0	416	0.02	-0.01	-0.04	-0.09	0.40	379	0.17	0.19	0.48	0.22	1.54
16.5	117	0.11	-0.02	0.08	-0.11	0.72	103	0.18	0.21	0.36	0.56	0.95

Range is -1 to 1 (-1=late, 0=on-time, 1=early)

[a-f]Different superscripts indicate significant difference in means: a=White vs. Black, b=White vs. Latino, c=White vs. Other, d=Black vs. Latino, e=Black vs. Other, f=Latino vs. Other

* p <.05, ** p <.01, *** p <.001

Table 2.9. Mean stage-normative and peer-normative pubertal timing by age and race/ethnicity among females

	Stage-normative pubertal timing						Peer-normative pubertal timing					
Age	N	White	Black	Latino	Other	F-value	N	White	Black	Latino	Other	F-value
11.0	98	0.05	-0.04	-0.14	0.00	0.28	88	-0.09	-0.05	-0.43	-0.40	0.83
11.5	451	0.04	0.03	0.10	0.08	0.10	421	-0.02	0.03	0.11	0.00	0.29
12.0	831	0.01	-0.03	0.03	-0.14	1.28	787	0.02	0.12	0.15	0.21	2.08
12.5	1240	-0.09	-0.03	-0.05	-0.01	1.39	1168	0.01	0.14	0.14	-0.01	3.37* [a]
13.0	1634	-0.07	-0.05	-0.08	-0.05	0.38	1547	0.02	0.18	0.12	0.08	6.17*** [a]
13.5	1806	0.00	0.05	0.00	0.01	0.84	1711	0.06	0.21	0.02	0.16	6.24*** [a]
14.0	1780	-0.03	-0.03	-0.08	0.04	1.00	1685	0.08	0.19	0.21	0.20	4.34** [a]
14.5	1418	0.07	0.00	0.02	0.01	1.94	1323	0.13	0.21	0.07	0.05	2.32
15.0	1041	-0.01	0.11	0.03	0.00	4.24** [a]	988	0.19	0.25	0.22	0.08	1.46
15.5	668	0.07	0.00	-0.05	0.10	1.25	636	0.19	0.25	0.32	0.17	0.66
16.0	346	0.10	0.03	-0.09	0.00	0.56	328	0.19	0.18	0.30	0.24	0.14
16.5	59	-0.10	-0.10	0.00	-0.20	0.16	56	0.16	0.07	0.20	0.40	0.37

Range is -1 to 1 (-1=late, 0=on-time, 1=early)

[a-f]Different superscripts indicate significant difference in means: a=White vs. Black, b=White vs. Latino, c=White vs. Other, d=Black vs. Latino, e=Black vs. Other, f=Latino vs. Other

* p <.05, ** p <.01, *** p <.001

Table 2.10. Simple Kappa statistics for the stage-normative and peer-normative pubertal timing measures, by age, sex, and race/ethnicity

	11.0	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**	**14.5**	**15.0**	**15.5**	**16.0**	**16.5**
Full sample	-0.012	0.129***	0.154***	0.179***	0.167***	0.186***	0.154***	0.146***	0.135***	0.130***	0.150***	0.029
White	-0.095	0.160***	0.195***	0.214***	0.217***	0.218***	0.191***	0.193***	0.150***	0.153***	0.143**	0.098
Black	0.156	0.053	0.143***	0.126***	0.101***	0.121***	0.097***	0.108***	0.099***	0.096**	0.147**	-0.045
Latino	0.032	0.019	-0.023	0.134	0.159*	0.256***	0.017	0.079	0.200*	0.148	0.211*	0.064
Other	-0.346	0.438***	0.045	0.230***	0.114*	0.246***	0.198***	-0.015	0.113	0.142	0.201*	0.067
Female	-0.036	0.169***	0.207***	0.207***	0.171***	0.171***	0.141***	0.133***	0.111***	0.104**	0.160***	-0.131
White	-0.121	0.203***	0.271***	0.247***	0.256***	0.203***	0.159***	0.167***	0.135***	0.082*	0.147*	-0.024
Black	0.226	0.096	0.173***	0.132***	0.076**	0.098***	0.097***	0.100***	0.048	0.094*	0.165**	--
Latino	--	0.035	-0.009	0.204*	0.240*	0.312**	0.026	0.238*	0.269*	0.290	0.286	-0.250
Other	0.286	0.542***	0.063	0.278***	0.045	0.280***	0.259***	-0.014	0.099	0.254*	0.246	0.286
Male	0.038	0.080*	0.088**	0.144***	0.163***	0.202***	0.168***	0.159***	0.157***	0.155***	0.141***	0.101
White	-0.100	0.106*	0.097**	0.174***	0.178***	0.234***	0.222***	0.217***	0.161***	0.208***	0.140**	0.158
Black	0.142	0.003	0.104*	0.117**	0.134***	0.152***	0.095**	0.118***	0.153***	0.098*	0.129*	-0.007
Latino	-0.333	0.111	-0.034	0.089	0.095	0.216**	0.011	-0.057	0.149	0.073	--	0.205
Other	--	0.345*	0.026	0.168*	0.214*	0.205**	0.117	-0.018	0.130	0.046	0.165	0.115

Range is -1 to 1 (-1=late, 0=on-time, 1=early)

-- Not enough information present in all cells to compute a Kappa statistic

Kappa statistic <.40=marginal, .40-.75=good, >0.75=excellent [11]

* *p* <.05, ** *p* <.01, *** *p* <.001

CHAPTER 3: THE STABILITY OF PERCEIVED PUBERTAL TIMING ACROSS ADOLESCENCE

Introduction

The most significant biological changes that occur during adolescence are the onset and completion of puberty. Puberty is not a one-time distinct event, but is a process of sequential events that has variable onset and progression.[50] There are gender and racial/ethnic differences in the onset and tempo of puberty, as well as individual differences within groups. [13,51,53,55,97-101,Chapter 2] These differences have prompted an interest in pubertal timing, defined as an adolescent's development relative to their peers. Pubertal timing can be measured objectively based on biological referents by comparing the adolescent's pubertal status to the average pubertal status of peers (stage-normative pubertal timing). It also can be measured subjectively based on the adolescent's self-assessment of pubertal development compared with peers (peer-normative pubertal timing).

Whether perceived pubertal timing is a stable construct throughout adolescence has not been established, perhaps due to a lack of longitudinal studies. At question is whether perceived pubertal timing changes as puberty progresses among adolescents and their peers, as is therefore unstable, or whether perceived pubertal timing is an important component of adolescent identity formation that is fixed early in pubertal development, and is therefore a stable construct. Stage-normative pubertal timing and peer-normative pubertal timing measure different components of pubertal development and have been found to have little concordance, so it is reasonable to expect there could also be stability differences between these two measures.[Chapter 2] Compared with stage-normative pubertal timing, peer-normative pubertal timing may better reflect an adolescent's assessment of timing relative to peers and may be more immutable and reflect greater stability compared with stage-normative pubertal timing. The purpose of this study is to examine and compare the stability of two perceived pubertal timing measures, an objective stage-normative measure and a subjective peer-normative measure, using random effects ANOVA modeling and latent class analysis with a diverse longitudinal sample of rural adolescents aged 11 to 17.

Theoretical considerations of pubertal timing across adolescence

Studies assessing the relationship between pubertal timing and behavior have been conducted with adolescents of varying ages. Uncertainty as to whether perceived pubertal timing is stable across adolescence presents a challenge for researchers interested in the impact of pubertal timing across the span of adolescence. If the construct is unstable, any relationships involving pubertal timing could be transitory, with perhaps limited impact on adolescent development. Accordingly, relationships detected at one age could not be expected to persist at other ages. On the other hand, if the construct is stable, assessment of the impact of pubertal timing at any one age could have implications for other ages. How pubertal timing is measured may have implications for the likely stability or instability of the construct.

Stage-normative pubertal timing is measured by comparing an adolescent's pubertal status, using indicators of physical development, to the average pubertal status of the sample, normed by demographic characteristics. Pubertal development for most adolescents is ongoing. Not only is the adolescent changing but their referent peer group is also changing. Therefore, it is plausible that stage-normative pubertal timing is unstable across adolescence because an adolescent's pubertal status is changing and how his/her status compares to peers is changing as well. For example, an adolescent who is classified as early developing at age 11 could be re-classified as on-time at age 15 once her peers are more developed.

Peer-normative pubertal timing is not based on pubertal status but instead is reliant on a social comparison process where an adolescent compares her/his pubertal development to peers. Peer-normative pubertal timing is thus considered to be a more subjective measure of pubertal timing (compared to stage-normative pubertal timing) because it takes into account both biological and social assessment. Contrary to stage-normative pubertal timing, theory suggests that peer-normative pubertal timing should remain stable throughout adolescence.

According to Erikson's theory of psychosocial development, adolescence is a developmental stage focused on the formation of personal identity, of which puberty plays an important role.[106] In order to establish ego identity – knowledge of who you are and how you fit into the broader society – the adolescent interacts and compares himself or herself to significant others, a process known as *psychosocial reciprocity*.[93,107] Pubertal onset and timing are highly salient in early adolescence and are associated with emotions ranging from embarrassment to empowerment.[89-92] Pubertal timing has also been shown to impact relationships with parents, teachers, and peers.[88] According to the theory, these interactions influence the adolescent's identity formation such that the perception of pubertal timing during this formative time is internalized and considered constant, regardless of actual pubertal development. These early experiences of pubertal development thus become a part of adolescent identity, such that peer-normative pubertal timing should remain stable throughout adolescence.

<u>Empirical studies of pubertal timing across adolescence</u>

Most previous studies of the stability of perceived pubertal timing have been based on a stage-normative measure. As indicated above, perceived pubertal timing based on a stage-normative measure could be expected to change over time. In early adolescence, when pubertal development typically is just beginning, an early-developing adolescent is non-normative while on-time and late developers are normative. In contrast, in late adolescence, when pubertal development is typically concluding, early and on-time developers are normative and a late-developing adolescent is non-normative. Stage-normative measures of pubertal timing thus may lack stability and be dependent on adolescent age.

Empirical evidence only partially supports the hypothesis that stage-normative measures of pubertal timing lack stability. This could be because the studies, with one exception, have only used two waves of data to assess stability, and the analyses have not been stratified by age, despite a wide age range in the sample. Combining the sample could mask the differences expected at the younger and older ages of the pubertal development process. For example, one study of adolescent males between the ages of 12 and 16 found that the correlation of stage-normative pubertal timing measured one year apart was .63.[15] Another study of adolescents aged 12 to 16 found the correlation, this time measured two years apart, was .82 for males and .87 for females.[17] In contrast, and more in line with the expectation that stage-normative pubertal timing is unstable, one study of early adolescents (aged 10 to 13) using a stage-normative measure found that about half of the off-time adolescents at baseline were reclassified as on-time one year later (a stability coefficient was not reported).[16] And another study of stage-normative pubertal timing among twins 12 years of age at baseline found a substantial proportion switched from one category of timing (early, on-time, or late) to another at a two-year follow-up; although a stability coefficient was not reported, the proportion was deemed great enough that the authors chose to use seven categories of timing (consistently on-time, consistently early, consistently late, and four groups reflecting change from off-time to on-time and vice versa) as predictors of behavior.[18] While past research has found racial and ethnic differences in pubertal status and pubertal timing (e.g., African-American adolescents develop earlier than White adolescents and perceive their development to be earlier compared with White youth), no studies have looked at racial or ethnic differences in the stability of stage-normative pubertal timing. [13,51,53, 55,97-101]

Erikson's theory of psychosocial development, as described earlier, would suggest that the peer-normative measure of pubertal timing is more stable across adolescence because the perception of pubertal timing in early adolescence is an important part of adolescent identity and is unchanged, regardless of biological changes. However, two studies that used a peer-normative measure of perceived pubertal timing found lower stability than reported for stage-normative measures.[13,14] One study of high school students found the Kappa statistic for peer-normative pubertal timing assessed one year apart to be .61 for females and .48 for males. Only one study to date has examined the stability of peer-normative pubertal timing across more than two waves, and the analyses were limited to comparisons of two waves at a time.[14] This study found that females appeared to be more consistent in reporting their peer-normative pubertal timing over time compared with males, and that the correlation appears to strengthen as the age of the adolescent increases, likely because towards the end of the pubertal development process it is easier for adolescents to determine how they compare to their peers. As with stage-normative pubertal timing, no studies to date have examined racial/ethnic differences in the stability of peer-normative pubertal timing.

<u>Longitudinal considerations for the measurement of pubertal timing</u>

Assessment of the stability of pubertal timing has thus far been based on crude correlation analyses that are based on limited longitudinal samples. Longitudinal data analysis is important because it allows for the assessment of dynamic relationships and provides the ability to understand the heterogeneity among subjects.[65] Both of these benefits are crucial for understanding pubertal timing because pubertal development is an ongoing and individually variable process that unfolds over several years.

An important consideration in conducting the analyses for this study is the underlying assumptions of different longitudinal modeling techniques. At issue is whether pubertal timing is a construct that has a reliable and distinguishable pattern across adolescence. Calculating stability using the intraclass correlation coefficient (ICC) in a random-effects ANOVA model is useful for longitudinal data.[108] The ICC makes no assumption of an underlying pattern of responses over time, but instead calculates the average reliability of the measure of interest from one time point to the next. In contrast, the assumption of another person-centered analytic technique, latent class analysis (LCA), is that there are underlying response patterns in a sample; variation from the underlying patterns is treated as measurement error.[109]

Due to the different assumptions, the two analytic techniques could result in different conclusions concerning measurement stability. For example, using the peer-normative pubertal timing measure, an adolescent may respond early at age 12, on-time at age 12.5, and early at age 13. There would thus be variation from ages 12 to 12.5 and from ages 12.5 to 13, but no variation from age 12 to 13. Many adolescents could have this slight variation in their perceived pubertal timing across adolescence. Using random effects ANOVA models, the within-subject variance would be high compared with the total variance, resulting in a lower ICC, leading to the conclusion that peer-normative pubertal timing is unstable.

In contrast, using latent class analysis, the observed variation in pubertal timing is thought of as measurement error. That is, an adolescent has an underlying perception of pubertal timing and deviation from this perception is not a result of a change in perception but rather a random departure. This hypothesis can be tested in LCA by treating the adolescent as the unit of analysis and examining whether there are distinct classes of perceived pubertal timing that remain stable across adolescence. In the case above, the adolescent would have a high probability of being in an early developing class because two of the three responses were early. If there was a consistent pattern of change in perceived pubertal timing across adolescence (for instance, if a large proportion of adolescents believed they were early developers until they started high school when they switched to believing they were late developers) then the LCA would identify this response pattern as a class. Based on the theory of psychosocial development, LCA would be a more appropriate analytic technique than the ICC for the examination of the stability of pubertal timing throughout adolescence.

Study purpose and hypotheses

The purpose of this study is to examine the stability of perceived pubertal timing in a diverse sample of rural adolescents aged 11 to 17. First, the stability of two pubertal timing measures, stage-normative pubertal timing and peer-normative timing, is compared descriptively using random effects ANOVA modeling. Based on Erikson's theory of psychosocial development, I hypothesize the peer-normative measure of pubertal timing will be more stable than the stage-normative measure because the peer-normative measure is a key component of adolescent identity development. Because previous research has found gender and racial/ethnic differences in pubertal status and pubertal timing I will also examine gender and racial/ethnic differences in the stability of the two measures.[13,51,53,55,97-101, Chapter 2]

Latent class analysis will be conducted to explore the stability of both measures of pubertal timing by determining whether distinct patterns of perceived pubertal timing exist. Based on Erikson's theory of psychosocial development, I hypothesize that peer-normative pubertal timing will be stable and there will be three distinct classes of pubertal timing – early, on-time, and late. I hypothesize that stage-normative pubertal timing will be less stable than peer-normative pubertal timing and there will be five distinct classes – always early, always on-time, always late, early in early adolescence moving to on-time in mid-adolescence, and on-time in early adolescence moving to late in mid-adolescence.

