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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

Table 1 Descriptive Statistics of CCFT scores and salivary sex hormone concentrations.

	Age	Minimum	Maximum	Mean	SD
Salivary T (pg/ml)	8	0.52	32.37	7.33	5.22
	10	4.44	32.57	14.20	7.01
	12	0.55	75.14	26.54	18.94
Salivary E2 (pg/ml)	8	0.04	2.49	0.53	0.45
	10	0.09	5.74	1.25	1.13
	12	0.07	3.52	0.86	0.74
Salivary T/E2 ratio	8	3.89	125.73	23.27	26.64
	10	3.40	203.73	19.25	27.13
	12	1.69	203.39	45.20	40.38
CCFT scores	8	5.00	30.00	21.67	6.10
	10	11.00	37.00	26.60	5.58
	12	13.00	40.00	28.70	5.52

boys, while the difference between 10 and 12-year-old boys was not statistically significant. (2) salivary T level was significantly different between three groups ($F = 31.364$, $p = 0.000$), and dramatically increased with age ($p < 0.05$, $p < 0.01$).

3.1. Correlations in separate age groups

Pearson Correlation-coefficients were computed between salivary T, E2 concentrations, T/E2 ratios (salivary T concentration to E2 concentration), BMIs and intelligence test performance in each group (Table 2). Salivary T, E2 concentrations and T/E2 ratios were log transformed when necessary. The results showed that (see Fig. 1): in 8-year-old group, there was no significant correlation among salivary T, E2 concentrations and CCFT scores; in 10-year-old group, there was a positive correlation among salivary T, E2 concentrations and CCFT scores((T-CCFT: $r = 0.385$, $p < 0.01$, E2-CCFT: $r = .353$, $p < 0.01$); while in 12-year-old group, a negative correlation was detected between salivary T level and CCFT scores ($r = -0.361$, $p < 0.05$). The correlations between T, E2, T/E2 ratio, BMI and four subtests of CCFT were also displayed in Table 2.

3.2. Regression analysis in different T level groups

Correlation analysis unfolded a transition of positive to negative correlation between salivary T and fluid intelligence from age 10 to 12. To investigate T-intelligence correlation in all cases, curve estimation was used to sketch an overview of T-CCFT relationship. Curve estimation analysis showed a significant quadratic correlation between salivary T concentration and CCFT score (R square = 0.083, $p = 0.001$, see Fig. 2). According to the correlation results and curve observation, all cases were then divided into two groups according to mean salivary T concentration (14 pg/ml) of 10-year-old boys. The two groups were named higher-T group (T > 14 pg/ml) and lower-T group (T < 14 pg/ml). Stepwise multivariate linear regression was used to investigate whether there was a

Table 2 Correlations between salivary sex hormone concentrations and fluid intelligence (CCFT scores), using the Pearson correlation analysis.

Age	Variables	CCFT score	CCFT subtests			
			Series	Classification	Matrices	Topology
8	LgT	0.031	−0.102	0.070	0.045	0.136
	E2	−0.052	0.041	0.051	−0.216	0.010
	LgT/E2	0.006	−0.122	0.051	0.164	−0.086
	Boy's BMI	0.109	0.079	0.217	−0.001	0.018
10	T	0.385**	0.375**	0.082	0.226	0.296*
	LgE2	0.353**	0.355**	0.206	0.189	0.151
	LgT/E2	−0.084	−0.088	−0.135	−0.039	0.044
	Boy's BMI	0.102	−0.048	0.125	0.059	0.133
12	T	−0.361*	−0.435**	−0.225	−0.361**	0.037
	LgE2	−0.138	−0.194	−0.138	−0.233	0.215
	LgT/E2	−0.184	−0.267*	0.001	−0.196	−0.057
	Boy's BMI	0.033	−0.018	0.085	−0.034	0.049

* $p < 0.05$.
** $p < 0.01$.

