Research paper

Acta Neurobiol Exp 2016, 76: 66–74

ACTA NEUROBIOLOGIÆ EXPERIMENTALIS

Testosterone metabolism: a possible biological underpinning of non-verbal IQ in intellectually gifted girls

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The extraordinary giftedness is apparently a unique manifestation of a mutual interconnection between genes and environment. One of the possible etiological factors of intellectual giftedness is testosterone which is believed to affect the brain organization and function. The aim of our study was to analyze associations between 2D:4D digit ratio (a proxy of prenatal testosterone) and/or salivary testosterone levels with non-verbal IQ in intellectually gifted girls. Fifty-one girls with an age range of 10 to18 years and IQ scores higher than 130 were tested. Saliva samples were collected to obtain levels of salivary testosterone. 2D:4D digit ratio was measured on both hands as an indicator of prenatal testosterone. IQ parameters were assessed employing standardized set of tests. The CAG repeat polymorphism in exon 1 of the androgen receptor gene was analyzed to assess the sensitivity of androgen receptor. Testing of between-subjects effects proved significant interactions between right and left 2D:4D ratio, genetic variability in androgen receptor, and also salivary testosterone level with non-verbal IQ in gifted girls. Our results point out that the variability in parameters of androgenicity contributes to the variability of nonverbal IQ in gifted girls. However, the exact molecular mechanism of how testosterone acts on the brain and affects this cognitive domain remains still unclear.

Key words: testosterone, intellectually gifted girls, androgen receptor, 2D:4D, non-verbal IQ

INTRODUCTION

Although the etiology of giftedness is a widely debated topic, its molecular mechanisms still remain unclear. Common folklore claims "the genius is born, not made". Results from a large sample study support this belief and prove the pleiotropic effect of various genes. Genes were shown to be responsible for about half of the correlation between verbal and nonverbal cognitive abilities (Trzaskowski et al. 2013).

A widely accepted opinion about the sex differences in intelligence quotient (IQ) is that both males and females possess the same average IQ. However, some authors observed a small advantage in IQ for males compared to females of the same age. This was shown mostly from age 15 and above (Flores-Mendoza et al. 2013, Lynn and Tse-Chan 2003). Also, literature reports a presence of a clear specific gender difference. For example, men were shown to retain greater variance in the distribution of their IQ than females (Hedges and Nowell 1995). The question arises whether this effect can be partly explained by different testosterone exposure divergently affecting brain organization in both the genders. Recently, there is an increasing number of published evidence on the links between the effect of biological factors/hormones, brain anatomy, physiology, and cognitive performance (Filova et. al 2015, Haier et al. 2004, 1992, Mitsushima et al. 2009). Geschwind and Galaburda (1985) suggested testosterone could play a role as a possible determinant of brain organization in giftedness. Their model of cerebral dominance hypothesizes that concentrations of testosterone higher than normal *in utero* may inhibit aspects of the brain development (typically aspects of left-hemisphere functioning) while enhancing other areas (typically right-brain development). This developmental trajectory among gifted males or females might be later responsible for extraordinary mathematical performance, although it is closely connected with the increased probability of language-related disorders (Geschwind and Galaburda 1985). Several neurobiological phenomena (for example right hemisphere dominance, disproportionate left-handedness, disabilities in

Received 25 August 2015, accepted 11 March 2016

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verbal development) were reported in a gifted population to prove their atypical brain organization (Winner 2000).

The action of testosterone is limited within the boundaries of genetic background of the individual. Its effect on tissues, brain being no exception, can be mediated via the androgen receptor (AR) in a classical genomic pathway. An androgen receptor is a nuclear transcription factor whose N-terminal transactivation domain is encoded by a variable sequence of CAG triplets with a normal range from 11 to 30 repeats in humans (Greenland and Zajac 2004). Within this range, higher number of CAG repeats (indicating lower transactivational activity of AR) positively correlates with increased speed of neural transmission (measured in simple reaction experiments). Moreover, population differences in the number of CAG triplets were shown to be accompanied with differences in IQ. Based on these findings, AR is presumed to be a modifier of both the neural transmission speed and intelligence (Manning 2007).

