Sex differences in cognitive functions: a study of same-sex and opposite-sex twin pairs

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Studies concerning cognitive sex differences have indicated that, on average, females outperform males in some verbal abilities, whereas males outperform females in some visual-spatial abilities. Prenatal hormones play important role in sexual differentiation. Presence of androgens is believed to cause male brain differentiation. According to animal studies prenatal exposure to testosterone in females can result in masculinized behaviour or physiological traits. Human studies of possible masculinization of females from opposite-sex twin pairs are controversial. Some studies have indicated that female members of opposite-sex twins may be masculinized in some traits, while other studies show no evidence of masculinization. Hence the aim of the present study is to investigate sex differences and possible masculinization of cognitive functions in young adult twins. Subjects (N=336) were recruited from the ongoing longitudinal FinnTwin16 study of Finnish twins born in 1974-1979.

Results indicate female superiority in verbal and executive functions and male superiority in visual and working memory functions. Further, in female members of opposite-sex twin pairs the visual abilities were enhanced to the male level. However, they still outperformed males in verbal and executive functions. In male members of opposite-sex twin pairs there were no signs of better performance in functions that favored females. Nor there were evidence of reduced performance in functions that favored males.

This study suggest that there occurs masculinization of cognitive functions in females who have a male co-twin. In contrast, males with female co-twins are not feminized in their cognitive functions. These results indicates some benefits of twinship in female members of opposite-sex twin pairs in cognitive abilities. Whether the masculinization is a result of organizational effects of prenatal testosterone or postnatal environmental influences could not be resolved. Future research, with control over environmental influences, is needed to determine the origin of masculinization of cognitive abilities.

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Tiivistelmä - Referat – Abstract

Kognitiivisten toimintojen sukupuolieroja koskevat tutkimukset osoittavat naisten olevan keskimäärin miehiä parempia joissakin verbaalisissa kyvyissä, kun taas miehet ovat keskimäärin naisia parempia joissakin visuaalis-spatiaalisissa toiminnoissa. Raskauden aikaiset hormonit ovat tärkeitä sukupuolien erilaistumisessa. Eläintutkimusten mukaan naaraiden altistuminen mieshormoneille raskauden aikana saattaa johtaa fyysisten ominaisuuksien tai käyttäytymisen muuttumisen sellaiseksi, joka on enemmän koiraalle ominaista (maskulinisaatio). Ihmisillä voidaan mahdollista maskulinisaatiota tutkia kaksosilla. On olemassa tutkimuksia, jotka osoittavat maskulinisaatiota naisilla, joilla on kaksosveli. Toisaalta osassa tutkimuksissa ei ole merkkiä siitä, että naiset joilla on kaksosveli, poikkeaisivat muista naisista. Tämän tutkimuksen tarkoitus on selvittää eroavatko naiset, joilla on kaksosveli, niistä naisista joilla on kaksossisko kognitiivisissa toiminnoissa. Tämän tutkimuksen koehenkilöt (N=336) olivat nuoria aikuisia kaksosia käynnissä olevasta suomalaisesta Nuorten Kaksosten Terveystutkimuksesta (FinnTwin16). Koehenkilöt olivat syntyneet 1974-1979.

Tulosten mukaan naiset olivat keskimäärin miehiä parempia verbaalisissa tehtävissä ja toiminnan ohjauksessa. Miehet taas olivat keskimäärin naisia parempia visuaalisissa tehtävissä ja kuulonvaraisessa työmuistissa. Eri sukupuolta olevien kaksosparien naisten visuaalinen suoritus oli parantunut samalle tasolle kuin miesten suoritus. Samalla he olivat miehiä parempia verbaalisissa tehtävissä ja toiminnan ohjauksessa. Eri sukupuolta olevien kaksosparien miesten suoritus naisia suosivissa tehtävissä ei ollut parantunut. Eikä heidän suorituksensa miehiä suosivissa tehtävissä ollut huonontunut.

Tutkimus osoittaa, että naiset joilla on kaksosveli saattavat olla maskuliinistuneita kognitiivisissa toiminnoissa. Sen sijaan miehet, joilla on kaksossisko, eivät näyttäisi olevan alttiita kognitiivisten toimintojen feminisaatiolle. Tutkimus tuo esiin kaksosuuden hyödyn kognitiivisissa kyvyissä naisilla, joilla on kaksosveli. Vaikka tulokset tukevat hypoteesia, että raskauden aikaisen testosteronille altistumisella on maskulinisoivaa vaikutusta, ei tämän tutkimuksen peruusteella voida sanoa johtuuko tämä sittenkään raskauden aikaisesta hormoniympäristöstä vai syntymän jälkeisistä kokemuksista. Tulevissa tutkimuksissa tulisi ottaa huomioon ympäristötekijöitä, jotta voitaisiin selvittää kognitiivisten toimintojen maskuliinistumisen alkuperää.

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CONTENTS:

1. INTRODUCTION

Cognition is the information-handling dimension of human behavior (see e.g. Lezak, 1995, p. 20). Cognitive functions include sensation, perception, memory, learning, thinking, attention, and expressive functions. The cognitive functions can be observed separately but they are not independent from each other. Cognitive functions can be measured by neuropsychological tests and they can be correlated with brain anatomy and functioning.

Males and females are different by their biology but they also differ from each other in cognitive functions (Kimura, 1999). Traditionally, differences in spatial, verbal and quantitative abilities have been studied. Studies have demonstrated, for example, a male advantage in some spatial abilities (Crucian and Berenbaum, 1998) and a female advantage in some verbal abilities (Chipman and Kimura, 1999). There are also sex differences in prevalence of some neurological and psychiatric disorders (see Swaab and Hofman, 1995). For example, attention deficit hyperactivity disorder (Andersen and Teicher, 2000), autism (Baron-Cohen, 2002), and dyslexia (Stein and Walsh, 1997) are all more prevalent in boys than in girls, while after puberty depression is more common in girls (Cyranowski, Frank, Young & Shear, 2000).

