Phenotypic Features in Autistic Individuals: The Finger Length Ratio (2D:4D), Hair Whorl, and Hand Dominance

Funda AKSU[1], Burak BAYKARA[2], Canem ERGİN[3], Candan ARMAN[4]

SUMMARY

Objective: The aim of this study was to compare the finger length ratio (2D:4D), hair whorl direction, and hand, foot, and eye dominance in autistic and healthy individuals, and to investigate the phenotypic characteristics of autism.

Materials and Methods: The study included 37 males diagnosed with autistic disorder and 121 healthy males, all aged 4-18 years. The length of the index and ring fingers of both hands—from the proximal bend of the metacarpophalangeal joint to the fingertips—was measured with digital calipers and the index-ring finger (2D:4D) ratio was determined. The distance between hair whorls, their perpendicular distance from the mid-sagittal line, and their direction of rotation were calculated in the autism and control groups. Hand, foot, and eye dominance were determined in both groups. The findings were evaluated using SPSS v.15.0.

Results: The autism group had a greater number of hair whorls than the control group. The distance between hair whorls and the mid-sagittal line was longer in those with left hand and left eye dominance. A significant difference in the 2D:4D ratio of the right and left hands between the 2 groups was not observed.

Conclusion: The autism group had more hair whorls than the control group and the hair whorls in the autistic individuals with left hand and left eye dominance were located further from the mid-saggital line. We think that these novel findings might contribute to the determination of the phenotypic features specific to autism.

Keywords: Autism, finger ratio, hair whorl, hand dominance.

INTRODUCTION

Autistic disorder (AD) is a pervasive developmental disorder characterized by marked impairment in brain development beginning during the intrauterine period and an etiopathogenesis in which multiple genes play an important role (Manning-Courtney et al. 2003). A large body of evidence indicates that early brain development is affected by AD (Krajmer et al. 2011). A high level of testosterone during brain development reported that may play a role in the etiopathogenesis of AD (Krajmer et al. 2011; Bloom et al. 2010; Noipayak 2009; Falter et al. 2007; De Bruin et al. 2006; Knickmeyer and Baron-Kohen 2006; Knickmeyer et al. 2006, 2005; Lutchmaya et al. 2004; Manning et al. 2001). It was reported that the length and ratio of the second and fourth fingers of both hands (2D:4D ratio) are affected by the level of fetal testosterone (FT) (Beaton et al. 2011; Bloom et al. 2010; De Bruin et al. 2009, 2006; Noipayak 2009; Jackson 2008; McIntyre 2006; Lutchmaya et al. 2004; Manning et al. 2004, 1998; Csatho et al. 2003; Klar 2003; Maestro et al. 2002; Baron-Cohen et al. 1996; Dawson et al. 1990; Garn et al. 1975). The fourth finger grows relatively longer than the second finger due to FT (Krajmer et al. 2011; Bloom et al. 2010; McIntyre 2006). When the FT level is high the 2D:4D ratio is low (Noipayak 2009; Lutchmaya et al. 2004; Manning et al. 200); in other words, there is a negative correlation between the intrauterine FT level and the 2D:4D ratio.

Received: 07.03.2012 - **Accepted:** 06.07.2012

[1]Assistant Prof., [4]Associate Prof., PhD, Department of Anatomy., [2]Assistant Prof., [3]Assistant, MD, Deparment of of Child & Adolescent Psychiatry, School of Medicine, Dokuz Eylül University, Izmir, Turkey.

E-mail: *funda.tastekin@deu.edu.tr*

The 2D:4D ratio remains constant throughout life, starting from the 14th week of gestation (Manning et al. 1998; Garn et al. 1975).

A low 2D:4D ratio has been observed in individuals with left hand dominance, good visual-spatial skills, autism, Asperger disorder, good analytical thinking, orderliness, good executive functioning, and a good attention span, versus a high 2D:4D ratio in those with good verbal fluency and a high level of emotional expressiveness (Aksu et al. 2010; De Bruin et al. 2009; Lutchmaya et al. 2004). A positive correlation between attention deficit-hyperactivity disorder (ADHD) and a low 2D:4D ratio has also been reported (Stevenson et al. 2007). The 2D:4D ratio is low in left-handed individuals, there is a correlation between left-handedness and an elevated FT level, and a there is a correlation between the FT level and the testosterone level in adults (Beaton et al. 2010).

