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Cognitive effects of variations in pubertal timing: Is puberty a period of brain organization for human sex-typed cognition?☆

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ABSTRACT

There is considerable interest in the organizational effects of pubertal sex hormones on human sex-related characteristics. Recent evidence from rodents suggests that there is a decreasing window of sensitivity to sex hormones throughout adolescence. If adolescence also represents a period of brain organization in human beings, then the timing of exposure to sex-typical hormones at puberty should have long-term effects on sex-typed characteristics: individuals with early timing should be more sex-typed than individuals with late timing. We tested this hypothesis in 320 young adults by relating their pubertal timing (retrospective comparison to peers) to cognitive abilities that show sex differences. Results provide partial support for the hypothesis. For men, pubertal timing was inversely related to scores on a test of three-dimensional mental rotations. Effects do not appear to be due to duration of hormone exposure (time since puberty), but other potential influences need further study.

Introduction

Sex hormones present during early development are well known to have permanent effects on sex-related behaviors in a variety of species, including human beings (for reviews, see Becker et al., 2008; Berenbaum and Beltz, 2011; McCarthy, 2010; Wallen, 2009). In people, for example, prenatal androgens masculinize a variety of sex-typed characteristics. The most compelling evidence concerns activities and interests, with androgens facilitating interest and engagement in male-typical activities. There is also good evidence for masculinizing effects of prenatal androgens on spatial abilities, sexual orientation, and some personal and social characteristics, such as aggression and interest in babies.

Recent work has renewed interest in puberty as another organizational period for the effects of sex hormones (Romeo, 2003; Schulz et al., 2009a; Sisk and Zehr, 2005). In particular, Sisk and colleagues proposed that the brain has decreasing sensitivity to the organizational effects of sex hormones across age, with the window of sensitivity closing in early adulthood. Evidence to support this hypothesis comes from several studies in rodents, as seen in the following examples. First, adult mating behavior in gonadectomized male Syrian hamsters was facilitated by testosterone administration simulating early or on-time puberty, but not by testosterone administration simulating late puberty; this shows that delayed puberty is associated with brain insensitivity to organizational effects of sex hormones (Schulz et al., 2009b). Second, food-guarding behavior in female rats was disrupted (became male-typical) when they were gonadectomized neonatally or pubertally, but not in adulthood; this suggests that this sexually dimorphic behavior is organized by ovarian hormones prior to adulthood (Field et al., 2004). Third, brain estrogen expression and sexual receptivity in adult female mice was reduced when they had been exposed to stress in adolescence, but not in early adulthood; this indicates that adolescent stress suppresses estrogen and interferes with the organization of adult mating behavior (Laroche et al., 2009). Moreover, female mice exposed to stress in early adolescence showed more disturbed sexual behavior than those exposed to stress in late adolescence, emphasizing the importance of timing of exposure even within adolescence (Ismail et al., 2011). The role of puberty in organizing the brain and behavior has not been well-tested in primates (human or nonhuman), but it seems likely that such effects exist, given the extensive cross-species similarities in organizational effects of early hormones (see, e.g., Becker et al., 2008; Berenbaum and Beltz, 2011; McCarthy, 2010; Wallen, 2009).

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If human beings also show declining sensitivity to organizational effects of sex hormones at puberty, then timing of pubertal development should have long-term behavioral effects: the age at which adolescents experience puberty should be inversely associated with the sensitivity of the brain to the sex hormone surge, and consequently, the effectiveness of those hormones (Schulz et al., 2009a). Thus, individuals with early timing should be more sex-typed than individuals with late timing. The sex hormones that are important are thought to be those that are sex-typical, that is, androgens for males, and estrogens for females.

There is keen interest in the hypothesis that puberty is another organizational period for human behavior, but there have been no direct tests of it because human hormones cannot be manipulated experimentally (Berenbaum and Beltz, 2011; Blakemore et al., 2010; Forbes and Dahl, 2010; Steinberg, 2008). Nevertheless, existing data collected for other purposes provide some indirect evidence for the potential behavioral importance of pubertal timing. First, sex differences in some sex-typed cognitive abilities increase in adolescence (reviewed in Blakemore et al., 2009; Liben et al., 2002).

Second, variations in pubertal timing are linked to behavior problems that show sex differences (reviewed in Negriff and Susman, 2011). In one exemplar study, early maturing adolescent girls reported greater depression than on-time and late maturing girls, and on-time maturing adolescent boys reported greater substance abuse than late maturing boys (Graber et al., 1997). There is accruing evidence that some behavioral effects of pubertal timing persist into adulthood (Copeland et al., 2010; Graber et al., 2004; Zehr et al., 2007). Although these links are often considered to reflect social processes (e.g., responses from peers and adults to a youth's changing body), it is possible that they reflect hormone effects.

