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The association between 2D:4D ratio and aggression in children and adolescents: Cross-cultural and gender differences

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ABSTRACT

Background: Two recent meta-analyses have suggested the association between digit ratio (2D:4D) and aggression is weak. This conclusion has been criticised because the meta-analyses conflate forms of aggression that show strong sex differences with those that do not, and most studies have considered post-pubertal participants.
Aims: We test the influence of 2D:4D and ethnicity in the expression of aggression in children and adolescents in four ethnic groups of European and African origin.
Study design: Buss and Perry aggression questionnaire. Direct measurement of the 2nd and 4th digits.
Subjects: 1296 children and adolescents from Tanzania and Russia from 4 ethnic groups – Datoga, Meru, Russians, Tatars.
Results: There were ethnic and gender differences in ratings on aggression with boys consistently reporting more physical aggression. In all four samples right 2D:4D was significantly lower in boys, compared to girls. With regard to our total sample of boys, the right 2D:4D was significantly and negatively associated with self-ratings on physical aggression, but no association was found for left 2D:4D. No associations between 2D:4D and physical aggression were found for girls. Hostility was negatively correlated with 2D:4D for boys, and anger was positively correlated with 2D:4D in girls.
Conclusion: Sex differences were strongest for right 2D:4D (boys < girls), and for physical aggression (boys > girls). Right 2D:4D was negatively related to physical aggression in boys only, suggesting possible relationship to prenatal androgenization.

1. Introduction

There is evidence that the prenatal hormonal environment acts as a powerful determinant of gender differences in behavior [1]. However, levels of early sex hormones are very difficult to measure directly, and a readily accessible biomarker for their effects would greatly facilitate studies of the etiology of aggression. Manning et al. [2] have suggested that the ratio of second to fourth finger length (2D:4D) is a correlate of prenatal sex steroids, such that low 2D:4D correlates with high testosterone and low estrogen in the fetus and high 2D:4D with low fetal testosterone and high fetal estrogen [3]. The 2D:4D is sexually differentiated, with males tending to have longer 4D relative to 2D than females (male 2D:4D < female 2D:4D). Empirical evidence suggests there are lateralized effects in the association between 2D:4D and sex steroids. Particularly, right 2D:4D tends to show stronger associations with hormonally influenced target traits than left 2D:4D and a greater sex difference than left 2D:4D [4]. One possible explanation for this is that right 2D:4D may be more sensitive to fetal sex hormones than left 2D:4D [4,5].

The 2D:4D ratio may be directly influenced by genes. Particularly, it is known that the androgen receptor gene (AR) shows a polymorphism for CAG repeat number in exon 1 of the gene, and the number of CAG repeats ranges from CAGn = 10 to about CAGn = 30, the highest sensitivity to testosterone reported when CAGn is low [6]. The evidence that 2D:4D may be positively correlated with CAGn in men has been reported in some studies [7,8], and not replicated in others [9–12]. Loehlin et al. [10] also reported a significant positive correlation between left 2D:4D and CAGn in women. The link between 2D:4D and CAGn could be complex because high CAGn may be correlated with high production of testosterone. Hampson and Sankar were not able to show such an interaction in adults [11]. However, Knickmeyer et al. [13] have reported that CAGn and testosterone in newborns do not

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individually correlate with 2D:4D, but a composite variable of CAGn and testosterone was significantly related to 2D:4D, such that low CAGn and high testosterone are related to low 2D:4D, as well as low CAGn negatively related to aggression in males [14].

In recent large-scale genome-wide association meta-analysis, a weak support for an association between AR CAG-repeat length and 2D:4D on both hands were found, but for women only [15]. There have been reports of 2D:4D measured directly in both fetuses and children, confirming that human fetal 2D:4D sexual dimorphism appears early, probably by the end of the first trimester [16]. This finding has been replicated in a mouse model by Zheng and Cohn [17]. In humans, Galis et al. [18] measured 2D:4D in 327 deceased human fetuses, ranging from 14 to 42-weeks-old, and reported a small, but significant sexual dimorphism, with mean 2D:4D in males being lower than in females. The fetal 2D:4D was lower than earlier reported for children and adults. The strength of the sexual dimorphism in fetuses was similar to that found for children, but lower than for adults. The 2D:4D ratio may increase after birth in both men and women, with the second digit growing faster than the fourth digit, thus the sexual dimorphism may be determined both, by prenatal as well as by postnatal developmental processes. Other studies suggest that in children the sexual dimorphism is determined early in life, and 2D:4D remains relatively stable with growth [19,20].

Prenatal androgens might play organizational effects on the developing brain by increasing its sensitivity to testosterone in later life [17,21]. In this regard, aggression (particularly physical aggression) may be one such trait that is influenced by the organizational changes brought about by prenatal sex hormones [8,22–23]. Relatively recent data revealed a significant positive correlation between 2D:4D ratio and gray matter volume of the dorsal anterior cingulate cortex (dACC), a brain region supporting emotion regulation, conflict monitoring, and behavioral inhibition [24]. The reduced (masculinized) gray matter volume in the dACC mediated the relationship between 2D:4D ratio and aggression in women, but not men [24]. Analyses of associations between 2D:4D and target traits have included aggression [4], risk-taking [25], Big Five personality traits [26,27], sensation-seeking [28], same-sex friendship choice [29], impulsivity and neurochemical receptor genes [30], conduct disorders in children [31] in addition to various endocrinology dysfunctions, mental disorders [32], cardio-vascular and other health problems [5,33], general life expectancy [34].

At present there is controversy concerning the nature of the links between 2D:4D and various types of aggressive behavior. The prediction is that low ("masculinized") 2D:4D ratio will be associated with aggression, particularly with physical aggression. In accordance with this low 2D:4D has been reported to be associated with higher physical aggression, predominantly in adult men, but not in women [35], as well as for adolescent boys opposed to girls [36]. A significant negative correlation was observed between 2D:4D ratio and aggression in soccer players [37] and in street fighting [38]. There have also been a number of reports of no association between 2D:4D and aggressive behavior both in men and women and in traditional and modern societies [22]. Meta-analyses have concluded that associations between 2D:4D and aggression are weak and close to being non-significant but that correlations between 2D:4D violent behavior are stronger and significant [39,40]. Various forms of aggressive behavior vary with regard to their sex differences. Ellis & Hoskin [41] and Hoskin & Meldrum [42] have suggested that 2D:4D is significantly related to those forms of aggression that are more common among men (e.g. physical aggression).

"The challenge hypothesis", originally proposed to explain the testosterone-aggression associations in monogamous birds, recently, has been successfully used to explain patterns of aggression in humans [43]. It predicts that testosterone would rise around puberty to support the reproductive physiology and behavior. Sexual arousal and physical challenges, associated with sexual competition would raise testosterone levels in young men and facilitate direct competitive behavior, including aggression [44,45,50]. A decline in testosterone following paternal involvement with infants reported in humans has been in line is consistent with predictions of challenge theory [46–48]. There is growing evidence that the relationship between aggression and 2D:4D is far from simple, rather it is context specific [48–49]. Indeed, it has been reported that the association between 2D:4D and aggression became more obvious under challenge situations, including sports-related competition and experiments with "challenges" that may stimulate short-term spikes in testosterone [37,49–55]. This "challenge hypothesis" may be linked to short-term spikes in testosterone in competitive situations and its association with 2D:4D and various forms of aggression.

Much previous research into the links between 2D:4D and aggression has focused on adults and in particular university undergraduates, or sportsmen. A few ethnic studies based on relatively large population samples provided further evidence of stable sex difference in 2D:4D ratio in European, Oriental and Black children, with boys having lower 2D:4D compared to girls [36,56–58]. The relationships between 2D:4D and aggression on the largest ever presented sample of children and adolescents, represented by a Russian sample, revealed a negative association between 2D:4D and aggression in boys, but not in girls [36].