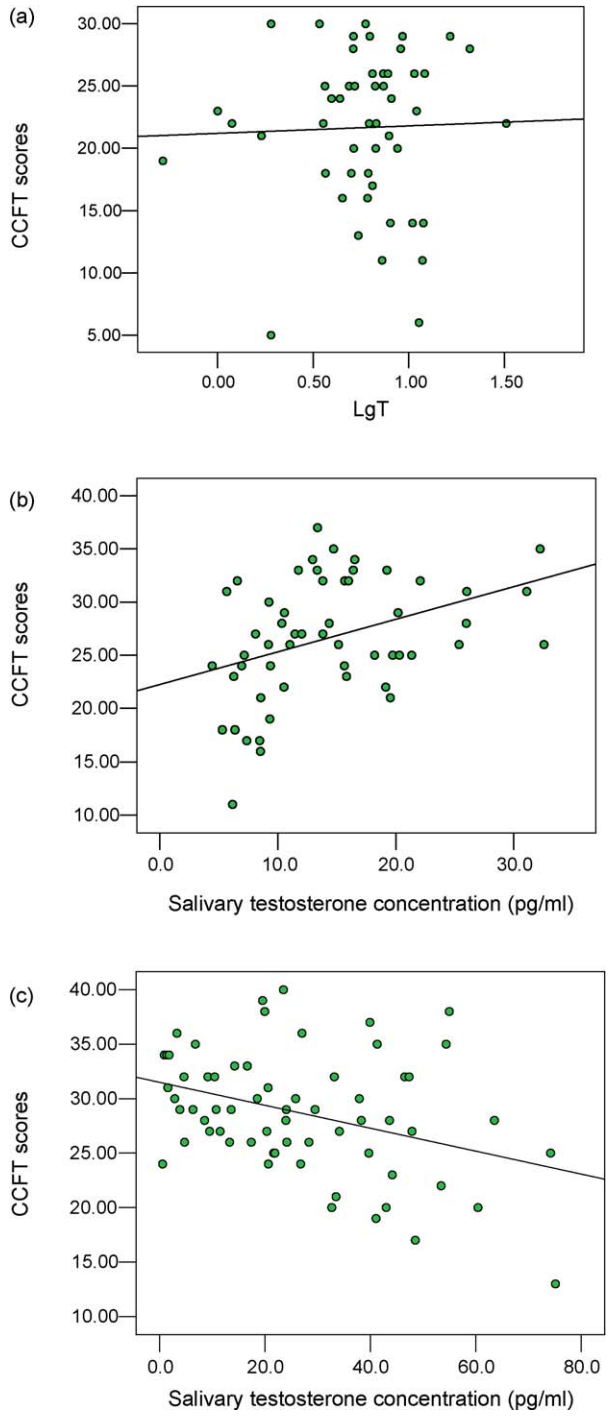

Fig. 1 Scatter spots showing correlations between salivary T concentrations and CCFT scores in the age groups.

significant correlation between salivary T concentration and fluid intelligence with age considered and whether salivary E2 concentration was a regulator. Results of regression showed: (1) in both groups, E2 concentration was not a significant regulator; (2) in the lower-T group, the level of salivary T had no correlation with CCFT scores, while age was a strongest effector on CCFT scores in this group (R^2 of the model was 0.223, $p = 0.000$, Fig. 2); (3) in the higher-T group, age did not play a significant role, while salivary T concentration was the predictor of the regression model (R^2 of the model was 0.058, $p = 0.042$, Fig. 2).

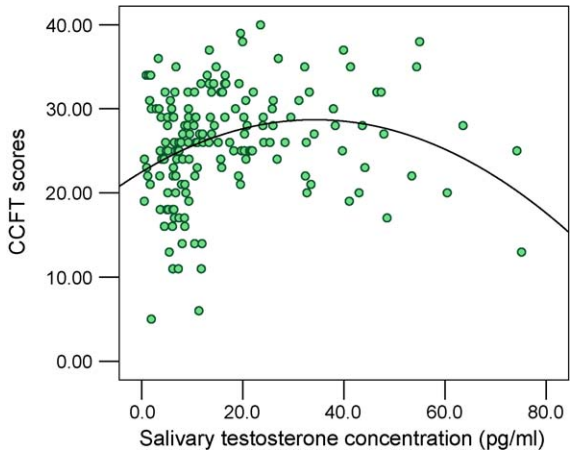

Fig. 2 Curve estimation on the relationship between salivary testosterone concentrations and CCFT scores.

3.3. Discriminant analysis

To evaluate the accuracy of salivary testosterone concentration as a predictor of CCFT score in the sample studied with BMI and parental variables considered, discriminant analysis was used in further investigation. Intelligence level was used as a grouping variable. This time the 166 boys were divided into three groups according to their intelligence scores, with approximately equal number of subjects in each group. The three groups were: higher intelligence (CCFT score > 28), average intelligence (CCFT score range: 24—28) and lower intelligence (CCFT score < 24). Independent variables included age of boys, salivary T and E2 concentrations, age and BMI of their parents. A discriminant model was obtained and it contributed to 83.2% of variance (eigenvalue = 0.257, canonical correlation coefficient = 0.452, $p = 0.003$). The dicriminant model was expressed as (Model 1):

$$\begin{aligned} D = {} & 0.872 \times \text{boy Age} + 0.290 \times \text{father BMI} \\ & - 0.028 \times \text{mother BMI} + 0.014 \\ & \times \text{boy BMI} + 0.687 \times \text{father Age} \\ & - 0.545 \times \text{mother Age} + 0.042 \times \text{LgT} \\ & + 0.133 \times \text{LgE2} \end{aligned} \quad \text{(Model 1)}$$

Age of the boys and their parents, salivary T concentration, and BMI of their mothers were most strongly correlated with the discriminant function. Cross validation results showed that according to the above model, 48.9% of original grouped cases was correctly classified and 43.0% of cross-validated grouped cases were correctly classified. The rates of accuracy for classification were qualified.