Prenatal gonadal hormones play an important role in the development of sex differences in brain and cognition (Gooren and Kruijver, 2002; Thijssen, 2002). Prenatal exposure to testosterone in females might result in masculinization of behavior (Berenbaum, 1998), cognitive functioning (Helleday, Bartfai, Ritzén & Forsman, 1994) or physiological traits (Brown, Hines, Fane & Breedlove, 2002).

However in some domains of behaviour, no evidence for masculinization has been observed in a large twin study from Finland (Rose et al., 2002). In animals, the females adjacent to males in utero can be anatomically, behaviorally and physiologically masculinized due to prenatal testosterone transfer from male fetuses (for a review see Ryan and Vandenbergh, 2002). Similarly in humans, it can be expected that female members of opposite-sex twins may be masculinized. For this reason the present study investigates if the female members of opposite-sex twins are masculinized in cognitive abilities.

1.1. Sex and gender

Both words, “sex” and “gender” are used in studies of differences between males and females. By word sex, some authors refer to the biological distinctions between males and females, and word gender is used when differences are of psychosocial origin (Halpern and Wright, 1996). In this study the term sex is used to refer both “sex” and “gender” differences. This is reasonable, because it is usually hard to know whether the differences between males and females are consequences of biological or environmental factors (Halpern and Tan, 2001). The present study focuses on the neuropsychology of sex differences, and describes the biological factors related to these differences.

1.2. Sexual differentiation

In humans, sex differentiation is induced by Y chromosome on the 23rd pair of chromosomes. One X and one Y chromosome are needed for becoming a male and two X chromosomes are needed for becoming a female. On the very early stage, the embryo can become either male or female. Testis-determining factor, SRY gene (Sex-determining Region, Y chromosome gene) is playing an important role in the development of undifferentiated gonads as testes (Arnold, 1996). Testes produce testosterone, which is needed for male development (Vilain and McCabe, 1998). Embryo has two sets of ducts: Wolffian (male) and Müllerian (female). Testes produce two important hormones. Testosterone is needed for the development of Wolffian ducts. Anti-Müllerian hormone (AMH) causes the disappearance of the Müllerian ducts. Female embryos have no AMH, which allows Müllerian ducts to develop as the Wolffian ducts vanishes (Lee and Donahoe, 1993).

Sexual differentiation occurs also in the brain. Traditionally it has been assumed that the presence of androgens results as a male brain differentiation and the absence of androgens causes the female brain differentiation (Gooren and Kruijver, 2002). But also the ovarian hormones have effects on the sexual differentiation of the brain (for review see Fitch and Denenberg, 1998). Normal development of the whole reproductive axis, which includes hypothalamus, pituitary, adrenals, and gonads, is needed for normal sexual development (Vilain and McCabe, 1998).

1.3. Structural brain differences

Sexual differentiation in the human brain takes place also after birth. There occurs sexual differentiation of hypothalamus (clump of nuclei that is regulating sexual behaviors) between 4 years and puberty (Swaab and Hofman, 1995). Some hypothalamic areas differ in size between males and females. The bed nucleus of the stria terminalis (BST) is larger and contains more neurons in adult males than in females (Chung, De Vries & Swaab, 2002). The sexually dimorphic nucleus of the preoptic area (SDN-POA) is larger in size and neuron density in men than in women (Swaab, Chung, Kruijver, Hofman & Ishunina, 2001).

The largest structural sex difference in the human brain is its size. The male brain weights on average approximately 100 grams more than female brain, even if the comparison is made for men and women of equal body size (Ankney, 1995). Studies have also indicated that women have greater volume of gray matter (Gur et al., 1999) and men have greater volume of white matter (Passe, Rajagopalan, Tupler, Byrum, MacFall & Krishnan, 1997; Gur et al., 1999).

The structural sex differences in corpus callosum are controversial. Men have a larger corpus callosum than women relative to their brain size (Sullivan, Rosenbloom, Desmond & Pfefferbaum, 2001). However, it is suggested that women have larger posterior region of corpus callosum (splenium) than men (Kimura, 1999). A recent magnetic resonance imaging (MRI) study supports this idea (Dubb, Gur, Avants & Gee, 2003), but this finding is not well replicated (for a review see Bishop and Wahlsten, 1997).

1.4. Functional brain differences

Besides structural brain differences between males and females, there are also several functional differences. Studies suggests that male brains are more lateralized than female brains in both visual (Davidson, Cave & Sellner, 2000) and verbal (Shaywitz et al., 1995; Volf and Razumnikova, 1999) processing. Similarly, a meta-analysis of 36 studies also indicates slightly larger laterality of speech production in males (Medland, Geffen & McFarland, 2002). The studies in damaged brains also reveal sex differences in within-hemisphere functions. The incidence of aphasia (speech disorder) and apraxia (movement disorder) is higher after anterior damage in women. In men, incidence is higher after posterior damage (Kimura, 1999).

There are also sex differences in levels and distribution of some neurotransmitters. Women have higher striatal dopamine availability than men in caudate nucleus and in putamen (Mozley, Gur, Mozley & Gur, 2001). Further, men have more lateralized dopamine receptors in striatum (Andersen and Teicher, 2000). Inhibitory gamma amino butyric acid (GABA) neurotransmitter also shows sex differences (see McCarthy, Auger & Perrot-Sinal, 2002).

1.5. General intelligence (g) and sex differences

Traditionally it has been widely accepted that there exists no sex difference in general intelligence (g) (e. g. Halpern, 1986; Kimura, 1992). However, sex differences in g and in intelligent quotient (IQ) as measured by Wechsler Adult Intelligence Scale (WAIS) or other intelligence tests have been observed (Alexopoulos, 1996; Allik, Must & Lynn, 1999, Lynn, 1999 ; Lynn, 2002). According to Lynn (1999), there is a male advantage of approximately four IQ points correlation with larger brain size in men. The sex difference in intelligence begins to appear at the age of 15 (Lynn, 2002).