The goals of current study are to test the influence of biological (2D:4D as a marker of prenatal androgenization and age) and cultural (ethnic and gender roles) variables in the expression of aggression in children and adolescents in the largest ever sample, representing two populations of European (Russia, two ethnic groups) and African (Tanzania, two ethnic groups) origin. We will then consider whether these new findings support an interpretation of the links between 2D:4D and aggression in the light of the "challenge hypothesis".

2. Materials and methods

2.1. Participants

The total sample consisted of 1296 children and adolescents (607 boys, 689 girls) of the ages from 9 to 20 years ($M \pm Std = 13.74 \pm 1.87$) from Tanzania ($n = 480$) and Russia ($n = 816$). Individuals > 18 years (0.4% of the total sample) were included in the African sample and considered in the analysis, as in Tanzania students of these ages are not exceptional in the last classes of secondary school. Ethnicity was determined on the basis of respondent's self-reports The Tanzanian sample comprised members of two ethnic groups – Datoga and Meru (all were students in boarding school), and the Russian sample comprised Russians and Tatars.

2.1.1. The Datoga

The Datoga are traditional, seminomadic pastoralist people, known in Tanzania by different names (Tatoga, Taturu, Barabaig, or Mang'ati). Their language is linked to the Kalenjin cluster of the southern Nilotic languages – a branch of the eastern Sudanic language family [22,59]. The Datoga population is estimated with 50,000 to 100,000 [60]. The Datoga are polygynous and male reproduction is positively related to their wealth [22,59,61].

2.1.2. The Meru

The Meru (Wameru, Rwa, Rwo) of Tanzania live in the south-eastern and eastern slopes of Mount Meru. They practice intensive agriculture. 94% of Meru are Christians (75% protestants, 25% Catholics), and 3% adhere to Islam. Anthropologically, Meru are metis population, formed by the mixing of Eastern Bantu and Maasai tribes [62]. The Meru are a typical example of a patriarchal, patrilocal, clan-organized society [62,63].

2.1.3. The Russians

The Russian people of this sample are schoolchildren from the modern urban environment, including the city of Moscow and the greater Moscow region (Krasnogorsk) as well as Cheliabinsk. The

majority of them are Christians. The Russians are monogamous.

2.1.4. The Tatars

The Tatars are a Muslim group from the Volga region (Republic of Tatarstan). They are the westernmost of all Turkic nationalities living in Russia, and speak Turkic language. The basis of the traditional economy of the Volga Tatars was agriculture, cattle breeding, crafts and trading (Rorlich, 2017). The Tatars are bilingual, i.e. they speak Turkic and Russian languages. They are monogamous, but polygamy occurs under the influence of Islam.

2.2. Questionnaires

All participants completed a demographic questionnaire to determine their age, sex, and ethnicity, and the Buss and Perry [64] aggression questionnaire (AQ). The AQ had been used in a variety of settings [8,14,22,23,36], has moderate construct validity and high test-retest reliability [65]. The questionnaire comprises 29 statements corresponding to four subscales: physical aggression (nine items), verbal aggression (five items), anger (seven items), and hostility (eight items). The AQ uses a Likert–type scale for responses, ranging from one (extremely uncharacteristic) to five (extremely characteristic). We used the Russian and Swahili versions, which were initially translated and validated by us, and applied in previous studies [8,36,66]. If a subject omitted at least one item, the subscale to which this items belonged for him/her was not calculated. Reliabilities (Cronbach α) for the AQ subscales were as follows: physical aggression (Russia: 0.68; Tanzania: 0.63), verbal aggression (Russia: 0.52; Tanzania: 0.53), anger (Russia: 0.62; Tanzania: 0.60), hostility (Russia: 0.60; Tanzania: 0.59).

2.3. Digit ratio

After completing the questionnaires, the 2nd and 4th digits of participants were measured directly (with a Vernier caliper measuring to 0.01 mm) from the basal crease to the tip on both hands [2]. Where there was a band of creases at the base of the digit, the most proximal crease was used [67]. Participants who reported injuries or deformities of the 2nd or 4th digits were excluded from the statistical analysis. Direct measurements avoid the problem of distortion when palms are being placed on a photocopier or scanner [68] and are straightforward to collect in field settings. Each measurement was collected twice from all participants. The means of the first and second measurement of right and left 2D and 4D, the right and left 2D:4D ratios were calculated following the procedure as described by Manning et al. [2,3]. The intra-class correlation coefficient (ICC) was used to assess the repeatability of right and left hand 2D:4D. The ICCs were 0.93 and 0.94 for the right 2D:4D and left 2D:4D in the Russian sample and 0.94 and 0.93 for the Tanzanian sample, respectively.

The protocol was approved by the Scientific Council of the Institute of Ethnology and Anthropology of the Russian Academy of Sciences. All participants provided consent for participation, either written or verbal. The local school administrations were informed about the purpose of this study and gave their consents.

3. Results

Gender differences in 2D:4D ratio and Buss-Perry AQ Scales ratings in each of four study groups of children and adolescents are given in Table 1. We found significant gender differences in 2D:4D ratio on the right hands in all ethnic groups, on the left 2D:4D ratio in all Russians and Meru children (Table 1). No sex differences were found in aggression scales in Datoga children and adolescents. In Meru, Russian children and adolescents we found significant gender differences in physical aggression, but not in Tatars. Verbal aggression was significant for Tatar only, anger and hostility – for Russians (Table 1). Ethnic differences on AQ subscales and 2D:4D ratio for males and females are presented on Figs. 1 and 2.

A series of 2 (ethnicity) x 2 (sex) ANOVAs with right or left 2D:4D as dependent variables revealed the following results. There was an effect of ethnicity on right 2D:4D ($F_{(3,1282)} = 51.278$, $p < 0.001$, eta-squared = 0.107) and left 2D:4D ($F_{(3,1088)} = 12.462$, $p < 0.001$, eta-squared = 0.033). Right 2D:4D of the Datoga and Meru was lower than those of Russians (Bonferroni post-hoc test, $p < 0.001$, and $p < 0.01$, respectively) and Tatars (both $p < 0.001$, and $p < 0.01$), with no difference between Datoga and Meru ($p = 1.00$), and Russians and Tatars ($p = 1.00$). Sex differences (males < females) were detected for right 2D:4D ($F_{(1,1282)} = 21.909$, $p < 0.001$, eta-squared = 0.017) and left 2D:4D ($F_{(1,1282)} = 15.499$, $p < 0.001$, eta-squared = 0.014). There was no interaction effect of ethnicity * sex on either right 2D:4D ($p = 0.791$) or left 2D:4D ($p = 0.251$).

With regard to age of participants, there were differences between the ethnic groups ($F_{(3,1288)} = 34.892$, $p < 0.001$, eta-square = 0.075) but no sex difference ($p = 0.139$). Datoga participants were older than Meru, Russians, and Tatars (all $p < 0.001$) with no difference between the latter three ethnic groups.

A multivariate analysis of covariance (MANCOVA) was performed with the four AQ measures as dependent variables, ethnicity and sex as factors, and age as covariate. Table 2 summarizes the multivariate statistics of the MANCOVA. The main effects of sex were significant for all scales except verbal aggression. For ethnicity and age main effects were detected for verbal aggression and anger. In all cases the effect sizes were small.

To further investigate the relationships between measures of aggression and 2D:4D, linear regression analyses were performed for the whole sample with the AQ scales as dependent variables, and independent variables sex, age and right or left hand 2D:4D respectively (Tables 3 and 4). The linear regressions, conducted for the total sample, revealed the significant effects of R2D:4D in a negative direction for physical aggression and hostility, and significant negative effect of sex for physical aggression and positive effect of sex for hostility (Table 3). The significant positive effects of sex, age and R2D:4D for anger were obtained, and positive effects of R2D:4D and age for verbal aggression were demonstrated (Table 3). When the left hand 2D:4D was included in regressions instead of the right hand 2D:4D, sex was the only significant and negative predictor in the case of physical aggression, anger was significantly positively associated with sex and L2D:4D, and hostility was positively correlated with sex (Table 4). Significant positive effects of L2D:4D and age were reported for verbal aggression (Table 4).