Method

The Context Study

This study was conducted through the secondary analysis of five waves of data from the Context of Adolescent Substance Use study (Context Study), a school-based longitudinal study of three cohorts of adolescents from three North Carolina counties. Wave 1 began in the Spring of 2002 when adolescents were enrolled in the 6^{th} to 8^{th} grades and data collection occurred every semester until the Spring of 2004 (Wave 5). All adolescents in the grades of interest in the sampled schools (eight middle schools, two K-8 schools, six high schools, and three alternative schools) were considered eligible for participation. Adolescents in self-contained special education classes and adolescents who had English as a second language and had insufficient reading skills to complete the questionnaire in English were excluded from the study. Response rates ranged from 88 percent at Wave 1 to 76 percent at Wave 5.

The Context Study was approved by UNC's School of Public Health IRB in the Office of Human Research Ethics. The study received a waiver of written parental consent; written adolescent assent was obtained. Parents received a letter by mail describing the study approximately four weeks before each wave of data collection. This information was also sent home with each eligible adolescent from school. Consent materials were distributed in Spanish as needed. Parents were asked to telephone the research office (toll-free) or to return a signed form (postage-paid) if they did not want their child to participate in the particular wave of the study. Written adolescent assent was obtained on the day of data collection by trained data collectors. Data were collected in a group setting in the schools using self-administered questionnaires designed for optical-mark reader scanning. Each classroom had at least one data collector from the research team and larger classrooms were assigned two data collectors. Data collectors returned to the school on as many as four additional days after primary data collection to attempt to reach absent adolescents.

Adolescents whose parents refused permission for participation were excused from the classroom and sent to a pre-designated location in the school. Remaining adolescents were given two assent forms (one copy for the researchers and one for the adolescent to keep) and the questionnaire in a manila envelope with a label on front with the adolescent’s name and predetermined subject ID number which was peeled off as it was handed to the adolescent. After the questionnaire distribution the data collector followed a scripted protocol to describe the study and to obtain adolescent assent. Adolescents who did not assent were excused from participating. The data collector then read the instructions for completing the questionnaire.

Teachers remained in the classroom to maintain order among the students but, to protect confidentiality, teachers were not allowed to walk around the classroom during the data collection or answer student questions about the study. Adolescents were asked to enclose their completed questionnaire in the same manila envelope and seal the envelope before turning it back in to the data collector. The completion time for the questionnaire was approximately one hour and there was no monetary compensation for participation in the study.

Study Sample

The current study is based on data from adolescents who participated in at least one wave of data collection (N=6,892). Approximately 13 percent of adolescents participated in one wave, 13 percent participated in two waves, 15 percent participated in three waves, 17 percent participated in four waves, and the majority, 42 percent, participated in all five waves of data collection. Participants missing information on age, gender, or race/ethnicity were excluded from analyses (N=295 excluded) and the sample was limited to adolescents aged 11 to 17 (N=172 excluded). Excluded adolescents were less likely to be White ($p<.001$), less likely to be in the other racial/ethnic category ($p<.05$), and more likely to be male ($p<.001$). Excluded adolescents were also less likely to have participated in all five waves of data collection ($p<.001$). The final sample included 6,425 respondents (50 percent male, 53 percent White, 36 percent African-American, 4 percent Latino, and 7 percent indicating another racial/ethnic category). The mean ages at each wave were 13.1 (SD=0.97), 13.5 (SD=0.96), 14.0 (SD=0.95), 14.5 (SD=0.94) and 15.0 (SD=0.92).

Measures

Pubertal timing

Stage-normative pubertal timing was calculated based on a revised version of the Pubertal Development Scale (PDS).[58] The PDS consists of five questions assessing development of body hair growth, skin changes, height, voice and either facial hair growth for males or breast development for females. The range of the items is 1=not yet started to 4=seems complete. Females are also asked if they started menstruating (1=no, 4=yes), and at what age. The items were averaged to obtain a mean PDS score (alphas by wave ranged from 0.68 to 0.73 for females and 0.76 to 0.81 for males). To measure stage-normative pubertal timing, I first calculated the mean pubertal stage among adolescents in the sample by age, and at each age by gender, race/ethnicity, and gender by race/ethnicity. I then compared each adolescent's pubertal status to the mean for the demographic subgroup. Adolescents were classified as "early" (1=more than one standard deviation above the mean pubertal stage), "on-time" (0), or "late" (-1=more than one standard deviation below the mean pubertal stage) based on the norm for their demographic subgroup.

Peer-normative pubertal timing is based on adolescent perceptions of their pubertal development relative to their peers. Adolescents were asked one item about how they believe their physical development compared with others their own age and sex (1=much earlier to 5=much later). Adolescents indicating their development was much or somewhat earlier than their peers were classified as "early" (1), about the same as their peers as "on-time" (0), and somewhat or much later than their peers as "late" (-1) developers.

Demographic variables

Age was calculated using adolescent date of birth and the date of the interview. Age was recoded into twelve half-year categories, ranging from 11 to 16.5. Race/ethnicity was recoded into four categories: White, Black or African-American, Hispanic or Latino, and Other (including American Indian or Native American, Asian or Pacific Islander, multiracial, other, and adolescents who answered don't know).

<u>Analyses</u>

For all analyses, the sample was reconfigured to use age as the unit of time instead of wave of data collection. Because The Context Study was a longitudinal study of cohorts in three different grades at baseline, there is wide variation in age at each wave, which would be ignored in analyses based on data collection wave. It is also appropriate to look at a biological process such as puberty by age rather than wave of data collection or school grade.

To test whether an individual's perceived pubertal timing is stable across the ages of 11 to 16.5, a series of one-way ANOVA random effects models was conducted using SAS 9.1 with each measure of pubertal timing separately. A random-effects ANOVA model is different from a standard one-way ANOVA model such that the grouping variable is treated as a level of nesting, not a fixed effect. In longitudinal studies such as the current research, the grouping variable is the individual. Between-group and within-group differences were determined using the intraclass correlation coefficient (ICC). The range of the ICC is from 0 to 1. An ICC closer to 1 indicates that the adolescent's perception of their pubertal timing (early, on-time, or late) does not change over time. An ICC below .40 indicates poor stability, between .40 and .59 is fair, between .60 and .74 is good, and between .75 and 1.00 indicates the measure shows excellent stability.[74]

Calculating stability using the ICC in a random-effects ANOVA model is preferable to traditional methods of reliability, such as the Pearson correlation coefficient, for longitudinal data.[75] The random effects model allows for more than two scores per individual. Individuals are not assumed to have equally spaced measurement and do not have to have values on the same number of time points. It is therefore possible to include adolescents who have missed one or more of the measurements, which allows for the retention of the full analytic sample, decreasing the chances of selection bias. As with the earlier analyses, the sample was split by gender and race/ethnicity to determine if there were sample differences in the stability of pubertal timing.

Latent class analysis (LCA) was used to determine stability via the underlying patterns of peer-normative and stage-normative perceived pubertal timing. LCA is known as a person-centered approach; the goal is to determine if subgroups or classes of individuals exist based on their patterns of item response.[109] The result is a set of latent classes where the membership within a class is more homogenous than between classes. However, individual membership in a specific class is not definite but is stated in terms of a probability estimate. In other words, LCA tells us how likely it is that each individual belongs to each class.

Latent class analysis can be used with longitudinal data to identify underlying patterns of responses.[109] LCA has been used in previous studies to assess the reliability of multiple measures within a cross-sectional dataset and this technique can be expanded to longitudinal data.[see 110,111 for examples] With LCA it is possible to determine if there are classes, using the response pattern as the unit of analysis, while accounting for potential measurement error. In this type of analysis LCA is similar to factor analysis, except that in LCA the assumption of normally distributed errors does not have to be met. This is important when analyzing categorical data, such as the perceived pubertal timing measures in this study.

The first step in the latent class analysis was to test a single-class latent growth curve model to assess the underlying structure of the overall means. The next step was to determine the number of classes for each measure of perceived pubertal timing. One methodological debate regarding LCA concerns whether the determined number of classes is accurate or is biased by the properties of the measure under analysis.[112] To lessen the likelihood of misspecification, the number of classes was determined using theoretical justification in combination with fit indices.[112,113] The fit indices used in this study included the Bayesian information criteria value (BIC) and the Lo, Mendell, and Rubin likelihood ratio test (LMR-LRT). The model with the lowest BIC and a significant LMR-LRT *p*-value compared with a model with one fewer classes was considered the best fitting model. In addition, the best fitting model should successfully converge, have an entropy value close to 1, have greater than 1% of the population in each class, and have posterior probabilities close to 1.[113] For all models the variances of the slope and intercept were set to zero for all classes. After determining the number of classes, the sample and estimated means of peer-normative and stage-normative perceived pubertal timing at each age for the three classes were examined. If the estimated classes are a perfect fit the sample means and estimated means should not differ. The posterior probabilities, which can be interpreted as the reliability of class assignment, were also examined. The latent class analyses were conducted using MPlus Version 5.1.[80]

Results

Table 3.1 presents the means and variances for the two pubertal timing measures by age. The means of stage-normative pubertal timing were close to zero at all ages, which is to be expected because the stage-normative measure was normed by age, gender, and race/ethnicity. The means of the peer-normative pubertal timing measure were in general more positive than the stage-normative measure, suggesting that adolescents were on average likely to perceive themselves as early developing compared with their peers. In general, with both measures, it appeared that the means increased with increasing age. The variances were higher with the peer-normative measure compared with the stage-normative measure.

Overall, based on the ICCs, the two measures of pubertal timing showed poor to fair stability (ICC=.400 for stage-normative and ICC=.388 for peer-normative, Table 3.2). In general, and contrary to expectations, the stage-normative measure of pubertal timing was more stable among participants compared with the peer-normative measure. However, among White females the peer-normative measure of pubertal timing showed greater stability than the stage-normative measure. Both measures of pubertal timing were more stable among females compared with males and among White participants compared with participants from other racial/ethnic groups.

Latent Class Analysis

Because the sample means tended to increase with increasing age a linear model was tested to assess the underlying structure of peer-normative and stage-normative perceived pubertal timing for the overall sample. The linear model was a good fit for both the peer-normative pubertal timing data (CFI=.98, TLI=.99, RMSEA=.015 (.011-.019)) and the stage-normative pubertal timing data (CFI=.95, TLI=.96, RMSEA=.028 (.025-.031)). The linear model was thus chosen as the underlying structure for the class models.

The three-class solution was the best fit for both measures; three classes were hypothesized for the peer-normative measure and five classes for the stage-normative measure (Table 3.3). In order to interpret the latent classes, the sample and estimated means of peer-normative and stage-normative perceived pubertal timing at each age for the three classes are presented in Figures 3.1 and 3.2. For the stage-normative measure, the means differed the most in the late developing class. For the peer-normative measure, the estimated means were most different from the sample means at the youngest ages in the sample.

Based on an examination of the estimated means, the three classes were interpreted as “always early” (Class 1), “always on-time” (Class 2), and “always late” (Class 3). Table 3.4 presents the percentage of adolescents in each class and the average probability of membership for each class for both the peer-normative and the stage-normative measures of perceived pubertal timing. More adolescents had a probability of being in the early class using the peer-normative measure (28%) compared with the stage-normative measure (13%). However, there was little difference between the two measures in the probability of being in the late class (12% using the peer-normative measure vs. 13% using the stage-normative measure). The posterior probabilities for class membership were relatively high for both measures (above .80), but were higher for the stage-normative measure.

A final exploratory step was to determine if gender or race/ethnicity predicted class membership. There were no gender or racial/ethnic differences in class membership for the stage-normative pubertal timing measure. Using the peer-normative measure, however, Black adolescents were more likely than White adolescents ($p<.001$) and Latino adolescents ($p=.022$) to be classified as early developing. Female adolescents were more likely than male adolescents to be classified as late developing ($p<.001$).

Discussion

This study demonstrates the complexity of pubertal development in adolescence. I compared the stability of two self-reported measures of pubertal timing using two different longitudinal analytic strategies. Based on the ICC results it can be concluded that pubertal timing, both measured as stage-normative and peer-normative, is unstable. This extreme instability was contrary to hypotheses. In contrast, the latent class analysis revealed that both measures show stability across adolescence. For both the stage-normative and peer-normative measures of pubertal timing a three-class solution fit the data best – always early, always on-time, and always late. This finding of stability in the latent class analysis was contrary to hypotheses for the stage-normative measure but confirmed the hypotheses for the peer-normative measure. The latent class analysis results also revealed differences between the two pubertal timing measures in the proportion of adolescents assigned to the three classes and in the predictors of class membership, which indicates the two measures are distinct measures of the pubertal development process.

Both the stage-normative and peer-normative measures of perceived pubertal timing showed poor to fair stability over time in the ANOVA random effects models. This means that perceived pubertal timing, either stage-normative or peer-normative, is likely different depending on the age of assessment. Both measures of pubertal timing appeared to be slightly more stable among females compared with males and also slightly more stable among White adolescents compared with non-White adolescents. It is important to note that these demographic differences are purely descriptive and cannot be statistically tested. Contrary to my theoretical hypothesis, the stage-normative measure of pubertal timing showed slightly higher stability for most groups compared with the peer-normative measure, but this does support the empirical evidence that suggested stage-normative pubertal timing is more stable than peer-normative pubertal timing. However, both measures showed poor to fair stability overall so the differences in stability in the two measures may not have practical implications.

Despite the poor stability of the two perceived pubertal timing measures in the multilevel analyses, the latent class analyses (LCA) showed three distinct response patterns – always early, always on-time, and always late. The key reason for these differing results from the ANOVA random effects models is that LCA takes into account measurement error. The measurement error in this study can be thought of as an adolescent's deviation from their "true", or most commonly answered, pubertal timing response. The LCA results demonstrate the importance of utilizing more sophisticated analyses to understand measurement stability. The results from this study show that, in general, adolescents may have variation in their perceived pubertal timing (both stage-normative and peer-normative), which results in low ICCs. But when we are able to see the full pattern of responses across adolescence using LCA we can see that perceived pubertal timing actually remains consistent.

In some ways, the LCA models support the multilevel stability analyses, in that the stage-normative measure appeared to be more stable than the peer-normative measure. The sample and estimated means were more closely aligned with the stage-normative measure compared with the peer-normative measure. And the posterior probabilities, which can be thought of as test of reliability of classification, were higher with the stage-normative measure compared with the peer-normative measure. While the findings from this study confirmed my hypothesis that the peer-normative measure of pubertal timing would be stable based on the theory of psychosocial development, I had hypothesized that stage-normative pubertal timing would be less stable than peer-normative pubertal timing. It is possible that the truncated age range of the sample resulted in the appearance of more stability in the stage-normative measure. However, as with the multilevel analyses, the posterior probability differences in the LCA were not that profound between the stage-normative and peer-normative measures. This shows that while there may be more variation in adolescent responses in the peer-normative measure compared with the stage-normative measure, both can be good assessments of adolescent pubertal timing when measurement error is taken into account with LCA.

An important finding of the latent class analysis was the difference in proportions in latent class membership and difference in predictors of class membership between the two measures of pubertal timing. The peer-normative pubertal timing measure explicitly invoked a social comparison process. In contrast, the stage-normative pubertal timing measure invoked assessment of the completeness of pubertal development; whether adolescents made social comparison in this assessment is unknown but may also be present. The proportions of adolescents who were classified as late developing were similar across the two measures but adolescents were twice as likely to classify themselves as early developing using the peer-normative measure compared with the more objective classification of the stage-normative measure. This could be due to a social desirability for earlier development, especially for male and Black adolescents.[13,97,98,101-103] While there were no demographic differences in the likelihood of class membership in the stage-normative measure, I found that females were more likely than males to consider themselves late developing and Black adolescents were more likely to be in the early developing group compared with White and Latino adolescents using the peer-normative measure. These differences demonstrate that while the stability of the two measures may be similar, the two measures are assessing different aspects of pubertal development.

The results from this study suggest the importance of using latent class analysis to discern the stability patterns of pubertal timing across adolescence, not just because of the longitudinal aspect but also because the technique takes into account measurement error. Furthermore, these results imply that longitudinal patterns of pubertal timing should be used as predictors of behavior, not pubertal timing assessed at a single point in time. Based on the ICC analyses it is clear that assessment of pubertal timing at one age is not necessarily the same as at a different age. Only by incorporating the longitudinal patterns of responses and measurement error is it possible to see the actual pubertal timing classes for adolescents.