However, when speaking of general intelligence or IQ, the question remains of what is intelligence and how is it measured? Furthermore, the definition of intelligence can result in sex differences depending on what kind of abilities are emphasized. Ankney (1995) points out that in the study of Lynn (1999) almost 90 percent of the male advantage in g is derived from the spatial and reasoning abilities. However, the study of the largest sample (4256 females and 6219 males) on which the sex difference in g has ever been tested, reported no sex difference (Colom, Juan-Espinosa, Abad & Garcia, 2000). Hence, there is a need for further research in this controversial question.

1.6. Cognitive functions and sex differences

Sex differences in cognitive functions have been widely studied. Most studies have categorized the cognitive sex differences as results of verbal, quantitative or spatial abilities (e.g. Linn and Petersen, 1985; Hyde and Linn, 1988; Hyde, Fennema & Lamon, 1990). However, the concepts of verbal, quantitative, and spatial are not so unitary and clear. Verbal abilities include all components of language: grammar, spelling, oral comprehension, verbal analogies, vocabulary, and word fluency. Spatial perception, mental rotation and spatial visualization are all categories of spatial ability. Quantitative abilities include geometry, mathematical sentences, mathematical reasoning, probability, and statistics.

Halpern and Wright (1996) have proposed an alternative approach to cognitive sex differences called a process oriented model of cognitive sex differences. The focus in the theory is on the processes that are needed in different kinds of cognitive tasks. According to the process oriented model males outperform females in tasks that require maintaining and manipulation of information in short term memory, and females outperform men in tasks that require rapid access and retrieval from long term memory (Halpern and Wright, 1996).

Most studies of cognitive sex differences have been conducted using paper-and-pencil tests. The tests often measure primarily one type of ability, thus not corresponding very well the demands of everyday life, which requires many capacities simultaneously. There are male and female advantages in cognitive abilities depending on the content of a problem.

One of the largest sex differences may be a male advantage in mental rotation tasks (Linn and Petersen, 1985; Kimura, 1992; Crucian and Berenbaum, 1998). On average, men also outperform women in perception of linejudgement, in mathematical reasoning, and in route-navigating, whereas women usually outperform men in tasks of perceptual speed, finger dexterity, verbal fluency, verbal and item memory (Kimura, 1992; Kimura, 1996; Chipman and Kimura, 1998; Weiss, Kemmler, Deisenhammer, Fleischhacker & Delazer, 2003.). Spatio-motor targeting abilities, which favor males (Westergaard, Liv, Haynie & Suomi, 2000), demonstrate sex differences in more ecologically valid situation than the paper-and-pencil tasks. The modern neuro-imaging techniques like functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have revealed sex differences in brain function while performing cognitive tasks (Mansour, Haier & Buchsbaum, 1996; Cahill et al., 2001; Canli, Desmond, Zhao & Gabrieli, 2002; Jordan, Wustenberg, Heinze, Peters & Jäncke, 2002). Men and women also use different kind of strategies while doing the same cognitive task (Dabbs, Chang, Strong & Milun, 1998; Choi and Silverman, 2003).

Some authors have reported diminished sex differences in cognitive abilities (Feingold, 1988; Baenninger and Newcombe, 1995). In contrast, Hedges and Novel (1995) stated that the average differences have remained over the past 30 years. Similarly, many studies do not report that the differences would be vanishing (e.g. Collins and Kimura, 1996; Colom, Quiroga & Juan-Espinosa, 1999).

1.7. Hormones and cognitive functions

There is evidence that sex hormones affect cognition, creating differences in cognitive functions both between sexes and within sexes (Kimura, 1996). Hormones affect the cognition in two ways: activational effects refers to fluctuations in the levels of hormones in adulthood and organizational effects refers to long-lasting influences of prenatal gonadal hormones.

Activational influences include diurnal, menstrual and seasonal changes of hormones. Diurnal changes of testosterone (T) levels are related to variation in spatial abilities in males (Moffat and Hampson, 1996). Cognitive functions are also influenced by estrogen levels during the menstrual cycle in women (Postma, Winkel, Tuiten & Honk, 1999; Alexander, Altemus, Peterson & Wexler, 2002). Males perform better in spatial tasks in spring (T levels lower) than in fall (T levels higher) which is related to seasonal changes in T levels (Kimura, 1996).

In spatial tasks, females perform better with high T levels, whereas males perform better in low T levels (Gouchie and Kimura, 1991; Moffat and Hampson, 1996). This suggests that there is an optimal level of testosterone needed for good spatial abilities. Sex differences in cognitive abilities do not result only from fluctuations of hormones but also originate from prenatal hormonal environments (Sanders and Waters, 2001).

1.8. Organizational effects of prenatal hormones

Sex hormones influence the prenatal development of brain structures. Androgens are believed to cause the male differentiation of the brain during the prenatal development (Thijssen, 2002). Organizing effects of gonadal hormones are considered to influence masculinization (development of male-typical characteristics) or feminization (development of female-typical characteristics) (Collaer & Hines, 1995). The influence of organizational effects of androgens in humans is often studied in clinical populations with rare disorders. Congenital adrenal hyperplasia (CAH) is a rare inherited disorder where the embryo is exposed to excessive amounts of androgens (Berenbaum, Korman & Leveroni, 1995). Girls with CAH are born with masculinized genitalia and this condition is usually corrected with surgery.

Studies concerning the cognitive abilities of CAH individuals have demonstrated the effects of androgens in prenatal development in humans. CAH girls have shown enhanced spatial abilities in tests where men usually get higher scores (Nass and

Baker,1991; Berenbaum et al., 1995). On the contrary, in CAH boys the increased exposure to androgens may decrease performance in skills that typically favor males (Kimura, 1999). Of course, altered cognitive abilities in CAH individuals might be result of the complications of the illness.