It is known that a variety of genes play a role in the pathogenesis of AD (Sugie et al. 2009). It was reported that there is a relationship between HoxD genes, and autistic spectrum disorder (ASD), finger morphogenesis, and a low 2D:4D ratio (Sugie et al. 2009). During embryonic brain development hemisphere lateralization defects, minor neurological problems, and hair whorl dysmorphology can occur (Weber et al. 2006; Klar 2003). There is evidence that language development and the normal lateralization process are impeded in AD (Kleinhans et al. 2008). Hair whorl direction is a biological marker of lateralization. The mechanisms that determine hair whorl direction and hand dominance stem from common genetic origins (Weber et al. 2006; Klar 2003); this relationship is also closely connected to language dominance.

There is a relationship between left-handedness, counterclockwise hair whorls, and atypical language dominance (Weber et al. 2006; Klar 2003). Hair whorl configuration develops from the same germ layer, the ectoderm, as does the nervous system between the 10th and 16th week of gestation, and its shape, number, and location are associated with various neurodevelopmental factors (Weber et al. 2006). To date, the literature does not contain any evidence of a relationship between AD, and hair whorl differences, hand dominance, or the 2D:4D ratio, and no study has identified the phenotypic features specific to AD (World Health Organization 1992).

The present study aimed to compare the 2D:4D ratio in an AD group and a control group (Krajmer et al. 2011; Bloom et al. 2010; Noipayak 2009; De Bruin et al. 2006; Manning et al. 2001). We hypothesized that the 2D:4D ratio would be smaller in the AD group and that there would be significant differences in hair whorl direction, and hand, foot and eye dominance between the 2 groups.

MATERIALS and METHODS

Autism group

In total, 49 male patients out of a pool of 61 male patients that were diagnosed with autism according to DSM-IV-TR (American Psychiatric Association (2000) were selected to participate in the study. The patients were aged 4-18 years and received outpatient treatment at Dokuz Eylul University, Department of Pediatric Psychiatry between 2007 and 2010. In all, 37 of the 49 patients agreed to participate in the study. The study was conducted with male participants only, as it would have been very difficult to observe and determine the hair whorl configuration and number in 4-18 year-old females, who generally have long hair. Those with a history of neurological disorders and head injury were excluded from the study.

Control group

The control group consisted of 121 boys aged 4-18 years, 33 of which presented to Dokuz Eylul University Hospital, General Pediatrics Department between January and May 2010 and 88 (aged 7-13 years) that were selected from a primary school in the epidemiological catchment area of the university hospital. Those with a history of child psychiatric admittance, a psychiatric diagnosis, and academic failure were excluded from the study.

The patient and control groups were comprised of age-matched males. Legal permission was received from the Provincial Directorate of National Education and the school's principal for the healthy controls to participate in the study. This study protocol was approved by the Dokuz Eylul University Ethics Committee. Written informed consent was obtained from parents of the patients and controls.

Evaluation

AD is diagnosed based on DSM-IV-TR (American Psychiatric Association 2000) criteria and the Childhood Autism Rating Scale (CARS-ÇODÖ) (Incekas 2009). CARS-ÇODÖ is a 15-item scale that was developed in order to diagnose autism, to distinguish between children without a pervasive developmental disorder that have developmental disability, and those with a pervasive developmental disorder. Diagnosis is performed by a clinician via clinical examination. The Turkish version of CARS-ÇODÖ was reported to be valid and reliable for use in Turkey (İncekaş 2009). The cut-off score is 30; those that score >30 are diagnosed with AD. CARS-ÇODÖ

further differentiates patients with severe autism from those with mild-to-moderate autism.

2D:4D ratio measurement

The 2D:4D ratio was determined by measuring the index and ring fingers of both hands using a digital compass with a sensitivity of 0.01 mm (Mitutoyo, Japan), starting from the proximal baseline on the palmar side of the metacarpophalangeal joint to the finger tip. Those with osteoarthritis or any structural deformity related to a hand injury, and those with a history of hand trauma were excluded from the study.