We tested the direction and significance of the effects of R2D:4D and L2D:4D on AQ scales ratings separately for each sex with regression analysis. For boys the effect of R2D:4D for physical aggression was significant and negative ($F_{(1,604)} = 5488$, $p = 0{,}019$) (Fig. 3a), but not significant for girls ($F_{(1,679)} = 0{,}531$, $p = 0{,}467$) (Fig. 3b). The effects of the left hand for physical aggression were not significant for both sex: boys ($F_{(1,517)} = 1178$, $p = 0{,}278$), girls ($F_{(1,573)} = 0{,}014$, $p = 0{,}908$) (Fig. 4a, b). The effect of R2D:4D for anger was not significant for boys ($F_{(1,605)} = 0{,}1534$, $p = 0{,}216$), and positively significant for girls ($F_{(1,680)} = 15{,}865$, $p = 0{,}0001$) (Fig. 5a, b). For the L2D:4D, significant positive effects for anger were obtained for boys ($F_{(1,518)} = 4089$, $p = 0{,}044$), as well as for girls ($F_{(1,574)} = 8289$, $p = 0{,}004$) (Fig. 6a, b). For the hostility scale, the effect of R2D:4D was significantly negative for boys ($F_{(1,603)} = 6836$, $p = 0{,}009$), and not significant for girls ($F_{(1,680)} = 3024$, $p = 0{,}082$) (Fig. 7a, b). The effect of the L2D:4D on hostility for boys was significantly negative ($F_{(1,518)} = 3892$, $p = 0{,}049$), and insignificant for girls ($F_{(1,574)} = 0{,}007$, $p = 0{,}932$) (Fig. 8a, b). For verbal aggression the effect of the R2D:4D was significant and positive both for boys ($F_{(1,605)} = 6055$, $p = 0{,}014$), and girls ($F_{(1,679)} = 5223$, $p = 0{,}023$) (Fig. 9a, b). The effect of L2D:4D on verbal aggression was not significant for both sex: boys ($F_{(1,518)} = 2703$, $p = 0{,}101$), and girls ($F_{(1,\ 573)} = 3644$, $p = 0{,}57$) (Fig. 10a, b).

Table 1
Gender differences in 2D:4D ratio and Buss-Perry AQ Scales ratings in study groups of children and adolescents (*t*-test).

Ethnic	Parameters	Sex	N	Mean	Std. deviation	*t*	*p*	95% confidence interval of the difference	
								Lower	Upper
Datoga	2D:4D ratio right hand	Male	35	0.937	0.035	−2.254	**0.028**	−0.03889	−0.00231
		Female	25	0.957	0.035				
	2D:4D ratio left hand	Male	32	0.974	0.037	−0.336	0.738	−0.02496	0.17796
		Female	25	0.978	0.043				
	Physical aggression	Male	35	22.83	4.872	1.060	0.293	−11,267	3,66385
		Female	25	21.56	4.104				
	Verbal aggression	Male	35	14.43	3.728	−0.995	0.324	−3.0471	1.02420
		Female	25	15.44	4.093				
	Anger	Male	35	16.49	4.481	0.896	0.374	−12,404	3.25183
		Female	25	15.48	3.991				
	Hostility	Male	35	20.94	4.795	−0.752	0.455	−3.5778	1.62351
		Female	25	21.92	5.187				
Meru	2D:4D ratio right hand	Male	194	0.938	0.043	−2.832	**0.005**	−0.01960	−0.00354
		Female	225	0.950	0.041				
	2D:4D ratio left hand	Male	111	0.955	0.037	−4.266	**0.000**	−0.03183	−0.01172
		Female	119	0.977	0.041				
	Physical aggression	Male	194	22.51	5.055	3.158	**0.002**	0.60038	2.57953
		Female	226	20.92	5.218				
	Verbal aggression	Male	194	14.07	4.172	−0.614	0.539	−10,505	0.55070
		Female	226	14.33	4.150				
	Anger	Male	194	16.60	4.180	0.890	0.374	−0.43518	1.15464
		Female	226	16.24	4.090				
	Hostility	Male	194	21.06	6.638	0.330	0.742	−1.0116	1.41975
		Female	226	20.86	6.001				
Russian	2D:4D ratio right hand	Male	352	0.968	0.036	−6.273	**0.000**	−0.2177	−0.01139
		Female	401	0.984	0.035				
	2D:4D ratio left hand	Male	351	0.976	0.034	−5.330	**0.000**	−0.01806	−0.00834
		Female	401	0.989	0.033				
	Physical aggression	Male	351	21.74	7.837	2.587	**0.010**	0.33626	2.45141
		Female	406	20.35	6.984				
	Verbal aggression	Male	352	16.34	6.707	1.719	0.086	−0.10626	1.60430
		Female	406	15.59	5.274				
	Anger	Male	352	16.93	5.969	−3.641	**0.000**	−2.5264	−0.75649
		Female	407	18.57	6.381				
	Hostility	Male	352	18.97	6.186	−4.000	**0.000**	−2.8219	−0.96391
		Female	407	20.87	6.762				
Tatar	2D:4D ratio right hand	Male	26	0.959	0.033	−2.878	**0.006**	−0.04325	−0.00774
		Female	31	0.984	0.033				
	2D:4D ratio left hand	Male	26	0.968	0.049	−1.676	0.099	−0.04047	0.003603
		Female	31	0.987	0.043				
	Physical aggression	Male	26	24.23	6.042	1.586	0.118	−0.64767	5.56082
		Female	31	21.77	5.637				
	Verbal aggression	Male	26	12.58	3.276	−3.286	**0.002**	−5.9265	−1.4358
		Female	31	16.26	4.858				
	Anger	Male	26	15.23	4.519	−1.201	0.235	−4.3767	1.09630
		Female	31	16.87	5.596				
	Hostility	Male	26	19.77	5.062	−1.774	0.082	−4.8195	0.29345
		Female	31	22.03	4.564				

4. Discussion

Aggression is a complex phenomenon affected by many factors and their interactions, including genes, hormones, family and social environment, as well as education. Our data revealed, significant cultural and gender differences in ratings on Buss-Perry AQ Scales, adolescent boys rating more physical aggression in all four ethnics which is in line with generally reported world tendencies [69,70]. Particularly, similar data were obtained for physical aggression with Buss-Perry instrument for US, Argentinean, Greek, Italian, Russian, Ossetian, Chinese, Indian (West Bengal and Karnataka) and Turkish samples [36,71–79]. There was some inconsistency in gender difference on the rating for the other three scales in our four samples, which is, again in line with reports of other scholars. For example, girls scored higher on indirect scales, such as anger and hostility in Greek samples [77], but no gender differences on AQ scales were found for Iranian adolescents [80].

The latter raise the question of ethnic differences in self-ratings on aggression, possibly associated with social desirability and social expectations. In our sample, maximum ratings on physical aggression was demonstrated by Tatars in each sex cohort, maximum anger in Russian girls, and maximum hostility ratings in Tatar girls. However, these data had limitations, as two of our samples (Datoga and Tatars) were rather small.

As in majority of previous data reported [2,4,18,22,30,31,35,36,55,58,67,81], in all the four samples tested by us in this study, the right hand digit ratios were significantly lower in boys, compared to girls. Although, a few studies did not find sex differences, or even reported differences in the reverse direction [82,83]. The data on sex differences in 2D:4D as a possible proxy for prenatal androgenization may be particularly important, while searching for possible predictors of physical aggression. Although, the evidence that 2D:4D is correlated with the androgen receptor gene (AR) polymorphism for CAG repeat number in exon 1 in men is inconsistent [7–12], it was found by us earlier, that the number of CAG was negatively correlated with aggression in adult men and their reproductive success in some traditional African populations [23].