In humans the organizational effects of testosterone can be studied also in opposite-sex twins. Animal studies have shown that the intrauterine transfer of testosterone during fetal development results in masculinized anatomical, physiological and behavioural traits in adult females who have shared the uterus with male fetuses (Ryan and Vandenbergh, 2002). In humans there occurs same kind of prenatal sex hormone transfer that is evident in animals (for a review see Miller, 1994). Female members of opposite-sex twins are inherently exposed to testosterone in their uterine environment.

Studies concerning prenatal masculinization of females with twin brothers have been controversial. One study found no evidence of behavioural or physiological masculinization in Finnish twins (Rose et al., 2002). Similarly, there were no clear masculinization effects in personality measures in an Australian population (Loehlin and Martin, 1999). On the contrary, in otoacustic emissions (OAEs) there is evidence of prenatal masculinization in females with twin brothers. OAEs are spontaneous sounds produced in inner ear and they can be detected by using sensitive microphones. Females usually exhibit more OAEs than males but in females with co-twin brothers OAEs are reduced to the same level as in male twins and in non-twin males. (McFadden, 1993; McFadden, Loehlin, Pasanen, 1996; for a review McFadden, 2002). Further, in a study of cerebral lateralization, females with male co-twins had a more masculine pattern of functional cerebral lateralization in dichotic listening task than females with female co-twins (Cohen-Bendahan, Buitelaar, van Goozen & Cohen-Kettenis, in press). Similarly, another study of cognitive functions showed masculinization of opposite-sex twin females in spatial abilities (Cole-Harding, Morstad & Wilson, 1988).

To summarize, the studies of possible masculinization effets of prenatal testosterone transfer indicates that more research in this area is needed. Particularly cognitive functions could be sensitive to organizing effects of testosterone.

1.9. Aim of this study

The present study focuses on sex differences in cognitive functions among young adult twins and compares these functions in same-sex and opposite-sex twin pairs. Specifically, the aim of the present study is to examine whether the female twins of the opposite-sex twin pairs resemble their male co-twins or males from the same-sex twin pairs in cognitive functions, thus showing effects of masculinization.

2. METHODS

This study is part of the ongoing longitudinal FinnTwin16 study of Finnish twins born in 1974-1979 (see Kaprio, Pulkkinen & Rose, 2002). The current study of five birth cohorts was funded by National Institutes of Health, USA, and the Academy of Finland, and it is headed by Professor Jaakko Kaprio, University of Helsinki and Professor Richard Rose, Indiana University. Starting from the spring 2001, twins who had replied to a fourth questionnaire between 2000 and 2002, were invited to a clinical study in Helsinki. The study protocol includes blood samples for zygosity and other blood tests, structured psychiatric interview, neuropsychological testing and EEG/ERP measures. This study comprises subjects who participated between 18th of April 2001 and 25th of September 2003.

2.1. Subjects

336 subjects included 180 females and 156 males. There were 134 same-sex female (SSF), 111 same-sex male (SSM), 46 opposite-sex female (OSF) and 45 opposite-sex male (OSM) twins. In one SSM twin pair only the other of them participated in the study. Age at testing ranged from 23 to 28 years old (M = 25.26, SD = 1.08). 296 of subjects were right handed. About 3% of subjects had completed compulsory schooling only, 26% vocational, 8% institute, 41% high school, 14% vocational high school and 7% university education. Many were still students. Majority of the subjects (86%) were from urban areas of Finland (for demographic variables see Table 1 in results).

All the travel and accommodation expenses of subjects participating in the study in Helsinki were paid. They also received gift certificate worth of 50 euros. The study was fully described to the subjects before they signed the informed consent. The study protocol was approved by the ethical committee of the Helsinki and Uusimaa Hospital District. From the final analyses one subject with a brain injury and two subjects with a rare neurological disorder were excluded.

2.2. Neuropsychological tests

General cognitive ability was measured with the Vocabulary subtest from the Wechsler Adult Intelligence Scale-Revisited (WAIS-R) (Wechsler, 1981). This subtest is the best single measure for general cognitive ability in well-socialized persons who are not speech- or language-impaired patients (Lezak, 1995). In Finnish normative data the correlation between the Vocabulary and full test performance has been .81 - .84, for 24-28-year-olds. The reliability of Vocabulary has been .91 - .94. (Wechsler, 1992). In the Vocabulary subtest the subject was asked to explain the meaning of a list of words. As a time saving procedure only every other item from the original version was given. According to Zytowski and Hudson (1965) the validity coefficient of split-half administration scores correlates above .90 for vocabulary subtest.

Verbal attention and working memory were measured with the Digits Forward and Digits Backward tests, respectively, from the Wechsler Memory Scale-Revisited (WMS-R) (Wechsler, 1987), and Letter/Number Sequencing from WAIS-III (Wechsler, 1997). The Digit Span test consisted of seven pairs of number sequences.

The examiner read out the numbers at the rate of one per second. The span length increased by one digit at a time. In Digits Forward the subject had to repeat the given numbers in the same order in which they were red by the examiner. In Digits Backward the subject's task was to repeat the given numbers in the reverse order. When the subject failed to repeat both sequences of same length, the test was stopped. According to Finnish normative data the reliability for Digit Span has been .74 - .76, for 24-28-year-olds (Wechsler, 1996). In Letter/Number Sequencing task the examiner read aloud spans with both numbers and letters (every second unit was number and every second unit was a letter). The subject's task was to enumerate first the numbers in ascending order of size and then the letters in alphabetical order. Of each span length, a three trial block was administered. The task was continued till the subject failed in all three trials of similar length. The task began from a block of only two units and the span length increased by one unit at a time. The longest span consisted of eight units. Reliability data for Finnish subjects is not available.

According to Lezak (1995) the Digits Forward is a test of auditory attention and Digits Backward requires more active working memory processes. Therefore in this study, auditory attention was measured with Digits Forward and auditory working memory with Digits Backward and Letter/Number Sequencing. Both the span length and the number of correct answers were taken into account. Digits Forward variable was calculated by combining the number of correct trials and the span length. Digits Backward variable was calculated by combining the number of correct trials and the span length and the Letter/Number Sequencing score was calculated in the same way: number of correct trials plus the span length.