Measurement of hair whorl, and hand, foot and eye dominance

After locating the protruding tip of the nasion, inion, and vertebra prominence (the 7th cervical vertebra), one of the authors identified the midline with a 0.3 mm-thick fishing line and marked it. Another author calculated the 90° distance between the mid-sagittal line and the central point of each participant's hair whorl using a measuring tape with a sensitivity of 1 mm. In cases of multiple hair whorls, each was numbered from the ventral side towards the rostral side, and the whorl at the most lateral end of the mid-sagittal line was measured and recorded. The distance between hair whorls was measured with a measuring tape with a sensitivity of 1 mm. The direction of rotation of each hair whorl (clockwise or counterclockwise) was also noted.

Hand dominance was determined based on clinical examination; for autistic patients that did not cooperate with the examination hand dominance was determined based on parental reports. Participants were asked to hold a toy, fork, knife, pencil, and scissor, which were on a table. If the participant failed to follow the instructions, the necessary information was gathered from the parents.

To determine foot dominance participants were first told to hit a dead ball, to hit a ball thrown at him, and finally to move from one place to another by jumping on 1 foot for a distance of approximately 3 m. The preferred foot was recorded while performing these tasks.

For determination of eye dominance each participant was told to look through a kaleidoscope with 1 eye, if he could, and the preferred eye was noted.

Statistical analysis

SPSS v.15.0 for Windows was used for statistical analysis of the data. To calculate differences in means between the 2 groups Student's T-test (a parametric test) and the Mann-Whitney U test (a non-parametric test) were performed. Differences in the means of >2 groups were calculated using one-way ANOVA. The chi-square test was used to compare discrete data and Pearson's test was used to determine correlations. The level of statistical significance was set at $P < 0.05$.

Table 1. Mean parameter values in the autism and control groups

	Group	Mean ± SD	p*
Age (months)	**Autism n = 37**	113.25 ± 40.74	0.313
	Control n = 121	120.38 ± 30.04	
Number of Hair Whorls	**Autism n = 37**	1.27 ± 0.50	**0.031****
	Control n = 121	1.09 ± 0.31	
Distance between the central point of hair whorls and the mid-sagittal line (mm)	**Autism n = 37**	18.16 ± 12.98	0.633
	Control n = 121	17.02 ± 11.32	
Right-hand 2D:4D ratio	**Autism n = 37**	0.95±0.05	0.676
	Control n = 121	0.96±0.03	
Left-hand 2D:4D ratio	**Autism n = 37**	0.96 ± 0.05	0.226
	Control n = 121	0.95 ± 0.03	

*Student's t-test
* Pearson Chi square-----

Table 2. Comparison of hand dominance, and mean distance between the central point of hair whorls and the mid-sagittal line in the autism and control groups (mean ± SD)

		Hand Dominance		p*
		Right	Left	
Distance between the central point of hair whorls and the mid-sagittal line (mm)	**Autism**	15.61 ± 10.48	31.40 ± 16.95	0.037
	Control	16.73 ± 11.56	18.94 ± 9.67	0.374

*Mann-Whitney U test

RESULTS

Mean values for the parameters in the autism and control groups are given in Table 1. There wasn't a significant difference in age between the autistic patient and control groups ($p = 0.313$).

Hair whorls

The mean number of hair whorls in the autism group was significantly higher than that in the control group (Pearson Chi-square 6,917; $p = 0.031$). The distance between the hair whorl center and mid-sagittal line did not significantly differ between the 2 groups ($p = 0.633$). Based on the chi-square test there wasn't a significant difference in the relationship between hair whorl direction of rotation, and hand, foot, or eye dominance between the 2 groups ($p > 0.05$).