There are limitations to the current research. The youngest adolescents in the study sample were 11 years of age, but the first stages of pubertal development typically begin by age 9 or 10.[54] In addition, the oldest adolescents in the study sample were up to 17 years old, which is, on average, prior to the completion of pubertal development. Therefore, this study is an examination of the stability of perceived pubertal timing during the midst of pubertal development. Future studies should be conducted to include mid-childhood and early-adulthood ages to determine if the stability of pubertal timing differs when including the full pubertal development process. It is possible that I did not find the two additional latent classes proposed for the stage-normative measure (transitioning from early to on-time and from on-time to late) because this sample is lacking information from late childhood and late adolescence. It is possible that there were demographic differences in the predictors of latent class probability between the stage-normative and peer-normative measures of pubertal timing because the peer-normative measure only asked adolescents to compare their development to peers of the same age and gender and did not mention race or ethnicity while the stage-normative measure was developed within age, gender, and racial/ethnic group. It would be worthwhile to compare the peer-normative measure used in this study with a new measure that asks specifically about age, gender, and race/ethnicity.

The most controversial aspect of LCA is the determination of the number of classes. Misspecification of the number of classes could dramatically alter the study conclusions. However, in this study, we followed recommendations of using a combination of theoretical justification and statistical tests in order to determine the number of classes.[112,113] The use of the BIC and the LMR-LRT fit statistics has been supported in simulation studies.[113,114] One statistic that was not used in this study that has been shown to accurately assess the number of classes is the bootstrap likelihood ratio test (BLRT).[114] Due to computational burden, the BLRT could not be calculated for the 4-class or higher models (for the 2-class and 3-class models the p-value was less than 0.001, suggesting there were at least 3 classes). Nylund and her colleagues found that the BIC was accurate 100 percent of the time when the sample size was 1,000, much lower than this study's sample size of over 6,000.[114] In addition, they noted that the misclassification in the LMR-LRT was likely to be in favor of fewer classes than the true model, rather than more. The 3-class model also makes theoretical sense when looking at the estimated means. For example, the majority of adolescents had the greatest likelihood of being in the on-time class.

Conclusion

The two sets of analyses in this study considered together yield important conclusions regarding the measurement of pubertal timing. Based on the ICCs, it was evident that both stage-normative and peer-normative measures of perceived pubertal timing have variation across adolescence. However, based on the latent class analysis, I found that three underlying and stable classes of pubertal timing for both measures were present once measurement error is taken into account. These results suggest the need to take into account the longitudinal pattern of pubertal timing in adolescence rather than measuring pubertal timing at one point in time. The results also demonstrate the importance of matching theoretical considerations and analytic technique; the latent class analysis confirmed hypotheses regarding the stability of peer-normative pubertal timing based on the theory of psychosocial development.

Table 3.1. Means and variances of stage-normative and peer-normative pubertal timing, by age

Age	Stage-normative pubertal timing (n=6,392)		Peer-normative pubertal timing (n=6,292)	
	Mean	**Variance**	**Mean**	**Variance**
11	-.023	.302	-.034	.479
11.5	.009	.373	.069	.456
12	.006	.339	.101	.460
12.5	-.034	.336	.106	.475
13	-.024	.307	.131	.459
13.5	-.012	.277	.134	.471
14	-.034	.268	.146	.451
14.5	.030	.277	.161	.463
15	.015	.274	.182	.461
15.5	.038	.295	.188	.439
16	.033	.327	.159	.435
16.5	.001	.269	.157	.439

Range is -1 to 1 (-1=late, 0=on-time, 1=early)

Table 3.2. Intraclass correlations (ICC) for stage-normative and peer-normative pubertal timing, by sex and race/ethnicity

	N	Stage-normative pubertal timing	Peer-normative pubertal timing
Full sample	6425	.400	.388
White	3393	.424	.443
Black	2335	.374	.323
Latino	254	.302	.213
Other	443	.386	.328
Female	3212	.425	.441
White	1672	.437	.493
Black	1185	.423	.383
Latino	117	.339	.194
Other	238	.388	.238
Male	3213	.374	.327
White	1721	.411	.391
Black	1150	.316	.243
Latino	137	.275	.228
Other	205	.387	.182

Note: ICC<.40 indicates poor stability, .40-.59 is fair, .60-.74 is good, and .75-1.00 is excellent

Table 3.3. Fit indices for Latent Curve Analysis (LCA) models with 1-5 classes, by measure of perceived pubertal timing

	LL	**BIC**	**LMR-LRT**	**Entropy**
Stage-normative pubertal timing				
1	-17892.2	35907.1	--	--
2	-16523.6	33196.2	<.0001	.779
3	**-15488.7**	**31152.7**	**<.0001**	**.808**
4	-15417.8	31037.1	.4646	.779
5	Did not converge			
Peer-normative pubertal timing				
1	-21444.8	43012.1	--	--
2	-20055.8	40260.3	<.0001	.588
3	**-19437.5**	**39049.9**	**<.0001**	**.687**
4	-19426.2	39053.7	.3487	.669
5	-19419.4	39066.3	1.0000	.693

LL=log likelihood, BIC=Bayesian information criteria value, LMR-LRT=Lo, Mendell, and Rubin likelihood ratio test
Bolded row indicates best fitting model

Table 3.4. Membership in latent classes and posterior probabilities

	Stage-normative pubertal timing		**Peer-normative pubertal timing**	
	%	**Posterior probability**	**%**	**Posterior probability**
Early	13%	.86	28%	.85
On-time	74%	.94	60%	.86
Late	13%	.86	12%	.82

Figure 3.1. Sample and estimated means of stage-normative pubertal timing by class (n=6,392)

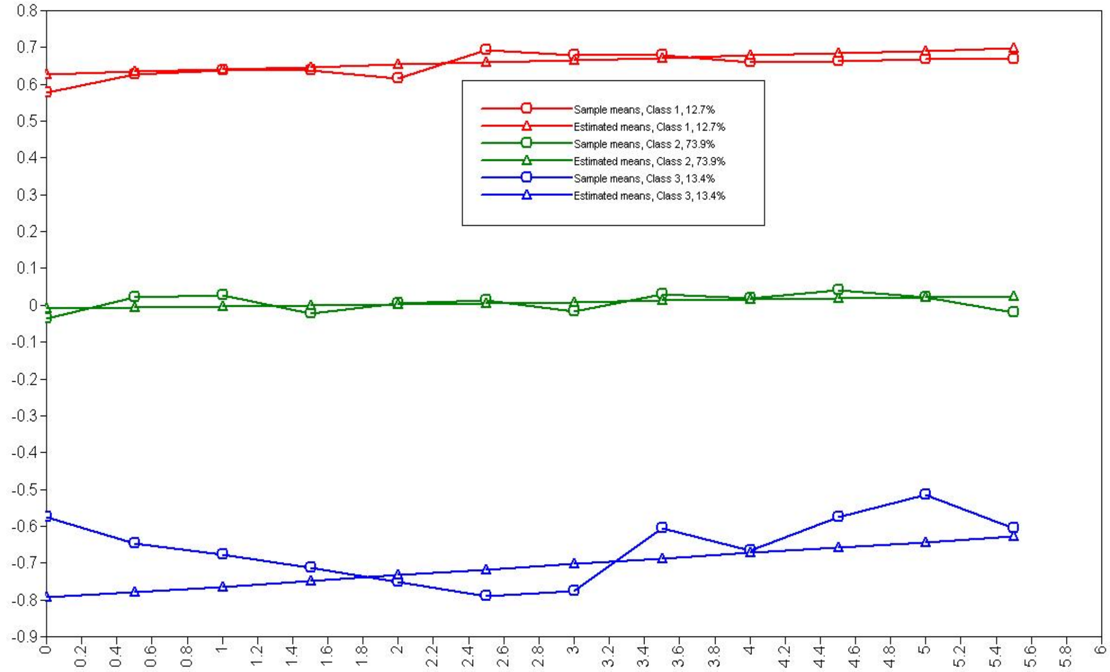
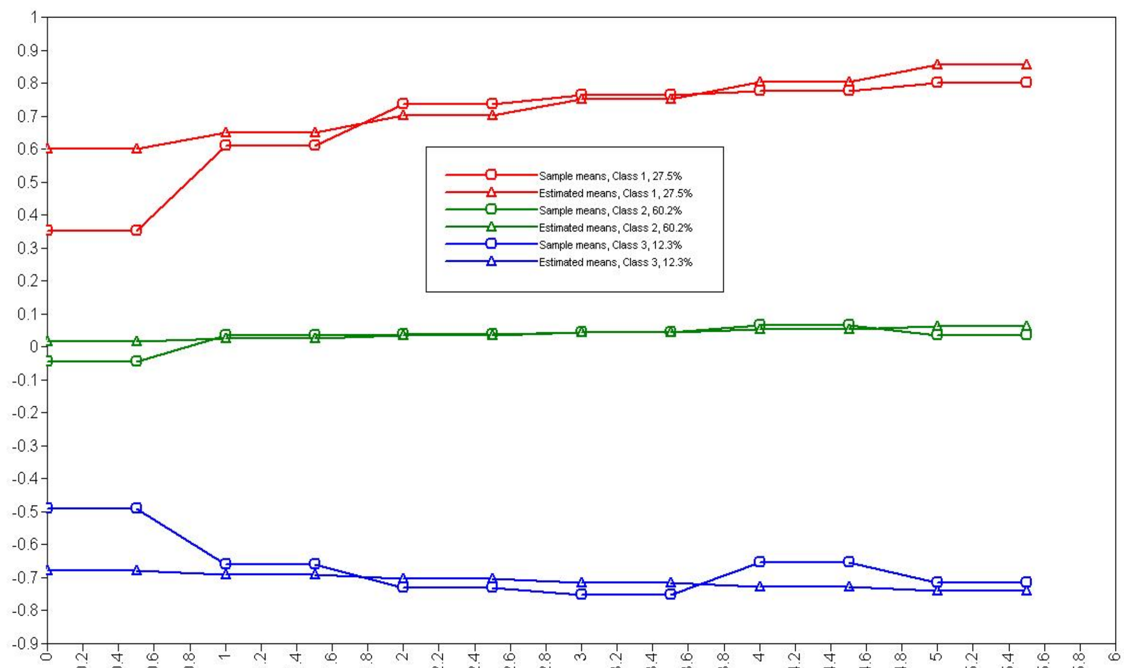


Figure 3.2. Sample and estimated means of peer-normative pubertal timing by class (n=6,292)



CHAPTER 4: PERCEIVED PUBERTAL TIMING AND SUBSTANCE USE AMONG ADOLESCENTS: A LONGITUDINAL PERSPECTIVE

Introduction

Substance use among adolescents has declined slightly over the past decade but remains pervasive, such that by the 12th grade almost 75 percent of adolescents have had a drink of alcohol, close to 50 percent have smoked a cigarette, and over 40 percent have tried marijuana.[30] Decades of research assessing whether pubertal timing – where an adolescent is in the pubertal development process compared with peers – influences substance use has yielded inconsistent findings. While there is widespread empirical support for the “early maturation” hypothesis that early maturing adolescents are at risk for elevated substance use, there is also evidence to support the “maturational deviance” hypothesis that adolescents whose pubertal maturation is either early or late are at risk.[24,27] The purpose of this study is to examine these two hypotheses by comparing the longitudinal influence of two measures of self-reported pubertal timing on recent cigarette, alcohol, and marijuana use among a sample of adolescents aged 11 to 17.

Pubertal development in adolescence

Puberty is the process of developing from a child into a sexually mature adult.[50] Important physical changes occur during this process, from skeletal and nervous system growth to the development of the endocrine system, but the changes occurring to the reproductive organs and secondary sexual characteristics gain the most attention. Pubertal development during adolescence has been found to be highly salient, resulting in powerful emotions on the part of the adolescent as well as changing relationships with peers, parents, and teachers.[88-92] There is wide variation in the onset and tempo of puberty by gender and race/ethnicity, as well as individual differences within groups.[13,51,53,55,97-101;Chapter 2]

This variation has drawn researchers to explore the impact of pubertal timing, defined as the comparative pubertal development of an adolescent in relation to peers, on adolescent risk behavior. There are two common ways of establishing self-report pubertal timing. The first, what I am referring to as stage-normative pubertal timing, is based on an adolescent's pubertal status, which is a measure of how developed an adolescent is in relation to the pubertal development process. To create a stage-normative pubertal timing measure, the adolescent's pubertal status is normed within study-defined demographic subgroups (typically, age, sex, and race/ethnicity). Adolescents are classified as early, on-time, or late based on the average pubertal status of their demographic subgroup. Stage-normative pubertal timing is therefore based on the adolescent's assessment of their physical development, typically using several indicators. In contrast, the second measure, what I'm calling peer-normative pubertal timing, is not based on pubertal status but instead on the adolescent's perception of timing relative to peers; adolescents are asked how they perceive their timing to be compared with their peers, typically using a Likert scaled measure. Thus, the peer-normative measure explicitly invokes a social comparison.

Both the stage-normative and peer-normative measures of pubertal timing are based on self-report and are therefore subject to bias compared to pubertal timing assessed by clinical means, such as hormone concentrations. But self-report of pubertal status, the basis of stage-normative pubertal timing, has been shown to be a valid assessment of pubertal status[1, 11] In contrast, peer-normative pubertal timing is considered to be a more subjective measure of self-report pubertal timing than stage-normative measures because it is not based on actual pubertal development differences but instead is based on the adolescent's interpretation of her or his pubertal status and how that compares with peers. The importance of peer comparison is supported by person-in-context theory, which postulates that an adolescent's identity is formed based on an understanding of the contexts in which she or he is embedded.[86] For an adolescent to determine her or his peer-normative pubertal timing, the adolescent must first analyze her or his personal pubertal development (presumably in a process similar to that of answering the pubertal status questions) and then engage in social comparison to determine how her or his pubertal status compares with peers. It is likely that such social comparison introduces a psychosocial component to the peer-normative pubertal timing measure that is missing from the stage-normative pubertal timing measure. This hypothetical difference between stage-normative and peer-normative pubertal timing has been supported in previous analyses with the same sample of adolescents used in this study.[Chapter 2] The two measures may be differentially related to substance use, as described below.

Pubertal timing and substance use

There are two competing hypotheses regarding the relationship between pubertal timing and adolescent substance use – the maturational deviance hypothesis and the early maturation hypothesis.[24, 27] According to the maturational deviance hypothesis, adolescents whose pubertal development is non-normative (either early or late compared with their peers) are more likely to engage in substance use, due to an increase in psychological distress. In contrast, the early maturation hypothesis states that early maturing adolescents are the only group at risk for substance use because others may view them as more mature and thus they are more likely to associate with older peers who provide exposure to substance use and other deviant behaviors.

