DEVELOPMENT OF TEST BATTERIES FOR DIAGNOSTICS OF MOTOR LATERALITY MANIFESTATION – LINK BETWEEN CEREBELLAR DOMINANCE AND HAND PERFORMANCE

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by

Martin Musálek

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I hereby declare that this thesis is the result of my own work. I have indicated all used information and literature sources. This thesis has not been used for obtaining either another or the same academic title.

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Dedication:

Dedicated to my parents which I greatly appreciate and to the memory of Prof. Blahuš who teached me first psychometric steps.

The only one unique painting of left-handed archer in the world at castle Houska in Czech republic

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ABSTRACT

The aim of this study is to contribute to the standardization of the new diagnostic tools assessing the motor manifestations of laterality in adults and children aged 8 to 10 years, both in terms of determining the theoretical concept and the selection of appropriate items, and the verification of structural hypotheses concerning the design of acceptable models, including the diagnostic quality of individual parts of the test battery. Moreover in this study we try to suggest new approach in assessing of motor laterality manifestation by means of relationship between cerebellar dominance and hand performance.

The first part of this thesis 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, the statistical method of structural equation modelling, and the actual design of test battery construction.

The last part of this thesis presents the results of structural equation modelling, i.e., the dimensionality and diagnostic quality, including the reliability of various proposed models. The results are two test batteries.

The test battery for the adult population consists of three parts: a questionnaire, a preference motor task part, and a performance test part. The questionnaire part of the test battery has a unidimensional nature called “Preference of Locomotive Organs”. The strongest indicators were those of an instrumental nature. An interesting finding is that the frequently used indicator “which hand do you use to write” had to be removed in the modelling of the structure of this part, because it showed strong multicollinearity.

The preference motor task part has a two-factor structure with the factors “Upper Limb Preference” and “Lower Limb Preference”. The results of modelling in this part of the test battery show that in order to obtain a more precise picture of motor manifestations of laterality it is appropriate to include tasks exhibiting the nature of unskilled spontaneous activity, in addition to skilled instrumental motor tasks.

The performance tests have a two-factor structure with the factors “Upper Limb Performance” and “Lower Limb Perfromance”. This part of the test battery tested the relationship between the cerebellar dominance and hand performance, which was found to be statistically significant, reaching the level of $p < 0.001$.

The test battery for the child population consists of two parts: a preference motor task part and a performance test part.

The preference motor task part has a two-factor structure with the factors “Upper Limb Preference” and “Lower Limb Preference”. It was found that the factor “Upper Limb Preference” is closely related to “reaching tasks”, where the subject can repeatedly work across the natural body axis. The perspective of the advantages and disadvantages of handling an object across the natural body axis could be the main indicator of preference.

The performance tests have a one-factor structure with the “Performance of Locomotive Organs” factor. The results of this part of the battery display a different lateralization of upper and lower limbs. The tests focusing on lower limbs showed that the more significant fine-motor nature emphasizing balance a certain activity exhibited, the less sensitive the tests were. This part also tested the relationship between cerebellar dominance and hand performance; as in the adult population, this relationship was statistically significant, reaching the level of $p < 0.001$.

The diagnostic quality in the form of generic reliability in both test batteries range from 0.78 to 0.95.

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, which 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 (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 (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 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 to the plane of 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).

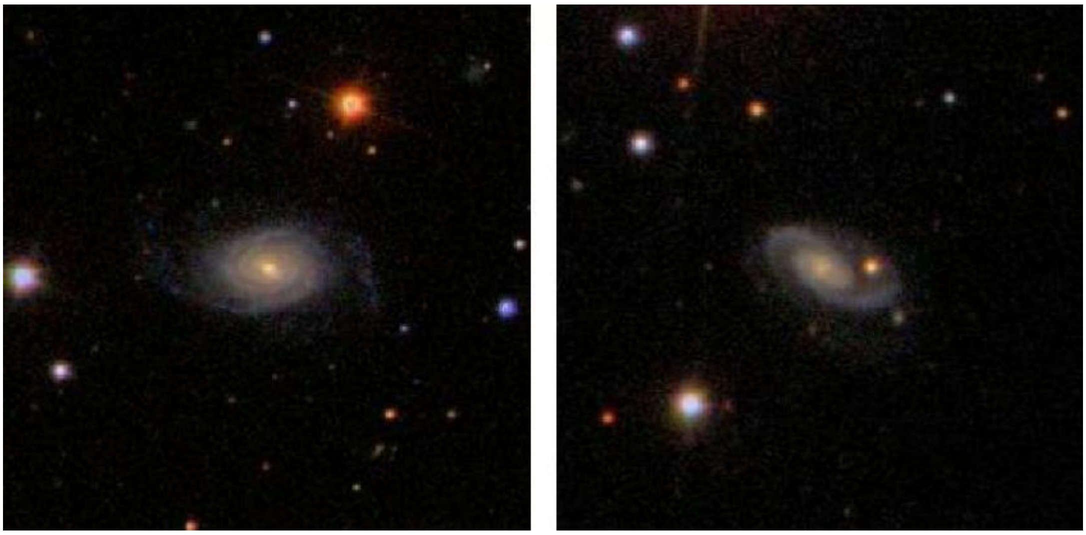


Fig. 1 *S* a *Z* type of galaxy (Slosar et al., 2009, p. 1228).

Galaxy in left field is so called *S* galaxy which is rotating against clock wise. In right field is *Z* galaxy which is rotating clock wise.

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 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 in microcosm. 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. When the two types of crystals from industrially produced acid were separated, it was found that the crystals in one type of acid rotated polarized light clockwise, while the crystals in the other type rotated polarized light counter-clockwise. 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 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 right side; with regard to amino acids, it is solely the L-form (laevo), derived from the Latin word for 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 *(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 acquire 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 probably 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 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 say 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 most likely forms a genetically determined human characteristic that displays more stable personality traits, it is important to realize that it does not have absolute stability over time. 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. Damaged to them results in temporary or permanent loss of a certain function. Brain research and issues related to the exploration of asymmetry and laterality are nothing new. 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 Strucutral 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 left hemisphere, and its posterior part is larger than the same region of the right hemisphere (Bradshaw, & Nettleton, 1983).

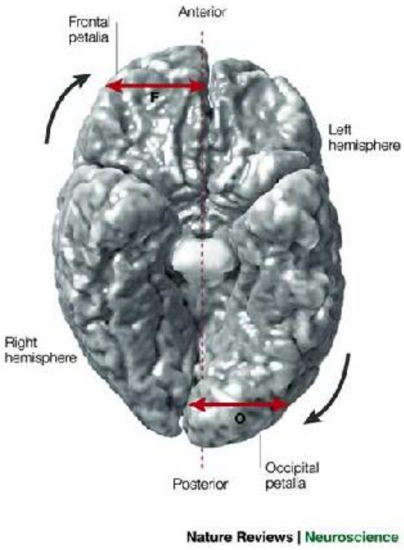


Fig. 2 Human brain, below perspective (Toga, & Thompson, (2003, p. 43).

It is generally accepted that the most significant relationship to structural asymmetries of the brain hemispheres is represented by hand preference. 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 stronger 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. 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 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 (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, H. 1990). Therefore, it was suggested that planum temporale asymmetry is not constant throughout life, but that it can probably 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 Brodmann 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).