Circulating levels of testosterone were also documented to be associated with cognitive performance. Azurmendi and others (2005) found a positive correlation between fluid intelligence and salivary testosterone levels in 5 year old boys, and a negative relationship between verbal intelligence and androstenedione levels in girls. In 8 to 12 year old Chinese boys, a correlation between salivary testosterone and intelligence was also revealed. Interestingly, the strongest correlation was reported when testosterone levels were increased, indicating the link between puberty timing and fluid intelligence (Shangguan and Shi 2009). However, no clear correlation was observed between the concentration of steroid hormones and intelligence in a healthy adult population (Flegr et al. 2012). The population of intellectually gifted individuals has not been widely studied. Our previous study revealed lower salivary testosterone levels in intellectually gifted prepubertal males compared with a control population (Ostatnikova et al. 2007). The role of testosterone in affecting the variability of exceptional IQ is still unknown in both the gifted males and females.

The fact that men predominate in the group of the intellectually gifted individuals, along with the increasing number of evidences confirming that sex steroid hormones organize brain architecture (Goel and Bale 2008, Hedges and Nowell 1995) modulating cognitive functioning it allows one to hypothesize that testosterone can be considered as a striking biological factor being involved in the etiology of an exceptional intellectual profile. The majority of already published studies have focused on the analysis of adult males or prepubescent boys, while no noticeable attention was paid to the biology of extraordinary cognitive abilities in girls. The aim of our study was to investigate whether prenatal testosterone exposure, salivary testosterone levels, and variability in androgen receptor contribute to the variability of IQ, particularly in the population of gifted girls in pubertal age.

METHODS

Fifty-one intellectually gifted girls between 10 and 15 years of age participated in our study. Girls were attending the special school for intellectually gifted pupils founded in Bratislava, Slovak Republic. Participants and their parents were informed about the concept of the study, and signed the inform consent. There is no sample overlap between the current report and our prior papers published on giftedness in adolescence (Durdiakova et al. 2015, 2013).

All procedures were approved by the Ethics Committee of the Faculty of Medicine and the University Hospital in Bratislava, Slovak Republic. The ethics committee is independent and is organized and operates according to ICH GCP 135/95 requests and the applicable laws and regulations. Participants were requested to collect one saliva sample into sterile tubes (Sarstedt, Nümbrecht, Germany) between 8:00 to 10:00 AM. with respect to the circadian rhythm of testosterone. All volunteers were instructed not to eat, drink, or wash their teeth 30 minutes prior to the collection procedure.

General intellectual ability was assessed with the standardized general Wechsler Intelligence Scale for Children, 3rd. ed. (WISC-*III*). The complete test assessing general intelligence was administered individually to each child and evaluated by a trained professional psychologist.

Genomic DNA from saliva was extracted using the silica membrane based kit (Qiagen, Hilden, Germany) following the manufacturer's instructions (QIAamp DNA Blood Mini Kit Handbook 04/2010) according to the DNA purification protocol for blood/body fluids. The (CAG)n repeat polymorphism in exon 1 of the androgen receptor gene was amplified using polymerase chain reaction (PCR) in 20 µl reaction volume with 250 nmol/L primers: forward 5´ GCGCGAAGTGATCCAGAAC 3´ tagged with *6-carboxyfluorescein* and reverse 5´ CTCATCCAGGACCAGGTAGC 3´, 1× Taq buffer (Fermentas, Vilnius, Lithuania) and 1U of Taq DNA polymerase (Fermentas, Vilnius, Lithuania). The following PCR program was used: initial denaturation step at 94°C for 4 min, followed by 35 cycles each consisting of denaturation at 94°C for 45 s, annealing at 59.5°C for 45 s, and polymerization at 72°C for 45 s. The length of the final fragment was 181 bps. The number of repeats was analyzed by capillary electrophoresis. AR gene is located on the X chromosome. Two AR alleles are present in women, of which one is randomly inactivated. According to previously published literature, the number of repeats in two alleles can be averaged to yield the biallelic mean (Migeon 2007). For the female sample in this study the average CAG number of the two alleles was reported .