Most of the research conducted on pubertal timing and substance use has supported the early maturation hypothesis, regardless of the measure of pubertal timing used. In particular, female adolescents who develop earlier than their peers appear to be at the highest risk for substance use.[3-5, 7,8,10, 13, 16-18, 23,24,26,116,117-121] However, a number of these studies have grouped together on-time and later developing females which prevents a test of the maturational deviance hypothesis. Two studies that used stage-normative measures and separated these two groups of females found that late developing females were also more likely to be substance users compared with those who were developing on-time, thus supporting the maturational deviance hypothesis.[4,115]

The maturational deviance hypothesis postulates off-time adolescents, both early and late, are at higher risk for substance use due to the psychological stress associated with being different from others. This theoretically suggests late developing adolescents would be at higher risk for substance use using the peer-normative pubertal timing measure, which takes into account the psychosocial process of pubertal development, compared with the stage-normative pubertal timing measure. However, the few studies that have used a peer-normative measure so far have supported the early maturation hypothesis.[3,5,8,13,116] This could be because most of the studies have been cross-sectional,[3,8,13,116] and the one longitudinal study using a peer-normative measure compared early developing females to all other females, which prevents a test of the maturational deviance hypothesis.[5]

Few studies on the links between pubertal timing and substance use have included males in their sample and the results have been mixed. As with female adolescents, most of the research with males supports the early maturation hypothesis.[3, 4, 8, 9, 16-18, 23, 24,116,118] But there is also limited support for the maturational deviance hypothesis, such that males who develop later than their peers have been found to be more likely to drink or smoke.[25] The few studies that have looked at whether adolescent sex moderates the relationship between pubertal timing and substance use have also been mixed, with some suggesting the relationship may either be nonexistent or weaker for males,[119,120] and others finding the relationship to be stronger for males.[17,121]

Most of the studies on the relationship between pubertal timing and substance use have focused on either alcohol or tobacco use. Few studies have examined the differential association between pubertal timing and various substances, and almost no studies have included illicit drugs, such as marijuana use, as the outcome of interest. While some studies have found no difference in the relationship between pubertal timing and various substance use outcomes,[18,23] there is some evidence to suggest differential relationships.[3,16,115] For example, one study of Norwegian youth that utilized a peer-normative measure found early developing males and females were more likely to be drinking, but among middle school boys both early and late developing males were more likely than on-time males to be smoking.[3] Another study of German youth found that early timing, assessed with a stage-normative measure, predicted both past year alcohol and cigarette use at one-year follow-up but the relationship was stronger for cigarette use.[16] Finally, Marklein and colleagues found that later pubertal timing, assessed with a stage-normative measure, was associated with more alcohol use but there was no association between pubertal timing (either early or late) and cigarette or marijuana use.[115]

While the two measures of pubertal timing, stage-normative and peer-normative, are often used interchangeably in the literature, this may be inappropriate because the two measures have been found to have very little concordance, likely because the subjective peer-normative measure includes both an objective assessment of pubertal development based on biological referents and the adolescent's psychological experience of pubertal development due a reliance on social comparison.[Chapter 2] While most studies on the relationship between pubertal timing and substance use have used a stage-normative measure of pubertal timing, such as age of first menarche or the Pubertal Development Scale (PDS), it has been suggested that peer-normative pubertal timing may be a better determinant of risk behavior than stage-normative pubertal timing because of the inclusion of the social experience. However there has been very little research comparing the impact of the two measures on adolescent risk behavior. One study of Norwegian youth that did a comparison of the association of the two measures to number of alcohol intoxications in the past year was contrary to theoretical expectations; controlling for age and gender the stage-normative measure was more highly associated with past year intoxications than the peer-normative measures .[17]

<u>Longitudinal considerations</u>

Puberty is not a distinct one-time event but rather a process that is ongoing throughout adolescence. Hence, in examining the relationship between pubertal development and substance use, longitudinal considerations are critical. Very little research has been done to determine if perceived pubertal timing is stable throughout adolescence. Most studies that have looked at the stability of pubertal timing have found pubertal timing to be relatively unstable, but that research has been based on limited longitudinal samples and crude correlation analyses.[13-18] In a previous study, I confirmed the instability of both stage-normative and peer-normative pubertal timing, but found that much of this instability could be considered measurement error. Using latent class analysis, which considers patterns of responses over time and takes into account measurement error, I found that three classes of pubertal development best described adolescents in this sample regardless of the measure of pubertal timing: as always early developing, always on-time, and always late developing.[Chapter 3] I use these classes in the current analyses.

While a number of studies have shown an association between perceived pubertal timing and substance use, many have been cross-sectional[3,8, 9,10,13,23,115,116] or based on only two time points,[4,5, 7, 16-18, 24,117,120] However, both pubertal development and substance use are processes that develop over time and thus previous studies limit the ability to understand the longitudinal relationship between pubertal timing and substance use. For example, one cross-sectional study assessing the relationship with middle and high school students found the impact of stage-normative pubertal timing to be stronger in midadolescence compared with early adolescence, with early developers at highest risk.[17] Two studies using latent transition modeling confirmed the cross-sectional research by finding females who developed earlier begin substance use earlier and transition into more advanced patterns of substance use faster than other females[5, 7] but other longitudinal studies that have found the effect of early maturation on substance use decreases over time, suggesting that on-time and late developing adolescents "catch up" with their early developing peers.[117,121] And another study with London students aged 11 to 16 found that the catch-up effect varied by adolescent gender, such that the association between current smoking and early development decreased significantly for boys but not girls.[119] All of these studies used a stage-normative measure for pubertal timing, but they point to the importance of using longitudinal methods to understand the relationship between pubertal timing and substance use. As currently conceptualized, the early maturation and maturational deviance hypotheses do not incorporate the consideration of a catch-up effect. Rather, once an adolescent is at risk for substance use, she or he is presumed to remain at risk. If a catch-up effect is present it suggests a need to revise these hypotheses to better reflect the longitudinal relationship between pubertal timing and substance use.

Purpose and hypotheses

The purpose of this study is to examine the longitudinal relationship between pubertal timing and recent substance use across adolescence. Specifically, I will test the early maturation and maturational deviance hypotheses by comparing the impact of two measures of pubertal timing, stage-normative and peer-normative pubertal timing, on the development of recent cigarette, alcohol, and marijuana use from ages 11 to 17 using latent class growth analysis. Adolescents will be classified based on their probability of membership in three latent classes: always early, always on-time, and always late. Because there is some suggestion that the relationship between pubertal timing and substance use varies by adolescent sex, I will also test whether there are any differences by adolescent sex.

I hypothesize the stage-normative pubertal timing measure will support the early maturation hypothesis, such that adolescents in the always early class will be at greatest risk for substance use at age 11 compared with adolescents in the always on-time or always late classes. Furthermore, I hypothesize adolescents in the always on-time and always late classes will have similar rates of substance use development across adolescence. The early maturation hypothesis postulates that early developing adolescents are at greater risk for substance use compared with other adolescents because the appearance of more advanced development among these adolescents will cause them to be more likely to associate with older peers who are more likely to engage in substance use.

I hypothesize the peer-normative pubertal timing measure will support the maturational deviance hypothesis because the peer-normative measure incorporates social comparison, which could lead to psychological distress if the adolescent perceives timing misfit. I hypothesize that adolescents in both the always early and always late classes will be at greater risk for substance use at age 11 compared with adolescents in the always on-time class, but that late developing adolescents will have lower use at age 11 compared with early developing adolescents.

I do not propose hypotheses regarding differential effects of pubertal timing on the three substances examined (cigarettes, alcohol, and marijuana) because of insufficient evidence on which to base the hypotheses.

I propose two additional hypotheses based on the empirical literature, not suggested by either pubertal timing hypothesis. I hypothesize that adolescents in the always on-time and always late classes will have a greater increase in substance use (higher slope) compared with adolescents in the always early class using both measures of pubertal timing. I also hypothesize adolescent sex will moderate the relationship between either measure of pubertal timing and recent substance use, such that the differences between females in the always early class and other female adolescents will be stronger than the differences between males in the always early class and other male adolescents.

Method

The Context Study

This study was conducted through the secondary analysis of five waves of data from the Context of Adolescent Substance Use study (Context Study), a school-based longitudinal study of three cohorts of adolescents from three North Carolina counties. Wave 1 began in the Spring of 2002 when adolescents were enrolled in the 6th to 8th grades and data collection occurred every semester until the Spring of 2004 (Wave 5). All adolescents in the grades of interest in the sampled schools (eight middle schools, two K-8 schools, six high schools, and three alternative schools) were considered eligible for participation. Adolescents in self-contained special education classes and adolescents who had English as a second language and had insufficient reading skills to complete the questionnaire in English were excluded from the study. Response rates, based on eligible subjects at each wave, ranged from 88 percent at Wave 1 to 76 percent at Wave 5.

The Context Study was approved by UNC's School of Public Health IRB in the Office of Human Research Ethics. The study received a waiver of written parental consent; written adolescent assent was obtained. Data were collected in a group setting in the schools using self-administered questionnaires designed for optical-mark reader scanning. Each classroom had at least one data collector from the research team and larger classrooms were assigned two data collectors. Data collectors returned to the school on as many as four additional days after primary data collection to attempt to reach absent adolescents. Adolescents whose parents refused permission for participation or who did not give assent were excused from the classroom and sent to a pre-designated location in the school. The data collector was responsible for following a scripted protocol to describe the study and obtain adolescent assent, as well as to read the instructions for completing the questionnaire.

Teachers remained in the classroom to maintain order among the students but, to protect confidentiality, teachers were requested not to walk around the classroom during the data collection or answer student questions about the study. The completion time for the questionnaire was approximately one hour and there was no monetary compensation for participation in the study.

Study Sample

The current study is based on data from adolescents who participated in at least one wave of data collection (N=6,892). Approximately 13 percent of adolescents participated in one wave, 13 percent participated in two waves, 15 percent participated in three waves, 17 percent participated in four waves, and the majority, 42 percent, participated in all five waves of data collection. The sample was limited to adolescents aged 11 to 17 (N=178 excluded) and participants missing information on demographic variables were excluded from analyses (N=878 excluded). Excluded adolescents were less likely to be White ($p<.001$), more likely to be African-American ($p<.01$), more likely to be Latino ($p<.001$), and more likely to be male ($p<.001$). Excluded adolescents were also less likely to have participated in all five waves of data collection ($p<.001$). The final sample included 5,836 respondents (50 percent male, 53 percent White, 36 percent African-American, 4 percent Latino, and 7 percent indicating another racial/ethnic category, 62 percent had a parent with at least some college education, and 67 percent lived in a two parent household). The mean ages at each wave were 13.1 (SD=0.96), 13.5 (SD=0.96), 14.0 (SD=0.93), 14.5 (SD=0.94) and 15.0 (SD=0.92).

Measures

Substance use

The three substance use outcomes of interest are recent cigarette use, recent alcohol use, and recent marijuana use. Adolescents who responded affirmatively to a question about lifetime cigarette use were asked on how many days in the past three months they had smoked a cigarette (six response options, from 0 days to 20 days or more). Similar questions about alcohol use were asked. If an adolescent said they had drank at least one or two sips of alcohol in their lifetime, they were asked on how many days they had one or more drinks of alcohol in the past three months (six response options, from 0 days to 20 days or more). Adolescents were asked how often they had used marijuana in the past three months (five response options, from none to 10 times or more). All of the substance use measures had low response frequency variance, so three dichotomous measures were created with 0=no recent use and 1=any recent use.

Pubertal timing

Stage-normative pubertal timing was calculated using a revised version of the Pubertal Development Scale (PDS).[58] The PDS consists of five questions assessing development of body hair growth, skin changes, height, voice and either facial hair growth for males or breast development for females. The range of the items is 1=not yet started to 4=seems complete. Females are also asked if they started menstruating (1=no, 4=yes), and at what age. The items were averaged to obtain a mean PDS score (alphas by wave ranged from 0.68 to 0.73 for females and 0.76 to 0.81 for males). To measure stage-normative pubertal timing, I first calculated the mean pubertal stage among adolescents in the sample by age, and at each age by gender, race/ethnicity, and gender by race/ethnicity. I then compared each adolescent's pubertal status to the mean for the demographic subgroup. Adolescents were classified as "early" (1=more than one standard deviation above the mean pubertal stage), "on-time" (0), or "late" (-1=more than one standard deviation below the mean pubertal stage) based on the norm for their demographic subgroup.

Peer-normative pubertal timing is based on adolescent perceptions of their pubertal development relative to their peers. Adolescents were asked one item about how they believe their physical development compared with others their own age and sex (1=much earlier to 5=much later). Adolescents indicating their development was much or somewhat earlier than their peers were classified as "early" (1), about the same as their peers as "on-time" (0), and somewhat or much later than their peers as "late" (-1) developers.

As noted earlier, previous research with this sample using latent class analysis (LCA) demonstrated underlying patterns of peer-normative and stage-normative perceived pubertal timing.[Chapter 3] LCA is known as a person-centered approach; the goal is to determine if subgroups or classes of individuals exist based on their patterns of item response.[122] The result is a set of latent classes where the membership within a class is more homogenous than between classes. However, individual membership in a specific class is not definite but is stated in terms of a probability estimate. In other words, LCA tells us how likely it is that each individual belongs to each class.

The LCA was based on an underlying linear structure for changes over time in both the stage-normative and peer-normative pubertal timing measures. It was found that a three-class solution was the best fit for both measures. Based on an examination of the estimated means, the three classes can be interpreted as "on-time (Class 1)", "always early" (Class 2), and "always late" (Class 3). The posterior probabilities for class membership were relatively high for both measures (above .80), but were higher for the stage-normative measure. More adolescents had a probability of being in the early class using the peer-normative measure (28 percent) compared with the stage-normative measure (13 percent) but there was little difference in the probability of being in the late class (12 percent using the peer-normative measure compared with 13 percent using the stage-normative measure). These pubertal timing latent classes are used in the current analyses.

Demographic variables

Age was calculated using the difference between the adolescent date of birth and the date of the interview. Age was recoded into twelve half-year categories, ranging from 11 to 16.5. Adolescent race/ethnicity, household status, and parent education were entered into the models as predictors of the latent classes. Race/ethnicity was recoded into four categories: White, Black or African-American, Hispanic or Latino, and Other (including American Indian or Native American, Asian or Pacific Islander, multiracial, other, and adolescents who answered don't know). Adolescents were asked who they lived with most of the time: mother and father, mother and stepfather, stepmother and father, mother only, father only, stepmother only, stepfather only, or other. This was dichotomized to living in a two-parent household versus other arrangement. Parent education was used as a proxy for family socioeconomic status and calculated using the highest education attained by either parent and coded as a categorical variable with three levels: high school graduate or less, some college, and graduated from community college/technical school or more. Household status and parent education were taken from the earliest wave available.

Analytic Strategy

The primary analytic approach was latent class growth analysis, using an accelerated longitudinal design, which maximizes the advantages of the cohort sequential design of the Context Study.[76-78] An accelerated longitudinal design, also known as a cohort-design or cross-sequential design, is one where multiple cohorts are followed over time.[79] Because there are different cohorts in an accelerated longitudinal design, such as the grade cohorts in the Context Study, it is possible to look at changes over time using alternative measures of chronological time (other than survey wave). Rather than analyzing five waves of cohort data with varying ages at each wave, the analyses examine the development of substance use from ages 11 through 16.5. Although there are inherently missing observations in this design because adolescents do not provide data at each age, the assumption is that the data are missing completely at random.

An important assumption in the accelerated longitudinal design is that there are no differences in any of the variables of interest between cohorts at corresponding ages. In other words, a 13 year old in cohort 2 is the same as a 13 year old in cohort 1, though they turned 13 during different calendar years. This assumption was tested by determining if cohort membership predicted latent class membership probability or the fixed effects of the substance use growth models. There were no cohort differences except for stage-normative pubertal timing. Adolescents in the youngest cohort were more likely to be classified as late developers than as on-time compared with adolescents in the middle cohort (B=.376, p=.001). As such, all of the analytic models include cohort one membership as a control variable.

Latent class growth analysis is a special case of growth mixture modeling, which is an extension of longitudinal growth modeling.[123,124] In variable-centered approaches, such as traditional regression analysis, a mean intercept and slope is calculated for the full sample. Person-centered approaches such as longitudinal growth modeling differ from variable-centered approaches such that each individual has their own intercept and slope based on their own repeated measures.[78] The mean intercept and slope for the sample, known as the fixed effects, are determined by pooling all of the individuals' growth model parameters (intercepts and slopes). Of interest is how each individual's intercept and slope vary from the mean, known as the random effects.

The differences between the person-centered analytic techniques are based in model assumptions. One important assumption in longitudinal growth modeling is group homogeneity, such that the estimated mean curve is assumed to be a good fit for the full sample. In other words, though there is individual variation around the estimated mean curve, all individuals are assumed to be drawn from the same population. The main hypothesis of this study is contrary to this assumption; I believe the development of substance use differs by pubertal timing class, and thus reflects different populations. Growth mixture modeling does not make this assumption and instead allows one to test whether growth model parameters vary by unobserved subpopulations.[123,124] The unobserved subpopulations in this study are the individuals in each pubertal timing latent class. Separate longitudinal growth models are estimated for each pubertal timing latent class and it is possible to test whether these models statistically differ. In growth mixture modeling, individuals within each subpopulation are considered to be heterogenous (that there is individual variation within a sub-population). In contrast, the analytic technique used in this study, latent class growth analysis, makes the assumption that the heterogeneity in substance use development is accounted for by latent class membership and thus the within-class variances (random effects) are fixed to zero. Thus individuals within each pubertal timing latent class are assumed to have the same substance use development.