In this study we found, the right 2D:4D ratio was significantly and negatively associated with self-ratings on physical aggression Buss-

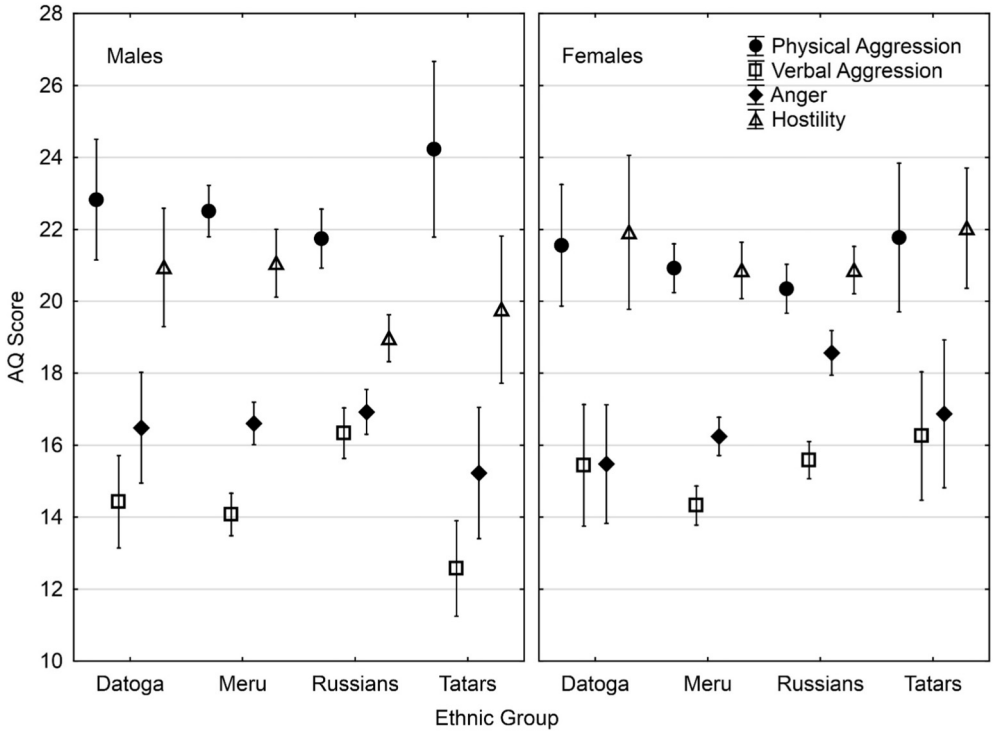

Fig. 1. Mean scores on AQ subscales in males and females from four ethnic groups.

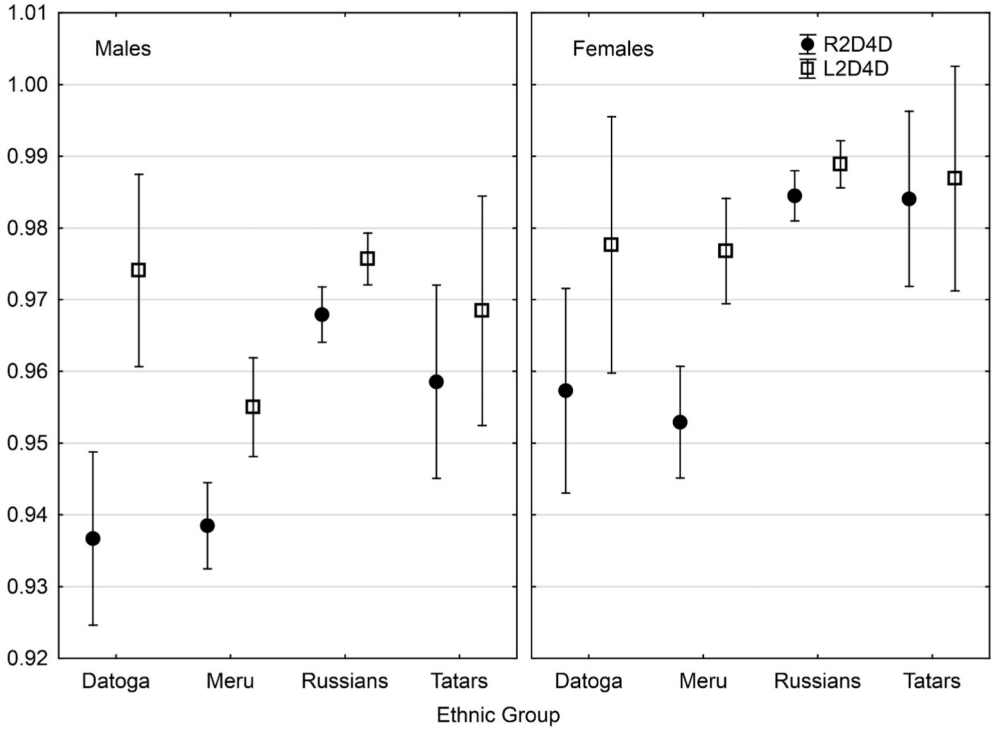

Fig. 2. Mean digit ratios in males and females from four ethnic groups.

Perry AQ for boys, while no effect of L2D:4D was obtained for this subscale. No associations between digit ratios on any of hands and physical aggression were found for girls. These differences may be interpreted as support for the original hypothesis concerning digit ratio as a marker of prenatal androgenization. Hostility was negatively correlated with right 2D:4D in both sexes, but this effect was significant for the boy's sample only. Besides, the L2D:4D effect on hostility was significant in boys as well. These findings may be due to correlation between physical aggression and hostility ratings in adolescents, given the high level of competition in this period of life history.

There was a significant positive effect of R2D:4D for AQ anger scale in girls, and positive effect of L2D:4D for anger in both sex. The effect of prenatal estrogenization may be suggested as one of possible explanation. The R2D:4D was also positively associated with ratings on verbal aggression, same explanation may be also valid here as well.

To sum up, our relatively large sample of children and adolescents,

Table 2
The MANCOVA test with AQ subscales as dependent variables and sex, ethnicity as independent variables and age as covariate.

Independent variables	Dependent variables	df	Mean square	F	Sig.	Partial eta squared
Sex	Physical aggression	1	704.618	16.382	0.000	0.013
	Verbal aggression	1	0.813	0.029	0.865	0.000
	Anger	1	293.003	9.745	0.002	0.008
	Hostility	1	476.757	11.940	0.001	0.009
Ethnic	Physical aggression	3	94.369	2.194	0.087	0.005
	Verbal aggression	3	364.121	13.016	0.000	0.029
	Anger	3	288.594	9.598	0.000	0.022
	Hostility	3	83.817	2.099	0.099	0.005
Age	Physical aggression	1	4.420	0.103	0.749	0.000
	Verbal aggression	1	480.508	17.176	0.000	0.013
	Anger	1	338.063	11.244	0.001	0.009
	Hostility	1	58.136	1.456	0.228	0.001

a. R squared (physical aggression) = 0,018 (adjusted R squared = 0,015).
b. R squared (verbal aggression) = 0,036 (adjusted R squared = 0,032).
c. R squared (anger) = 0,032 (adjusted R squared = 0,028).
d. R squared (hostility) = 0,016 (adjusted R squared = 0,012).

represented by four ethnic groups from two countries – Russia (Europe) and Tanzania (East Africa), demonstrated a negative association between the right hand 2D:4D ratio and physical aggression in boys (although, the effect size was relatively small), but not in girls. For the left hand this effect was not obtained. These data are an important addition for already existing findings, concerning the possible effect of prenatal androgenization in utero. The differences, obtained in this study for the right hand and the left hand, may be explained by the fact that the right 2D:4D is more sensitive to fetal sex hormones than left 2D:4D [4,5].