2.2 Brain Organization and Motor Control

In this part of thesis we will deal with basic description of six brain areas that involved different level of motor control of human.

a) Brainstem

The brainstem, formed inside the skull and structurally continuous with the spinal cord, consists of three basic structures: the medulla oblongata, the pons, and the mesencephalon. The anatomy of the brainstem, whose structure is represented by the reticular formation, is important. The reticular formation consists of more than 50 brain nuclei (reticular formation is also located in the thalamus), which form a polysynaptic and multisensory system in the brainstem; the system receives impulses from all specific neural pathways. The brainstem is the area that receives input from receptors that are directly linked to vital and other somatic functions and internal organs (Urban, & Caplan, 2011).

b) Cerebellum

The cerebellum “sits” directly on the brainstem; it is located partly between the occipital lobes of the brain hemispheres and partly under them. The cerebellum consists of two cerebellar hemispheres; each hemisphere is responsible for carrying out the function ipsilaterally. All information processed by it serves both to consciously maintain the balance of the postural system and to co-ordinate controlled fine motor movements in space (Barlow, 2002).

c) Thalamus

The thalamus, which is a grouping of different types of nuclei, is located in the rear of the diencephalon. Its structure contains, for example, nuclei that transfer impulses from the periphery to the sensory cortex areas. Furthermore, there are nuclei that transfer impulses from the cerebellum to the motor cortex, and nuclei transferring impulses from the diencephalon to the limbic cortex. The thalamus mediates the transfer of information from the periphery to specific projection and association areas of the cerebral cortex and to the important centres of the cerebellum. The thalamus also has another important function: it enables mutual interaction of higher parts of the CNS (Beaumont, 2008).

d) Basal ganglia

The basal ganglia are composed of the caudate nucleus, the globus pallidus, and the putamen; they are related to a wide range of systems in the cerebral cortex responsible for different behaviours. They operate simultaneously with other output systems of the cerebral cortex. These other corticofugal systems have a leading role in generating specific behaviour. The function of the basal ganglia is associated with the extrapyramidal motor system. Increased activity of the basal ganglia has been observed before the beginning of movement, as well as during constant slow and focused movements. In contrast, increased activity was not observed during fast or jerky movements (Steiner, & Tseng, 2010).

e) Primary motor cortex

The primary motor cortex is composed of six layers of neurons; it is a crucial structure for the control of fine and precise voluntary movements. The primary motor cortex is located in both frontal lobes anterior to the Rolandic sulcus in the gyrus praecentralis. Cells in this area are directly contralaterally connected with spinal motor neurons through a single-neuron pyramidal tract: the tractus corticospinalis. Damage to the pyramidal tract leads to a reduction in the functionality of acral muscles, i.e., muscles at rear parts of the body, in this case particularly the function of hand muscles. Destruction of the primary motor cortex in one of the frontal lobes leads contralaterally to a chronic loss of fine motor activity of the hand, fingers, and face. It also leads to a reduction in limb movement speed and the power capabilities of limbs (Beaumont, 2008). The primary motor cortex also plays a key role in the early stages of the acquisition of many motor skills (Brashers-Krug, T., Shadmehr, R. & Bizzi, 1996; Lu, & Ashe, 2005; Pascual-Leone, Grafman, & Hallett, 1994), and under certain conditions, it can facilitate the process of learning specific motor tasks through the modulation of its activity (Antal, Nitsche, Kincses, Kruse, Hoffmann, & Paulus, 2004).

f) Premotor cortex

The premotor cortex (supramotoric area, suplementar motor area) (Amber, 2008) is located in the rear parts of the frontal gyri anterior to the primary motor cortex (Bear, Connors, & Paradiso, 2007). Cells in this area contribute to motor control by creating links in several subcortical centres, particularly in the basal ganglia. Premotor cortex lesions mainly cause an inability to integrate individual limb movements and gross motor activity into a smooth movement pattern (Beaumont, 2008).

3. GENETIC MODELS OF RIGHT AND LEFT SIDEDNESS

Each of us comes into the world with a certain genetic makeup that creates the originality of our personality. We are born with character traits, physical proportions, and predispositions to diseases. Therefore, it is no surprise that human laterality has also a genetic basis. Since approximately 90% of individuals in society prefer their right hand for motor activity, with only 10% preferring their left hand, researchers have been trying, for more than 40 years, to discover whether and how this strong right-hand preference could be genetically determined, and what factors influence the formation of left-hand preference. However, at the present time the exact genetic determination of this phenomenon has not yet been specified. This chapter will deal with three proposed genetic models determining handedness that are based on different principles. These are supplemented by additional hypotheses about the possible genetic determination of laterality.

3.1 Different Gene Expression in Right and Left Hemispehere as Based of Neural Hemispheric Asymmetry

During the development of the central nervous system, the telencephalon displays a three-dimensional structure consisting of an anterior-posterior part, a dorsoventral part, and a left-right part (Grove, & Fukuchi-Shimogori, 2003; O'Leary, Chou, & Sahara, 2007). Brain development and formation is probably initiated by molecules secreted from these parts, known as pattern centres. With respect to the early stages of the development and formation of the brain, three pattern centres have been identified:

- Ventral characteristics are regulated by the sonic hedgehog (Shh) from the mesendoderm under the telencephalon (Machold et al., 2003). The sonic hedgehog is a protein that plays a key role in vertebrate organogenesis; for example, it controls the growth of phalanges, and it is involved in the structural organization of the brain (Wilson, & Maden, 2005).
- Anterior characteristics are controlled by the fibroblast growth factor 8 (Fgt8), which occurs in the middle of the anterior telencephalon (Garel, Hoffman, & Rubenstein, 2003). Fibroblast growth factors are heparin proteins that play a key

role in the processes of proliferation and differentiation of various cells and tissues (Coumoul, & Deng, 2003).

- Bone morphogenetic proteins (BMP) and signalling proteins (Wnts) that occur in the middle of the dorsal cortex regulate the formation of dorsal characteristics, and play a key role in the process of embryogenesis and cell division (Golden, Bacilovi, McFadden, Beesley, Rubenstein, & Grinspan 1999; Zhao, Avilés, Abel, Almli, McQuillen, & Pleasure, 2005).

Since it was discovered that the signalling pathways of Shh, Fgt8, and other molecules, together with their downstream genes (transcription suppressing genes), play a crucial role in determining left-right asymmetry of the body, including the orientation of internal organs (Hamada, Meno, Watanabe, & Saijoh, 2002; Wright, 2001), research has been carried out in order to determine whether genes that are involved in shaping the asymmetry of internal organs also differ in their expression in the right and left hemisphere, i.e., whether the different expression of genes is involved in the formation of hemispheric asymmetry. Current research into 12-week human foetuses has identified 27 genes that showed different expressions in both the left hemisphere and in the right hemisphere (Sun, & Walsh, 2006). The function of these genes with different expressions in the right and left hemisphere was related to the regulation of cell signal communication and gene control or protein expression (Sun, Collura, Rubilo, & Walsh, 2006). The conclusions of this research suggest that different gene expressions may play an important role in the neurogenesis and formation of neural connections, through the regulation of cell signalling and gene expression in the early development of the brain. On the basis of this assumption, they probably also lead to the formation of hemispheric asymmetry (Hugdahl, & Westernhausen, 2010).

The formation of a tubular structure called the neural tube is the decisive moment in the early development of the central nervous system. The cortex is located in the anterior part of the neural tube (Tanabe, & Jessell, 1996). The study by Dodd et al. (1998) suggested that the middle structures in the anterior part of the neural tube, i.e., the future cerebral cortex, called the notochord and floor plate, may be potential molecular candidates forming neural asymmetry (Dodd, Jessell, & Placzek, 1998). This hypothesis was expanded with further research carried out by Tannahill et al. (2005) suggesting that the notochord secretes molecules such as Shh between the left and right telencephalon unevenly, leading to the formation of hemispheric asymmetry (Tannahill, Harris, & Keynes, 2005). In addition, a certain part of the neural tube is also a source of morphogens such as BMP and Wnts (Chiznikov, & Millen, 2005), and the fibroblast growth factor 8 (Fgt8) also occurs temporarily in the most anterior cortical area (Fukuchi-Shimogori, & Grove, 2001). Based on this information, despite an unconfirmed relationship between the development of hemispheric asymmetry and right-left orientation of internal organs or hand preference (Kennedy, O`Craven, Ticho, Goldstein, Makris, & Henson, 1999; McManus, Martin, Stubbings, Chung, & Mitchison, 2004; McManus, 2005), it is assumed that the joint secretion of BMP, Wnts, and Fgt8 molecules is in a way involved in the formation of the left and right telencephalon asymmetry in the early stage (Hugdahl, & Westernhausen, 2010). Other subsequent studies that have focused on the verification of different gene transcripts in specific brain regions have identified 44 genes with enriched expressions in the frontal cortex and in the superior temporal area of human foetuses' brains (Abrahams, Tentler, Perederiy, Oldham, Coppola, & Geschwind, 2007).