All analyses were conducted using MPlus 5.1, a comprehensive modeling program that is able to handle observed and latent variables as well as longitudinal data.[80] MPlus also provides options for modeling dichotomous outcomes. The models were estimated using the maximum likelihood (ML) estimator with robust standard errors. Simulation studies have found that this estimator produces consistent and unbiased estimates, trustworthy chi-square estimates, and relatively unbiased standard error estimates if the data are missing at random or missing completely at random.[66, 67] By using this estimator all adolescents with at least one wave of data were able to be retained in the analytic sample. MPlus is also able to handle multilevel data. I controlled for the nesting of individuals in schools by using the cluster modeling option. The school level variable was calculated as the first school available (range 1-19).

The first analytic step was to determine the functional form of the unconditional longitudinal growth models for each substance of interest (cigarettes, alcohol, and marijuana). Because substance use was measured dichotomously, the outcome is interpreted as the proportion of adolescents reporting current use of the substance of interest. The unconditional longitudinal growth model is the mean development in the proportion of users of alcohol, tobacco, and marijuana use across adolescence. The first model tested was an intercept-only model, with only one fixed component, the intercept (baseline proportion of users). This model assumes that there is no growth in the proportion of substance users over time. The second model, the linear model, has two fixed components – the mean intercept and mean slope (the change in the rate of proportion of substance users over time). The random components include the variance around the mean intercept and mean slope, the covariance between the intercept and slope, and the time specific residual variance. The final model tested, the quadratic model, has three fixed components (mean intercept, mean slope, and mean quadratic term) and three additional random components (variance around the mean quadratic term, the covariance between the intercept and the quadratic, and the covariance between the slope and the quadratic).

One of the benefits of using MPlus is the ability to model dichotomous outcomes. However, because the outcomes of interest are dichotomous, there are some important differences to note between the results of this study and other studies using continuous outcomes. Because the maximum likelihood robust estimator is the best estimator to use for models with dichotomous outcomes and missing data, standard fit statistics (e.g., standardized root mean residual, Tucker-Lewis fit index, comparative fit index, and root mean squared error of approximation) could not be used to determine the functional form. Instead I used the likelihood ratio chi-square test to determine the best fit. A p-value of .05 or lower indicated an improvement in fit compared with the previous model. Additionally, the best fitting model should have the lowest values for the Bayesian information criterion (BIC), sample-size adjusted BIC (aBIC), and Akaike information criterion (AIC).

When modeling dichotomous or ordinal data, MPlus uses thresholds as a corrective procedure. At issue in MPlus is that the default when analyzing longitudinal categorical outcomes is to set the intercept to zero and estimate the thresholds. In order to have an identified model I instead fixed the thresholds to zero and allowed for the estimation of the intercept.[66,125,126] The intercept is thus interpreted as the amount of deviation from 50 percent probability of the outcome. It is then possible to plot the estimated probabilities based on the probit regression parameters.

After determining the functional form of the unconditional growth model for each substance, the latent class growth models were fit. Substance use growth parameters were estimated for each pubertal timing class to determine if the development of substance use varied by pubertal timing.[78] In order to keep latent class membership constant across the three substance use models I fixed the mean and variance components for each latent class. Sex, race/ethnicity, household status, and parent education were added as predictors of the pubertal timing latent classes. The interest in these models is in how the exogenous variable, pubertal timing latent class, predicts the fixed effects of each substance use curve. The differences in the fixed effects by pubertal timing latent class were tested using contrast statements in the MPlus Model Constraint command and differences were considered statistically significant if the p-value was less than .05.

The potential moderating effect of adolescent sex on the relationship between pubertal timing and the development of substance was tested by regressing the fixed effects of the substance use growth curve on adolescent sex. This is analogous to testing a pubertal timing class by sex interaction effect on the substance use growth model fixed effects. The differences in these paths were also tested using MPlus Model Constraint contrast statements. As with the previous analyses, differences were considered statistically significant if the p-value was less than .05.

Results

Based on the likelihood ratio chi-square test and the AIC, BIC, and aBIC values, I found the best fitting form of the unconditional growth model for all three substances was the quadratic model (Table 4.1). The functional form was confirmed when examining the fixed effects for each substance use outcome (Table 4.2). For all three substances the mean intercept, slope, and quadratic fixed effects were statistically significant. This indicates that the proportion of current users increased from early adolescence and this growth began to desist, or slow down, in later adolescence. All of the random effects were significant, meaning that there was individual variability in the fixed effects.

After determining the functional form for the outcomes the next step in the analyses was to examine whether there were differences in the development of substance use based on pubertal timing. The intercept, slope, and quadratic fixed effects for each substance were compared across the three pubertal timing latent classes (on-time, early, and late) for both stage-normative and peer-normative pubertal timing (Table 4.3). To help with interpretation, I plotted the mean substance use curves for each pubertal timing latent class, by pubertal timing measure (Figures 4.1-4.6).

As hypothesized, the stage-normative pubertal timing models were consistent with the early maturation hypothesis; the intercepts were higher for early developing adolescents compared with on-time adolescents. And, consistent with my hypothesis of a catch-up effect, for the cigarette and marijuana models, on-time adolescents had a greater slope compared with early developing adolescents. In other words, using the stage-normative measure of pubertal timing, there was a higher proportion of early developing adolescents currently using cigarettes, alcohol, and marijuana at age 11 compared with on-time adolescents, but the proportion of substance users increased more across adolescence for on-time adolescents compared with early developing adolescents. The only exception to this pattern was the alcohol stage-normative model, where there were no slope differences between the two groups. There was a higher proportion of early developing adolescents using cigarettes and marijuana at age 11 compared with late developing adolescents. There were no significant differences in the quadratic terms in any of the stage-normative pubertal timing models, indicating that the desistance in the proportion of substance users was similar for all adolescents.

I found only limited support for my hypothesis that the peer-normative pubertal timing measure would support the maturational deviance hypothesis. I found the intercepts for all three peer-normative models were higher for early developing adolescents compared with on-time adolescents and on-time adolescents had a greater slope compared with early developing adolescents. As with the stage-normative models, there were higher proportions of early developing adolescents currently using cigarettes, alcohol, and marijuana at age 11 compared with on-time adolescents, but the proportion of users increased across adolescence more among on-time adolescents compared with early developing adolescents. The intercept differences between early developing and late developing adolescents were significant in the marijuana peer-normative model and approached significance in the cigarette peer-normative model ($p=.063$) and the alcohol peer-based model ($p=.059$), indicating a greater proportion of users among early developing adolescents at age 11 compared with late developing adolescents. However, the only significant difference between on-time and late developing adolescents occurred with the cigarette peer-normative model. Consistent with the maturational deviance hypothesis, late developing adolescents had a higher intercept compared with on-time adolescents. This indicates that, when using the peer-normative measure of pubertal timing, the proportion of cigarette users at age 11 was higher among late developing adolescents compared with on-time adolescents. There were no significant differences in the quadratic terms in any of the peer-normative pubertal timing models, indicating that the desistance in the proportion of substance users was similar for all adolescents.

The final analytic step was to determine if the relationship between pubertal timing and substance use varied by adolescent sex. Contrary to my hypothesis, there were very few differences across the models. The exception was the alcohol peer-normative model; the differences were due to differences between early developing males and early developing females (Figure 4.7). Early developing males had a higher proportion of current users at age 11 compared with early developing females (p=.088), the proportion of current users significantly decreased throughout adolescence for early developing males instead of increasing (p=.010), and instead of desisting, the proportion of current users among early developing males increased in later adolescence (p=.013). This resulted in more significant differences between early developing and other adolescents among males compared with females, but in a direction inconsistent with my hypothesis. The sex contrasts (equivalent to interaction terms) for slope differences between early developing and on-time adolescents were significant (p=.021), while the intercept contrasts (p=.089) and quadratic contrasts approached significance (p=.064) (Table 4). The contrasts between early and late developing adolescents for slope differences (p=.045) and quadratic differences (p=.041) were significant. A similar trend was seen in the stage-normative marijuana model but the differences were not as pronounced.

Discussion

The results from this study demonstrate that the relationship between pubertal timing and substance use is complicated. I found the relationship varied by both the substance of interest (cigarettes, alcohol, or marijuana) as well as by the measure of pubertal timing (stage-normative vs. peer-normative). The findings clearly substantiated the early maturation hypothesis that early pubertal timing places adolescents at higher risk for substance use in early adolescence compared with their on-time or late developing peers. But there was also limited support for the maturational deviance hypothesis, that late development also places adolescents at risk. Finally, there was evidence of longitudinal changes in the association between pubertal timing and substance use.

As hypothesized, I found support for the early maturation hypothesis using the stage-normative measure of pubertal timing. There was a higher proportion of current cigarette, alcohol, and marijuana users at age 11 among early developing adolescents compared with on-time adolescents. And, for cigarette and marijuana use, there was a statistically significant difference between early and late developing adolescents at age 11. Besides the slope differences between on-time and early developing adolescents in the cigarette and marijuana models, which will be discussed in detail later, there were few differences between the three pubertal timing classes using the stage-normative measure. This indicates that pubertal timing has the strongest influence on current substance use in early adolescence. While longitudinal considerations were not explicitly a part of the early maturation hypothesis, these analyses confirm the reasoning behind the theory that early pubertal timing places an adolescent at risk due to affiliation with older peers. If adolescents begin their affiliation with older peers prior to age 11 it is unlikely this affiliation would cease in mid to late adolescence. Therefore the risk would continue to be present for early developing adolescents, as I found with this sample.

I had hypothesized the peer-normative measure would show a higher proportion of early and late developers using substances compared with on-time developers because the basis of the maturational deviance hypothesis is that off-time adolescents are at risk for substance use due to psychological distress. I hypothesized that if an adolescent engages in social comparison and believes s/he is early or late compared to peers, that adolescent is at greater risk for psychological distress than adolescents who believe they are on-time, and this psychological distress would put the adolescent at higher risk for substance use. Contrary to my hypothesis, there was limited support for the maturational deviance hypothesis using the peer-normative measure. The one exception was that I found a higher proportion of cigarette users among late developers at age 11 compared with on-time developers. Because there were no significant differences in the slope or quadratic factors between the two groups, this resulted in a higher proportion of cigarette users among late developers compared with early developers across adolescence. The differences between late developing and on-time adolescents were not found for alcohol or marijuana use. This is not the first study to find differential effects of pubertal timing depending on the substance use outcome. One study of middle school boys also found late developers were more likely to be daily or occasional smokers than on-time developers but found no significant differences between late developers and on-time peers in regards to alcohol use.[3] In contrast to alcohol or marijuana, cigarettes are a substance adolescents can ingest in public spaces without concern of legal consequences. It is possible that adolescents who perceive themselves to be late developing compared with their peers are more likely to engage in cigarette use because of the expectation that smoking will make them appear older.

While not statistically tested, the strength of the relationship between early pubertal timing and current substance use appeared to be stronger using the peer-normative measure compared to the stage-normative measure. This is contrary to one study that found a stage-normative measure was more strongly correlated with alcohol use compared with peer-normative measures.[17] But the finding supports the conceptualization put forth by others that the perception of comparative pubertal development is more important than actual pubertal timing differences.[11] While the early maturation hypothesis postulates that early developers are at risk because of their association with older peers, the finding that the differences were more pronounced using the peer-normative measure also suggests that psychological factors, such as anxiety, depression, or body dissatisfaction, may be influencing the relationship. There is a substantial literature demonstrating the association between pubertal timing and psychological distress but studies of whether these factors mediate the relationship between pubertal timing and substance use have been limited.[8,10,13,23]

My hypothesis in regards to a catch-up effect for on-time and late developers relative to their early developing peers was only partially supported. While there was evidence of a greater increase in the proportion of current substance users among on-time developers compared with early developers for both measures of pubertal timing, in general, on-time developers never fully caught up with their early developing peers. The one exception was alcohol use; when using the peer-normative measure I found the proportion of current users was highest among on-time developers after age 16. And late developers did not differ from early developers in their progression of substance use over time. Thus while there was some evidence of a catch-up effect, it was not enough to surpass the impact of pubertal timing on adolescent substance use in early adolescence. Again, this points to the important role early pubertal timing plays in the use of substances early in adolescence. The results show that once early adolescents are engaging in current substance use, their use is not likely to decline until later in adolescence.

My final hypothesis was that adolescent sex would moderate the relationship between pubertal timing and recent substance use. Contrary to my hypothesis, I found very few sex differences. And, the differences I found were in the opposite direction as predicted. Using the peer-normative measure, I found that early developing males had the opposite trend of current alcohol use compared with early developing females. The intercept differences approached significance and showed that at age 11 there was a higher proportion of current alcohol users among early developing males compared with early developing females. This is similar to research conducted using stage-normative measures.[17,121] It is possible that at age 11 early developing males have fewer societal controls in regards to alcohol use compared with early developing females. For example, parents of early developing males may be less concerned about their adolescents associating with older peers compared with parents of early developing females. Future research needs to be done to determine if parenting factors moderate the relationship between pubertal timing and substance use, and if these factors explain the gender differences in early pubertal timing and alcohol use.

I also found that the catch-up effect for on-time developers was greater for males than females, which had not been previously tested. The catch-up effect for on-time males resulted in on-time developers having a greater proportion of current alcohol users in later adolescence compared with any other group. This suggests that, contrary to cigarette or marijuana use, alcohol use among older male adolescents is likely a confluence of factors, of which pubertal timing plays a less significant role.

This study is not without limitations. The study sample was 11 to 17 years of age, which did not capture very early maturers or the completion of the pubertal process for some.[54] Therefore, this study is an examination of the impact of perceived pubertal timing on substance use during the midst of pubertal development. Both measures of pubertal timing latent class were categorical, which has been shown to be less predictive of delinquent behavior than continuous measures.[129] Furthermore, while this study theoretically tested the differential impact between objective and subjective pubertal timing, both measures are based on adolescent self-report. It is unknown whether the objective self-report measure used in this study (stage-normative pubertal timing) is strongly correlated, and thus synonymous, with stage-normative pubertal timing assessed clinically. The peer-normative measure was based on one item assessing how adolescents perceived their overall development to be compared with peers. This is a common way of assessing peer-normative pubertal timing,[3,8,13,17,116] but it is possible that a scale of items assessing how adolescents perceived their development of specific characteristics (e.g., body hair, breast development) may have been more comparable to the stage-normative pubertal timing measure used in this study. Current substance use was low in this sample, especially among the youngest adolescents, which prevented examining the relationship between pubertal timing and continuous measures of substance use. The dichotomous measures could have decreased the association between pubertal timing and substance use because the substance use measures include a range of substance use, from adolescents who experimented once in the last three months to daily users. While the substance use measures were self-report, research has supported the use of self-report measures in assessing adolescent risk behavior.[130] Finally, participants were not asked questions about body mass index, which could partially explain differences in the classification of adolescents into pubertal timing latent classes based on pubertal timing measure.

Despite these limitations, this study adds to the current understanding of pubertal timing and adolescent risk behavior in a number of ways. The analyses were conducted using a longitudinal sample and advanced statistical methods that allowed for the control of the measurement error associated with pubertal timing classification. This study tested two hypotheses in the literature regarding the relationship between pubertal timing and risk behavior and compared the longitudinal impact of two self-report measures of pubertal timing on three different substances commonly used in adolescence – cigarettes, alcohol, and marijuana. The findings confirm previous findings that, in general, early developing adolescents are at highest risk for substance use throughout adolescence, but that the impact is strongest in early adolescence. There was strong support for the early maturation hypothesis, particularly when using a stage-normative measure of pubertal timing. However, when using a peer-normative measure of pubertal timing I found late developing adolescents were also at increased risk for cigarette use compared with their on-time peers, which supports the maturational deviance hypothesis. Finally, pubertal timing based on peer comparison appears to be a better determinant of substance use risk for adolescents compared with measures of self-report pubertal timing based on biological assessment.