ELISA assay, using the commercial Salivary Testosterone ELISA kit, was used according to manufacturer's instructions (DRG Instruments GmbH, Marburg, Germany). The intraassay coefficient of variation was 4.3% and the interassay variation was 7.2%.

It has been proposed that the second-to-fourth digit (2D:4D) ratio may be a proxy of prenatal androgen exposure, i.e. low 2D:4D ratio is associated with high prenatal androgen exposure (Beaton et al. 2011, Manning et al. 2000, 1998, Manning and Fink 2008, Manning and Robinson 2003, Zheng and Cohn 2011). Participants ventral surface of both their hands were scanned. The length of the second and fourth digit was measured and calculated using Auto Metric software (http://facelab.org/debruine/Programs/autometric.php). Measurements were conducted by a single observer.

Multivariate analysis of covariance (MANCOVA) was used to confirm the significance of the effect of individual parameters of androgenicity (salivary testosterone, digit ratio and sensitivity of androgen receptor) on nonverbal and full-scale IQ. Correlation analyzes between IQ and biological data were performed using Pearson's test. Table 3 summarizes results of simple correlations between all variables described by a correlation coefficient (r). P-values less than 0.05 were considered significant. Holm-Bonferroni method was used to counteract the problem of multiple comparisons in correlations. The correction was applied for eight individual parameters possibly correlated with nonverbal IQ and eight individual variables possibly correlating with for full-scale IQ. For the correlation between parameters of androgenicity, 28 individual comparisons were corrected. GraphPad Prism 5 and SPSS Statistics were used for the statistical analyzes.

RESULTS

In our study we analyzed several biological parameters related to testosterone and its metabolism. We tested intellectually gifted girls (N=51) with mean age of 13±1 (mean ±SD) and averaged IQ scores of 136±6 (mean ±SD). Descriptive statistics are summarized in Table I.

Table I. Descriptive statistics of analyzed parameters in the group of gifted girls

parameter	mean ±SD
age (years)	13±1
salivary testosterone (pmol/L)	92±69
2D:4D_R	0.989±0.032
2D:4D_L	0.985±0.028
delta R-L 2D:4D	0.005±0.033
(CAG)n in AR_averaged	22±2
full-scale IQ	136±6
nonverbal IQ	126±9

Test of between-subjects effect shows statistically significant effect of independent variables (salivary testosterone levels, mean CAG in AR, mean right–left 2D:4D) on the dependent variable (IQ, nonverbal IQ). It revealed (Table II) that the 2D:4D ratio on the right hand ($F=5.35$, $P<0.05$, $df=1$), left 2D:4D ratio ($F=5.57$, $P<0.05$, $df=1$), mean right–left 2D:4D ($F=5.73$, $P<0.05$, $df=1$), genetic variability in androgen receptor ($F=4.39$, $P<0.05$, $df=1$), and also salivary testosterone level ($F=5.47$, $P<0.05$, $df=1$) contribute to the variability of nonverbal IQ in gifted girls. The model test confirmed the model as a whole accounts for the variance in the dependent variable (nonverbal IQ) ($F=1.99$, $P=0.05$, $df=12$). Significant effect of right ($F=6.20$, $P<0.05$, $df=1$), left ($F=6.13$, $P<0.05$, $fd=1$), and mean right–left 2D:4D ($F=6.69$, $P\leq0.01$, $df=1$) on full-scale IQ in gifted girls was observed. The variation in analyzed parameters involved in this model did not significantly contribute to the variation in the dependent variable (total IQ) ($F=1.38$, P=ns, $df=12$).