The following reported genetic models have been designed mainly on the basis of the results of diagnostics of motor manifestations of laterality through questionnaire surveys or simple motor tests. The psychometric characteristics of questionnaires, as screening tools determining the level of preference, are further discussed in section 6.1.2.

3.2 Genetic Model of Handedness Marion Annett, Right Shift Theory

The single gene model is based on the assumption that there is a gene (genetic factor) that can determine the inheritance of right-handedness, but not the inheritance of left-handedness (Annett, 1972). In her study from 1972, Annett assumes that normal distribution of differences between parts is an essential characteristic of laterality, although she also suggests that there is a right-shift (RS) factor that shifts this distribution to the right. According to Annett, the side preference itself is influenced by two main factors:

- an unpredicted and congenital, but not genetic factor,
- a possible genetic RS factor.

The genetic information for the formation of the left and right side could be the same, but the RS genetic factor affects the transfer of genetic information to muscles, nerves, blood supply, and other characteristics important for organ function (Annett, 2006). An important shift in this model is represented by the assumption that people's hand preference (handedness) is considered to be a result depending on the aspect of probability. If a person lacks the RS+ factor, the probability of left-hand preference is equal to the probability of right-hand preference (PL = PR = 0.50) (Van Strien, 2000). In other studies, Annett modified her model with the aspect of the relationship between hand preference and speech representation, whose centre is usually located in the left hemisphere, concluding that in humans the RS+ allele determines the left hemisphere as dominant – and more favourable. If the RS+ allele is not present, the formation of cerebral dominance and hand preference is accidental (Annett, 1995). In the following research, the model was refined with the information that in the homozygous genotype RS++ the right shift (RS) tendency is expressed more strongly, about two standard deviations to the right, compared to the heterozygous genotype RS+-, whose rightward tendency is expressed by one standard deviation. In individuals displaying recessive homozygous allele RS--, the distribution of data, capturing left or right upper limb preference, shows the shape of a normal Gaussian distribution curve without deviation to any side, and handedness is accidental. According to Annett, lateralization of speech and hand preference is independent in this case (Annett, 2000). Interestingly, Annett points to the assumption that the presence of the RS gene does not determine hand preference directly, it only increases the probability of better motor skills of the upper right limb (Annett, 2006).

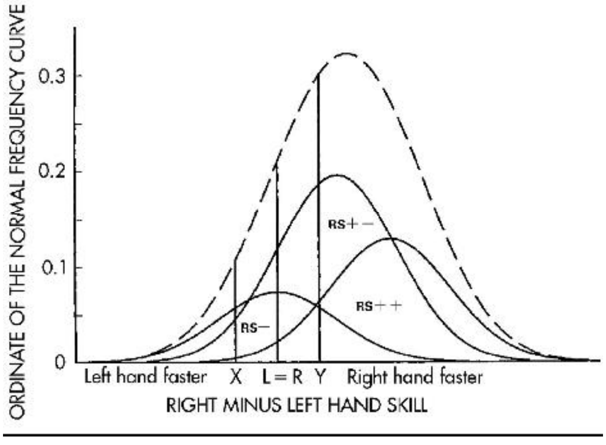


Fig. 3 Distribution of handedness based on performance between right and left hand, RS model with alells RS--, RS+- a RS++ (Annett, 1998, p. 463)

The important information in this model is that, according to Annett, the occurrence of the RS+ gene is only typical for humans, and the whole model is to some extent influenced by the social aspect of the right-hand oriented society and other environmental influences that can change hand preference in humans (e.g., birth stress). Subsequent studies dealing with the relationship of the single gene model and inheritance of hand preference in humans supported the idea that there is a gene for speech lateralization in the left hemisphere that affects handedness distribution to the right (Annett, 2003). Support for this model has also come from research into the heritability of the size of cerebral lobes in twins. The conclusions of this research showed that genetic factors in right-handed twins affect the size of the right and left cerebral hemisphere twice as significantly as in twins with at least one left-handed representative. In contrast, these pairs displayed significant attenuation in the genetic control of the size of cerebral hemispheres (Geschwind, Miller, DeCarli, & Carmelli, 2002).

Annett concludes her current research with a very interesting question. What is the primary cause of the right side (RS) tendency in human handedness, and what is the advantage of the left hemisphere? (Annett, 2006). Her model also views handedness as a continuous variable, i.e., hand laterality may show some degrees of distinction projected to the different level of performance of the left and right hand, from extreme left-handedness to extreme right-handedness (Annett, 2002).

3.3 Genetic Model of Handedness Chris McManus, D and C alleles

Chris McManus, the author of another genetic model, shares Marion Annett’s opinion that both hand preference and cerebral dominance are influenced by one gene. Therefore, his approach can also be described as a single gene model. According to McManus, handedness is determined by the autosomal centre, which contains two alleles: D (dextral) and C (chance). If individuals’ genotype contains the homozygous dominant allele DD, it means that the individuals should all be right-handed. The presence of the heterozygote DC reduces the probability of right-handedness to 75% (McManus a), 1985). In the case of homozygous recessive allele CC, the individuals’ lateralization is affected by the mechanism of randomness, called fluctuating asymmetry; therefore, the predicted probability of right-handedness or left-handedness equals 50%. In his studies, McManus also applies this model to speech dominance. The main assumption in this model is that the D allele implies the determination of right-hand preference and the location of the speech centre in the left hemisphere, while the C allele implies a chance factor for both hand preference and speech dominance; both of these variables are mutually independent (McManus, & Bryden, 1992). There is an important difference between the interpretation of Annett's and McManus's single gene model hypothesis: McManus considers handedness to be a discrete variable with dichotomic division, clearly separating boundaries of preference, as a centre located in one of the hemispheres, and quality of performance between upper limbs in a motor activity (McManus, 1984; McManus, 1985).

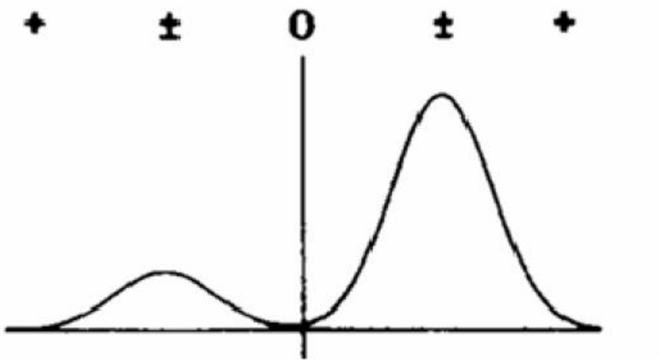


Fig.4 Laterality score, bimodal distribution of hand preference in population (McManus, 1984, p. 128)

In the study "On the Genetics and Measurement of Human Handedness", the authors, including McManus, argue that, despite the proposed single gene model, the issue of handedness heritability has a multifactorial nature with many laterality profiles, though a strong relationship among them has not yet been found (Bryden, Roy, McManus, & Bulman-Fleming, 1997).