Because pubertal timing is not a risk factor that can be altered through psychosocial interventions, the implications for interventions to prevent future substance use among off-time developers are less straightforward than with other risk factors. Clearly the findings from this study support prior research suggesting a need for substance use prevention programming at young ages, because by age 11 differences in use by pubertal timing class are already present.[131] The impact of pubertal timing on substance use appears to be greater when using a measure that takes into account the social process of puberty rather than measures based only on biological factors. This implies the impact pubertal development has on the psychosocial development of adolescents is a critical component of understanding the link between pubertal timing and substance use. Clearly more work needs to be done to understand the psychological and social implications of perceived pubertal off-timing for adolescents. Finally, parents and teachers need to be provided the resources to counsel adolescents through this transitional period in their lives, focusing not just on the biological aspects of puberty but what these changes mean for the adolescent and their interactions with others.

Table 4.1. Unconditional latent growth model fit statistics, by current substance use outcome

	Intercept Only Model				**Linear Model**					**Quadratic Model**				
	AIC	**BIC**	**aBIC**	**LL**	**AIC**	**BIC**	**aBIC**	**LL**	**LRT**	**AIC**	**BIC**	**aBIC**	**LL**	**LRT**
Cigarettes (n=5801)	17863.4	17876.7	17870.4	-8929.7	17223.3	17256.7	17240.8	-8606.7	646.0 ***	17085.5	17145.5	17116.9	-8533.7	146.0 ***
Alcohol (n=5793)	19988.6	20001.9	19995.5	-9992.3	19186.0	19219.4	19203.5	-9588.0	808.6 ***	19071.6	19131.6	19103.0	-9526.8	122.4 ***
Marijuana (n=5824)	15102.0	15116.2	15109.9	-7549.4	14094.3	14127.7	14111.8	-7042.2	1014.4 ***	13920.3	13980.4	13951.8	-6951.2	182.0 ***

*p<.05, **p<.01, ***p<.001

Note: AIC = Akaike Information Criteria, BIC = Bayesian Information Criteria, aBIC= adjusted Bayesian Information Criteria,
LL = log-likelihood, LRT = log-likelihood ratio test

Table 4.2. Fixed and random effects for the unconditional latent growth models, by current substance use outcome

	Cigarettes (n=5801)		**Alcohol (n=5793)**		**Marijuana (n=5824)**	
Intercept Mean	-6.047	***	-5.176	***	-9.284	***
Intercept Variance	11.561	***	9.081	***	15.419	***
Slope Mean	1.626	***	1.424	***	2.752	***
Slope Variance	4.396	***	4.197	***	7.849	***
Quadratic Mean	-0.175	***	-0.124	***	-0.288	***
Quadratic Variance	0.113	**	0.085	***	0.179	**

*p<.05, **p<.01, ***p<.001

Table 4.3. Parameter estimates of current substance use by substance use outcome and pubertal timing latent class

Stage-normative pubertal timing

	Cigarettes			**Alcohol**			**Marijuana**		
	Intercept	**Slope**	**Quadratic**	**Intercept**	**Slope**	**Quadratic**	**Intercept**	**Slope**	**Quadratic**
Early	-1.506 *** $^{o\,l}$	0.332 ^{o}	-0.033	-2.252 *** ^{o}	0.910 ***	-0.100 *	-3.412 *** $^{o\,l}$	0.897 * ^{o}	-0.070
On-Time	-3.459 *** ^{e}	1.149 *** ^{e}	-0.121 ***	-3.343 *** ^{e}	1.167 ***	-0.115 ***	-5.242 *** ^{e}	1.765 *** ^{e}	-0.188 ***
Late	-4.208 *** ^{e}	0.688	-0.020	-3.828 ***	0.519 *	0.009	-7.454 *** ^{e}	1.653 $^{+}$	-0.095

Peer-normative pubertal timing

	Cigarettes			**Alcohol**			**Marijuana**		
	Intercept	**Slope**	**Quadratic**	**Intercept**	**Slope**	**Quadratic**	**Intercept**	**Slope**	**Quadratic**
Early	-1.762 *** ^{o}	0.777 *** ^{o}	-0.091 *	-1.813 *** ^{o}	0.721 *** ^{o}	-0.087 *	-3.434 *** $^{o\,l}$	1.210 *** ^{o}	-0.127 ***
On-Time	-5.094 *** $^{e\,l}$	1.484 *** ^{e}	-0.141 ***	-4.319 *** ^{e}	1.463 *** ^{e}	-0.135 ***	-7.156 *** ^{e}	2.313 *** ^{e}	-0.227 ***
Late	-3.173 *** ^{o}	0.884 $^{+}$	-0.078	-3.773 ***	1.333 **	-0.153 *	-6.353 *** ^{e}	2.459 ***	-0.323 ***

+p<.10, *p<.05, **p<.01, ***p<.001

^{eol} Different superscripts indicate significant differences. e=different than early, o=different than on-time, l=different than late

Figure 4.1. Proportion of current cigarette users by stage-normative pubertal timing class

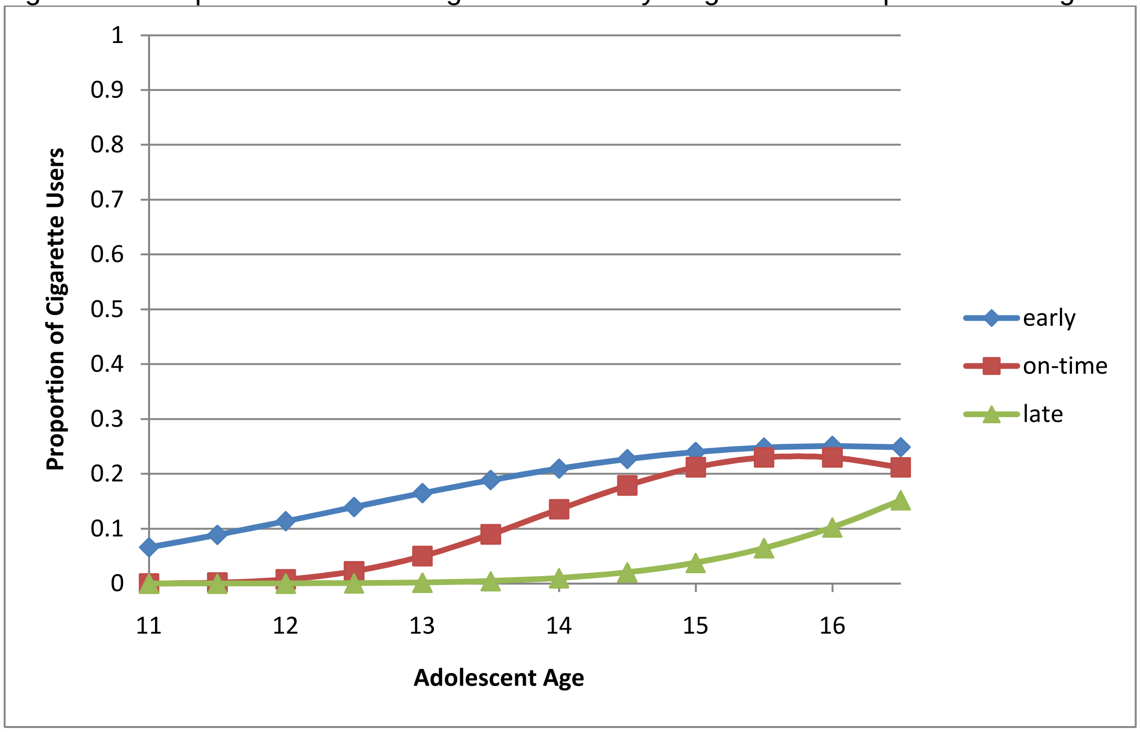


Figure 4.2. Proportion of current cigarette users by peer-normative pubertal timing class

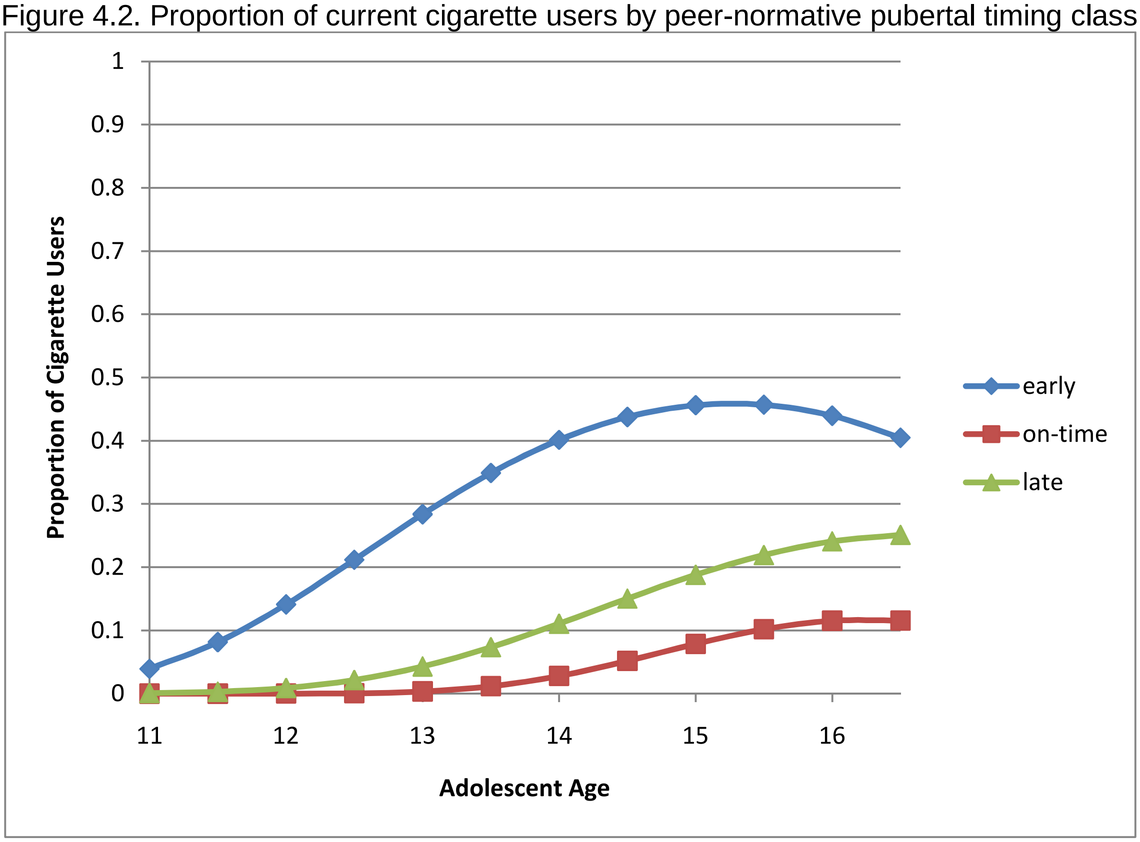


Figure 4.3. Proportion of current alcohol users by stage- normative pubertal timing class

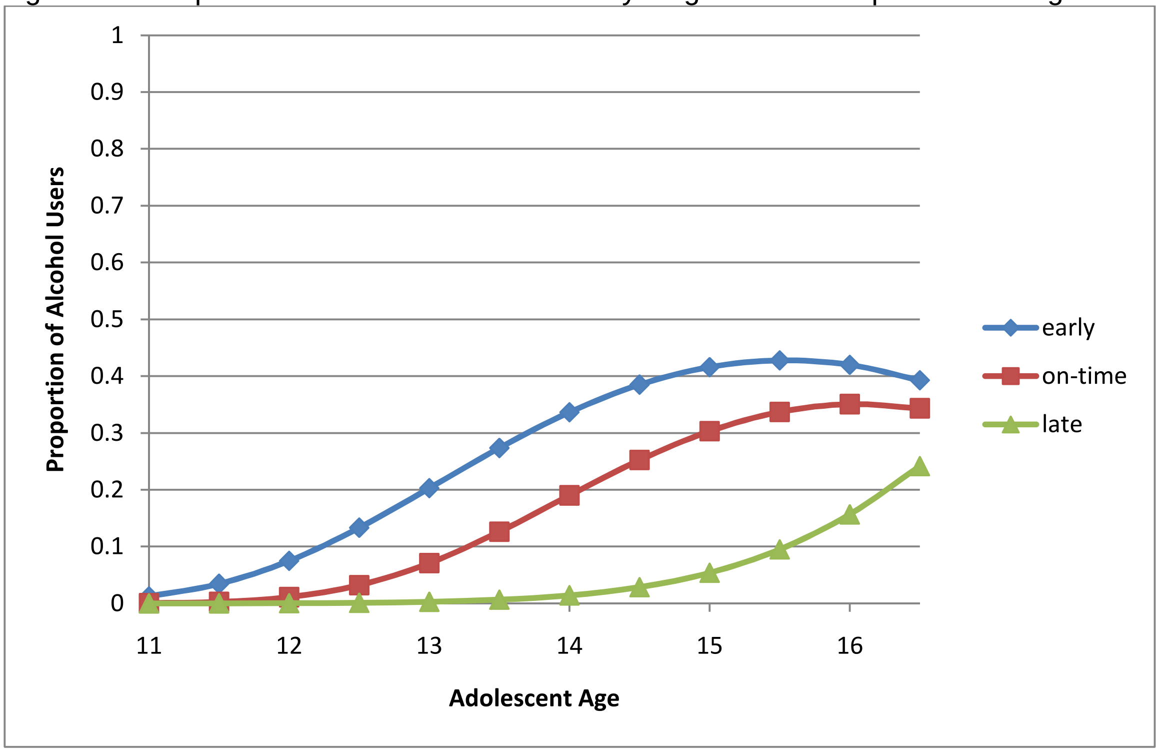


Figure 4.4. Proportion of current alcohol users by peer- normative pubertal timing class

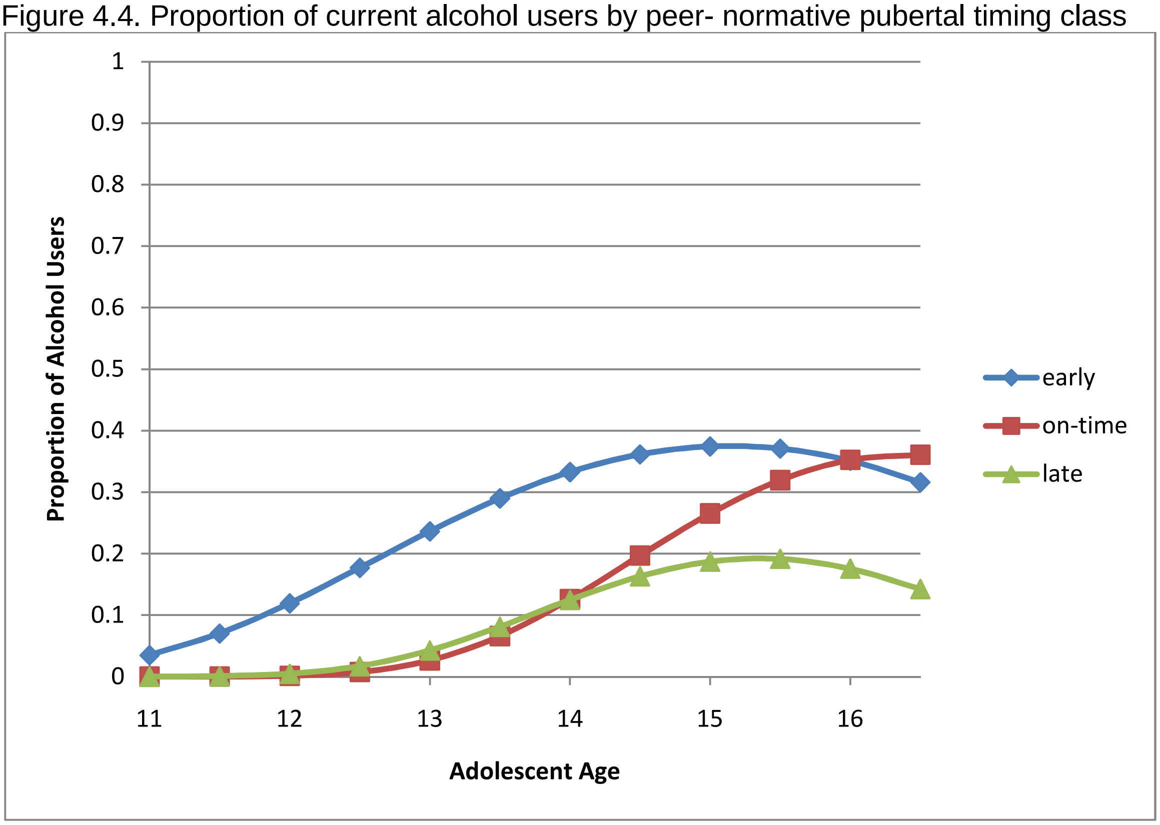


Figure 4.5. Proportion of current marijuana users by stage- normative pubertal timing class