There have been a number of reports that the association between 2D:4D and aggression becomes significant under challenge situations, or provocation [49–54]. Challenge conditions also lead to an increase in upper body strength and the 2D:4D ratio has been reported to show a negative correlation with hand grip strength after exposure to challenge condition (aggressive video show) [55]. The associations of lower 2D:4D ratio and higher aggression were more consistent in situations of real sporting competitions (real challenge situations) [37,54,55]. Functional explanation being currently provided: the relationship between 2D:4D ratio with aggression may be due to a testosterone-spike in response to a challenge situation [53,55]. Our findings may be directly related to these data. We hypothesize that in the evolutionary perspective the physical competition may be very strong among boys (but not girls) in the adolescence period. Ability to compete may be important for gaining higher positions in social hierarchies among same-sex peers, and may be beneficial for obtaining higher status in adulthood (as being positively connected with reproductive success). This transitional age-period in many traditional cultures has been strongly associated with various kind of initiation ceremonies and advertisements of individual strength and fighting abilities. For boys such ceremonies also include physical competition and demonstration of endurance, and in some cultures (Datoga, Maasai being examples), aggression may be positively encouraged by adults. This may explain why the negative associations between the right 2D:4D and physical aggression was found in our study for adolescent boys (but not girls). Other scholars on the basis of data on large representative sample of schoolchildren around 11–12 years of revealed the association of lower R2D:4D with high sprinting speed, endurance and hand grip strength in boys, but not in girls [84]. Of course, a social desirability of boy's competitive qualities may influence the self-ratings on physical aggression, and obscure the prenatal androgenization effect.

Our study has certain limitations. Measurement errors may not be totally excluded, and thus they are likely to attenuate the correlations obtained. Another limitation of our study concerns the small sample sizes of the two of our tested ethnic samples, causing some problems with data interpretation for separate ethics, hence such analyses for association between 2D:4D and AQ scale ratings were not conducted. It has been said that the 2D:4D may be an inexact measure of prenatal T exposure, and it may be influenced by a number of factors, which were not considered in our study. Effect sizes for 2D:4D vary from strong (e.g. associations with middle- and distance-running speed) to weak (the Big Five). Such variance is unlikely if 2D:4D is a weak correlate of prenatal sex steroids [4]. The effect size of correlations of digit ratio with physical aggression (in this study) and risk taking (in other studies), are small, thus limiting the validity of predictive power of this parameter. Focusing on context in aggression, including aspects of challenge, may reveal larger effect sizes that are intermediate between that of performance in sport and personality types.. At present the digit ratio remains a useful proxy for prenatal androgenization, until other measures of prenatal testosterone with higher validity are suggested.

Table 3
Linear regression analyses with the AQ measures as dependent variables, respectively, and right 2D:4D, age, sex independent variables for the whole sample.

Dependent variable	Independent variables	N	R^2	B	Std. error	Beta	*t*	Sig.
Physical aggression	Right 2D:4D	1286	0.016	−9.376	4.542	−0.059	−2.064	**0.039**
	Age			0.060	0.100	0.017	0.601	0.548
	Sex			−1.305	0.374	−0.099	−3.489	**0.001**
Verbal aggression	Right 2D:4D	1287	0.018	14.195	3.681	0.110	3.857	**0.000**
	Age			0.274	0.081	0.095	3.389	**0.001**
	Sex			−0.253	0.303	−0.024	−0.835	0.404
Anger	Right 2D:4D	1288	0.024	15.903	3.803	0.119	4.181	**0.000**
	Age			0.228	0.083	0.077	2.739	**0.006**
	Sex			0.747	0.313	0.067	2.385	**0.017**
Hostility	Right 2D:4D	1286	0.017	−12.147	4.374	−0.079	−2.777	**0.006**
	Age			0.149	0.096	0.044	1.555	0.120
	Sex			1.402	0.360	0.110	3.896	**0.000**

Table 4
Linear regression analyses with the AQ measures as dependent variables, respectively, and left 2D:4D, age, sex independent variables for the whole sample.

Dependent variable	Independent variables	N	R^2	B	Std. error	Beta	t	Sig.
Physical aggression	Left 2D:4D	1093	0.012	4.316	5.675	0.023	−0.761	0.447
	Age			0.113	0.107	0.032	1.060	0.289
	Sex			−1.436	0.420	−0.105	−3.420	**0.001**
Verbal aggression	Left 2D:4D	1094	0.010	12.019	4.580	0.081	2.624	**0.009**
	Age			0.197	0.086	0.069	2.279	**0.023**
	Sex			−0.198	0.339	−0.018	−0.583	0.560
Anger	Left 2D:4D	1095	0.025	17.170	4.784	0.110	3.589	**0.000**
	Age			0.146	0.090	0.049	1.627	0.104
	Sex			1.002	0.354	0.087	2.834	**0.005**
Hostility	Left 2D:4D	1095	0.019	−7.015	5.387	−0.040	−1.302	0.193
	Age			0.172	0.101	0.051	1.702	0.089
	Sex			1.686	0.398	0.130	4.234	**0.000**

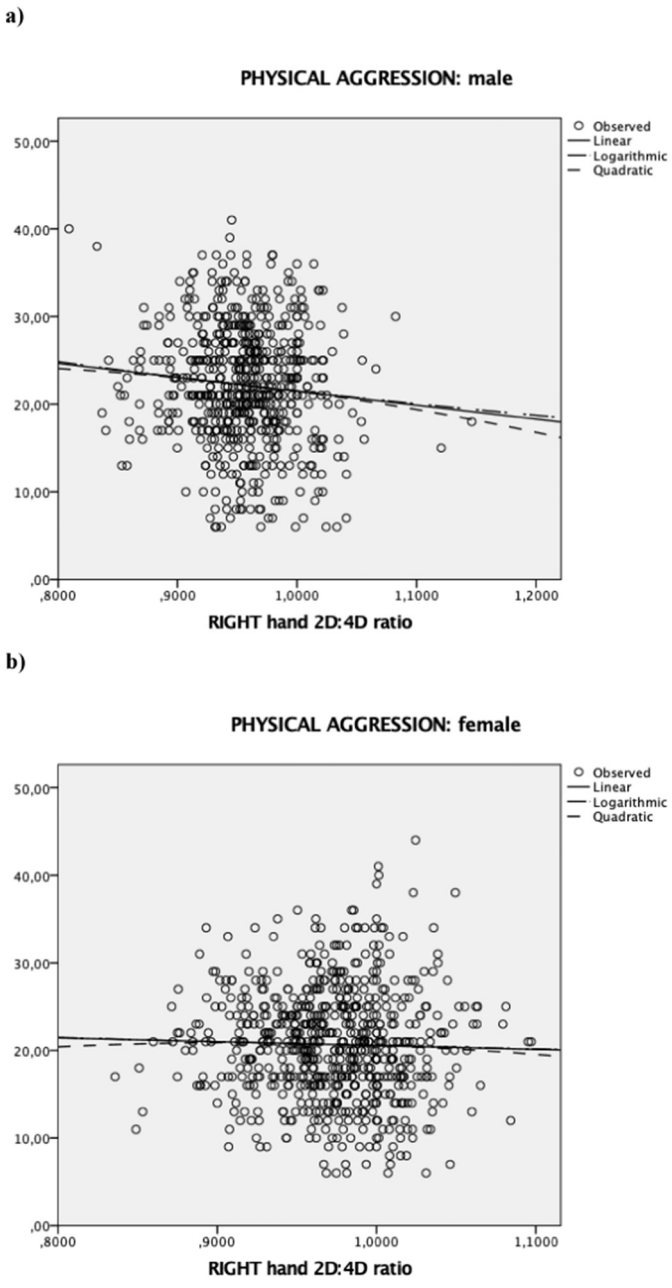

Fig. 3. Linear regression plots for physical aggression (dependent variable) and right 2D:4D ratio as independent variable: a) males, b) females.