3.4 Other Genetic Models of Handedness

Single gene models are not the only genetic models that have been created in the last 40 years.

a) In their study, Levy and Nagylak (1972) suggested that cerebral dominance and hand preference are determined by two diallelic loci. One genetic locus determines the dominant speech hemisphere, (L) or (l). The second genetic locus determines whether the preferred hand is the ipsilateral hand or the contralateral hand, (c) or (C), in relation to the dominant hemisphere. The dominant alleles (L) and (C) should represent a speech centre in the left hemisphere and hand preference for motor activity controlled contralaterally. Recessive alleles (l) and (c) should then show the dominance of the right hemisphere and ipsilaterally controlled motor activity of the hand. According to this model, left-handers should possess either the dominant (L) and recessive (c) allele or the recessive (l) and dominant (C) allele. Right-handers should possess either both alleles in the dominant form (LC) or both alleles in the recessive form (lc) (Levy, & Nagylak, 1972). With respect to this model, however, a sufficient model fit was not confirmed by later studies; therefore, the model is no longer used due to a number of discrepancies in estimates of heritability of cerebral dominance and hand preference in the data of monozygotic and dizygotic twins (Van Strien, 2000).

b) The polygenetic model of Gangestad and Yeo (1994) is another genetic model of handedness. This model was created on the basis of studies carried out by Van Valen (1978) and Markow (1992) dealing with handedness control in relation to fluctuating asymmetry (Van Valen, 1978; Markow, 1992), as well as a study carried out by McManus and Bryden (1992). This study found that the probability of left-handed parents having a left-handed child is only 26.5%; the probability of right-handed parents having a left-handed child is 9.5% (McManus, & Bryden, 1992). Therefore, the results of these studies contradict classic Mendelian laws of inheritance.

According to Gangestadt and Yeo, the development design of handedness is generally based on slight right-handedness: this design may be affected by genetic factors of developmental instability that affect the stability of the expected slight tendency to right-handedness. Developmental instability may be caused by minor physical anomalies (MPA) and fluctuating asymmetry (FA). They may cause a change from the expected slight right-handedness to left-handedness or extreme right-handedness (Gangestadt, & Yeo, 1994). Minor physical anomalies are characteristics associated with a number of neurodevelopmental disorders, including schizophrenia (Gualtieri, Adams, Shen, & Loiselle, 1982; Woods, 1998), autism (Campbell, Keller, Small, Petti, & Ferrit, 1978; Zoghbi, 2003), and hyperactivity (Barkley, 1997; Rapoport, & Quinn, 1975). Fluctuating asymmetries are deviations in the size of physical characteristics (foot width, ear width) on the right and left side of the body (Markow, & Wandler, 1986; Van Valen, 1962). The authors support their assumptions with the results of studies. The first of them showed a significant correlation between the composite score of developmental instability, consisting of the MPA and FA variables, and the lateral preference score of the upper limb in the questionnaire survey. In the second study, the composite score of developmental instability, consisting of the MPA and FA variables, significantly correlated with the results of a peg-moving task (Annett, 1985), which assesses the skill level of the hand. The results of these studies suggest that both left-handed and extremely right-handed individuals showed higher occurrence of developmental instabilities, and these individuals were more often children of left-handed parents. This model assumes that stabilizing factors have a polygenetic basis and that both left-handed and extremely right-handed individuals have a similar genotype (what is hereditary here is the level of deviation from modal handedness, rather than handedness tendency) (Markow, & Wandler, 1986).

c) A slightly different approach in the genetic determination of right-sidedness and left-sidedness is seen in the form of a hypothesis called the "gene-cultural model", presented by Laland, Kumm, Van Horn, and Feldman (1995), who argue that both left-handers and right-handers have the same genotype, and that there is no genetic variability conditioning (determining) handedness variability. Handedness variability arises in the early development of the individual, and it may be affected by various causes, which randomly provide the individual with a better skill or greater strength of one side. The crucial role in determining handedness is played by natural selection, which, say the authors, determines the probability of right-handedness at 0.78. Cultural factors are considered to be essential in this model hypothesis, with the most important being parents' handedness. If both parents are right-handed, the probability of a right-handed child reaches 0.92 (0.78 + 0.14); if both parents are left-handed, the probability of a right-handed child drops to 0.64 (0.78 – 0.14). If parents differ in their handedness, their child's handedness is not affected by this parental factor, and the probability of the child's right-handedness reaches 0.78 (Laland, Kumm, Van Horn, & Feldman, 1995). What is also fundamental in this theory is the fact that, according to the authors, the children's handedness is influenced by the overt motor activity of the parents. This aspect, however, contradicts the results of a previous study. It monitored the handedness of children in foster care and examined whether left-handed foster families display a higher frequency of left-handed children, although it did not confirm this relationship (Carter-Saltzman, 1980).

d) Other hypotheses about genes influencing hand preference

In recent years, there have also been attempts to identify the candidate single gene that is responsible for the expression of hand preference. Crow's study (2002) suggested that this gene is located on chromosomes X and Y in the homology region Xq21.3/Yp11.2, and that the most likely candidate is the protocadherin XY (Crow, 2002). However, subsequent extensive screening of the genome did not find any strong support for this hypothesis. The region 2p11.2-12 on chromosome 2 was identified as another possible region of the candidate gene's occurrence (Francks et al., 2002). However, this suggestion was also refuted by later research (Francks et al., 2003). One of the last hypotheses about the candidate gene determining handedness appeared in a study dealing with dyslexic siblings. In this research, the leucine-rich repeat transmembral neuronal 1 (LRRTM1) gene on chromosome 2p12, which is suppressed in the mother and is, according to the authors, associated with male gender, handedness, and schizophrenia, was chosen for the single gene (Francks et al., 2007). It was also found that LRRTM1 occurs only in chimpanzees and humans. However, this theory was not supported by the study of twins, and the research itself was heavily criticized due to methodological shortcomings (Crow, Close, Dagnall, & Priddle, 2009). In addition, other authors have argued that it is very unlikely that handedness and cerebral asymmetry were only determined by this gene. Therefore, LRRTM1 is currently viewed rather as a gene associated with dyslexia and schizophrenia, affecting human laterality only indirectly (Hughdal, & Westernhausen, 2010).

4. ENVIROMENTAL FACTORS AS POSSIBLE CAUSE IN CHANGE OF LATERALITY AT HUMAN

In parallel with genetic models that present hypotheses on the genetic determination of right-sidedness or left-sidedness in relation to handedness, assumptions have been postulated and hypotheses proposed concerning environmental factors affecting human laterality, especially left-sidedness. These hypotheses began to be of interest mainly because the heritability of laterality was not clearly demonstrated. In addition, as implied by chapter 3. in determining the probability of a right-handed or left-handed individual being born, classic Mendelian laws of inheritance were violated. Most hypotheses dealing with environmental factors affecting human laterality are based on the foundations of certain deviations which are considered pathological.

4.1 Birth Stress

One of the best known theories falling into the category of pathologically affected sidedness deals with problems related to birth stress and complications during the prenatal period of the foetus. Based on the results of the research, Bakan et al. (1973) suggested that left-handedness may be caused by cerebral anoxia, which can result from birth stress factor. According to the authors, anoxia may cause malfunction or even destruction of the motor area in the left hemisphere, which in order to preserve the function subsequently leads to a change in laterality in preference of motor activity of the hand – handedness. This research discovered that left-handers showed a double score in the medical history concerning conditions of birth stress (Bakan, Dibb, & Reed, 1973; Coren, 1992). The hypothesis concerning the influence of the environmental factor of birth stress on human sidedness was further supported by research which, in addition to the anoxia variable, included premature birth, low birth weight, and severe infections, including neonatal jaundice, among other aspects of the possible influence on laterality (Coren, 1995; Van Strien, Bouma, & Bakker, 1987). With respect to these results, Geschwind and Galaburda suggest that birth complications are the effect of the same factors that affect the brain development of the human foetus rather than the cause of left-handedness (Geschwind, & Galaburda, 1987). On the other hand, it should be noted that in the course of time the results differed considerably from the initial hypothesis, especially due to the research samples they were based on. For example, the results of the study by Leviton and Kilti (1976) and Badian (1983) only supported this hypothesis in the population of boys (Badian, 1983; Leviton, & Kilt, 1976). In contract, Annett and Ockwell (1980) and McKeever et al. (1995) confirmed the correlation of birth stress and left-handedness only in girls (Annett, & Ockwell, 1980; McKeever, Suter, & Rich, 1995). Research results presented by Baily and McKeever (2004) even point out that, out of the 25 selected birth stressors, only the mother's age stressor (variable) had a significant relationship to the left-handedness of the individuals born (Bailey, & McKeever, 2004).

