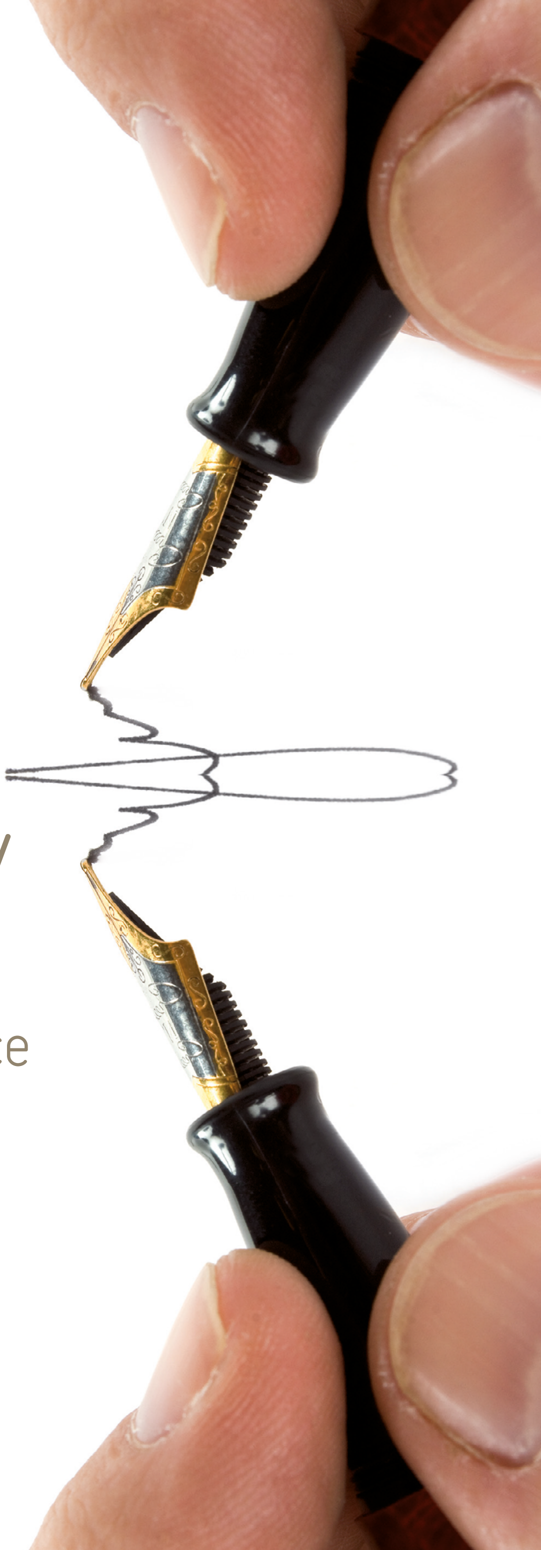
Martin Musálek

Development of Test Batteries for Diagnostics of Motor Laterality Manifestation – Link between Cerebellar Dominance and Hand Performance



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Development of TestBatteries for Diagnostics of Motor Laterality Manifestation –
Link between Cerebellar Dominance and Hand Performance

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Dedicated to the memory of Prof. Blahuš who taught me the first psychometric steps.

Contents

A unique painting of a left-handed archer, the only in the world, discovered at castle Houska in the Czech Republic

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List of Acronyms

ADHD	Attention Deficit Hyperactivity Disorder
AHPQ	Annett Hand Preference Questionnaire
ANOVA	Analysis of Variance
AP	Absolute Pitch
C	Chance
CCFA	Categorical Confirmatory Factor Analysis
CFA	Confirmatory Factor Analysis
CTT	Classical Test Theory
D	Dextral
DFWT	Dichotic Fused Words Test
DNA	Deoxyribonucleoid Acid
EHI	Edinburgh Handedness Inventory
FA	Fluctuating Asymmetry
IRT	Item Response Theory
LQ	Laterality Quotient
MPA	Minor Physical Asymmetry
MR	Multiple Regression
RS	Right Shift Factor
SEM	Structural Equation Modelling
SRM	Structural Regression Model
WFQ	Waterloo Footedness Questionnaire
WHCT	WatHand Cabinet Test
WHQ	Waterloo Handedness Questionnaire

Aim of this Book

The aim of this book is focused on better understanding of laterality phenomenon and its evaluation. All informations are presented in sense to contribute to the standardization of the new diagnostic tools assessing the motor manifestations of laterality in adolescents and adults aged 18–60 and children aged 8 to 10 years. Both in terms of determining the theoretical concept, the selection of appropriate items, and the verification of structural hypotheses concerning the design of acceptable models. Moreover in this monograph we try to suggest a new approach to assessing of motor laterality manifestation by means of relationship between cerebellar dominance and hand performance.