Table II. Results of testing for between-subjects effects

		F	Sig	df	PES
2D:4D_R	nonverbal IQ	5.35	0.03	1	0.12
	full-scale IQ	6.20	0.02	1	0.14
2D:4D_L	nonverbal IQ	5.57	0.02	1	0.13
	full-scale IQ	6.13	0.02	1	0.14
2D:4D R–L averaged	nonverbal IQ	5.73	0.02	1	0.13
	full-scale IQ	6.69	0.01	1	0.15
(CAG)n averaged	nonverbal IQ	4.39	0.04	1	0.10
	full-scale IQ	2.25	0.14	1	0.06
salivary testosterone	nonverbal IQ	5.47	0.02	1	0.13
	full-scale IQ	2.90	0.16	1	0.05
corrected model	nonverbal IQ	1.99	0.05	12	0.39
	full-scale IQ	1.38	0.22	12	0.30

R – right hand, L – left hand, R–L averaged – 2D:4D calculated from left and right hand, (CAG)n averaged – number of (CAG)n calculated from both alleles, PES – partial eta squared

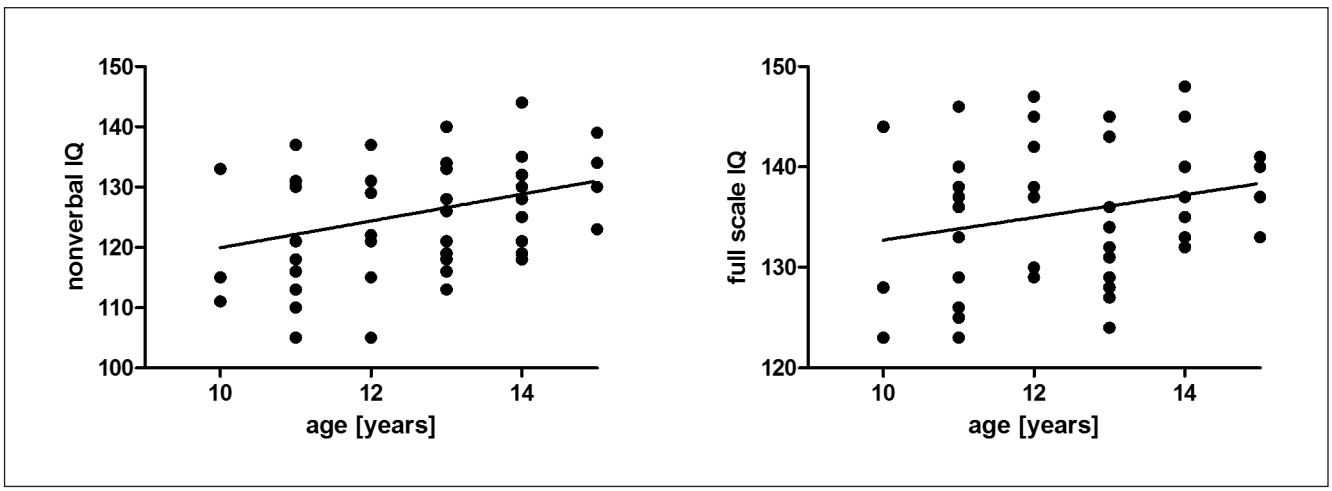

Fig. 1. Correlation analyzes between age and IQ. Nonverbal IQ score was positively correlated with age (r=0.35, p=0.01) not surviving the correction for multiple comparison. No significant effect was proved for full scale IQ (r=0.23, p=0.09).

Correlation analysis using Pearson's test (Table III) showed that the nonverbal IQ score was positively correlated with age (r=0.35, p=0.01), which does not survive the corrections for multiple comparisons, as the threshold *p*-value after Holm-Bonferroni correction was 0.0063 (for eight variables tested for the association with nonverbal IQ) (Fig. 1). No significant correlations were detected between other test variables and nonverbal or full-scale IQ (Fig. 2)

Correlations between parameters of androgenicity were also found. Left hand digit ratio is negatively correlated with biallelic mean of CAG repeats in AR (r=–0.28, p=0.04) (Tab. III). When Holm-Bonferroni correction for multiple comparisons was applied the effect did not remain significant (adjusted p-value was 0.0018). No significant correlation was detected between the average CAG number of the two alleles and baseline salivary testosterone levels (r=0.26, p=0.05), although a positive correlation between single allele and salivary testosterone was shown to be nominally significant (r=0.37, p=0.005). Higher age is correlated with higher salivary testosterone (r=0.64, p<0.0001) remaining significant after the correction was applied (adjusted p-value was 0.0018).