4.2 Higher Level of Hormone Testosteron in Uterus

Another hypothesis dealing with the influence on laterality was presented by Geschwind and Galaburda (1987), who suggested that laterality related to the motor activity of the hand (handedness) can be changed depending on the level of testosterone in the womb (Geschwid, & Galaburda, 1987). According to Geschwind, functional asymmetry has its origin in the anatomical asymmetry of the cerebral cortex. The planum temporale asymmetry is one of the major anatomical asymmetries related to the specialization of speech: the planum temporale was found to be larger in the left hemisphere in more than 65% of the population (Geschwind, & Levitsky, 1968). Since the right hemisphere develops earlier, Geschwind and Galaburda suggest that it can be much easier for intrauterine factors to affect the left hemisphere, which is vulnerable for a longer period. This theory is based on research which found that higher or lower levels of testosterone in the womb can either speed up or slow down the embryological migration of neurons from the neural crest to the cerebral cortex. An increased level of testosterone found in male foetuses is the cause of reduced migration, especially in the left hemisphere, and therefore a reduced level of hemispheric specialization was observed (Geschwind, & Behan, 1982; Johnson, 2005). Based on this hypothesis, individuals with significantly smaller differences in brain asymmetry show the same probability of being right-handed or left-handed, and thus fall into to a group called anomalous dominance. This group also includes individuals with less clear-cut left-hemispheric dominance for speech.

Increasing levels of testosterone in the womb can also affect the development and function of the thymus, which may subsequently lead to a higher incidence of immune disorders. As early as 1982, Geschwind and Behan created a model which related the variables of handedness and autoimmune disorders (Geschwind, & Behan, 1982). A meta-analytical study by Bryden, McManus, and Bulman-Fleming (1994), using a sample of over 56,000 correlating handedness and immune disorders, found that left-handers exhibit only negligibly higher frequency (1,003) of these disorders than the control group of right-handers (Bryden, McManus, & Bulman-Fleming, 1994). Another debated area of this hypothesis is the fact that any manifestation of non-right-handedness is automatically viewed as a manifestation of abnormal dominance, regardless of whether the individual is, for example, a natural left-hander. According to the model created, any person who is not right-handed is automatically classified as exhibiting abnormal dominance (Previc, 1994). Moreover, it has been shown in recent years that it is the right hemisphere that is more sensitive to the effect of intrauterine factors (Lutchmaya, Baron-Cohen, & Raggatt, 2002; Van Strien, 2000). Some authors consider the position of the foetus in utero with limited space and possibilities of moving the head and hand on one side as another environmental factor affecting laterality and thus the hemispheric specialization of an individual. This limitation is based on the shape of the uterus (Johnson, 2005; Previc, 1991). As a result, a hypothesis was presented, based on the finding that newborns exhibit a strong tendency to tilt – lean – the head to one side (Turkewitz, & Kenny, 1982). Several studies confirmed that if a newborn lies on its back, its head is generally tilted to the right, and only rarely to the left. As a result of the head tilt to one side in the course of an infant's passive lying, one hand is often placed in the individual's visual field. According to the findings, this spontaneously observed limb becomes preferred (Hopkins, Lems, Janssen, & Butterworth, 1987). However, the study also found that this development was only confirmed in infants not older than two months.

The previous two chapters clearly show that both laterality and its motor manifestations form a very complex multi-factor field in humans which is, in addition to the genetic basis of an individual, also affected by environmental factors; these can most probably affect genetic information.

5. TYPES OF LATERALITY

The following chapter and subchapters analyze the multifactoriality of laterality also in terms of motion control. We will also focus on the two basic types of laterality, which are closely related, as well as various kinds of functional manifestations of laterality.

Laterality can be either morphological or functional. Morphological laterality assesses disproportions of parts of the body and organs (Mohr, Thut, Landis, & Brugger, 2003). Functional laterality is understood as asymmetry of locomotive (hands, legs) or sensory (an eye, ear) paired organs (Hatta, Ito, Matsyuama, & Hasegawa, 2005) that is demonstrated by preferred use of one the paired organs.

5.1 Functional Motor Laterality Manifestation

Functional laterality is a sign of brain activity that is reflected both in the motor activity of motor organs and direction and the coding of (the impulse of) the signal through sensory organs, both paired and unpaired (tongue). Control of motor activity is projected onto paired motor organs differently, which is expressed by different levels of motor manifestations of the left or right motor organ (legs, hands). The direction and coding of the signal, which, in the form of an impulse, is processed by a sensory organ, is usually based on a different function of this paired organ: different processing of auditory information by the right and left ear; different processing of visual information by the right and left eye.

Therefore, functional laterality means functional asymmetry of paired motor organs (hands, legs) or paired sensory organs (eyes, ears) (Hatta, Ito, Matsyuama, & Hasegawa, 2005). This is manifested in the preferred use (preference) of one of the paired organs, which usually also operates faster or better. Functional lateralization is thus a reflection of the dominance of one cerebral hemisphere (Annett, 1985; Bryden, 2000; Mohr, Thut, Landis, & Brugger, 2003).

5.1.1 Preference

Preference is defined as the preferred use of one of the motor or sensory organs whose control centre is located in the right or left hemisphere of the telencephalon.

Based on the principal component method, it has been suggested that preference in motor and sensory organs is multidimensional in nature (Bryden, MacRae, & Steenhuis, 1991). Two main dimensions form skilled and unskilled types of activity (Steenhuis, & Bryden, 1999). The results of studies suggest that one motor organ apparently exhibits more types of motor activity control that are located in different centres of the cortical and subcortical area, depending on the nature of the activity (Steenhuis, & Bryden, 1989). Differing views on the phenomenon of preference reflect its very nature; as already mentioned in chapter 4., some researchers consider preference to be a continuous variable (Annett, 1970; Annett, 2002; Bryden, 1977), while others prefer the view that preference is a discrete variable (Dragovic, Milenkovic, & Hammond, 2008; McManus, 1985;).

5.1.2 Performance Expression of Different Skill of Locomotive Organs in Motor Activity

Different motor performance in the same activity of two identical organs is another aspect of functional laterality that can be observed. There is currently no uniform terminology for the area concerning the determination of motor activity in which different performance of motor organs is assessed. In this thesis, we have decided to determine this different performance in two basic types of motor activities: gross motor and fine motor.

- Gross motor is understood as different performance of motor organs in activities that have the character of simple muscle work, or even the work of a larger muscle group without the need for fine motor skills (e.g., upper limb dotting test, lower limb tapping, grip strength).
- Fine motor or skill, is understood as different performance of motor organs in activities that exhibit a fine motor character and that require a very sensitive involvement of small muscle groups, located on the distal parts of the body, in the final movement. With regard to fine motor assessment, it generally applies that the more significant the fine motor character of an activity is, the more evident differences in performance between limbs are observed, e.g., in speed and quality of execution of the activity (Annet, 1992).

In connection with research dealing with distinguishing characteristics of individual indicators for determining the level of performance, it has been stated that the attribute of performance, like preference, has a multidimensional nature (Brown, Roy, Rohr, Snider, & Bryden, 2004; Corey, Hurley, & Foundas, 2001; Steenhuis, 1996).