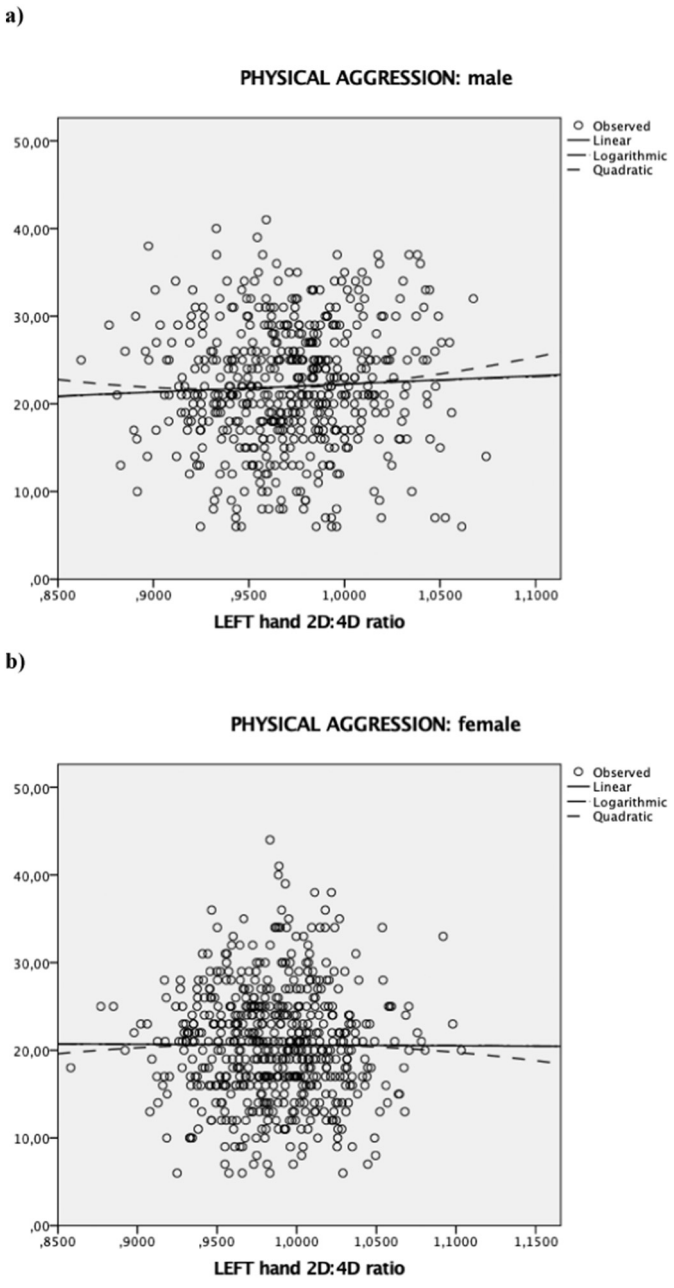

Fig. 4. Linear regression plots for physical aggression (dependent variable) and left 2D:4D ratio as independent variable: a) males, b) females.

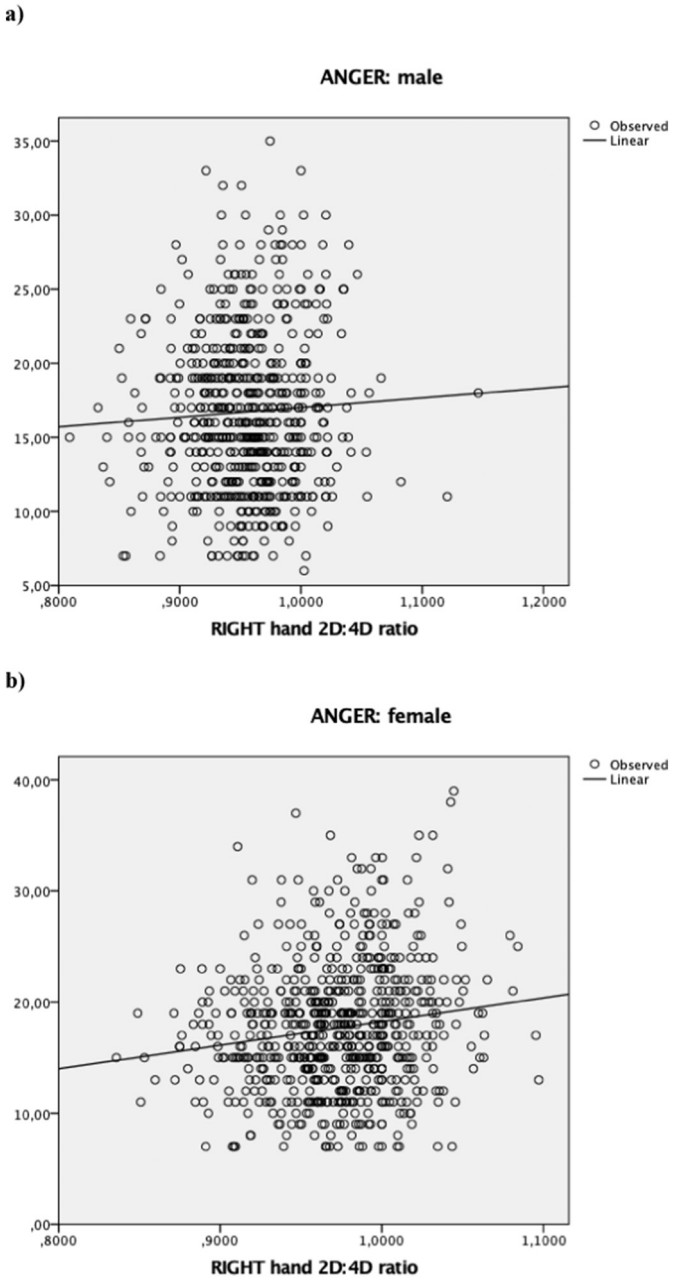

Fig. 5. Linear regression plots for anger (dependent variable) and right 2D:4D ratio as independent variable: a) males, b) females.

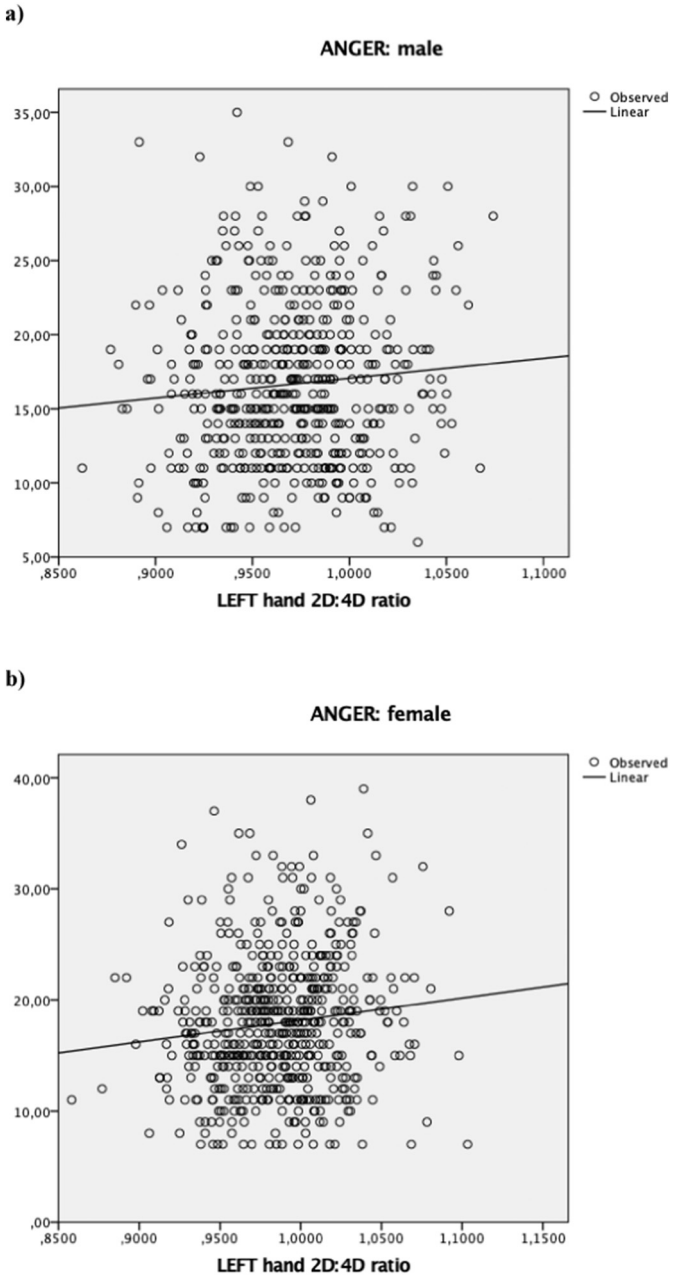

Fig. 6. Linear regression plots for anger (dependent variable) and left 2D:4D ratio as independent variable: a) males, b) females.