Verbal memory and learning were studied with the California Verbal Learning Test (CVLT) (Delis, Kramer, Kaplan & Ober, 1987). In CVLT the examiner read aloud five times a 16-item list, which is called “Monday shopping list”. After each five trials, the subject had to repeat as many words as recalled of the list in free order. Each of the items belonged to one of the four semantic categories (spices, tools, fruits and clothes). After that the interference list (“Tuesday shopping list”) was presented. Immediately after the interference list, the “Monday list” was asked to be remembered, and again in approximately 20 min delay, both in free and cued recall. CVLT provides many measures of learning strategies and memory functions. In this study the measures of total recall, semantic clustering, short and long delay recall, and recognition hits were studied. There is no reliability data for the Finnish test, but the estimation of the total-test reliability in the CVLT test manual is .77 (Delis et al., 1987).

Psychomotor performance was measured with the Digit Symbol subtest from the WAIS-R. Visuo-motor coordination, motor persistence, sustained attention and response speed are needed in Digit Symbol (Lezak, 1995). In Digit Symbol there were 100 blank squares in (seven first ones for practice), each paired with number from one to nine. Subject’s task was to copy symbols in the blank squares below the numbers as fast as possible. The key was presented on the top of the paper for paired numbers and symbols. Time was taken and the test was stopped after 90 seconds. The score of this test was simple the number of correctly filled squares. Reliability for Digit Symbol has been .82 - .88 according to Finnish normative data (Wechsler, 1992).

Executive functions were studied with two commonly used tests: Trail Making and California Stroop. Trail Making is a paper and pencil test with two parts. It is a task of complex visual scanning with a motor component. In the part A subject had to connect the numbered (from 1 to 25) circles in numeric order as quickly as possible. In the part B the subject had to connect as quickly as possible both numbered (from 1 to 13) and lettered (from A to L) circles alternately, numbers numerically and letters in alphabetical order. Test was administered in the Reitan (1958) way, which means the errors were pointed out by the examiner. In both parts the time to connect all the items correctly was measured. A difference score of the time used in parts B and A was calculated. California Stroop test consisted of three trials. There were 60 items for each trial from which the ten first were for practicing. In first trial there were color squares for simple color naming. The second consisted of words of colors printed in black ink for simple word reading. Third one had color words printed in ink that had a different color than the one indicated by the word; the subject's task was to name the color of the ink. The colors as well as the color words in all trials were red, green and blue. In each trial the time was taken and the errors were counted. The Stroop interference effect was calculated (the difference between color-word score and predicted color-word score). The difference score of the Trails (B-A), and the Stroop interference score were used as variables of executive function.

Abstraction ability and time for decision making process were studied using the Abstraction and Working Memory (AIM) task (Glahn, Cannon, Gur, Ragland & Gur, 2000). It was administered by computer applying the Power Laboratory program (Chute and Westall, 1997). Subjects were shown five shapes on the computer screen. Two were in the upper-left corner, two in the upper-right corner and one (target) in the centre of the screen below the other shapes. The subject had to pair the target object with the objects in left or right. Stimuli included red, yellow or blue circles, squares and triangles, which were distorted in shape to reduce their verbalizability. In the memory condition there was delay between appearance of the target and the other stimuli. Target stimulus was presented for 500 msec after which the screen was blank for 2.5 seconds before the objects in the upper corners appeared. After each trial the subject received feedback as word “correct” or “incorrect” appeared on the screen after the response. AIM task took about seven minutes to complete and the two conditions alternated. Correct answers and the time for decision making process were calculated. For detailed information about the AIM task see Glahn et al. (2000).

Visual processing was tested with two psychophysical tests: trajectory discrimination task (Motion Task) and trajectory recognition memory task (Motion Memory Task) (Farmer, O’Donnell, Niznikiewicz, Voglmaier, McCarley & Shenton, 2000; Brenner, Lysaker, Wilt & O’Donnell, 2002). These computerized tests measured individual’s performance threshold as a function of visual noise. Motion Task consisted of 100 dots moving either rightward or leftward across the screen. Subject’s task was to say whether the dots were moving to ‘right’ or ‘left’. After two successful trials noise was added: randomly moving dots appeared among the dots moving right or left. After two correct judgements noise was increased and after one incorrect judgements noise was reduced. This procedure defined the subject’s threshold of motion discrimination. In the Motion Memory Task, there first appeared a screen of moving dots, which were moving upwards, downwards, rightwards or leftwards. After that, the screen was blank and then another group of moving dots appeared (up, down, right or left). The subject’s task was to determine whether the two groups of moving dots were moving in the same direction or in the different direction. The noise was added or removed in the same way as in the Motion Task. In both tasks all the dots were black and there were a total of 50 trials for detecting the subject's threshold. For further information of these tests, see Brenner et al. (2002) and Farmer et al. (2000).

The neuropsychological battery took approximately one hour to complete. All the computerized tests were administered using an Apple iMac computer. Most of the neuropsychological testing was done by the author of this study. Besides, there were three extensively trained and supervised testers.

2.3. Statistical analyses

All statistical analyses were performed using the SPSS version 11.0 program. Although there were total of 336 subjects in this study, not all them were included in the factor analysis because of some missing data. Factor analysis was performed to 279 subjects, from which 115 were SSF, 92 SSM, 37 OSF and 35 OSM twins. The probability level of under 0.05 indicated statistical significance in all analyses. The sex differences in demographic variables were analyzed by χ^2 test. Further, in comparison of OSF and OSM twins, paired *t*-tests were used because the dependency of opposite-sex twins had to be taken into account.

3. RESULTS

There were no statistically significant differences in any of the demographic variables (Table 1).

Table 1

Number of twins in demographic variables.