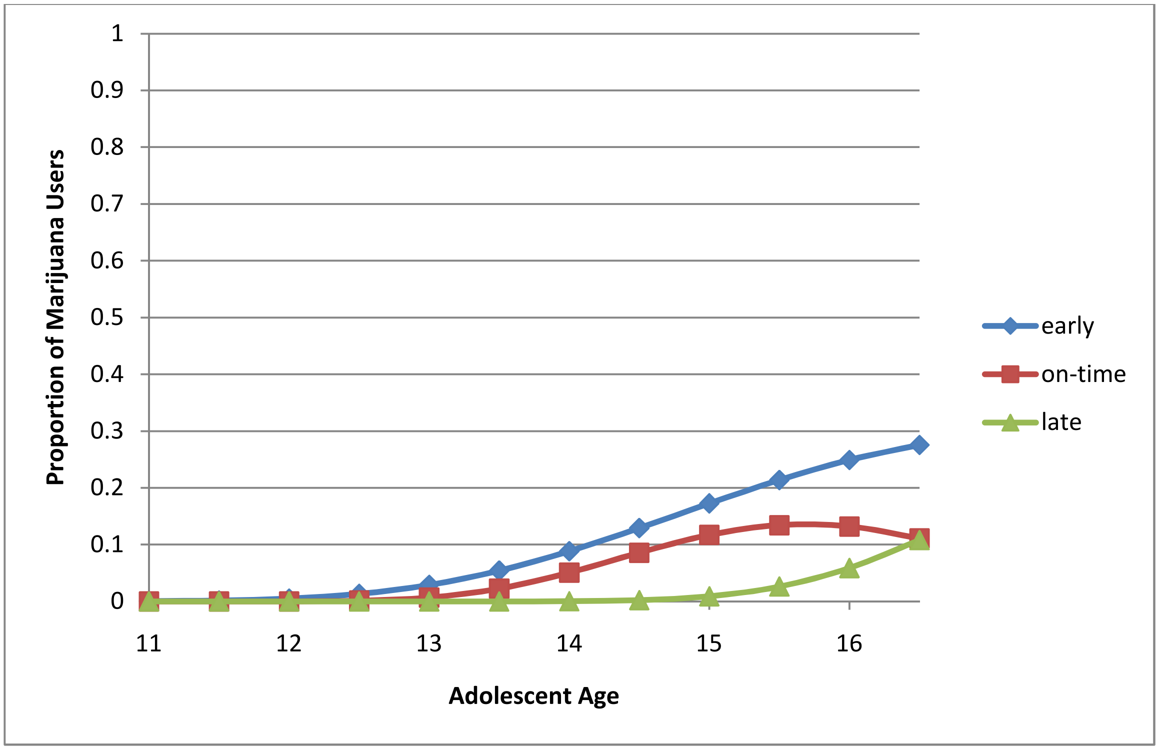


Figure 4.6. Proportion of current marijuana users by peer- normative pubertal timing class

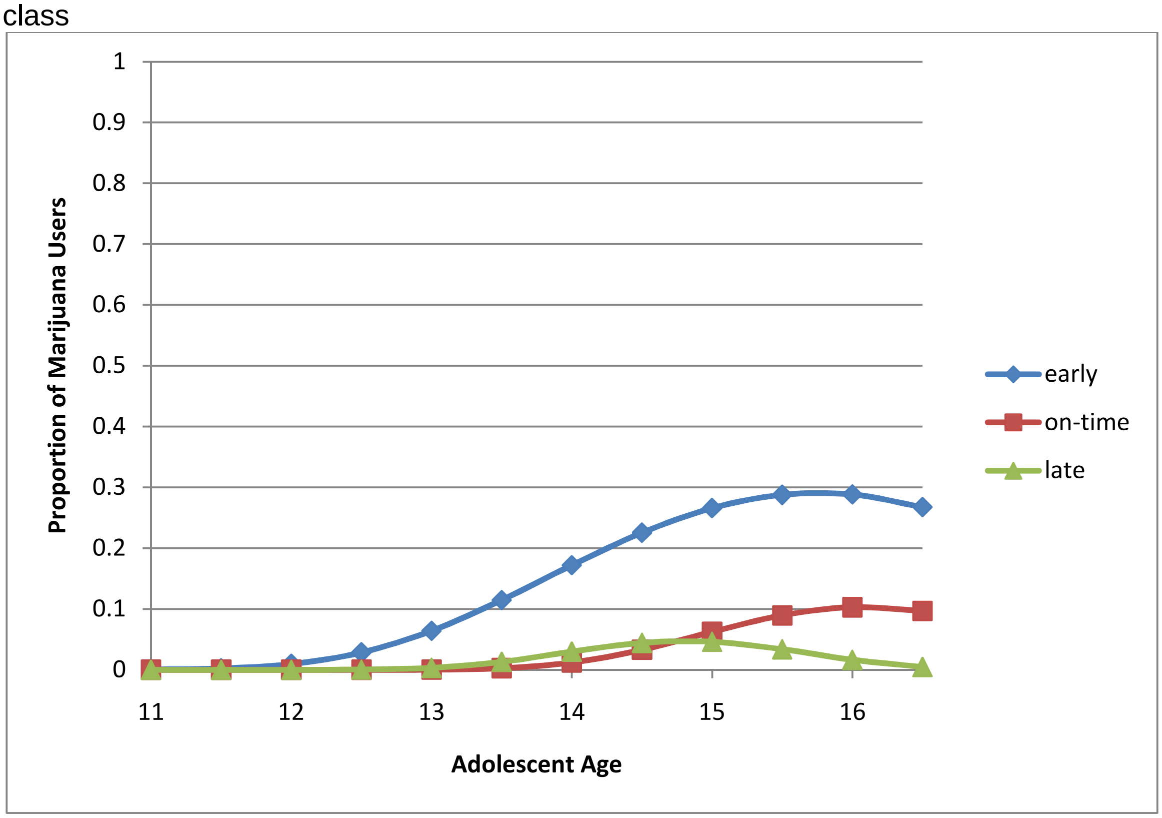


Figure 4.7. Proportion of current alcohol users by peer- normative pubertal timing class and adolescent sex

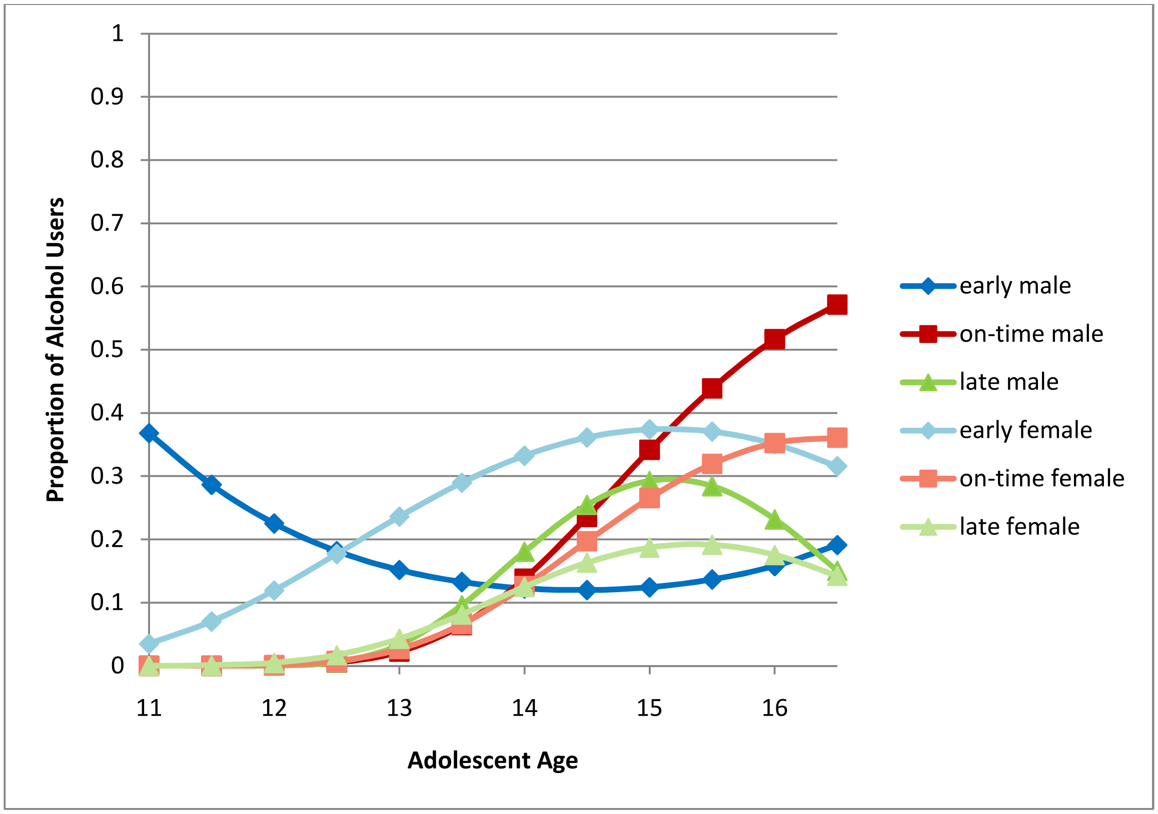


Table 4.4. Model contrasts testing sex differences (male vs. female), by substance use and pubertal timing measure

		Intercepts			Slopes			Quadratics		
		On-time vs. Early	**On-time vs. Late**	**Late vs. Early**	**On-time vs. Early**	**On-time vs. Late**	**Late vs. Early**	**On-time vs. Early**	**On-time vs. Late**	**Late vs. Early**
Cigarettes	**stage-normative**	-.705 (p=.453)	-2.251 (p=.177)	1.546 (p=.430)	.451 (p=.427)	1.613 (p=.117)	-1.163 (p=.346)	-.055 (p=.621)	*-.280 (p=.090)*	.225 (p=.281)
	peer-normative	-.707 (p=.376)	.607 (p=.664)	-1.314 (p=.353)	.498 (p=.435)	.385 (p=.743)	.112 (p=.915)	-.083 (p=.459)	-.116 (p=.606)	.033 (p=.860)
Alcohol	**stage-normative**	-.007 (p=.993)	-1.948 (p=.375)	1.942 (p=.360)	-.077 (p=.842)	1.596 (p=.237)	-1.673 (p=.194)	.031 (p=.588)	-.270 (p=.177)	.302 (p=.119)
	peer-normative	*-1.683 (p=.089)*	-3.039 (p=.175)	1.356 (p=.432)	**1.240 (p=.021)**	**2.183 (p=.045)**	-.942 (p=.370)	*-.139 (p=.064)*	**-.282 (p=.041)**	.143 (p=.354)
Marijuana	**stage-normative**	-1.028 (p=.378)	-3.094 (p=.222)	2.066 (p=.382)	*.846 (p=.081)*	*2.626 (p=.087)*	-1.779 (p=.261)	-.130 (p=.161)	**-.435 (p=.041)**	.304 (p=.225)
	peer-normative	-1.081 (p=.492)	1.121 (p=.390)	-2.202 (p=.179)	.853 (p=.242)	-.431 (p=.619)	1.284 (p=.246)	*-.149 (p=.082)*	.073 (p=.620)	-.222 (p=.224)

CHAPTER 5: DISCUSSION

The purpose of this dissertation was to better understand the role and meaning of pubertal timing throughout adolescence. There is a large body of research dedicated to disentangling measures of pubertal development, but much of this research has focused on the differences between clinically assessed measures and self-report measures. In this dissertation I examined two commonly used self-report measures of pubertal timing that theoretically have different implications for how puberty is understood and experienced by adolescents and potentially have different relevance to substance use and other health risk behaviors. The first measure, stage-normative pubertal timing, was constructed by comparing the adolescent's self-perceived pubertal status based on biological indicators to the self-reported pubertal status of peers averaged by age, gender, and race/ethnicity. The second measure, peer-normative pubertal timing, was based not on biological indicators of puberty reported by adolescents and their peers but rather on the adolescent's self-perception of their pubertal timing compared with peers, which takes into account not only a personal biological assessment but also a psychosocial interpretation of how that assessment compares with peers. The findings from the three studies of this dissertation confirm that the two measures of pubertal timing are not synonymous measures and indicate that pubertal development is a complicated process that encompasses both biological and social factors.[52,87,94,95] Below I discuss the key findings of this dissertation, present limitations, and suggest implications for future research and practice.

Summary of Key Research Findings

Comparison of stage-normative and peer-normative pubertal timing

A primary goal of this dissertation was to determine if the measures of stage-normative pubertal timing and peer-normative pubertal timing were concordant. In the first paper, I hypothesized the two measures would not have perfect concordance due not only to empirical evidence but also according to person-in-context theory, which suggests the peer-normative pubertal timing measure would be different than the stage-normative measure because it is based on the adolescent's interpretation of their biological development and a psychological assessment of how that development compares to the peers with whom they interact.[86] Nevertheless, I expected at least a modest positive relationship between the two measures because they share in common self-assessment of pubertal development.

I found the two measures to have almost no relation, with the overall Kappa statistic not even reaching the threshold for modest concordance. The second paper of this dissertation provided further evidence of the discordance between the two measures; almost twice as many adolescents were in the early developing latent class using the peer-normative measure compared with the stage-normative measure and while there were no demographic predictors of the stage-normative latent classes, both adolescent sex and race predicted membership in the peer-normative latent classes. And in the third paper of this dissertation, I found the two measures of pubertal timing differentially predicted current substance use across adolescence (the implications of the analyses from the third paper are discussed below).

Based on the findings from this dissertation I can conclusively state the two measures of pubertal timing, stage-normative and peer-normative, are not analogous. It is important to note that the differences found between the stage-normative and peer-normative pubertal timing measures do not imply that one of the measures is invalid or inaccurate. Instead, I believe the two measures are assessing different aspects of pubertal development. The stage-normative measure is tapping primarily into the biological process of pubertal development as assessed by physical markers and answers the question of how developed an adolescent is compared with peers of the same age, sex, and race/ethnicity. In contrast, the peer-normative measure is assessing the social process of pubertal development. As hypothesized by person-in-context theory, adolescents evidently do not evaluate their pubertal timing based solely on biological development but interpret this facet of identity based on their interactions with others. When asked the peer-normative measure, adolescents assess their pubertal development and then look to peers to determine the meaning of that pubertal development. With the peer-normative measure it is not just the age, sex, and race/ethnicity of the adolescent that determines pubertal timing, but also the peer group(s) with whom the adolescent affiliates.

Apart from substantive reasons for the discordance between the two measures, there may be methodological reasons as well. Both measures are based on self-reports and therefore dependent on adolescent interpretation. I expected that any self-report bias, ranging from accidental misinterpretation of biological cues to purposeful misreporting due to social desirability, would be present in both measures. It is possible, though, that there was less of a chance of social desirability bias in the stage-normative measure because it was based on a series of items assessing the completion of the pubertal development process, without a normative reference, compared with the peer-normative measure that specifically asked adolescents to comparing themselves to peers.