Table III. Correlation matrix table with the variables analyzed in population of gifted girls. Table summarizes results of simple correlation (Pearson's test) between all variables described by correlation coefficient (r). p<0.05 is considered as significant

	2D:4D_L	delta R-L	(CAG)n allele_1	(CAG)n allele_2	(CAG)n averaged	salivary testosterone	IQ nonverbal	IQ full-scale	age
2D:4D_R	0.42 p=0.002	0.62 p<0.0001	–0.31 p=0.02	–0.18 p=0.21	–0.25 p=0.07	–0.02 p=0.89	–0.06 p=0.67	–0.03 p=0.84	–0.13 p=0.35
2D:4D_L		–0.46 p=0.0004	–0.22 p=0.11	–0.23 p=0.09	–0.28 p=0.04	0.07 p=0.60	–0.07 p=0.64	0.002 p=0.98	0.02 p=0.91
delta R–L			–0.11 p=0.41	0.02 p=0.84	–0.005 p=0.96	–0.08 p=0.56	0.002 p=0.99	–0.03 p=0.83	–0.14 p=0.31
(CAG)n allele_1				0.54 p<0.0001	0.84 p<0.0001	0.37 p=0.005	–0.20 p=0.15	–0.14 p=0.34	0.28 p=0.04
(CAG)n allele_2					0.89 p<0.0001	0.16 p=0.26	–0.01 p=0.93	–0.07 p=0.63	0.27 p=0.05
(CAG)n averaged						0.26 p=0.05	–0.11 p=0.43	–0.12 p=0.41	0.31 p=0.02
salivary testosterone							0.19 p=0.17	0.17 p=0.24	0.64 p<0.0001
IQ nonverbal								0.84 p<0.0001	0.35 p=0.01
IQ full-scale									0.23 p=0.09

R – right hand, L – left hand, delta R–L – right 2D:4D minus left 2D:4D, (CAG)n averaged – number of (CAG)n calculated from both alleles