Table 3. Comparison of foot dominance, and mean distance between the central point of hair whorls and the mid- sagittal line in the autism and control groups (mean ± SD)

		Foot dominance		p*
		Right	Left	
Distance between the central point of hair whorls and the mid-sagittal line (mm)	**Autism**	16.64 ± 10.72	29.00 ± 15.90	0.097
	Control	16.04 ± 10.77	23.16 ± 12.42	0.014

*Mann-Whitney U test

Table 4. Comparison of eye dominance, and mean distance between the central point of hair whorls and the mid-sagittal line in autism and control groups (mean ± SD)

		Eye dominance		p*
		Right	Left	
Distance between the central point of hair whorls and the mid-sagittal line (mm)	**Autism**	11.92 ± 7.65	28.50 ± 16.06	**0.016***
	Control	**16.46** ± 10.65	18.59 ± 13.05	0.473

*Mann-Whitney U test

Table 5. Comparison of right and left 2D:4D ratios between mild-to-moderate and severe autism patients, according to CARS- ÇODÖ (mean ± SD)

2D:4D	The Severity of Autism	Mean ± SD	p*
Right Hand	**Mild-to-Moderate n = 13**	0.96 ± 0.06	0.656
	Severe n = 24	0.95 ± 0.04	
Left Hand	**Mild-to-Moderate n = 13**	0.96 ± 0.06	0.849
	Severe n = 24	0.96 ± 0.05	

*Mann-Whitney UtTest

The Mann-Whitney U non-parametric test was performed to compare the mean distance between the central point of the hair whorls and the mid-sagittal line in right-handed and left-handed individuals in both groups. The distance between the central point of the hair whorls and the mid-sagittal line was significantly longer in left-handed autistic patients (p = 0.037) (Table 2), whereas there wasn't a difference between the left- and right-handed controls. The distance between the central point of the hair whorls and the mid-sagittal line in the autistic patients and controls with right-foot and left-foot dominance was compared using the non-parametric Mann-Whitney U test; a significant difference was observed between the autistic patients, whereas in the control group the distance between the central point of the hair whorls and the mid-sagittal line was significantly longer in those with left-foot dominance (p = 0.014) (Table 3). Additionally, the distance between the central point of the hair whorls and the mid-sagittal line in the autistic patients and controls with right- and left-eye dominance was compared using the non-parametric Mann-Whitney U test. The distance between the central point of the hair whorls and the mid-sagittal line in the autistic patients with left-eye dominance was significantly longer than in those with the right-eye dominance (p = 0.016); however, the difference between those in the control group was not significant (Table 4).

2D:4D Ratio

The 2D:4D ratio was compared between the right and left hands in both groups, but there wasn't a significant difference in either group (Table 1). The autism group was divided into 2 subgroups based on CARS-ÇODÖ scores, as those with mild-to-moderate autistic symptoms and those with severe autistic symptoms. These 2 subgroups were compared with regard to right and left 2D:4D ratios, but a significant difference was not observed (p > 0.05) (Table 5). These 2 subgroups were also compared with the control group in terms of right and left 2D:4D ratios, but the difference was not significant (one-way ANOVA, p > 0.05).

Correlations

The number of hair whorls, the distance between the central point of the hair whorls and the mid-sagittal line, right and left 2D:4D ratios, and CARS-ÇODÖ subscale scores and total score in the autism group were separately evaluated using Pearson's correlation analysis. A low degree of correlation was observed between the number of hair whorls, and the distance between the central point of the hair whorls and the mid-sagittal line in both groups. The correlation between the 2D:4D ratio in the left and right hands, and the distance between the hair whorl center and the mid-sagittal line were examined in the autism and control groups; there wasn't a significant correlation in the autism group, whereas in the control group there was a significant correlation between the 2D:4D ratios in both hands, and the distance between the hair whorl center and the mid-sagittal line.

DISCUSSION

A large body of evidence indicates that many gender-based differentiated behaviors, including sexual orientation, attention deficit disorder, autism, eating disorders, aggression, and risk-taking behaviors, affect the 2D:4D ratio, which is an indication of the prenatal androgen level (Beaton et al. 2011; Aksu et al. 2010; Bloom et al. 2010; Breedlove 2010; De Bruin et al. 2009, 2006; Noipayak 2009; Stevenson et al. 2007; McIntyre 2006; McIntyre et al. 2006; Milne et al. 2006; Manning et al. 2004). Manning et al. (2003) reported that there is a correlation between variations in androgen receptor genes and the 2D:4D hand ratio; the 2D:4D hand ratio was lower in males with highly sensitive androgen receptors. Aksu et al. (2010) studied 63 paramedic students and reported that the group with a low 2D:4D ratio (testosterone-dominant)

had higher scores on tests that measured decision making, orderliness, responsibility/decisiveness, and analytical thinking than those with a high 2D:4D ratio (estrogen-dominant). It was also reported that the right hand 2D:4D ratio was more sensitive to prenatal testosterone than the left hand ratio (Jackson 2008).