The first part of this book deals with the concept of laterality, its manifestations and meaning in non-living systems and living organisms. As a human characteristic, laterality is manifested in a variety of functional and structural asymmetries. This part also discusses ways of diagnosing motor manifestations of laterality and the issue of cerebellar dominance, including its reflection in the form of asymmetry of the extinction physiological syndrome of upper limbs.

The second part focuses on the process of the standardization study issues, the present approach of statistical method of structural equation modelling, and the actual design of test battery construction.

The last part of this book presents the results of the structural equation modelling, i.e., the dimensionality and diagnostic quality, including the reliability of various proposed models. All limitations of current research as well as final models and indicators are analysed in the discussion and conclusion of this book.

Keywords: asymmetry, laterality, handedness, cerebellar dominance, structural equation modelling, test development, dimensionality, reliability, kinesiology, motor control

1. Phenomenon Called Laterality

The entire next chapter is devoted to the concept of laterality, its derivation, and the place it holds within both non-living and living systems. All of this information will help us at the end of the chapter to formulate the actual relationship between laterality and humans.

1.1 Laterality as Concept

The basis for the definition of the concept of laterality, derived from the Latin word *latus*, meaning "side" (Kábrt, Kucharský, Schams, Vránek, Wittichová, & Zelinka, 2001), was the finding that most manifestations in living nature result from the spontaneous violation of symmetry. Symmetry is generally considered to be unstable (Coleman, Weinberg, & Lyman Laboratory of Physics, Harvard University, Cambridge, 1973). One of the possible causes of this violation is a loss of symmetry due to a transition from a certain energy state to a lower energy state (for example some symmetry is conserved in a certain energy state, but after the transition to a lower state, this symmetry disappears: spinning flywheel, stopping flywheel). Another case of spontaneous violation of symmetry is violation of parity – sameness. Generally, parity in the field of physics represents the symmetry property of physical quantities or processes under spatial inversion (Riehl, 2010). Spontaneous violation of symmetry leads to the creation of asymmetry (Senjanovic, Mohapatra, & Department of Physics, The City College of the City University of New York, New York, 1975; Viedma, 2007). The word *asymmetry* comes from Greek and refers to irregularity. Asymmetry can even be observed in the basic manifestation of the existence of matter – movement.

1.1.1 Asymmetry in Universe

When it comes to determining the origin of asymmetry in living nature, numerous studies deal with the asymmetry and its manifestations in the universe. Many studies dealing with asymmetry of galaxy spin are currently available. Observation and subsequent simulation studies have been performed, focusing on spiral galaxies that rotate the disk of baryonic matter (composed of protons, electrons, and neutrons). These studies are particularly concerned with the evolution of galaxy spin. In contemporary modern theory dealing with this issue, the "Tidal Torque Theory" model (Schäfer, 2009) is accepted. This assumes that proto-haloes (germs of galaxies) acquire most momentum in the early stage of their development. The perpendicular plane to the disk determines the axis of rotation, while the spiral arms, which are curled inwards, determine the direction of galaxy rotation in most spiral galaxies (Bailin, & Steinmetz, 2005; Porciani, Dekel, & Hoffman, 2002). Spiral galaxies are divided into those that spin clockwise, called "*Z*" galaxies, and those that spin counter-clockwise, called "*S*" galaxies (Sugai, & Iye, 1995). Interestingly, only about 4% of spiral galaxies display the "*S*" character, i.e., counter-clockwise spin (Slosar et al., 2009).

In examining asymmetry in the universe, some studies have also focused on our solar system. Interestingly, seven out of the current eight planets in our solar system orbit the Sun in one direction, and only one (inner planet) Venus goes in the opposite direction. It is also surprising that the actual rotation axis of the outer planet Uranus is situated in the plane of

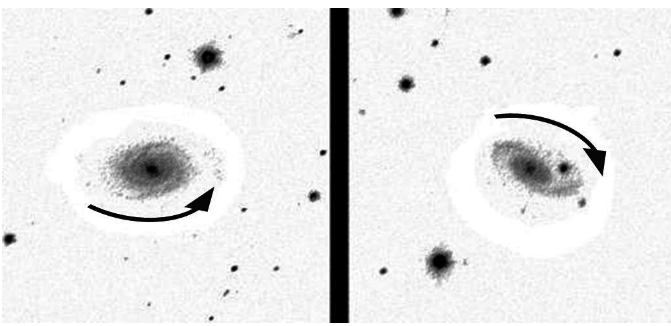

Fig. 1 *S* and *Z* type of galaxy
Galaxy in left field is so called *S* galaxy which is rotating counter-clockwise.
In right field is *Z* galaxy which is rotating clockwise.