4. Discussion

Children in late childhood are exposed to steroid hormones derived from adrenarche, but the level of hormones starts to

increase dramatically in early adolescence because of gonadarche. To our knowledge, the current study is the first to detect a change in the relationship between the level of salivary testosterone and fluid intelligence from late childhood to early adolescence.

The main finding of our study was that for boys, the correlation between the level of salivary testosterone and fluid intelligence did change from late childhood to early adolescent. Studies from Ostatnikova, 2000; Ostatnikova et al., 2007 indicated a negative or nonlinear correlation in 6–9 years old boys, but we found that testosterone and estradiol did not correlate with fluid intelligence in 8-year-old boys. One explanation of these inconsistent results about 8-year-old boys may be that we selected cases with intelligence normally distributed in each age group, which is different from the previous studies (Azurmendi et al., 2005; Ostatnikova, 2000; Tan and Tan, 1998). A normal distribution of intelligence is more representative of the population, so the results might be more convincing. The positive T-intelligence and E2-intelligence correlation in 10-year-old boys is a new result to this field, while the negative T-intelligence correlation in 12-year-old boys is not consistent with Tan's result of nonlinear T-intelligence correlation in young males (Tan and Tan, 1998). The reason might be that the adolescent brain development is dynamic and protracted. While the development occurs over the course of a decade or more, much is unknown about what will happen to the group of boys with age >13 which was not included in our study. Another preferred explanation of our negative correlation results in 12-year-old boys is that puberty timing might be a factor that influences fluid intelligence development. Early maturing may have disadvantage to male for the development of fluid intelligence at around 12 years old, although the earlier hormone secretion may benefit fluid intelligence at the very beginning of early adolescence (Nyborg, 1994). Individual variation in the age of puberty onset creates individual variation in the point at which the brain is influenced by hormones, consequently creating individual variation in developmental trajectory and behavioral maturation (Sisk and Zehr, 2005). It was suggested that the inhibitory effect of testosterone on synaptic pruning may account for greater frontal lobe volume in boys than in girls (Blakemore and Choudhury, 2006). Puberty timing also separates adrenarche and gonadarche effects. Sex hormones mainly derived from adrenarche or gonadarche may exert different effects on fluid intelligence. This may also contribute to different correlation direction in these three age groups.

The nature of sex hormone–brain interaction is far from clear. Scientists have not agreed on which and how much sex hormone plays the most important role in cognitive development. Some argued there should be an optimal cerebral estradiol range for optimal intelligence performance (Nyborg, 1994), and others suggested an optimal level of early androgen exposure beyond which spatial ability actually declines (Puts et al., 2007). At least, based on these theories, we may assume that too little or too much testosterone would be deterious to cognitive development (see curve estimation in Fig. 2). We considered this as a possible explanation of positive correlation in 10 years olds and negative correlation in 12 years olds. Since a large percent of adult fluid intelligence is acquired before 12 years old, negative correlation in this age group may reflect a similar picture in adults, that is, too much testosterone may be correlated with lower fluid intelligence. On the other hand, the positive correlation in 10-years-old boys is probably because before the beginning of puberty, the majority of boys still under the optimal sex hormone range. The nearer their sex hormone levels are to the optimal range, the better they perform on the intelligence test.

Regression analysis in different T level groups confirmed the correlation between testosterone level and fluid intelligence with age considered. The results showed that in boys with lower T level (<14 pg/ml), testosterone and estradiol did not make sense in intelligence individual difference, but age was a strong effector on individual difference of intelligence. However, in boys with higher T level (>14 pg/ml), testosterone acted as a negative regulator, while age and estradiol did not have significant effect. The regression results are not sufficient for optimal sex hormone assumption unless broader age range is considered. Discriminant analysis verified T-intelligence correlation with data of BMI and age of the boys as well as their parents considered. Estradiol does not seem to play crucial roles throughout all the analyses in this study.

A limit in our study is that we did not use Tanner stage as an index of pubertal timing, while the level of testosterone is an objective indicator of pubertal development. Another shortcoming of our study is that it did not cover the whole adolescence period, or even the adulthood to determine the dynamic changes afterwards. In our future studies, we will cover a wider range of age or find more evidence from longitudinal studies. And the future studies would also benefit from considering prenatal androgen exposure.

In conclusion, according to our results, puberty timing is related to fluid intelligence as early as in late childhood and at the beginning of adolescence, which reminds us of paying attention to effects of sex hormones on intelligence development when feeding our children. Intervention methods should be used to lower abnormally high testosterone level in early maturing boys and boys with obesity. It is better for us to explain this conclusion in an intra-individual view that boys who enters puberty early under certain unusual circumstance would not acquire as high intelligence as he could within his own genetic and environmental background.

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Conflict of interest

All the authors declare that they have no conflicts of interest.

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