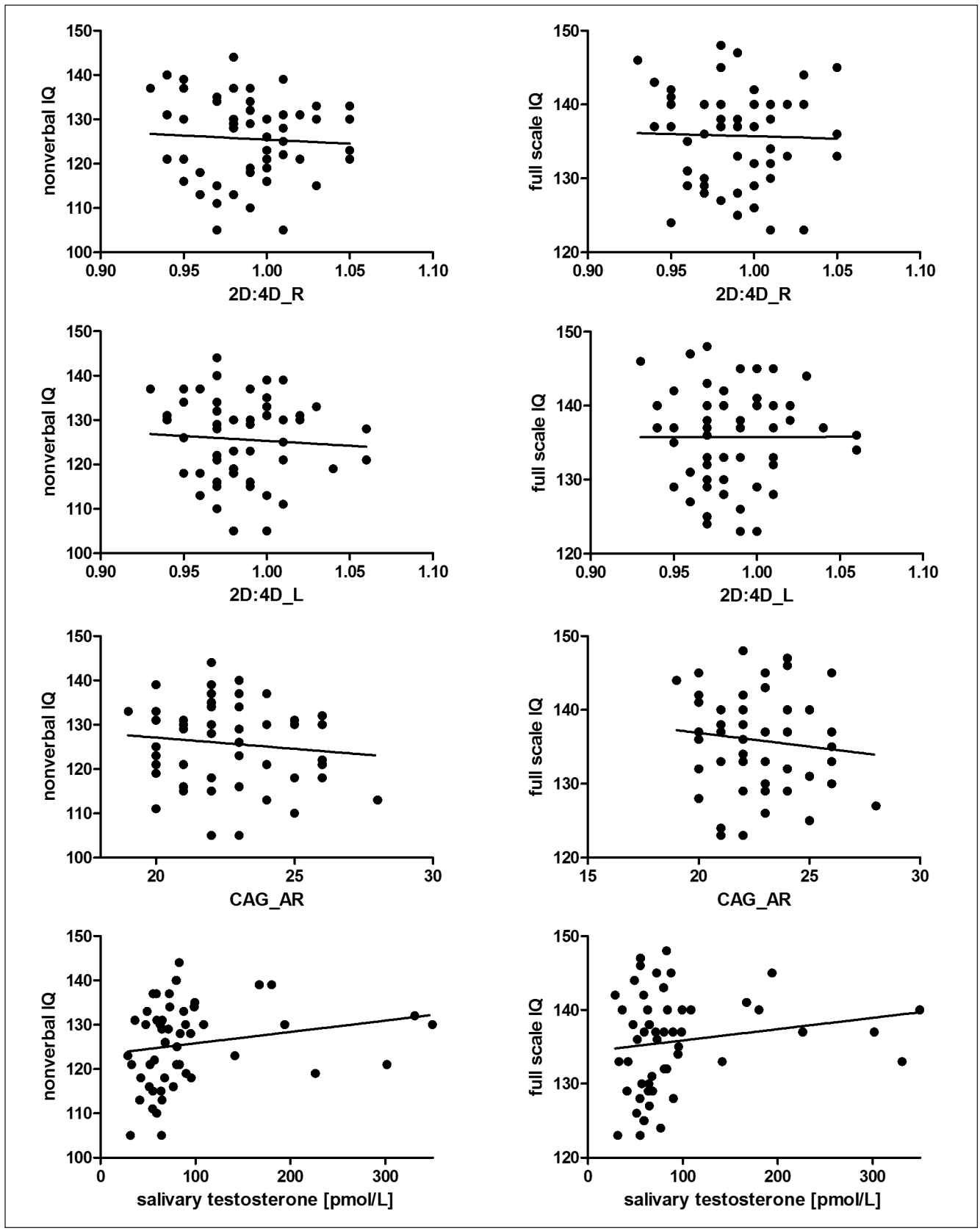

Fig. 2. Correlation analyzes between parameters of androgenicity and IQ. No significant correlation was reported between digit ratio, salivary testosterone, sensitivity of androgen receptor and nonverbal or full scale IQ. Detailed statistics in summarized in Table III.

DISCUSSION

While the origin of exceptional intelligence is an interesting and widely discussed topic, its basis still remains unclear. The model of cerebral dominance argues that concentrations of testosterone *in utero* higher than normal enhance right brain development resulting into patterns of precocity (Geschwind and Galaburda 1985). A recent review on monozygotic male twin put forward the argument of the existence of a connection between high intelligence and high testosterone levels in prenatal fetus (Fingelkurts and Fingelkurts 2002). While the effects of testosterone have been extensively studied, recently published data suggests it can be only one of the possible biological factors involved in brain organization and cognitive functions modulation (Auyeung et al. 2013).

In our study we provided evidence for a relationship between testosterone metabolism and nonverbal IQ in intellectually gifted girls in pubertal age. Multivariate analysis, a widely accepted approach of minimizing errors by introducing possible co-variants, proved that the variability in individual parameters of androgenicity had significant impact on IQ in gifted girls. We pointed out that salivary testosterone levels, prenatal testosterone exposure (reflected by 2D:4D digit ratio), and sensitivity of androgen receptor individually contributed to the variability of nonverbal IQ in this population. According previously published paper certain phenotypes cannot be predicted from single biological determinant. Activational effects of testosterone on adult social cognition may depend on early prenatal organization or the sensitivity of androgen signaling (van Honk et al. 2011). Therefore we tested whether the variance in IQ can be attributed to the potential interaction of CAG repeat polymorphism and salivary testosterone levels finding no significant effect (data now shown).

Our results point out positive correlation between salivary testosterone levels and nonverbal IQ in gifted girls. However, the risk of many other confounding variables is high. There is a reason to be skeptical about these results as they did not remain significant after Bonferroni correction. It was suggested that serum testosterone in young adults may be associated with visuo-spatial performance depending on sex and hand preference (Tan 1990). A previously published study carried out on right-handed adult males found a correlation between nonverbal intelligence and serum testosterone levels (Tan 1990). This conclusion, exhibiting a positive linear correlation between serum testosterone and nonverbal IQ, was later repeated in the study on right-handed young adult men (Tan et al. 1993). In females with consistent right-handedness, a negative linear correlation between nonverbal IQ and serum testosterone was observed. In females with moderate right-hand preference, a quadratic relationship was described between serum testosterone and nonverbal IQ (Tan 1990). Since handedness was not assessed in our study, different handedness phenotypes in a sample cannot be ruled out. Differences in the size of the sample and also the age of participants can be another source of the discrepancies between our results and already published data. It was suggested that the relationship between testosterone and intelligence varies from late childhood to early adolescence, and that puberty timing is closely related to fluid intelligence (Shangguan and Shi 2009). The fact that testosterone actually acts as a precursor of estradiol in some brain areas makes the studied topic even more complex. In future, large sample studies are necessary to confirm and clarify the mutual relationship between testosterone and nonverbal IQ.