5.1.3 Are Preference and Performance Communicating Vessels or Different Attributes?

Some authors consider the level of performance to be a result of the power of preference (Annett, 2002; Bryden, 1977); therefore, they tend to believe that motor manifestations of laterality represent a continuum.

However, other authors' studies have not confirmed a strong relationship between the attribute of preference and the attribute of performance (Peters, 1998).

Other studies dealing with this issue have focused on determining the difference in preference and the level of performance in autistic and normally developing children. In comparison with normally developing children, autistic children showed the same level of preference in the use of upper limbs, but significantly lower levels of performance (Hauck, & Deset, 2001; McManus, 2002). These authors consider preference and performance to be different attributes of the motor manifestations of laterality; preference is obviously projected onto the performing organs based on the location of the motor centre in the brain, but performance probably depend on the quality of brain connections.

5.1.4 Dominance

In connection with motor manifestations of laterality, the concepts of preference and performance are associated with the concept of dominance. The word "dominance" means "leadership" or "superiority" (Holubová et al., 2005). With respect to motor organs, the concept of dominance is only used for activities that have the character of bimanual actions, i.e., one organ has a leading function, and a second organ has an auxiliary function. In contrast, dominance in paired sensory organs is clearly determined by different functions. For example, ears have different functions in processing auditory information. One of the ears is dominant in processing speech stimuli, and the other is dominant in processing non-speech stimuli. Similar characteristics are displayed by eyes. Therefore, the concept of dominance is used in cases where paired organs have different determined functions in performing an activity or processing a stimulus, or they represent leading organs in the given activity. This is also related to the concept of "cerebral hemisphere dominance". Currently, the hemisphere that contains the centre of speech is considered to be the dominant (leading, superior) cerebral hemisphere. In 95% of the population, the centre of speech is located in the left hemisphere, and, therefore, the left hemisphere is considered to be the dominant hemisphere in the majority of the population (Knecht et al., 2000).

5.1.5 Laterality of Locomotive and Senzoric Organs

a) Handedness

Human handedness is the most transparent functional asymmetry. It is based on high demands on the manipulative function of the upper limb, which is also structurally adapted to this activity (spherical joint in the shoulder, opposition position of the thumb, rich innervation of fingers, etc.). The issue of handedness is often associated with the term "manual dexterity", which includes both the ability to handle objects and the fact that most people have one preferred upper limb to handle objects (Hughdal, & Westernhausen, 2010). For approximately 90% of people, the right upper limb is the preferred one; for 10% of people, the left upper limb is the preferred one (McManus, 1985). In connection with this proportion of handedness in society, the term "right-handed world" is used.

According to Hugdahl and Westernhausen (2010), this preference is easily recognizable in everyday activities, especially in unimanual activities where only one upper limb is involved. This preference can also be observed in bimanual activities where the dominant upper limb plays the leading role, and the non-dominant upper limb plays the auxiliary role (Hugdahl, & Westernhausen, 2010). Given the diversity of movements and types of activities that can be performed by upper limbs, research has focused on the question of whether handedness in both preference and performance is a unidimensional variable or a multidimensional variable. Steenhuis and Bryden (1989) have characterized the area of preference as multidimensional, with two main factors:

- skilled, including manifest variables that are culturally influenced (writing),
- unskilled, including spontaneous activities (picking items up, stroking a dog or cat) (Steenhuis, & Bryden, 1989).

Other research has also pointed to the multidimensionality of the actual activity of upper limbs, i.e., whether it is unimanual or bimanual activity (Büsch, Hagemann, & Bender, 2010). The research carried out by Beukelaar and Kroonenberg (1983), who performed an exploratory factor analysis of the results of an extensive questionnaire survey identifying handedness, suggests that there may even be four factors in upper limb preference. The first factor represents the activities performed by the hand and wrist; the second factor involves the shoulder joint activity (throwing); the third factor only relates to activities performed by fingers; and the fourth factor represents bimanual activities (holding a broom) (Beukelaar, & Kroonenberg, 1983). With regard to upper limb performance, the hypothesis that performance is a multidimensional trait with independent factors (Fleishman, 1964) has long been accepted. In 1970, Barnsley and Rabovitch, using the exploratory factor analysis, found that hand performance comprises nine factors: reaction time, dexterity, stabilized hand preference, wrist and finger speed, targeting, hand stability, arm movement stability, finger tapping, and grip strength. Five of these factors (targeting, finger dexterity, tapping, hand stability, and grip strength) were found to be valid factors in determining handedness (Annett, 1976; Barnsley, & Rabovitch, 1970). An explorative approach was used by the researchers to determine the dimensionality of upper limb performance. Based on the results, a multidimensional structure was also proposed, consisting of the factor of proximal movements, which involve the whole upper limb including the shoulder joint, and the factor of distal movements, which mainly involve end parts of the upper limb, from the wrist to the fingers. These studies supported the hypothesis that the control of the upper limb motor activity can be performed by different areas of the brain (Healy et al., 1986; Rigal, 1992; Steenhuis, & Bryden, 1989)

b) Footedness

The main function of the human lower limb is locomotion, i.e., a change in path with respect to time using force (Alexander, 2003). Humans mostly perform locomotion by motor activity in the form of bipedal walking. However, the lower limb also fulfils the manipulative function, so, just as in handedness, most people exhibit dominance of one of the lower limbs for a specific activity. Footedness thus represents another manifestation of functional laterality. Functionally, however, the lower limb is not adapted for such a wide range of movements as the upper limb. In addition, many activities display bilateral co-operation of the lower limbs; therefore, the manifestation of functional laterality in the lower limbs is not as distinct as in handedness. For a long time, it was not entirely clear which of the lower limbs should be considered dominant, whether the one used for springing, swinging, handling, or performing the postural function. It is currently accepted that one of the lower limbs fulfils the mobilization (manipulative) function, which is the lower limb that manipulates objects or that actively leads movement. This lower limb is considered dominant. The second lower limb fulfils the stabilizing, supporting, or postural function (Peters, 1988). Previc and Saucedo (1992) suggest in their study that footedness is apparently also closely related to human "turning behaviour" (Previc, & Saucedo, 1992). It is also very interesting that some authors consider footedness to be a more sensitive indicator of hemispheric specialization (which also includes specific cognition and motor proficiency) than handedness (Elias, Bryden, & Bulman-Fleming, 1998; Elias & Bryden, 1998; Iteya, & Kimura, 2004; MacNeilage, 1991; Peters, 1990).

c) Eyedness

Despite the amount of literature dealing with the issue of ocular dominance, this part of functional laterality remains less clear. The main function of eyes is to receive visual cues (stimuli) from the environment (Dylevský, Druga, & Mrázková, 2000), which is made possible by three basic abilities of the eye: detail recognition, spatial orientation, and object tracking using tools. Either eye projects the stimulus from a different half of the visual field. With regard to the functional laterality of eyes, it is very important that the brain is not lateralized for eyes (Mapp, Ono, & Barbeito, 2003); a hypothesis was even accepted in the past that ocular dominance is not related to cerebral laterality (Clark, 1957; White, 1969).

The most supported hypothesis views motor eye control as a manifestation of asymmetry (Annett, 1985; Bourassa, McManus, & Bryden, 1996). Money (1972) provides evidence from tachistoscopic experiments that found higher perception accuracy by the dominant eye in situations that require fast control (motor control) (Money, 1972). Based on research, it was found that ocular dominance comprises three factors:

- Acuity factor, i.e., one of the eyes exhibits a greater sensitivity to recognize contrast and depth of acuity (Coren, & Kaplan, 1973).

- Binocular rivalry factor, first described in 1593 by John Porta Babtista, i.e., one of the eyes plays a leading role in spatial orientation (Clark, & Warren, 1938; Coren & Kaplan, 1973; Porta, 1593).
- Observation (sighting) factor, i.e., preference of one of the eyes in monocular activities such as sighting down a telescope (Kommerell, Schmitt, Kromeier, & Bach, 2003).