5. Conclusion

Given the predictions of the evolutionary neuroandrogenic (ENA) theory, when "the brain is exposed to high levels of testosterone and related 'male sex hormones', its functioning is altered in ways that increase the probability of criminality and most other behaviors for which males and females differ" [41]. In this paper we were not dealing with criminality, but tested the association between self-ratings of aggression on four AQ scales with 2D:4D in boys and girls from four populations. In line with ENA predictions, males' R2D:4D was significantly lower in all study populations, while ratings on physical aggression were higher in all our samples. The sex differences on other three scales were not consistent. Hence, our data results support earlier data [14,36,69,85–88].

Recently some authors called for more detailed studies of the association of 2D:4D with social behavior in general (including altruism, physical aggression, social centrality, etc.) [89]. Our current data revealed significant negative effect of R2D:4D on physical aggression for the whole sample in boys, but not in girls, extending previous findings [36], both studies supporting the ENA. Kováříik et al. demonstrated, that low 2D:4D ratios were negatively associated with social centrality of men in groups, but not in women, suggesting that this pattern is gender-specific as well [89].

Our data suggest that the relationship between right 2D:4D and physical aggression is sex-specific. The associations may be blurred by ethnic-specific factors, given variations in cultural attitudes, and social desirability towards the use of physical aggression in same-sex peer groups. The role of physical aggression in acquisition of high social status in peer groups may be important here. Hence, the effect of prenatal androgenization on physical aggression deserves to be considered in any case, if we are truly intend to understand the comparative aspects of human behavior.

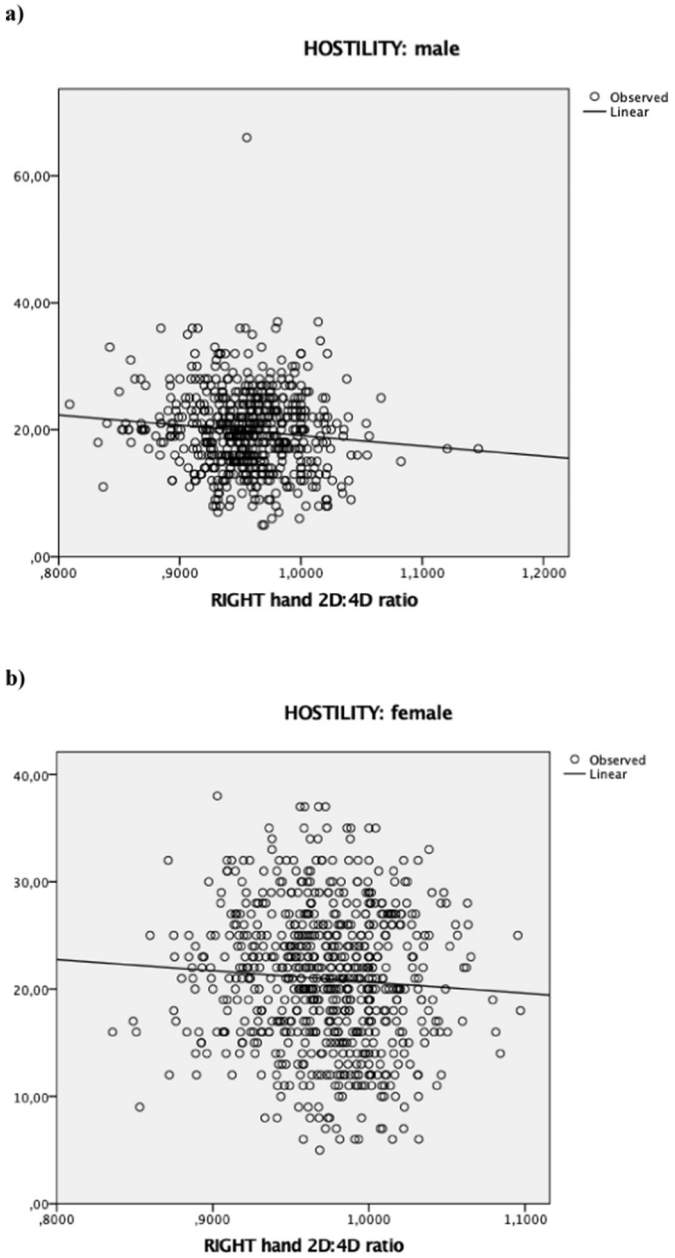

Fig. 7. Linear regression plots for hostility (dependent variable) and right 2D:4D ratio as independent variable: a) males, b) females.

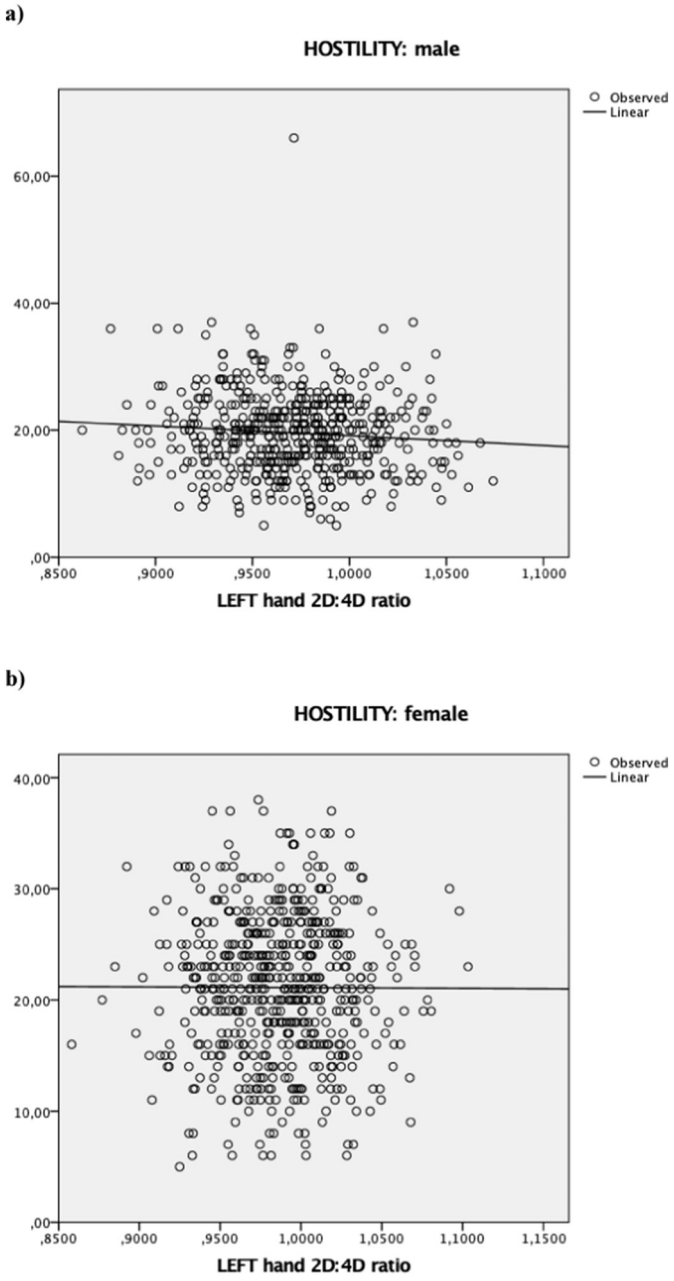

Fig. 8. Linear regression plots for hostility (dependent variable) and left 2D:4D ratio as independent variable: a) males, b) females.