Uranus's orbit around the Sun (i.e., the planet is the only one to "roll" on the orbit) (Dones, & Tremaine, 1993). These particularities are explained by interference from other cosmic bodies that have clashed with these planets.

1.1.2 Asymmetry and Chirality in Life System

The issue of asymmetry can also be examined at the microcosm level. Back in the 19th century, while observing the process of grape fermentation under a microscope, the famous French scientist Louis Pasteur discovered that two chemically identical substances can display different effects in the rotation of polarized light. Pasteur found that the acid from the natural fermentation process contains one type of crystal that rotates polarized light clockwise. However, the acid from the industrial fermentation of grapes contained two types of crystals that exhibited mirror uniformity, and did not rotate polarized light. It is also interesting that the acid-containing crystals that rotated polarized light clockwise enabled implemented microorganisms to reproduce and metabolize, while in the second type of acid (containing crystals that rotated polarized light counter-clockwise), microorganisms were not able to start the metabolism. At present, it is known that most molecules in laboratory conditions occur in two forms that are of mirror character (stereoisomer) to each other (Nicolle, 1962). These are also known as chiral molecules (Barron, 1982; Salam & Meath, 1998; Woolley, 1976). The term "chirality" is derived from the Greek word for hand, "*kheir*", and refers to the asymmetry of spatial distribution of an object that is not identical with its mirror image (Riehl, 2010). Although the molecules that make up the earth life organism include human body also occur in two forms in laboratory conditions, the human body always contains only one of them. With respect to saccharides, it is the D-form (dextral), derived from the Latin word for the right side; with regard to amino acids, it is solely the L-form (laevo), derived from the Latin word for the left side. Identification of the side is always based on where the substance rotates polarized light – whether to the right or to the left. This dominance of one type over another is not unique to humans, but applies to most living organisms on our planet (McManus, 2002). The state in which a substance naturally exists in the environment in only one form is called homochirality (Suzuki, Tanaka, Shiro, Shibata, Osaka, & Asahi, 2010).

The current view on the issue of asymmetry formation in biological substances provides two basic hypotheses. One assumes that the original representation of both forms was roughly the same (i.e., 50%), and that homochirality progressively changed depending on evolution. The second hypothesis is based on the idea that asymmetry leading to homochirality preceded the formation of life and comes from the universe. This hypothesis also has at present time more support *(Origin of Life on Earth: 'Natural' Asymmetry of Biological Molecules May Have Come from Space*, 2011; Breslow, 2011).

Based on the above examples and the outline of the importance of asymmetry and homochirality, viewed from different scientific perspectives, it is evident that these concepts form the basis for the selection of the side or direction in order to obtain certain features or benefits. Chirality clearly shows that due to differences in the spatial arrangement of molecules, two chemically identical compounds display vastly different characteristics. These can be generally termed favourable or unfavourable asymmetry, especially in the context of living organisms.

1.2 Laterality as Characteristic of Human

The important information arising from the previous chapter is that even organic substances – both the basic building blocks of living organisms (amino acids) and the basic units of energy (saccharides) – display chiral asymmetry. As mentioned in the previous chapter, in most cases amino acids occur in living organisms in the L-form and saccharides in the D-form. Due to their specific spatial arrangement, these substances have a certain characteristic. Since the concept of laterality is based on the concepts of asymmetry and chirality, it is possible to view laterality and its manifestations in the human organism as a human characteristic.