	SSF	OSF	SSM	OSM	χ^2	p
Education					5.89	.43
Compulsory or vocational	50	12	46	19		
High school	53	23	47	15		
Vocational high school or university	51	11	18	11		
Hand					4.58	.21
Right	122	41	96	37		
Left or ambidextrous	11	3	15	8		
Residence of living					5.12	.53
Helsinki and surrounding area	39	16	45	16		
City > 20 000 inhabitants	66	21	40	19		
City < 20 000 inhabitants or rural	28	26	9	10		
Economic status					6.83	.34
Good	40	11	41	13		
Average	45	22	50	18		
Poor	40	13	20	14		

Note. SSF = same-sex female, OSF = opposite-sex female, SSM = same-sex male, OSM = opposite-sex male.

Table 2 shows the comparisons of cognitive measures for SSF and SSM twins analysed with MANOVA.

Table 2

Overall comparison of cognitive measures for SSM and SSF twins

	Male Mean	SD	Female Mean	SD	Z
Vocabulary	19.73	4.76	20.57	5.27	-1.24
Digits Forward	14.14	2.81	13.40	2.81	-1.90†
Digits Backward	12.17	2.96	11.44	2.66	-2.13*
Letter/Number Sequencing	17.09	3.94	15.35	3.45	-3.67***
CVLT total words	54.84	7.92	59.38	7.51	-4.27***
CVLT semantic clustering	18.76	11.03	24.12	10.55	-3.83***
CVLT short delay [a]	.95	.14	.95	.12	-.27
CVLT long delay [b]	1.00	.15	.97	.11	-.55
CVLT recognition	14.91	1.36	15.11	.98	-.31
Digit Symbol	58.44	10.59	64.36	10.30	-4.16***
Stroop interference	36.12	9.21	33.50	9.51	-2.36*
Trail Making (B-A)	36.03	16.89	35.24	21.07	-.88
AIM correct	24.96	2.40	24.52	2.74	-.92
AIM memory correct	24.07	2.93	24.01	3.32	-.42
AIM response time	2161.74	658.12	2236.64	694.78	-.75
AIM memory response time	1560.63	477.79	1563.61	570.32	-.50
Motion Task	18.92	15.95	21.76	16.90	-1.55
Motion Memory Task	24.97	12.17	26.96	11.43	-1.90†

[a] CVLT Short delay = number of recalled words after interference list/number of recalled words before interference list. [b] CVLT long delay = number of recalled words after long delay/number of recalled words in short delay.

*** p < .001. ** p < .01. * p < .05. † p < .10.

In order to reduce the number of neuropsychological variables, a factor analysis was performed. All factors with eigenvalues over one were included. Principal component analysis with Varimax rotation resulted six-factor solution explaining 68.6% of the total variance. Further, the loadings for the first unrotated factor, considered as a g factor, were examined. The g factor explained 20.4% of the variance. Table 3 shows the factor loading matrix of these six components and also the first unrotated component (g). The factor loadings below 0.3 are not displayed, because they are not considered to meet the minimal level of significance.

Table 3

Rotated component matrix of the six factors and unrotated first factor

Neuropsychological measure [a]	Factor						
	Verbal factor	WM factor	EF factor	DMT factor	Visual factor	Memory factor	Unrotated first factor (g)
Digits Forward		.815					.434
Digits Backward		.740					.506
Letter/Number Sequencing		.816					.512
CVLT total words	.853						.730
CVLT semantic clustering	.828						.596
CVLT short delay						.881	.413
CVLT long delay						.925	
CVLT recognition	.694						.507
Digit Symbol			-.752				.556
Stroop interference	-.302		.673				-.535
Trail Making (B-A)			.717				-.573
AIM correct					.850		
AIM memory correct					.791		.353
AIM response time				.953			
AIM memory response time				.958			
Motion Task			.421		-.393		-.320
Motion Memory Task			.316		-.545		

Note. Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization. WM = working memory, EF = executive functions, DMT = decision making time.

[a]The Vocabulary score was not included in the factor analysis.

Six subscale scores were calculated from the six factor loadings and from the basis of the factor scores, the linear multiple regression analyses were performed. The scores from the six factors were entered to predict the performance on the Vocabulary task separately for men and women. As displayed in Table 4, two of the factors were significant predictors of the vocabulary performance in SSF twins [F (6) = 7.00, p <

.001], whereas in SSM twins only one of the six factors was a significant predictor of the Vocabulary performance [F (6) = 2.37, p < .05]. In opposite-sex female and male twins the factor score model was not a significant predictor of the Vocabulary performance.

Table 4

Multiple regressions predicting Vocabulary performance from six factor scores

Sex	Contributing factor	*B*	*SE B*	β
Female	Verbal	.97	.53	.15†
	WM	2.37	.45	.44***
	EF	-.81	.39	-.17*
	Memory	.97	.52	.16†
Male	WM	.95	.47	.21*

Note. Females are SSF and males are SSM twins.

*** p < .001. * p < .05. † p < .07.

Comparison of sex differences of the six subscale scores were analyzed with MANOVA. Table 5 shows the comparisons. The contrast analyses showed that there were significant differences between SSF and SSM twins in scores of verbal factor (p < .001), WM factor (p < .01), EF factor (p < .05) and visual factor (p < .05). Further there was a tendency (p = .057) of difference in visual factor scores between SSF and OSF twins. Moreover, there were significant differences between OSF and OSM twins in verbal factor (p < .05) and EF factor (p < .05) scores. However, there were no significant differences in WM factor and visual factor scores of OSF and OSM twins. Comparisons between OSF and OSM twins were also analyzed with paired *t*-tests: results of the contrast analyses were confirmed. Finally, there were no significant differences between SSM and OSM twins in any of the factors. According to ANOVA there were no group differences of g factor scores between SSF, OSF, SSM and OSM twins (F=1.69, df=3).

