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Puberty timing and fluid intelligence: A study of correlations between testosterone and intelligence in 8- to 12-year-old Chinese boys

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Summary Sex hormone such as testosterone was recently recognized as an important contributor of spatial cognition and intelligence during development, but the relationship between puberty timing and intelligence especially in children is largely unknown. Here in this study, we investigated the potential relationship between the level of sex hormones in saliva and fluid intelligence in 8- to 12-year-old Chinese boys. Fluid intelligence was measured by the Cattell's Culture Fair Intelligence Test. 1600 children aged 8—12 years were included in the Cattell's Culture Fair Intelligence Test and saliva samples were collected thereafter from 166 boys with normal intelligence distribution, composed of 49, 54 and 63 boys in 8-, 10- and 12-year-old group respectively. The level of salivary testosterone and estradiol was measured with enzyme-immunoassay technique. Data of BMI and age were collected. The relationship between the level of salivary sex hormones and fluid intelligence was analysed by correlation test. There was no significant correlation between salivary testosterone level and fluid intelligence in 8-year-old boys, whereas there was a significant positive correlation in 10-year-old boys and a significant negative correlation in 12-year-old boys between those two variable. To verify the correlation, we performed stepwise multivariate linear regression and discriminant analysis, with both the age and BMI of the boys and their parents, and salivary estradiol level considered. The results showed that the level of testosterone and intelligence was correlated, and the correlation was much stronger when the level of salivary testosterone was higher than 14 pg/ml. In summary, the study suggests that the relationship of testosterone and intelligence varies from late childhood to early adolescence, and the puberty timing is closely related with fluid intelligence.

1. Introduction

Not only does testosterone play a crucial role in brain organization necessary for sexual development and sexual behaviour, but is also very important in cortical regions for cognition (Janowsky, 2006). Testosterone was reported to

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correlate with spatial cognition and intelligence (Nyborg, 1994, 2007; Tan, 1990a,b; Tan and Akgün, 1992; Tan et al., 1993; Tan and Tan, 1998; Kutlu et al., 2001). However, it is still unknown in which period testosterone significantly affects intelligence development. The canonical view is that sex hormones activate neural circuits sexually differentiated during prenatal neural development. Recently, Sisk and Zehr (2005) argued that adolescence might be another sensitive period for sex steroid-dependent brain organization, and the variation in the timing of interaction between puberty hormones and the adolescent brain led to individual differences in adult behavior and risks of sex-biased psychopathologies. Schulz and Sisk (2006) showed that the organizational effect of gonadal hormones in Syrian hamsters during adolescence was related not only to sexual behavior, but also to a variety of social behaviors, indicating that pubertal hormones acting on the adolescent hamster brain exerted global and long-lasting influences on their adult behavior. Therefore, we hypothesize that neural circuits contributing to intelligence may also be organized by gonadal hormones during puberty, and different puberty timing may lead to individual differences of some aspects of intelligence.

In this study, we emphasize intelligence in the sense of reasoning and novel problem solving ability, which is also called fluid intelligence (Gf). Intelligence in this sense is not controversial, and is best understood at multiple levels of analysis. Gf is distinct from crystallized intelligence (Gc), which refers to overlearned skills and static knowledge such as vocabulary. Empirically, Gf is the best predictor of performance on diverse tasks, so Gf and general intelligence (g, or general cognitive ability) may not even be distinct psychometrically (Gray and Thompson, 2004). To our knowledge, there are accumulative evidences linking fluid intelligence and puberty timing (Shaw et al., 2006; Lynn, 1994, 1999). And also there has been increasing evidence of relationship between testosterone concentration and intelligence (T-intelligence relationship) in adulthood (Nyborg, 2007; Tan, 1990a,b; Tan and Akgün, 1992; Tan et al., 1993; Tan and Tan, 1998; Kutlu et al., 2001).

However, investigations of T-intelligence relationship in children are still scarce and controversial. Azurmendi et al. (2005) reported a positive relationship between fluid intelligence and testosterone level in 5-year-old boys, while Ostatnikova, 2000 reported that salivary testosterone level in 6- to 9-year-old gifted children is lower than nongifted peer boys ($p < 0.01$). Ostatnikova et al. (2007) showed that at age of 6 to 9 years old, the boys of average intelligence had significantly higher testosterone level than both mentally challenged and intellectually gifted boys, with the latter two groups showing no significant difference between each other. For girls, no difference in salivary testosterone level was found among intelligence quote (IQ) groups. Testosterone level in boys keeps lower in preadolescence and increases dramatically in early adolescence, while the T-intelligence relationship in these young boys is still not clear. Here we investigated the T-fluid intelligence relationship from late childhood to early adolescent boys. Salivary testosterone concentration is regarded as an indicator of puberty timing in our study. We also tested salivary estradiol (E2) concentration because estrogen was recently reported to be involved in cognition as well (Schirmer et al., 2008). We also included body mass index (BMI) in the study since it was reported previously that a higher BMI gain in childhood was related to an earlier onset of puberty (He and Karlberg, 2001).

2. Methods

Fluid intelligence was assessed by CCFT Chinese version on the day before saliva collection. The CCFT was administered to a group of 20 students supervised by one or two teachers. In total, there were more than 1600 students from two ordinary elementary schools taking the CCFT exam, including girls and boys. Mean score and standard deviation were computed in every age group of the 1600 students. Finally, we picked out 166 boys from the 1600 children to ensure a normal distribution of fluid intelligence in each age group (8, 10 and 12 years, respectively). BMI data of the boys, BMI and age of their parents were collected by a self-designed questionnaire.

Then these 100 and 66 boys were recruited for saliva collection. They were divided into three groups according to their age: 8 years (mean: 8.53 ± 0.29, range from 8.01 to 8.99), 10 years (mean: 10.44 ± 0.26, range from 10.00 to 10.95) and 12 years (mean 12.39 ± 0.27, range from 12.01 to 12.94) with the numbers of 49, 54 and 63 respectively. All the boys included belong to the Han nationality and were from families with lower socioeconomic status.

Salivary samples were collected in January, 2007. All samples were collected at the same hours within two days because we intended to minimize seasonal and diurnal variation as much as possible. On the saliva collecting day, the boys were asked to rinse their mouth thoroughly for three times at 8 o'clock. Then 2 ml saliva were collected from each boy respectively at 9 o'clock and 10 o'clock. Contamination from food debris was avoided by rinsing the mouth with water and by delaying the collection for more than 30 min after rinsing to prevent sample dilution. Subjects were asked not to eat or drink during the interval. Saliva was collected by unstimulated passive drool. Two samples from each subject ensure more reliable hormone level because of their episodic secretion pattern. The two successive saliva samples were mixed together into one test tube before analysis in the laboratory. Samples were stored at $-20\,^{\circ}$C as soon as possible. Parental consent was obtained prior to testing. Testosterone and estradiol kits from Salimetrics LLC, State College, PA, USA were applied to determine salivary T and E2 concentrations.

3. Results

In each age group, intelligence is normally distributed (Table 1). Descriptive statistics showed that salivary T concentration increased significantly with age, but salivary E2 concentration not, with a significantly higher mean concentration in 10-year-old boys than the other two age groups (Table 1). Differences in CCFT scores and salivary T and E2 concentrations between the three age groups were tested by one-way ANOVA with post-hoc Bonferroni comparison to determine individual group differences. A probability value of 0.05 or less was considered significant. ANOVA indicated that (1) CCFT scores increased with age. 8-year-old boys scored significantly lower than 10-year-old and 12-year-old