This characteristic is likely genetically determined, and some of its aspects are determined during early embryonic development (Wood, 2005). One area in which laterality is manifested (which is explored in detail in humans) is the left-right asymmetry of the arrangement of internal organs according to the vertical axis of the body. Deviations of this left-right asymmetry of internal organs in the form of an inverted arrangement in the abdominal cavity (Guichard et al., 2001; Wood, 2005), called situs inversus (Kosaki & Casey, 1998; Lopez-Garcia & Ross, 2007; Yokoyama, Copeland, Jenkins, Montgomery, Elder, & Overbeek, 1993), have frequently been detected in Kartagener syndrome, whose symptoms include reduced or absent mucus clearance from the lungs and male infertility (Kartagener, 1933). A heterozygous mutation of DNA/1 gene, which according to scientists is linked to a change in the asymmetry of internal organs, has been found in the genetic code of patients with Kartagener syndrome (Failly et al., 2009; Guichard et al., 2001; Leigh et al., 2009). Among other things, the change in this asymmetry may also lead to severe congenital defects affecting mainly the cardiovascular system. Some authors argue that gene mutations may cause changes in several aspects of chirality, which may in turn lead to situs inversus (Oliverio, Digilio, Versacci, Dallapiccola, & Marino, 2010). Despite the fact that laterality is a genetically determined human characteristic that displays more stable personality traits, it is important to realize that it does not have absolute stability over lifespan. Laterality is influenced by various environmental factors that may affect its form, even in the early postnatal period (Alibejk, & Angaji, 2010; Bakan, 1978; Elliot, & Roy, 1996; McManus, 1981; Orsini, & Satz, 1986).

As can be seen, laterality, as a human characteristic, plays a very important role in the own existence of humans. Therefore, the next chapter will focus on the most complex system known to us in which individual structural asymmetries are directly reflected in the external motor manifestations of humans: the human brain.

2. Human Brain

The human brain is currently the most complex system known to us that has a certain structure and very specifically differentiated functional centres. Damage to the brain results in a temporary or permanent loss of certain functions. Brain research and issues related to the exploration of asymmetry and laterality have been studied for many years. For instance the relationship between speech and a particular area of the brain was discovered by Pierre Paul Broca as early as in the 19th century.

2.1 Structural Hemispheric Asymmetry

This section deals with the issue of structural asymmetry of cerebral hemispheres related to motor activity and motor manifestations of laterality. The following information is based on current approaches to the assessment of brain structure.

Starting from the subcortical area of diencephalon, the brain displays a paired arrangement of its individual parts: the right and left part of the thalamus (Sherman, & Guillery, 2000), and the right and left half of the hypothalamus (Swaab, 2003). The cortical area is divided into two functionally distinct hemispheres (left and right), which are divided by a longitudinal fissure, and which communicate with each other through the corpus callosum. Since the function is superior to the organ, the most significant structural differences in the human brain are demonstrated by lateralization in cortical areas of the telencephalon.

Basic human brain asymmetry is evident at a glance. The right hemisphere is mostly wider than the left hemisphere in the frontal region. In addition, the right anterior frontal region is larger than the same region of the left hemisphere. By contrast, the occipital region is wider in the

Fig. 2 Human brain, below perspective – template (Toga, & Thompson, 2003)

left hemisphere, and its posterior part is larger than the same region of the right hemisphere (Bradshaw, & Nettleton, 1983).

It is generally accepted that one of the most significant relationship to structural asymmetries of the brain hemispheres is represented by handedness. Several anatomical asymmetries have been documented in right-handed individuals (Geschwind, & Galaburda, 1987). One of the most frequently observed asymmetries is the length and shape of cortical sulci, known as the Sylvian fissure. These deep sulci on the outer surface of the cerebral hemispheres form the boundary between the frontal, parietal, and temporal lobes. It is known from the postmortem studies conducted by Cunningham and Eberstaller in the late 19th century that the right Sylvian fissure and the left Sylvian fissure are typically asymmetric at the posterior end (Cunningham, 1892; Eberstaller, 1884). In most brains examined, the Sylvian fissure rises more at the end in the right hemisphere (Geschwind, & Galaburda, 1987; Hellige, 2001; Jäncke, & Steinmetz, 2004). This asymmetry has been verified in many contemporary studies, and it has been proved to be higher in right-handed individuals than in non-right-handed individuals. Based on the results of their research, in 1975 Hochberg and LuMay confirmed a significant difference in the height of the posterior end of the Sylvian fissure between right-sided and left-sided individuals. In right-sided individuals, the Sylvian fissure rose more in the right hemisphere in 67% of the cases examined. In left-sided individuals, the Sylvian fissure rose more in the left hemisphere in only 22% of the cases examined (Hochberg, & LuMay, 1975). It is also typical that the Sylvian fissure is longer in the left hemisphere than in the right hemisphere. In the study of Witelson and Kigar (1992) authors refer that handedness correlated with anatomy and asymmetry of the sylvian fissure in male. Surprisingly, hand preference was associated with a bilateral feature of morphology, and not with less asymmetry in non-right-handers discussed in the last part of this chapter (2.1.1 Structural Hemispheric Asymmetry in Relation to Gender). Another observed structural asymmetry is the proportion of the range of cortical areas in the Rolandic sulcus, representing the upper limbs.