Manning et al. (2001) investigated the 2D:4D ratio in autistic girls and boys (n = 72) and reported that there is a relationship between the 2D:4D ratio and autism. This study showed that the 2D:4D ratio in autistic individuals was lower than expected. Manning suggested that the 2D:4D ratio could be a marker of autism (Manning et al. 2001). Manning et al. (2002) reported as a result of 2D:4D studies, it was foreseen that shortness in CAG sequences of androgen receptor gene could widely be determined in autism and Asperger Syndrome.

Krajmer P (2011) suggested that autism might occur as a result of a high concentration of prenatal testosterone (Krajmer 2011). De Bruin et al.'s (2006) comparative study on 260 children showed that the 2D:4D ratio was lower in the participants with Asperger Syndrome than in males with attention deficit disorder and anxiety disorders (index finger is relatively shorter than ring finger). They also reported that elevated testosterone during the prenatal period might not affect only AD, but might also affect sub-types of pervasive developmental disorder and ADHD (De Bruin et al. 2006). De Bruin et al. (2009) studied 35 female and 147 male children, and reported that a low 2D:4D ratio could be used as a diagnostic indicator for autism. In the present study there wasn't a significant difference between right and left hand 2D:4D ratios in the autism and control groups.

Bloom et al. (2010) studieds 75 boys (92.6%) and 6 girls (7.4%) with ASD, and reported that the 2D:4D ratio in the girls was lower than that in the boys, although the difference was not significant (Bloom et al. 2010).

In has been reported that it is difficult to diagnose autism before 18 months of age and that the 2D:4D ratio may be a useful indicator (Noipayak 2009; Maestro et al. 2002; Baron-Cohen et al. 1996; Dawson et al. 1990).

Milne et al. (2006) studied 46 children, of which 23 had autism, and reported that autistic children with a low 2D:4D ratio (testosterone-dominant) have significantly lower motor coordination (Milne et al. 2006).

In a study on ethnic differences in the 2D:4D ratio it was noted that Asians had the highest ratio and that Africans had the lowest (Manning et al. 2004). Noipayak (2009) reported that the 2D:4D ratio was significantly higher in autistic children than in children without autism children in a study that included 46 Asian children aged 18 months-15 years. The researchers noted that a 2D:4D ratio on both hands of 0.96-1.01 was an important risk factor for autism and that the findings would help in the early detection of autism and improve the quality of life in children with the disease (Noipayak 2009).

The present study's findings differ from those of the Noipayak study, which may be due to differences in the methods used for measurement. Noipayak measured digit length on a paper, and then measured again with a digital compass on the paper. We think that method may be associated with a higher margin of error than the direct measurement method used in the present study. The fact that the 2D:4D ratio in Noipayak's study was higher than that reported from continental Europe that this finding could be special to Asians (De Bruin et al. 2006; Manning et al. 2001), it is asserted that differences were caused by ethnic differences. In this study we found no relationship between the 2D:4D and autism. It is not clear that whether this finding is associated with ethnic differences or because of the male only autistic and control groups or that there is actually no relationship between autism and the 2D:4D ratio? Broad perspective studies to be conducted in the future would help to find more clear findings about the relationship with 2D:4D and autism.

According to a study conducted with 1060 children aged 2-10 years, digital measurement of the 2D:4D ratio differed significantly based on ethnic group. The same study anticipated that different measurements depending on ethnicity and gender differences both could lead to conflicting results about 2D:4D ratio (McIntyre et al. 2006). In this study our study groups are quite homogeneous and error margin of 2D:4D measurements can be assumed to be less.

The number of hair whorls was examined for the first time in the autism group and was significantly higher than that in the control group; this finding can be considered an additional phenotypic finding in the early diagnosis of autism. In contrast to the report that there is a relationship between hair whorls with counterclockwise rotation and left handedness (Klar 2003), a significant relationship between hand, foot, and eye dominance, and direction of rotation of hair whorls was not observed in the present study; however, in the present study's autism patients with left-hand and left-eye dominance the distance from the center point of hair whorls to the mid-sagittal line was significantly longer, which can be considered a finding that supports the notion that hair whorl structure, hand and eye dominance, and hemisphere lateralization develop from the same embryonic site (Klar 2003).