Since the androgen receptor is the major mediator of testosterone action, a possible relationship between genetic variability in AR and specific cognitive function (affected by testosterone) can be assumed. The exact explanation of the relationship remains unclear due to the lack of relevant data. Based on the findings from population studies, it can be assumed that the higher number of CAG repeats along with lower DNA binding activity and weaker androgen signaling (Ding et al. 2004) might lead to a higher general factor of intelligence (Manning 2007). In contrast, our previous research indicated that shorter alleles in androgen receptor genes relate to an enhanced sensitivity of the receptor in a population of gifted boys (Celec et al. 2013). Lee and others (2010) examined the association between cognition and AR CAG repeat length in a large cohort of older men and observed no correlation between CAG repeat length and fluid intelligence. It is important to consider genetic mosaicism in number of androgen repeats due to the double X chromosome. Approximately half of the female cells express the proteins encoded by the mother's X chromosome, and the other half express the proteins encoded by the father's X chromosome. Hence, the biallelic mean, as reported in previously published papers, was used. However, the multivariate approach confirmed that the sensitivity of androgen receptor contributes to the variability of nonverbal IQ in gifted girls. We failed to demonstrate a linear correlation between the average number of CAG repeats and either nonverbal or full-scale IQ in pubertal gifted girls indicating more complex, nonlinear interactions. The exact molecular mechanism explaining how efficacy of androgen receptor affects nonverbal cognitive functions remains to be uncovered. It is worth noting that the method reporting biallelic CAG mean might not be optimal for the interpretation of findings in females, nevertheless it is commonly used in AR research (Migeon 2007). Other literature suggests analyzes by taking only the actually active AR allele into consideration, which would be a superior method (Rajender et al. 2007). However, this was not technically possible in our sample.

Some authors argue for a contribution of androgens to brain organization, and subsequently human cognition may be limited to organizational periods (Puts et al. 2010). We assume that the higher prenatal exposure reflected by the lower 2D:4D ratio (Brosnan 2006, Kempel et al. 2005, Malas et al. 2006, Manning and Fink 2008) can be associated with the right hemisphere dominance, and thus with both the better visuo-spatial performance and increased nonverbal IQ (Geschwind and Galaburda 1985). We confirmed the role of prenatal testosterone, indicated by the 2D:4D digit ratio of both hands, in affecting the intellectual ability, and nonverbal IQ in gifted girls. Also, to our best knowledge, this is the first study exploring the relationship between 2D:4D ratio and nonverbal IQ in pubertal gifted girls. However, significant correlation between 2D:4D ratio and nonverbal intelligence was not observed. In previously published papers, interest was paid to the results on the digit ratio and general spatial cognition or mental rotation, and provided conflicting results. Some authors suggest that low prenatal testosterone levels in men are responsible for better mental rotation ability later in life (Sanders et al. 2005). In contrast, others argue that low levels of prenatal androgens in men lead to poor spatial cognition (Burton et al. 2005). The same effect was observed also within a mixed sex sample (Peters et al. 2007). Grimshaw and others (2004) found the positive correlation between prenatal testosterone levels and mental rotation for 7 year old girls. In our previous work we did not confirmed the significant correlation between 2D:4D ratio and mental rotation ability in intellectually gifted boys in pubertal age (Durdiakova et al. 2013). Even though there is a certain degree of consensus regarding 2D:4D ratio as a relevant and valid marker of prenatal testosterone effect, it always brings debates on the extent to which the 2D:4D ratio is a proxy measure of prenatal androgen (Berenbaum et al. 2009, van Anders and Hampson 2005). Moreover, one can find a number of published studies supporting the idea that prenatal testosterone may be expressed in different manners between the hands, and between both females and males, suggesting thus the results may vary significantly by sample size, and gender, but also depending on which hand is used (Nye et al. 2012, Voracek 2013, Voracek and Loibl 2009). The overall lack of consistent outcomes suggests a potential interplay of multiple factors responsible for the variance in the 2D:4D ratio, as well as for spatial cognition performance or nonverbal IQ. Nowadays, there is an increased amount of already published data on more direct measurements of prenatal testosterone from amniotic fluid rather than depending on indirect measurements. A summary of amniotic testosterone studies, as well as results of correlation studies between analyzed parameters of androgenicity within pubertal gifted girls can be found in (Baron-Cohen et al. 2004).