The area in the left Rolandic sulcus representing the right upper limb is larger than the same area representing the left upper limb in the right Rolandic sulcus (White et al., 1994). Results of studies have also shown that the left Rolandic sulcus is deeper in right-handed individuals (the opposite being true in left-handed individuals), and that this asymmetry is more visible in right-sided individuals (Amunts, Hlaug, Schleicher, & Steinmetz, 1996). However, current research into Rolandic sulcus asymmetry has also led to the opposite results, and the original assumption of a strong correlation between structural asymmetry in this area and hand preference has been refuted by the findings of a study carried out by Davatzikos and Bryan (2002). In their study, a deeper and longer Rolandic sulcus was found in the right hemisphere; in addition, the study revealed that the variability of this asymmetry also depends on gender. The structural asymmetry was significantly higher in men than in women (Davatzikos, & Bryan, 2002). Based on these results, an analysis was carried out that found a significant correlation between the level of asymmetry, i.e., the depth in the Rolandic sulcus, and age; it supported the previous assumption concerning the variability of this asymmetry related to the gender of individuals (Cykowski et al., 2008).

Other cytoarchitectonic asymmetries were found in the temporal lobes, which are important for receiving speech stimuli. Structural differences were found between the left and right Heschl's gyrus where the primary auditory cortex is located. Results of studies have shown that Heschl's gyrus is larger in the left hemisphere (Rademacher, Caviness, Steinmetz, & Galaburda, 1993), due to the greater amount of white matter that Heschl's gyri are composed of. However, from the statistical point of view, the actual size of the primary auditory cortex in both Heschl's gyri is not significantly different (Morosan, Rademacher, Schleicher, Amunts, Schormann, & Zilles, 2001). In addition to Heschl's gyri, the structure of another part of the temporal lobes has been compared, specifically the left and right planum temporale. The planum temporale is larger (and longer) in the left hemisphere in right-sided individuals. Research has focused on the area known as the "Tpt", located around the planum temporale, which has been found to be larger in the left hemisphere in three out of four right-handed individuals examined (Galaburda, Sanides, & Geschwind, 1978). Interestingly, left-sided individuals did not exhibit a reversed size of the planum temporale but rather symmetry of these two areas of the temporal lobes (Geschwind, & Galaburda, 1987; Geschwind, & Lewitsky, 1968; Jäncke & Steinmetz, 2004). Particularly interesting results were produced by studies comparing the structural asymmetry in the temporal regions of different populations using magnetic resonance. The research group consisted of children with dyslexia, children with attention deficit hyperactivity disorder (ADHD), and a group of normally developing children. 70% of children with ADHD and normally developing children showed a larger planum temporale in the left hemisphere. In contrast, 90% of children with dyslexia showed a larger planum temporale in the right hemisphere. These children exhibited a significantly smaller planum temporale in the left hemisphere in comparison with the other groups, while the planum temporale in the right hemisphere did not differ in size from the average in other children (Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990). Differences in cytoarchitectonic structure and size were also confirmed in the parietal lobes: the left parietal lobe was larger than the right parietal lobe in most individuals (Eidelberg, & Galaburda, 1984). A significant correlation between the asymmetry in PG (the area related to speech) and the asymmetry in the planum temporale was also observed. With respect to the parietal lobe called PEG area (the area in the parietal lobe including non-speech functions), in which the importance of visual-orientation function is hypothetically assumed, the same study also revealed a generally larger area in the right hemisphere (Eidelberg, & Galaburda, 1984; Toga, & Thompson, 2003). Differences in the size of the planum temporale and in a certain parietal area were also found in children and adolescents (Larsen, Hoien, Lundberg, & Odegaard, 1990). Therefore, it was suggested that planum temporale asymmetry is not constant throughout life, but that it can likely be modelled using environmental and genetic factors (Schlaug, Jäncke, Huang, & Steinmetz,1995). Distinct structural asymmetry has also been found in the inferior part of the frontal gyrus called the pars opercularis (injury to it leads to aphasia in the Broca's area), the size of which is closely correlated with right-sidedness or left-sidedness. In right-sided individuals, this area is significantly larger in the left hemisphere (Dorsaint-Pierre et al., 2006; Foundas, Leonard, Gilmore, Fennell, & Heilman, 1996; Geschwind, & Galaburda, 1987; Keller, Crow, Fiundas, Amunts, & Roberts, 2007). The study by Foundas et al. (1998) first proved asymmetry also in left-sided individuals with a larger pars opercularis in the right hemisphere (Foundas, Hong, Leopard, & Heilman, 1998). These asymmetries in the inferior part of the frontal cortex are also supported by the finding of asymmetry in the white matter in this area, which connects the inferior part of the frontal cortex with the anterior part of the temporal cortex. Highley et al. (2002) discovered asymmetry in the white matter in this area in the brains of both men and women. White matter was on average 27% larger, and contained 33% more fibres in the right hemisphere (Highley, Walker, Esiri, Crow, & Harrison, 2002). Apart from cytoarchitectonic changes in individual cortical areas, research has also focused on possible structural differences in the corpus callosum, which forms the main communication channel between the hemispheres. The following variables were related: the size of the corpus callosum and the laterality of individuals (their side preference). It was found that in left-handed individuals and individuals without a definite side preference the corpus callosum is on average 11% larger than in right-handed individuals (Driesen, & Naftali, 1995; Witelson, 1985). Significant differences in the size of the corpus callosum were also confirmed by studies comparing the size of the corpus callosum in musically gifted individuals and the general population (Schlaug, Jäncke, Huang, Staiger, & Steinmetz, 1995).