Table 5

Sex comparison of the factor scores for SSM, SSF, OSM and OSF twins

Factor	SSF	SD	OSF	SD	SSM	SD	OSM	SD	F
Verbal factor	.31	.83	.12	1.03	-.31	1.05	-.33	1.03	8.70***
WM factor	-.26	.97	.02	1.04	.22	1.04	.25	.76	4.97**
EF factor	-.13	1.12	-.29	.84	.21	.88	.20	.91	3.63*
DMT factor	.01	1.03	-.06	.97	.01	.99	.05	.98	.06
Visual factor	-.20	1.09	.16	.99	.13	.90	.14	.86	2.63†
Memory factor	-.05	.84	-.12	.96	.08	1.10	.06	1.23	.51

*** p <.001, ** p <.01, * p <.05, † p =.51

Figure 1 shows mean scores of the two factors where females outperformed males (verbal and executive functions) and two factors where males outperformed females (working memory and visual) for, same-sex female, opposite-sex female, same-sex male, and opposite-sex male twins.

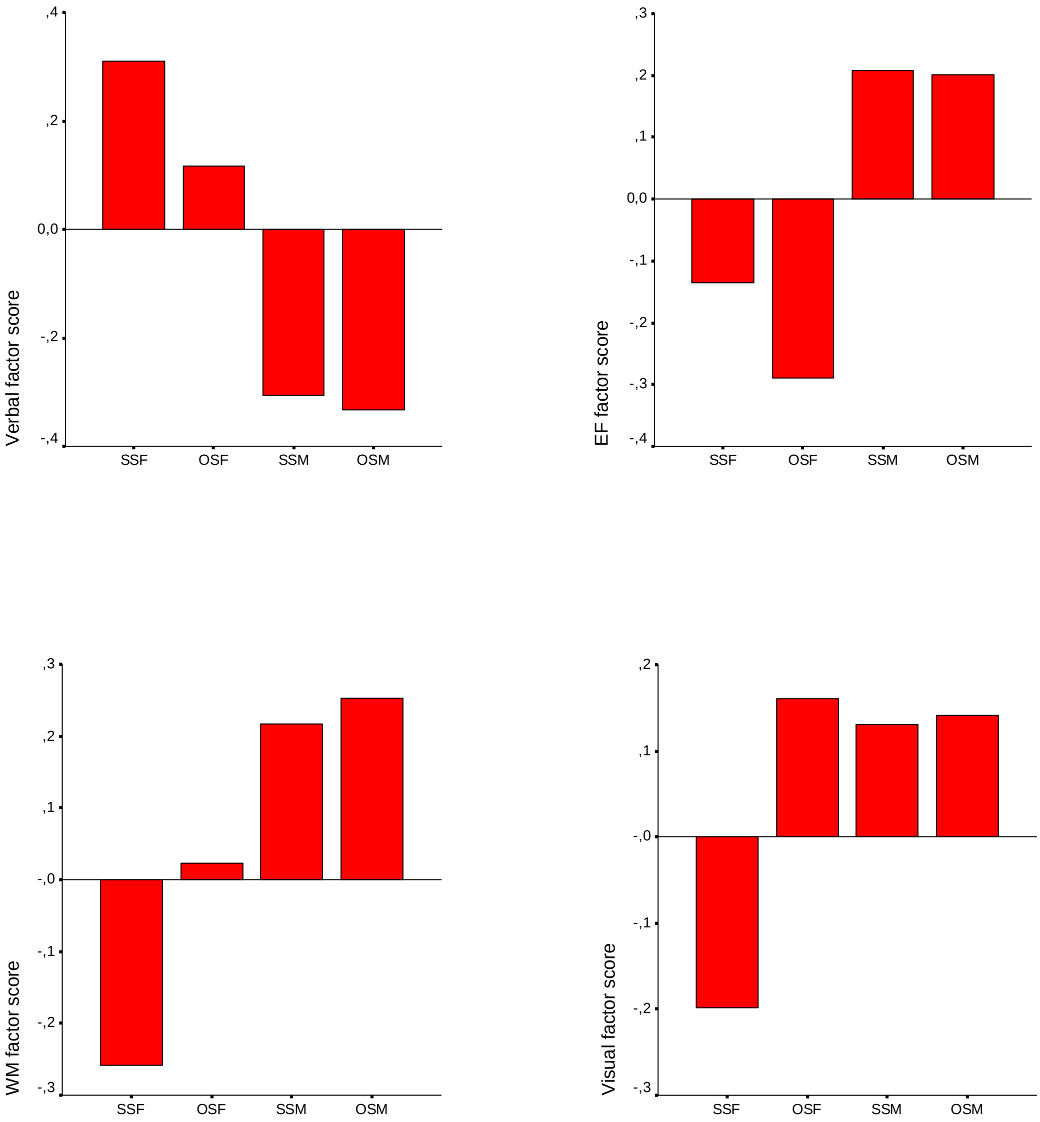

Fig. 1. Mean factor scores of verbal, executive function (EF), working memory (WM), and visual factor for same-sex female (SSF), opposite-sex female (OSF), same-sex male (SSM), and opposite-sex male (OSM) twins.

4. DISCUSSION

In the present study sex differences in cognitive abilities were detected. Females outperformed males in verbal memory. These results from the Finnish twin data are consistent with earlier studies of verbal memory (Delis et al., 1987; Chipman and Kimura, 1999). Females also had higher scores in the executive function factor (EF) which loaded at its highest on Digit Symbol task. The female advantage in Digit Symbol is well replicated in adolescents (Mann, Sasanuma, Sakuma & Masaki, 1990) as well as in older adults (Portin, Saarijärvi, Joukamaa & Salokangas, 1995).