Also, previously published studies reported the amplitudes of right, left, mean right-left 2D:4D ratio co-vary with a polymorphic repeat CAG sequence in exon 1 of the gene coding the AR (Butovskaya et al. 2012). However, a replication study carried out with a larger sample did not confirm these conclusions (Hampson and Sankar 2012). We hypothesized lower prenatal testosterone exposure might lead to enhanced bio-potency and sensitivity of androgen receptor in later postnatal life. Our findings revealed negative correlations between either left 2D:4D ratio or mean right–left 2D:4D ratio and number of CAG repeats supporting thus our hypothesis. However, this correlation failed the correction for multiple testing and cannot be considered as a conclusive finding. Moreover, meta-analysis employing extensive literature research (N=2909) did not support associations between androgen receptor gene efficacy and 2D:4D ratio (Voracek 2014). Based on literature, circulating testosterone levels have not been found to predict the digit ratio of the left and the right hand, respectively (Beaton et al. 2011) which is consistent with our findings. Inhibitory feedback influences might explain a correspondence of less sensitive AR to increased serum androgen levels and vice versa. If this assumption is true, positive correlations of CAG repeats and circulating testosterone would be expected. However, AR research brings unambiguous data. Among women, there are papers reporting a negative, instead of positive, correlation, whereas some authors found none (Skrgatic et al. 2012, Westberg et al. 2001). Similarly in our study, no significant correlation was found between biallelic CAG mean and salivary testosterone levels, which is consistent with our previously published paper analyzing the effect among boys (Durdiakova et al. 2013). The scenario is not clear and some complex effect (nonlinear association) might be a possible explanation.

A main limitation of our study is the small sample size, as men usually predominate among gifted individuals. It is rather difficult to test gifted girls to create a well-defined and homogenous sample as used in our study. More studies with bigger sample size are definitely needed to support our findings. Girls involved in this study are in pubertal age that can be linked with changes in salivary testosterone levels (Couillard et al. 2000). According to some studies in boys, puberty timing can be connected with fluid intelligence, and the correlation between testosterone and cognitive functions was proved to be the strongest (Shangguan and Shi 2009). The stage of puberty or menstrual cycle phase was not assessed here. The absence of control group matched by education, family situation or socio-economic status is also a weakness of our study. However, it should be emphasized that the main purpose of this study was to indicate the effect of testosterone metabolism on IQ in intellectual gifted girls.

The overall complexity of etiology of exceptional IQ comprehends mutually intertwined roles and effects of various genes with pleiotropic effect, variable biological substances and environmental factors. As the goal of our study was to shed more light onto the role of testosterone in the foundation of giftedness and exceptional nonverbal cognitive abilities, we proved the effect of testosterone plays a key role in the variability of nonverbal IQ in gifted pubertal girls. Our results, together with contradicting information in the literature, indicate that the relationship between testosterone metabolism and nonverbal IQ might not be linear suggesting thus the possibility of other interfering factors.

ACKNOWLEDGEMENTS

This work was supported by grant: VEGA 1/0052/15. This contribution/publication is the result of the project implementation: Comenius University in Bratislava Science Park supported by the Research and Development Operational Programme funded by the ERDF. Grant number: ITMS 26240220086. Podporujeme výskumné aktivity na Slovensku/Projekt je spolufinancovaný zo zdrojov EÚ.

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