Since the functions of the eye represent a natural manifestation of brain activity, and they are not influenced by social pressure as in handedness, some authors have considered the determination of ocular dominance as crucial in determining the motor manifestations of laterality (Bishop, 1983; Delacato, 1966; O'Connor, 1965).

However, this does not solve the problem of which of the basic factors of the eye should be considered the most significant in determining ocular dominance. Many authors have considered preference of the eye in monocular activity identified in the observation (sighting) factor as a manifestation of ocular dominance (Coren, & Porac, 1978; Crovitz & Zener, 1962; Hull, 1936); this preference is then related to hand preference (Howard, & Rogers, 2002; Porac, & Coren, 1976; Walls, 1951). However, according to other studies, the result of the binocular rivalry factor is decisive in determining ocular dominance, because, from a functional point of view, this is the most important role of the eye (Berens, & Zerbe, 1953). With regard to the observation (sighting) factor, say some authors, the preferred eye does not have a specific functional role in monocular activities (Mapp, Ono, & Barbeito, 2003). Other studies have suggested that monocular activity is probably related to the preferential activation of the systems ensuring attention in the contralateral hemisphere (Roth, Lora, & Heilman, 2002). Given that the functional nature of all three factors is different, several studies have also confirmed that the observation (sighting) factor does not strongly correlate with either with the binocular rivalry factor or with the acuity factor (Norman, Norman, & Bilotta, 2000). Compared to the observation factor, the binocular rivalry factor and the acuity factor correlated much less with hand preference (Bourassa, McManus, & Bryden, 1996). These results suggest that ocular dominance is probably related to factors of eye defects, mostly spherical (Eser, Durrie, Schwendeman, & Stahl, 2008). However, studies dealing with the relation between hand preference and ocular dominance (expressed through monocular activity) have found that unstable ocular dominance was displayed, for example, by dyslexic children (Stein, & Fowler, 1982; Stein, Richardson, & Fowler, 2000) or individuals with Williams-Beuren Syndrome (Van et al., 2005).

d) Earedness

Earedness is another manifestation of the functional laterality of sensory organs. The main function of the ear is to receive and process auditory stimuli. There are also two main capabilities: to receive and process logical symbolism in the form of speech, and to receive and process the tone and pitch of the sound stimulus. Both functions are controlled contralaterally. Since cerebral dominance and functional laterality are associated with the phenomenon of speech, the ear that processes the symbolism of speech stimuli is considered to be the dominant one. Determining earedness is usually performed by means of dichotic listening (Cherry, 1953), i.e., a different sound stimulus is presented to each ear of an individual. When determining ear dominance, it is assessed which stimulus the individual is able to discern: the stimulus that is presented to the left ear, or the stimulus that is presented to the right ear (Kimura, 1961). This method of determining ear dominance was adjusted by Johnson et al. (1977), who chose speech sounds as sound stimuli, calling the method the Dichotic Fused Words Test (DFWT) (Johnson, Sommer, & Weidner, 1977). Further modification of the stimuli was performed by Wexler and Hawles (1983), who used rhyming monosyllabic words (Wexler, & Hawles, 1983). In determining cerebral dominance and (functional) motor manifestations of laterality, the aspect of ear dominance is often left out due to its complexity (Reiss, & Reiss, 1999). For example, various studies have found that earedness is not related to eyedness (Noonan, & Axelrod, 1981), and that there is no genetic relationship between earedness and eyedness (Reiss, & Reiss, 1999). At the same time, some recent studies associate ear dominance with working memory in the brain (Penner, Schlafli, Opwis, & Hugdahl, 2009).

5.2 Structural Laterality of Locomotive Organs

Chapter 2.1 describes some important structural asymmetries of the brain. This chapter analyzes the issue of shape laterality of motor organs, which is a result of functional asymmetry. Shape laterality reflects the asymmetry of body segments and organs (Mohr, Thut, Landis, & Brugger, 2003). This asymmetry is viewed both in terms of dimensions (length or width) and in terms of the tissue size or density of individual parts of motor organs.

Several recent studies show that a general model has been found that confirms asymmetry in the bones of both upper and lower limbs. The basic dimensions that determine limb asymmetry include bone length, diaphyseal width, and joint width of the upper and lower limbs. Bone length, diaphyseal width, and joint width of the upper and lower limbs, determined particularly on distal epicondyles, show a consistent right-sided asymmetry in all dimensions. The conclusions of the studies agree that shape asymmetries observed in upper limbs are more significant, and they exhibit a regular tendency to right-sided asymmetry. Therefore, upper limbs display generally more noticeable asymmetry than lower limbs, and many authors suggest that this result has probably been caused by the release of upper limbs from motor limitations, their specialization, and less symmetrical mechanical loads. Lower limbs exhibit less obvious differences, and they can mainly be found in the knee area (Auerbach, & Ruff, 2006).

Both limbs also show consistent differences in the size of asymmetry for different structural characteristics. When comparing the measurements of individual segments, the most significant absolute asymmetry was observed in diaphyseal width, followed by bone length and bone size. Increased asymmetry in external diaphyseal width may be caused by the possible expansion in the subperiosteal area of long bones after the termination of growth in length (and possibly also joint size) (Garn, Rohmann, Wagner, & Ascoli, 1967; Heaney, Bargerlux, Davies, Ryan, Johnson, & Gong, 1997; Lazenby, 1990). Therefore, diaphyseal asymmetry may increase in adults due to bone length and joint asymmetry. When measuring individuals with respect to bone length and diaphyseal width asymmetries, no significant correlations were found, supporting their relative independence. Some correlations were found between articular asymmetries, bone length, and diaphyseal width asymmetries (Ruff, Walker, & Trinkaus, 1994). This finding also suggests that length and diaphyseal width are modular in the sense of autonomous development (Hallgrı´msson, Willmore, & Hall, 2002). It is possible that although, in the course of development, limbs are subject to the same perturbations, some bone dimensions can probably change more sensitively, both in utero and after birth (Hallgrı´msson, Muyake, Wilmore, & Hall, 2003). As shown earlier, joints follow a growth pattern that is similar to that seen in bone length. Both articular size and bone length appear to be less sensitive to mechanical stimuli than the influence of the cross-sectional dialysis dimension, i.e., they are more genetically regulated during growth (Biewener, & Bertram, 1993; Lanyon, 1980; Ruff, 2003). It is possible that mechanisms governing joint growth are, in some respects, a mediator between the length and width of the diaphysis (i.e., they are more genetically regulated than diaphyseal width, and they also have greater mechanical sensitivity than in length). This could explain the correlation of joint asymmetry with the above segments. Much narrower limited ranges of asymmetry in other limb dimensions are probably subject to higher genetic control. Differences in asymmetry can be observed both between individuals within a certain geographical area and across multiple geographical areas. Research has also revealed that the bone asymmetry of upper and lower limbs both between and within the populations examined is the most significant in diaphyseal width (Auerbach, & Ruff, 2004). Bone length and joint width do not exhibit such significant signs of asymmetry. This conclusion was based on the assumption that diaphyseal width is not dependent on completed bone growth, i.e., bone length and joint width (Ahlborg, Johnell, Turner, Rannevik, & Karlsson, 2003). However, in addition to right-sided bone shape asymmetry, left-sided asymmetry was found in the bones of lower limbs. This is primarily diaphyseal width and length of the thigh bone (femur) (Plochocki, 2004). Shape asymmetries are more noticeable in upper limbs. There are also significant differences in the described asymmetry between genders. Men exhibit considerable differences in the humeral diaphysis, while the length of the radius is more asymmetrical in women (Parker, Round, Sacco, & Jones, 1990; Round, Jones, Honour, & Nevill, 1999). Research has also been conducted that found that, despite changes in the load of upper limbs of current humans and paleolithic humans, changes towards the right-sided world do not occur (Gentry, & Gabbard, 1995; Porac, & Coren,1981), i.e., the percentage of left-handers does not change. An interesting result concerning lower limb asymmetry was presented by Faulkner et al. (1991). The authors found increased mineral mass in the non-dominant lower limb in children (Faulkner, Bailey, Drinkwater, McKay, Arnold, & Wilkinson, 1991). In contrast, tomographic research into upper limbs found that the distal end of the radius of the dominant upper limb shows increased bone density and increased mineral mass, which is, according to the authors, the result of the different load of upper limbs (MacIntyre, Adachi, & Weber, 1999).