The distance from the center point of hair whorls to the mid-sagittal line in the autistic individuals with left-hand and left-eye dominance was significantly longer in the present study, which can be considered a new addition to the AD phenotype. A significant correlation between the 2D:4D ratio on both hands, and the distance of the hair whorl center

from the mid-sagittal line was not observed in the present study's autism groups. The hypothesis that formed the basis of the present study is that the hair whorl structure in the autism group would differ significantly from that in the control group, in terms of its relationship to hand, foot, and eye dominance, and that the 2D:4D ratio would be lower in the autism group; however, there wasn't a significant difference in the 2D:4D ratio between the 2 groups, as previously reported, which may have been due to differences in such variables as ethnicity and methods of measurement. The number of hair whorls in the present study's autism group was significantly more than that in the control group, which supports the notion that hair whorls are closely related to neurodevelopmental disorders.

Conclusion

The present study's findings show that it might not always feasible to assume the 2D:4D ratio as one of phenotypic findings of autism. The number of hair whorls in the autism group was significantly higher than that in the control group, and the hair whorls in the autistic individuals with left-hand and left-eye dominance were further away from the mid- sagittal line—both novel findings of the present study; we think these findings will contribute to identifying phenotypes specific to autism.

Limitation

As girls aged 4-18 years generally have long hair, only boys were included in the present study's autism and control groups, as we anticipated having difficulty determining the types and number of hair whorls. Additionally, as autism is observed more frequently in male children, the study population was limited to males. Furthermore, as the study included only males, the 2D:4D ratios observed were small (<1), because testosterone exposure during the intrauterine period is naturally higher in males, which may be why there weren't any significant differences in the 2D:4D ratio.

REFERENCES

Aksu F, Tatar A, Türkmen S et al. (2010) Paramediklerde Psikolojik Değerlendirme ve Eldeki 2/4 Parmak Oranının Kişilik Yapısı İle İlişkisi. Dokuz Eylül Üniversitesi Tıp Fakültesi Dergisi, 24: 11-18.

American Psychiatric Association (2000) DSM-IV-TR - Diagnostic and Statistical Manual of Mental Disorders 4th Ed. Text Revision – American Psychiatric Association, Washington DC.

Baron-Cohen S, Cox A, Baird G et al. (1996) Psychological markers in the detection of autism in infancy in a large population. Br J Psychiatry, 168: 158-63.

Beaton AA, Rudling N, Kissling C et al. (2010) Digit ratio (2D:4D), salivary testosterone, and handedness. Laterality, 16:136-55.

Bloom MS, Houston AS, Mills JL et al. (2010) Finger bone immaturity and 2D:4D ratio measurement error in the assessment of the hyperandrogenic hypothesis for the etiology of autism spectrum disorders. Physiol Behav, 100:221-4.

Breedlove SM (2010) Minireview: Organizational hypothesis: instances of the fingerpost. Endocrinology, 151:4116-22.

Csathó A, Osváth A, Bicsák E et al. (2003) Sex role identity related to the ratio of second to fourth digit length in women. Biol Psychol, 62:147-56.

Dawson G, Hill D, Spencer A et al. (1990) Affective exchanges between young autistic children and their mothers. J Abnorm Child Psychol, 18: 335-45.

De Bruin EI, De Nijs PF, Verheij F et al. (2009) Autistic features in girls from a psychiatric sample are strongly associated with a low 2D:4D ratio. Autism, 13:511-21.

De Bruin EI, Verheij F, Wiegman T et al. (2006) Differences in finger length ratio between males with autism, pervasive developmental disorder-not otherwise specified, ADHD, and anxiety disorders. Dev Med Child Neurol, 48: 962-5.

Falter CM, Plaisted KC, Davis G. (2008) Visuo-spatial processing in autism--testing the predictions of extreme male brain theory. J Autism Dev Disord, 38:507-15.