Several structural asymmetries were also found in areas involved in motor and sensory functions, such as the caudate nucleus (Watkins et al., 2001) or cerebellum (Snyder, Bilder, Wu, Borgets, & Lieberman, 1995). The studies carried out by Volkmann et al. (1998) using magnetoencephalography revealed that grey matter is significantly larger in the motor cortex, which is located contralaterally to the preferred upper limb (Volkmann, Schnitzler, Witte, & Freund, 1998). Other studies have dealt with assessing the amount of grey matter cells in the right and left primary motor area. They found that this amount was generally greater in the right primary motor cortex, both in adults and children. The space between cells in the cortex, called the neuropil, which is composed of axons, dendrites, and synapses, was generally found to be greater in the left primary motor cortex. In the analysis of individual layers of primary motor cortex, differences in asymmetry of the cortex due to age were also identified. The supragranular layers showed significantly less asymmetry in children than in adults, while the infragranular layers showed similar levels of asymmetry in both age groups (Amunts, Schmidt-Passos, Schleicher, & Zilles, 1997).

Macrostructural asymmetry is complemented by microstructural differences. With respect to the Brodman area, right-sided individuals exhibited a more complicated and extensive internal structure in the left hemisphere. These asymmetries indicate a connection between hand preference and increased segmentation of the internal sulcus surface of the precentral gyrus (Hellige, 2001). Morphometry also revealed correlations between anatomic asymmetries in the planum temporale, the planum parietale, and hand preferences (Steinmetz, 1991). According to Chance, most hemispheric asymmetries are suppressed in individuals with the psychiatric diagnosis of schizophrenia (Chance, Casanova, Switala, & Crow, 2008). Despite the identification of many cytoarchitectonic differences between the two brain hemispheres, which are mainly related to hand preference in motor activity, it should be noted that hemispheric asymmetry is subject to interindividual variability (shape, size), which is also related to the functional lateralization of the human brain (Amunts, Schleicher, Bürgel, Mohlberg, Uylings, & Zilles, 1999; Eickhoff, 2005).

2.1.1 Structural Hemispheric Asymmetry in Relation to Gender

Deep mapping of hemisphere asymmetry were also focused on observing a significant differences between brain asymmetries at males and females. Witelson and Kigar (1992) submitted results which showed that handedness correlated with anatomy of the sylvian fissure in men and no association was found between hand preference and sylvian fissure anatomy in women. Study of Kovalev, Kruggel and Cramon (2003) which was focused on differences between male and female of global structural brain asymmetries found that male brains tend to be more asymmetric than female. This effect was obsereved in all brain areas. The most significant was in the superior temporal gyrus, Heschl's gyrus, the adjacent white matter regions in the temporal stem and the knee of the optic radiation, the thalamus, and the posterior cingulate. Additionaly the changes in brain structural asymmetry in context of age of male and female were evaluated. The brain asymmetry increases significantly with age in the inferior frontal gyrus, anterior insula, anterior cingulate, parahippocampal gyrus, retrosplenial cortex, coronal radiata, and knee region of the