Third, variations in pubertal timing have been examined in relation to cognition, although data were not specifically collected to test hypotheses about declining sensitivity to pubertal hormones. One set of studies was designed to test the hypothesis that puberty is a period of brain reorganization responsible for cognitive sex differences (male superiority in spatial abilities and female superiority in verbal abilities). Waber (1976) proposed that "sex differences in mental abilities … reflect differences in the organization of cortical function that are related to differential rates of physical maturation" (p. 572); she hypothesized that the male superiority in spatial skills and female superiority in verbal skills reflect boys' later maturation compared to that of girls. Her hypothesis was partially confirmed: late maturing boys and girls had higher spatial abilities (but not lower verbal abilities) than their early maturing counterparts. The neural mechanism underlying this effect was originally considered to be hemispheric specialization (lateralization), but confirming evidence was not straightforward, and Waber (1979) later suggested that some unspecified brain reorganization occurred during puberty that was related to sexual differentiation. Although there were some replications of Waber's results, there were also failures to replicate (see Linn and Petersen, 1985), and the inconsistencies led to declining interest in the hypothesis. Further, individuals were assessed during puberty in most studies (including Waber's original study), making it difficult to differentiate effects of pubertal timing from effects of pubertal status. Note that the association between pubertal timing and cognition was hypothesized to be in the same direction for girls but in different directions for boys by Waber (1976) versus Sisk and colleagues (Schulz et al., 2009a).

A second set of studies relevant to understanding cognitive consequences of pubertal timing focused on effects of lifetime estrogen exposure in women. These studies suggest that a longer reproductive period (from menarche to menopause) is associated with better cognition in later life, including verbal fluency (e.g., Ryan et al., 2009), consistent with hypotheses of both Waber (1976) and Sisk and colleagues (Schulz et al., 2009a). But, it is unclear whether effects reflect timing of initial estrogen exposure or duration of exposure, and whether effects are unique to female-superior cognitive abilities (versus overall cognitive function).

The purpose of the present study is to examine the association between pubertal timing and sex-related cognitive abilities in mature individuals. We set out to test the hypothesis of Sisk and colleagues regarding consequences of declining sensitivity to hormones (Schulz et al., 2009a), but we also considered our results in relation to the hypothesis of Waber (1976). Moreover, we tested whether timing-cognition links reflect duration of exposure to sex hormones, given that timing and duration are correlated. Using cognitive measures that show sex differences, we expected that early maturing individuals would perform better than late maturing individuals on sex-congruent tasks (spatial abilities for men and verbal abilities for women), and that such effects would not reflect time since puberty (duration of exposure).

Method

Participants

Participants were undergraduate students at a large public university in the Mid-Atlantic United States. They were selected from the university psychology subject pool, which consists of students enrolled in introductory psychology courses. Students at least 18 years of age were recruited from the pool across two consecutive semesters (1012 women and 524 men) to complete a self-report pubertal timing measure (described below), as part of a mass screening questionnaire. Responses to items on the pubertal timing measure were used to select participants for cognitive testing; individuals who reported early and late puberty were oversampled to ensure sufficient range in pubertal timing.

The final sample receiving cognitive testing consisted of 320 participants (203 women and 117 men) between 18 and 32 years of age ($M = 19.49$, $SD = 1.55$). The greater number of women than men in the sample reflects the demographics of the subject pool. Most participants were Caucasian (87%) and in their first year of college (71%). Men ($M = 20.05$, $SD = 1.96$) were older than women ($M = 19.16$, $SD = 1.14$), $t(318) = 5.16$, $p < .001$. Data from five participants were excluded: three participants (two men and one woman) were outliers with respect to age (three standard deviations above the mean), and two participants (women) were distracted during testing. In the final sample, men ($M = 19.88$, $SD = 1.41$) were older than women ($M = 19.11$, $SD = .83$), $t(313) = 6.11$, $p < .001$, so age was covaried from analyses of sex differences.

Measures and procedure

Participants completed a supervised online survey in a research laboratory. The hour-long survey contained cognitive tests and items about personal–social characteristics. Students received course credit for participating.

Pubertal timing

Participants were asked to provide the age at which they achieved a specific pubertal event (menarche for women and spermarche for men) and the timing of four pubertal events in relation to peers; the events are listed in Table 1 (women) and Table 2 (men). These events were chosen because they are the best self-report indicators of gonadarche, the phase of puberty during which gonadal sex hormones increase markedly (Dorn et al., 2006). Relative to their peers, participants indicated when they experienced each event: 1 (*much earlier*), 2 (*somewhat earlier*), 3 (*the same*), 4 (*somewhat later*), or 5 (*much later*). Responses to the four items were averaged to create a composite relative pubertal timing score; 10 men and 1 woman were missing data, so they had composite scores consisting of 3 averaged items. Similar measures (recalled age and relative timing) have been shown to be valid and reliable (Dorn et al., 2006; Dubas et al., 1991).