Garn SM, Burdi AR, Babler WJ et al. (1975) Early prenatal attainment of adult etacarpal-phalangeal rankings and proportions. American Journal of Physical Anthropology 43: 327-32.

Incekaş S (2009) Çocukluk Otizmini Derecelendirme Ölçeği Geçerlik Ve Güvenirlik Çalışması (Uzmanlık Tezi). Dokuz Eylül University Deparment of Child & Adolescent Psychiatry, Izmir.

Jackson C (2008) Prediction of hemispheric asymmetry as measured by handedness from digit length and 2D:4D digit ratio. Laterality, 13:34-50.

Klar AJS (2003) Human Handedness And Scalp Hair-Whorl Direction Develop From A Common Genetic Mechanism. Genetics, 165:269-76.

Kleinhans NM, Müller RA, Cohen DN et al. (2008) Atypical functional lateralization of language in autism spectrum disorders. Brain Res, 24:115-25.

Knickmeyer R, Baron-Cohen S, Fane BA et al. (2006) Androgens and autistic traits: A study of individuals with congenital adrenal hyperplasia. Horm Behav, 50: 148-53.

Knickmeyer R, Baron-Cohen S, Raggatt P et al. (2005) Foetal testosterone, social relationships, and restricted interests in children. J Child Psychol Psychiatry, 46: 198-210.

Knickmeyer RC, Baron-Cohen S (2006) Fetal testosterone and sex differences in typical social development and in autism. J Child Neurol, 21: 825-45.

Krajmer P, Spajdel M, Kubranska A et al. (2011) 2D:4D finger ratio in Slovak autism spectrum population. Bratisl Lek Listy, 112:377-9

Lutchmaya S, Baron-Cohen S, Raggatt P et al. (2004) 2nd to 4th digit ratios, fetal testosterone and estradiol. Early Hum Dev, 77:23-8.

Maestro S, Muratori F, Cavallaro MC et al. (2002) Attentional skills during the first 6 months of age in autism spectrum disorder. J Am Acad Child Adolesc Psychiatry, 41: 1239-45.

Manning JT, Baron-Cohen S, Wheelwright S et al. (2001) The 2nd to 4th digit ratio and autism. Dev Med Child Neurol, 43: 160-4.

Manning JT, Bundred PE, Flanagan BF (2002) The ratio of 2nd to 4th digit length: a proxy for transactivation activity of the androgen receptor gene? Med Hypotheses, 59:334-6.

Manning JT, Scutt D, Wilson J et al. (1998) The ratio of 2nd to 4th digit length: a predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. Human Reproduction, 13: 3000-4.

Manning JT, Stewart A, Bundred PE et al. (2004) Sex and ethnic differences in 2nd to 4th digit ratio of children. Early Hum Dev, 80: 161-8.

Manning-Courtney P, Brown J, Molloy CA et al. (2003) Diagnosis and treatment of autism spectrum disorders. Curr Probl Pediatr Adolesc Health Care, 33:283-304.

McIntyre MH, Cohn BA, Ellison PT (2006) Sex dimorphism in digital formulae of children. Am J Phys Anthropol, 129:143-50.

McIntyre MH (2006) The use of digit ratios as markers for perinatal androgen action. Reprod Biol Endocrinol, 26:10.

Milne E, White S, Campbell R et al. (2006) Motion and form coherence detection in autistic spectrum disorder: Relationship to motor control and 2:4 digit ratio. J Autism Dev Disord, 36:225-37.

Noipayak P (2009) The ratio of 2nd and 4th digit length in autistic children. J Med Assoc Thai, 92:1040-5.

Stevenson JC, Everson PM, Williams DC et al. (2007) Attention deficit/hyperactivity disorder (ADHD) symptoms and digit ratios in a college sample. Am J Hum Biol, 19:41-50.

Sugie Y, Sugie H, Fukuda T et al. (2010) Study of HOXD genes in autism particularly regarding the ratio of second to fourth digit length. Brain Dev, 32:356-61.

Weber B, Hoppe C, Faber J et al. (2006) Association between scalp hair-whorl direction and hemispheric language dominance. Neuroimage, 30:539-43.

World Health Organisation (1992) ICD-10 Classification of Mental and Behavioural Disorders. World Health Organisation, Geneva.