Equally, males performed better in two factors. The male advantage in visual factor is in line with studies suggesting male superiority in visual-spatial abilities as compared with females (Linn and Petersen, 1985; Weiss et al., 2003). Interestingly, tests that loaded on visual factor were all administered by a computer. In fact, it is known that there are sex differences in attitudes towards computers: females are generally more anxious than males when using computers (see Chua, Chen & Wong, 1999). Another factor that favored males was auditory attention and working memory. Previously Digit Span task has been considered a sex-neutral task (Collaer & Hines, 1995). However, according to process oriented model of cognitive sex differences males outperform females in tasks that require maintaining and manipulation of information in short term memory (Halpern and Wright, 1996). One possible explanation of male advantage could also be that males may have used visuospatial imagery, which is proved to be a good strategy for a better performance in Digit Span task (Hoshi et al., 2000). The fact that there was no sex difference in g factor score is consistent with previous studies (Aluja-Fabregat, Colom, Abad & Juan-Espinosa, 2000; Colom et al., 2000).

Performance in the Vocabulary test was predicted by working memory and executive functions in SSF twins and also by verbal abilities and memory, even though the verbal and memory functions did not reach the required significance level. On the contrary, performance in Vocabulary was predicted only by working memory in SSM twins. This may reflect the use of different kind of strategies among females and males while doing the same cognitive task. Previous studies of way-finding and route-learning have also revealed sex differences in using of strategies (Dabbs, Chang, Strong & Milun, 1998; Choi and Silverman, 2003). Similarly, the neuro-imaging studies have indicated sex differences in brain functioning when doing the same task (e.g. Mansour et al., 1996; Jordan et al., 2002). The better predictability of the Vocabulary performance in females can also imply that the vocabulary task is a wider measure of cognitive functioning in females than in males. Vocabulary task is probably better measure of general cognitive ability in females than in males, and that may result from the verbal character of the Vocabulary task.

The results demonstrate that female members of opposite-sex twins resemble their male co-twins and male twins from same-sex pairs in cognitive functions. However, there is not any evidence of feminization of male members of opposite-sex twins in cognitive abilities. OSF twins performed on the same level as SSF twins in two factors (verbal and executive functions) that favored females, which suggests that having a male co-twin does not defeminize the female members of opposite sex twins.

Although the difference of visual factor score between OSF and SSF twins did not reach the statistically significant level, it is noticeable that the visual factor score of the OSF twins was enhanced to the male level; in fact OSF twins had even a higher mean visual factor score than SSM and OSM twins. The difference in number of OSF twins (N=37) and SSF twins (N=115) explain why the difference did not reach the required significance level of $p < .05$. These results of enhanced visual abilities of OSF twins suggest that there occurs masculinization of cognitive functions in female members of opposite-sex twins. The present study allows not to draw conclusions on the effects of hormones as the current hormone levels were not measured in this study. Yet, it is known that activational effects of testosterone in adult brain are related to spatial abilities (Van Goozen, Cohen-Kettenis, Gooren, Frijda & Van de Poll, 1994; Moffat and Hampson, 1996; Neave and Menaged, 1999). However, in the current study all the neuropsychological tests were done approximately in same time of the day (nearly always in the morning between 9 and noon).

Still, these results are in line with the hypothesis of masculinization effects of the prenatal testosterone transfer. This result is congruent with earlier studies of prenatal masculinization of female members of opposite-sex twins in cerebral lateralization (Cohen-Bendahan et al., in press), spatial abilities (Cole-Harding et al., 1988), and in auditory systems (McFadden, 1993).

Furthermore, environmental effects were not controlled in current study. Hobbies, for instance, might influence the development of cognitive abilities (for a review see Baenninger and Newcombe, 1995). Even though, one study found no relationship between mental rotation performance and spatial play experiences. Instead, prenatal testosterone level was correlated with rotation ability in girls (Grimshaw, Sitarenios & Finegan, 1995). Another possible environmental influence, which was not controlled in this study, is the presence of older siblings in the family. At least in sex role development of children, having an older brother is related to more masculine behaviour in girls and boys (Rust, Golombok, Hines, Johnston, Golding & the ALSPAC study team, 2000).

Even so, the masculinization effects of prenatal testosterone transfer could explain the resemblance between OSF and OSM/SSM twins, it can not be ruled out that many postnatal experiences may have masculinized female members of opposite-sex. However, the fact that OSF twin's performance on two factors that favored females was not decreaced in the male level is congruent with study where testosterone levels were related to tasks that typically favor males, but not to tasks that favor females or are sex neutral (Gouchie and Kimura, 1991). Another thing that supports the biological origins of cognitive sex differences is a cross-cultural study which indicated that the sex differences in cognitive abilities are culture-independent (Mann et al., 1990).

To summarize, the current study shows evidence of enhanced cognitive abilities of female members of opposite-sex twins in tasks that favor males. At the same time, they perform in the same level as same-sex female twins in tasks that favor females. This demonstrates that OSF twins may be masculinized, but not defeminized, in their cognitive functions. Whether this is result of prenatal androgens or postnatal experiences cannot be decided. The relationship between prenatal androgens and later postnatal behaviour remains conjectural. At least, the results of this study are congruent with the prenatal testosterone transfer hypothesis. There is also evidence that Vocabulary performance may measure different kind of functions in females and males. Further, female members of opposite-sex twin pairs may differ from female members of opposite-sex twin pairs in the processes that are used while performing the Vocabulary task. This illustrates other kind of similarity in cognitive functioning between female members of opposite-sex twin pairs and male twins.

The future studies should measure the current hormone levels. Also, tasks that are more likely to favor males (e.g. mental rotation) should be included in further studies. Neuro-imaging studies of opposite-sex twins could also be very informative to explore the differences in brain functioning.

Finally, this study indicates some benefits of twinship in female members of opposite-sex twin pairs. They outperform males in some cognitive abilities and at the same time they approach males in cognitive abilities where males are usually better than females. Earlier, the favorable aspect of twinship was found in positive developmental environmental of socioemotional behavior among opposite-sex twins (Pulkkinen, Vaalamo, Hietala, Kaprio & Rose, 2003). Current study adds favorable development of cognitive functioning to the possible advantages of twinship in opposite-sex female twins.

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