Two recent meta-analyses suggested that any emphasis on the 2D:4D digit ratio as a reliable risk factor for aggressive and violent behavior should be abandoned [40,90]. However, we believe that these conclusions have obvious limitations, especially in relation to physical aggression. The authors merged all studies on aggression including those that show a strong sex difference (e.g. physical aggression) and those that are only weakly sexually dimorphic (e.g. verbal aggression). Another limitation of both meta-analyses concerns the samples of the groups, included in the analysis: as demonstrated by us in the current study, the samples must be quite large (at the minimum, exceeding 150 individuals in the case of control groups, or data randomly collected from the populations). In line with predictions of ENA, it is only physical aggression in men, that should be negatively associated with 2D:4D [41]. Another recent study demonstrated significant negative associations between the 2D:4D ratio and self-ratings of violent behavior in young non-criminal men, but not in women [42]. The fact, that association between 2D:4D and physical aggression is best revealed under challenge situations in men demonstrate the importance of experimental studies in solving the ENA dilemma [49–54]. Further studies should address the associations between 2D:4D and challenge-related physical aggression.

CRediT authorship contribution statement

M. Butovskaya: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **V. Burkova:** Data curation, Funding acquisition, Investigation, Resources, Visualization, Writing - original draft. **D. Karelin:** Data curation, Funding acquisition, Investigation. **V. Filatova:** Data curation, Funding acquisition, Investigation.

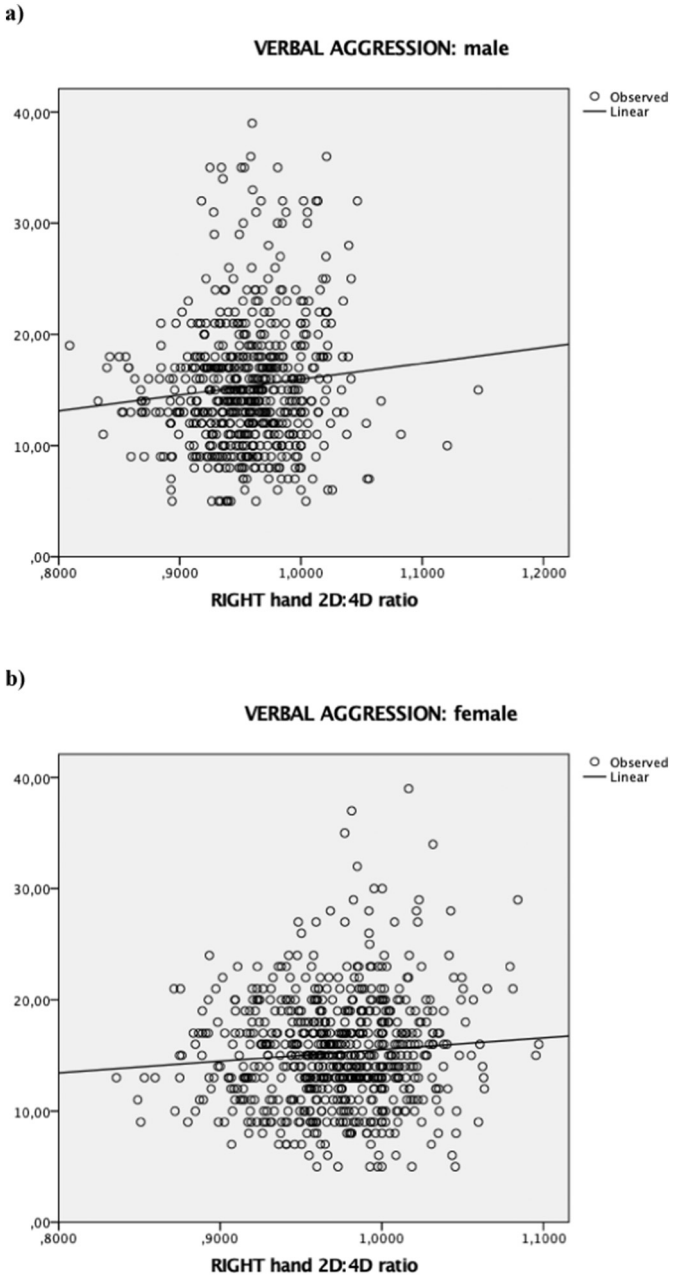

Fig. 9. Linear regression plots for verbal aggression (dependent variable) and right 2D:4D ratio as independent variable: a) males, b) females.

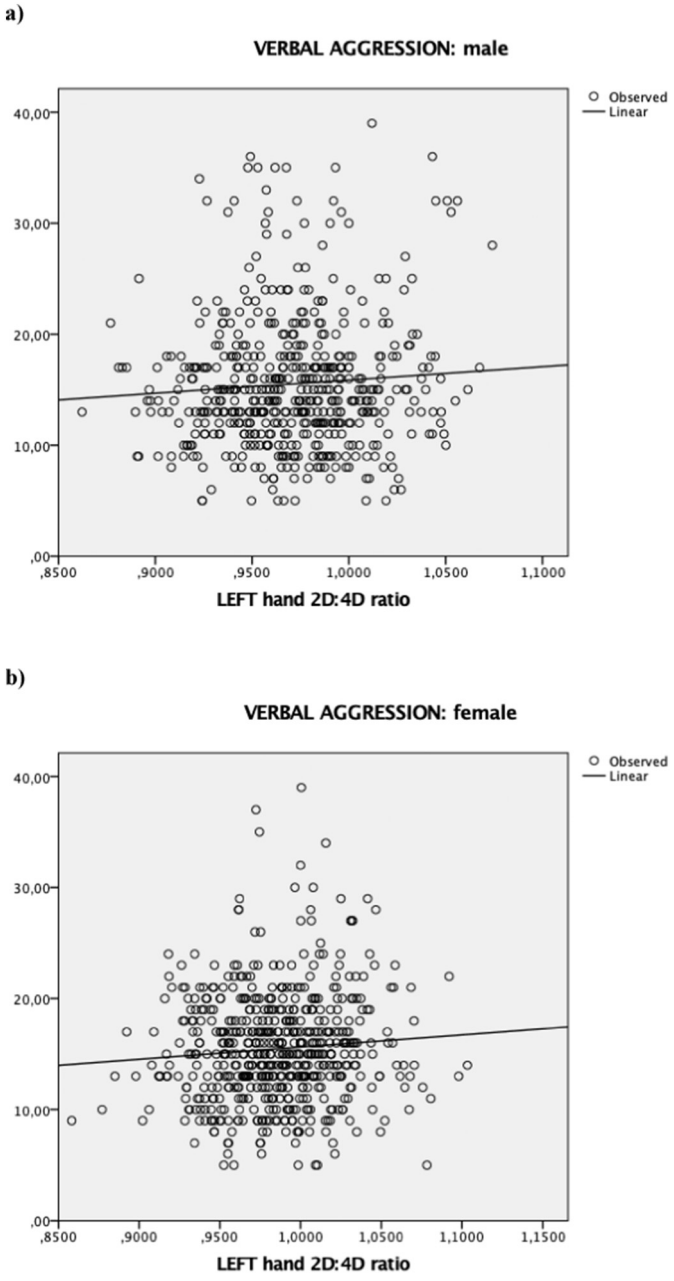

Fig. 10. Linear regression plots for verbal aggression (dependent variable) and left 2D:4D ratio as independent variable: a) males, b) females.

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