Another possible reason for the discordance is that the selection of the demographic norm reference groups for the stage-normative measure did not match the referent groups actually utilized by adolescents. The stage-normative measure was developed by norming pubertal status within age, sex, and race/ethnicity because of the demographic differences I found in pubertal status. It could be that adolescents are using different referent groups for the peer-normative measure; adolescents could be comparing themselves to others in their grade rather than peers of the same age, comparing themselves only to their close friends, or comparing themselves to peers involved in the same activities (e.g., football team). It is also possible that instead of considering the full spectrum of pubertal development, as assessed by the stage-normative measure, adolescents are comparing their pubertal development to their peers based on one or two key milestones, such as height or breast development.

<u>Stability of pubertal timing</u>

The purpose of the second paper was to examine and compare the stability of stage-normative and peer-normative pubertal timing using two different longitudinal methods, random effects ANOVA modeling and latent class analysis. There has been an extensive amount of research on pubertal timing in adolescence, but studies have been conducted with adolescents of varying ages and it is unknown whether pubertal timing remains a stable construct throughout adolescence. Empirical evidence suggests that pubertal timing is transitory, which would imply that the impact of pubertal timing on behavior at one age could not be expected to persist at other ages. However, according to Erikson's theory of psychosocial development, the perception of pubertal timing during early adolescence should be internalized as a part of personal identity and remain constant, regardless of actual pubertal development that occurs later in adolescence.[106] I hypothesized that both measures of pubertal timing would be stable across adolescence, but that the peer-normative measure would be more stable than the stage-normative measure because it takes into account the psychosocial process of puberty as part of identity formation.

I found both measures had poor stability when using random effects ANOVA models. Even with a short time span of six months, an adolescent's pubertal timing, both stage-normative and peer-normative, was variable. While this confirmed empirical evidence, it was contrary to my theoretical hypothesis. It is possible the instability was greater than expected because both measures only had three categories rather than continuous values. But it is interesting that adolescents made categorical shifts from believing they were on-time to then off-time, or vice versa, in a short amount of time. Based on this finding, researchers should be cautious in assuming that cross-sectional findings in relation to pubertal timing are comparable across adolescence.

I further tested the stability of pubertal timing across adolescence by using latent class analysis. Unlike random effects ANOVA modeling, latent class analysis tests whether there are underlying patterns in responses over time. Any variation from these underlying patterns is considered to be measurement error. Unlike the random effects ANOVA models, with the latent class analysis I found three stable and distinct response patterns that I categorized as always early, always on-time, and always late. These findings emphasize the need to utilize analyses that can take into account the longitudinal pattern of pubertal timing rather than looking at pubertal timing at one age, and also support the theoretical expectation that pubertal timing is a stable construct. How an adolescent perceives their pubertal timing in early adolescence holds throughout adolescence, suggesting that pubertal timing is part of identity development.

<u>Relationship between pubertal timing and substance use</u>

The final study of this dissertation tested two theoretical hypotheses related to pubertal development and risk behavior, the maturational deviance and early maturation hypotheses by comparing the impact of the two pubertal timing measures on the development of current cigarette, alcohol, and marijuana use. Other researchers have suggested that the subjective experience of pubertal development, as measured by peer-normative pubertal timing, may be more predictive of adolescent behaviors compared with objective measures of pubertal development, as measured by stage-normative pubertal timing.[11] But there has been no discussion as to whether the two measures of pubertal timing could differentially predict the adolescents at greatest risk for substance use.

I hypothesized the stage-normative measure would confirm the early maturation hypothesis and the peer-normative measure would confirm the maturational deviance hypothesis because the peer-normative measure is based on social comparison. The early maturation hypothesis theorizes that early developing adolescents are the only adolescents at risk for substance use because they are more likely to associate with older peers. The maturational deviance hypothesis is based on the theory that adolescents who are off-time (early or late) are at risk for substance use due to the psychological distress caused by timing misfit. There is strong support for the early maturation hypothesis using both measures, but I believed the peer-normative, which invokes social comparison, would be more likely to support the maturational deviance hypothesis because an adolescent who engages in social comparison and believes she or he is off-time compared to peers is more likely to experience psychological distress compared with adolescents who believe they are on-time compared with peers and may therefore more frequently use substances. The stage-normative measure is not based on social comparison but rather is an objective comparison of where the adolescent is in the process of pubertal development compared with peers; I hypothesized that only early developing adolescents would be at risk for substance use using this measure because their appearance of being more developed would cause them to associate more frequently with older peers, who would provide more opportunities for substance use.

As expected, the stage-normative measure of pubertal timing clearly supported the early maturation hypothesis, such that there was a higher proportion of current cigarette, alcohol, and marijuana users at age 11 among early developing adolescents compared with on-time adolescents and a higher proportion of current cigarette and marijuana users at age 11 among early developing adolescents compared with late developing adolescents. In only partial support of my hypothesis, I found the peer-normative measure of pubertal timing did not fully support the maturational deviance hypothesis. I had expected both early and late developing adolescents to be at higher risk for substance use than on-time adolescents and instead only found that relationship to be true for cigarette use. As with the stage-normative measure, there were higher proportions of cigarette, alcohol, and marijuana users at age 11 among early developing adolescents compared with on-time adolescents using the peer-normative measure. And there was a higher proportion of marijuana users at age 11 among early developing adolescents compared with late developing adolescents.

With both measures of pubertal timing I found that there were more differences in the intercepts between pubertal timing latent classes than differences in the slopes or quadratic factors. This suggests that pubertal timing has the greatest influence on substance use in early adolescence, particularly for early developing adolescents. There was some evidence that on-time adolescents increase their substance use throughout adolescence at a greater pace than early developing adolescents, but in general this increase was not enough to catch-up to their early developing peers.

The results from the third study provide further support that pubertal development plays an important role in early adolescence. And in the third paper I found a differential relationship between the two pubertal timing measures and substance use; the strength of the relationship between early pubertal timing and current substance use appeared to be stronger using the peer-normative measure compared with the stage-normative measure and late developing adolescents were at higher risk for substance use with the peer-normative measure compared with the stage-normative measure. This implies that the social nature of pubertal development is as important, if not more, than the biological process of puberty.

Limitations

This dissertation makes important contributions to the literature but is not without limitations. While the greatest strength of this research is that the results are based on a large and diverse longitudinal sample of adolescents, the first set of limitations concerns the study sample. In particular, the youngest adolescents in the study sample were 11 years of age. The first stages of pubertal development typically begin by age 9 or 10, and early developing adolescents could show signs of maturation as early as age 7 or 8. [54] Furthermore, the oldest adolescent in the study were younger than 17, which is earlier than the average completion of pubertal development. Therefore, differences in pubertal status or pubertal timing that could be occurring early or later in the development process could not be assessed. This would have had the greatest impact on the analyses in the second and third studies, where the patterns of responses across the age span were used to determine the latent classes of pubertal timing. It is possible that including adolescents younger than 11 and older than 17 would have created different patterns of responses, specifically in regards to the stage-normative pubertal timing measure, such as being early developing in late childhood/early adolescence and transitioning to on-time in later adolescence. And while there was notable diversity in this study sample, most of the adolescents were White or Black, which limited the statistical power to examine racial/ethnic differences beyond this two-group comparison. Furthermore, while I controlled for racial/ethnic group membership in all of the analyses, the existing complexity of the models in the third study prevented an analysis of whether race/ethnicity moderated the relationship between pubertal timing and substance use. Future research needs to incorporate a wider age range of adolescents and include a larger sample of adolescents from a variety of racial/ethnic groups.

There were also measurement decisions and limitations that should be noted. Clinical measures of pubertal development were not available so it is not possible to assess the validity of the self-reported pubertal status measure used in the first study that was also the basis of the stage-normative pubertal timing measure used in all three studies. Numerous studies, however, have suggested that self-reports of pubertal development correlate strongly with clinical measures. Adolescent body mass index was also unavailable, which has been shown to influence adolescent self-perception of pubertal timing and thus is an important confounder that should be included in future replications of this research. Both measures of pubertal timing were trichotomized into the classes of early, on-time, and late. The peer-normative measure was based on one item assessing how adolescents perceived their overall development to be compared with peers. This is a common way of assessing peer-normative pubertal timing,[13,14,98,101] but it is possible that a scale of items assessing how adolescents perceived their development of specific characteristics (e.g., body hair, breast development) may have resulted in a more comparable measure to stage-normative pubertal timing. The results may have differed if the peer-normative measure had used all five categories (very early, early, on-time, late, very late) or if the stage-normative measure had been calculated as a continuous measure (by regressing the adolescent report of pubertal stage on the mean pubertal stage for based on the adolescent’s age, sex, and race/ethnicity). The stage-normative pubertal timing measure used one standard deviation as the cutoff for off-timing. Using a different cut-off, such as two standard deviations from the mean, could have resulted in different concordance between the two measures, stability of the two measures, or a different number of pubertal timing latent classes. One standard deviation difference was chosen as the cutoff because a majority of the studies using stage-normative pubertal timing have used this cutoff and I was interested in determining how this classification was correlated with the similarly categorized peer-normative pubertal timing measure.

In regards to the third study, current substance use was low in the sample, especially among the youngest adolescents, which prevented the ability to look at the relationship between pubertal timing and continuous measures of substance use. This could have decreased the association between pubertal timing and substance use because the substance use measure includes a range of substance use, from adolescents who experimented once in the last three months to daily users. The substance use measures were self-report, but prior research has supported the use of self-report measures in assessing adolescent alcohol and other drug use.[130]

Future Research

Despite the limitations, there are a number of implications for future research based on the findings of this dissertation. The analyses should be replicated with study samples that include adolescents from a larger age range and more racial/ethnic diversity. The results from the first and second studies suggest that the differences between the social and biological constructions of puberty vary based on age, sex, and race/ethnicity, which highlights the need for diverse samples when examining pubertal development among adolescents. The third study of this dissertation demonstrated a differential impact of pubertal timing depending on the substance use outcome, so future research needs to be conducted to determine if there is also a longitudinal relationship between pubertal timing and other adolescent risk behaviors, including risky sexual activity, aggressive behaviors, and unhealthy weight control.

Measurement of pubertal timing

The findings from this dissertation demonstrate a need for further research on the measurement of pubertal timing. The stage-normative pubertal timing measure used in the three studies has been found to be comparable to clinically assessed biomarkers of pubertal development. However, there is no research comparing the peer-normative measure to biomarkers. I hypothesize that the concordance between the peer-normative measure and biological referents (e.g., hormone concentrations, age at peak velocity) would be poor but it is an important line of research that needs to be explored.

There is also a need for more detailed research to explore the nature of the comparisons adolescents make when they compare their pubertal development to their peers. For example, what physical characteristics are adolescents looking at in making their comparisons with their peers? Also, while the peer-normative measure used in this dissertation asked adolescents to compare within their own age and sex, were they also making comparisons with peers within their same racial/ethnic group? Focus groups with adolescents could help explain some of the cognitive processes occurring during such social comparisons of puberty and help with development of additional measures of peer-normative pubertal timing.

Exploration of the relationship between pubertal timing and substance use

I found in the third study of this dissertation that early pubertal timing, and to a limited extent late pubertal timing, put adolescents at risk for substance use. Unfortunately, pubertal timing is a biological trait that cannot be easily modified. Instead, research needs to be conducted to determine if there are mediating or moderating factors that could be targeted to decrease the negative impact of early or late pubertal timing.

The maturational deviance and early maturation hypotheses provide different explanations as to why pubertal timing may be a risk factor for substance use among adolescents.[24,27] According to the maturational deviance hypothesis, adolescents whose pubertal timing is non-normative are more likely to engage in substance use because they experience a higher level of psychological distress. The early maturation hypothesis states that early maturing adolescents are at risk for substance use because others view them as more mature and thus they are more likely to associate with older peers who are more likely to be engaging in substance use. These pathways need to be confirmed.

Most research has focused on the mediating role of either psychological or social variables, not both, as a way of testing the two theoretical hypotheses. But there is evidence that both psychological and social variables could be mediating the relationship between off-pubertal timing and substance use. There is evidence to support that early developing adolescents are more likely than their on-time or late developing peers to associate with older and more deviant peers who are more likely to expose the adolescent to substance use and other deviant behaviors.[9,15,1822,24] But both early and late developing adolescents experience more psychological distress (anxiety, depression, body dissatisfaction) than on-time adolescents and that psychological distress is linked to substance use. [8, 10, 13, 23,60-63]

The third study of this dissertation clearly showed that early developing adolescents were at highest risk for substance use compared with on-time or late developing adolescents, which would theoretically suggest that association with older or deviant peers plays a role. But the findings from the third study also showed that peer-normative pubertal timing may be more predictive of substance use than stage-normative pubertal timing, which could mean that both psychological and social factors are mediating the relationship. Future research should incorporate both psychological and social variables as mediators in order to determine the relative contribution of these variables.

Another way of exploring the relationship between pubertal timing and substance use is to consider which factors are moderators. Considering the relationship between pubertal timing and psychosocial factors as interacting rather than mediating is theoretically aligned with person-in-context theory.[86] Person-in-context theory postulates that an adolescent's personal identity is formed based on the interaction between the adolescent and the contexts in which an adolescent is embedded. There is evidence to support that different contexts moderate the relationship between pubertal timing and substance use. For example, it has been found that association with deviant peers increases the likelihood that early developing females use cigarettes or alcohol compared with on-time females.[118] But an adolescent's understanding of their pubertal development is not based just on peer reaction but also interactions with parents, schools, neighborhoods, and media. Future research needs to explore not only proximal contextual factors such as parent-child relationship characteristics and school connectedness, but also broader contextual factors including neighborhood characteristics and exposure to media messages. The results from this line of research would help to determine if there are modifiable contextual factors that will buffer the relationship between pubertal timing and substance use.

Public Health Implications

The results from the third study of this dissertation suggest the need to consider pubertal timing as a risk factor for substance use. Pubertal timing was predictive of cigarette, alcohol, and marijuana use in this study sample. Early developing adolescents were clearly at highest risk for substance use, regardless of the measure used. When using the peer-normative measure of pubertal timing I found late developing adolescents to also be at higher risk for cigarette use in adolescence compared with on-time adolescents. The elevated risk existed primarily due to the differences seen at age 11, the first age of assessment. This supports the need for prevention programming in late childhood, because by age 11 differences in use by pubertal timing class were already present.[131]

Differences between on-time and off-time adolescents appeared to be stronger using the peer-normative measure of pubertal timing compared with the stage-normative pubertal timing measure, which supports the belief that the social process of pubertal development is more predictive of substance use than the biological process. However, parents and teachers typically present pubertal development with pre-adolescents as a purely biological process. In other words, children are given “just the facts” of puberty – what are the changes that occur during puberty, when do these changes typically happen, and what is the purpose of these changes. In order to decrease the risk of substance use among off-time developers, the conversation needs to focus not just on biological development that occurs during adolescence but also the social meaning of this development and how adolescents can positively navigate the inevitable change. This could require a significant paradigm shift in the classroom and for parents; rather than keeping talking to a minimum while the facts are presented, adolescents should be encouraged to discuss their feelings about puberty. For example, are they scared or excited about puberty? Do they have older siblings or friends who have recently started puberty and what did they think about those changes? Do they think they will be treated differently by their parents, teachers, or friends once they start changing? Pubertal timing has been found to be related to a number of health risk behaviors, ranging from aggression to sexual activity, so this reframing of the discussion of the pubertal experience could impact not only substance use but many of the behaviors known to negatively impact adolescents.

Conclusion

In summation, this dissertation adds to the substantial body of literature regarding adolescent pubertal development in a number of ways. Pubertal development is a complicated and dynamic process that is not easily assessed. There are two general ways to measure self-report pubertal timing, stage-normative or peer-normative, and they are not synonymous. And it is crucial to consider the longitudinal pattern of self-report pubertal timing, rather than assessing pubertal timing at one point in time. Early developing adolescents are at higher risk for substance use than their on-time peers, especially in early adolescence, and late developing adolescents as identified using a peer-normative measure of pubertal timing are at higher risk for cigarette use than their on-time peers. Furthermore, peer-normative pubertal timing may be a better predictor of adolescent substance use than stage-normative pubertal timing, which suggests that it is not only biological development that puts an adolescent at risk but also the adolescent's perception of that development in relation to their peers. In order to buffer the risk of abnormal pubertal timing, more work needs to be done to address the social process of puberty among adolescents.

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