It was also found that there is crossed symmetry in bone length and diaphyseal width of bones between the upper and lower limb – contralaterally (Auerbach, & Ruff, 2004).

Shape asymmetry was also found in the hand and fingers. The volumetric analysis conducted by Purves et al. (1994) showed that the right hand is generally about 3.5% longer than the left hand (Purves, White, & Andrews, 1994). Radiography revealed asymmetry in the morphology of the hand: the second metacarpus, i.e., on the index finger, of right-handers showed a significantly longer dimension on the right hand than on the left (Vehmas, Solovieva, Riihimaki, Luoma, & Leino-Arjas, 2005;). In addition to differences in the morphology of the hand, research has focused on the dimensions and asymmetry of fingers. The best known asymmetry is the different length of the index finger and ring finger in men and women. Men usually exhibit a significant difference between the length of the index finger and ring finger, and the ring finger is significantly longer (Plato, Wood, & Norris, 2005). With regard to women, the difference in length is usually less significant, but the ring finger also tends to be slightly longer. The difference between the length of the index finger and ring finger in men and women is attributed to the level of testosterone to which the foetus is exposed during the prenatal period (Manning, Scutt, Wilson, & Lewis-Jones, 1998). This difference has also been found in some ethnic groups, e.g., in children from the Han ethnic group and in Afro-Caribbean children (Manning, Stewart, Bundred, & Trivers, 2004). Another study by Manning et al. has found differences between Europeans, Africans, and Chinese (Manning, Churchill, & Peters, 2007). Some studies have related the length and proportion of the index finger and ring finger to the increased activity of the right hemisphere. Men who displayed significant differences in the proportion of the length between the two fingers mentioned also showed better results in mental rotation tasks concerning two- and three-dimensional objects (Sanders, Bereczkei, Casatho, & Manning, 2005). Mental rotation is an aspect of imagination, i.e., part of the ability of abstraction, which is, as a complex process, one of the main specializations of the right cerebral hemisphere (Parsons, 2003). A relationship between the proportions of the index finger, ring finger, and reduced functionality of the left cerebral hemisphere has also been found. The study by Beech and Beauvois suggests that the masculine proportion of the index finger and ring finger in right-handers is related to impaired hearing (Beech, & Beauvois, 2006). The proportion of the length of the index finger and ring finger was also measured in right-handed and left-handed individuals. The individuals' handedness was mostly determined on the basis of preferences in holding a writing instrument. It was found that right-handers exhibit stronger asymmetry in the proportion of the length of fingers of the right hand. Left-handers exhibit the opposite asymmetry, and this asymmetry is not as noticeable (Manning, & Peters, 2009).

Significant shape asymmetries are visible, for example, in athletes. Shape laterality and its differences have been examined in tennis players in particular. Studies dealing with repetitive load in tennis players found that repeated load of the preferred upper limb leads to the formation of anatomical differences between the dominant and non-dominant upper limb (Colak, Bamac, Ozbek, Budak, & Bamac, 2004). Various studies have shown that adult tennis players at the top level exhibit more weight in the forearm, by approximately 12%, and arm, by approximately 6%, of the dominant upper limb (Noffal, 1999). At the widest point of the forearm circumference, the length was longer by 6–7% in the dominant upper limb, both in women and in men (Lucki, & Nicolay, 2007). Average 3% differences in forearm circumference and 5% differences in arm circumference were observed in adult female tennis and squash players. Shape asymmetry between the dominant and non-dominant upper limb, which is manifested in the difference in size, is explained by the increase in bone mass and muscle hypertrophy in the dominant upper limb (Kannus, Haaspasalo, & Sankelo, 1995).

In young tennis players, the mechanical load of the upper limb has a positive effect on bone development. With regard to muscle development, it is generally accepted that the intermittent activity of prepubertal children has a major impact on neural adaptations and only a minimal impact on muscle hypertrophy. Increased muscle mass was found in the dominant arm of prepubertal female players using magnetic resonance imaging (Daly, Saxon, Turner, Robling, & Bass, 2004). This result suggests that the increase in muscle mass in the upper limb in response to performance occurs before puberty.

5.3 Structural and Motor Manifestations of Laterality in the Ontogenetic Development of the Individual

This subchapter describes the development of structural and motor manifestations of laterality during human ontogeny. The main emphasis is on the period from prenatal development to the 12th year of life. At this age, the process of lateralization should be completed. The end of the subchapter also mentions the development of hemispheric specialization and maturation of the corpus callosum.

5.3.1 Prenatal Asymmetry

Asymmetry is assessed according to the speed and nature of hemisphere maturation. Certain areas of the right hemisphere mature much faster than the same areas in the left hemisphere. Delay in the appearance of cortical characteristics around the Sylvian fissure on the left side, compared to the right, has been observed. Similarly, bends around the Sylvian region appear later on the left side than on the right (Chi, Dooling, & Gilles, 1977). Chi et al. also found that some cortical signs at the top of the temporal region appear 1–2 weeks later on the left side than on the right. Interestingly, the dendritic protrusions which are important for speech and which are located mostly in the left hemisphere also develop with a delay. Eventually, however, the extent of these protrusions in the left hemisphere of adults is much larger (Simonds, & Scheibel, 1989). In the prenatal period, the right hemisphere develops more when the brain of the foetus receives various non-language sounds. Therefore, it is possible that the dominance of the right hemisphere is reflected in the behaviour and sorting of input – stimuli. This early experience is explained by the later dominance of the right hemisphere in the recognition of non-speech sounds. Further development of the left hemisphere is associated with the ability of the foetus to perceive the mother’s voice. This new acoustic information related to the dominance of the left hemisphere is explained by two factors (Turkewitz, & Kenny, 1982). The right hemisphere is determined for the perception of non-speech sounds (signals) and it becomes dominant for this function. This means that the right hemisphere is less available to respond to the mother’s speech than the left hemisphere. Since speech will be the primary function of communication, the left hemisphere becomes dominant, and this fact becomes the precursor of left hemisphere dominance for the whole process of speech.

Another view of asymmetry and its development is based on the idea that the development of areas important for visual cognition is associated with greater dominance of the right hemisphere at the time of birth and a short time afterwards. The right hemisphere is more sensitive to the visual information it receives. The visual system of newborns in particular is limited in sending visual information at high frequencies. This ability is improved in the first six months of the infant’s development. Therefore, the right hemisphere is dominant for a short period after birth. This hemisphere is responsible for the transfer of global information gained via ocular perception (Hellige, & Cox, 1989). In later development, relevant areas of the left hemisphere develop more than in the period after birth, and the individual receives visual information through the eyes at higher scales of visual frequencies (Hellige, 2001).

5.3.2 Craniofacial Development

In the general theory of the prenatal origin of hemispheric asymmetry in humans, several asymmetries are discussed. In approximately two-thirds of newborns, most cranial bones are wider on the right side, while the chin and jaw area is slightly larger on the left side. The craniofacial asymmetries begin to appear during the first trimester of pregnancy. These facts lead to the assumption that such asymmetries in the prenatal period are the basis for the dominance of the left hemisphere for speech comprehension and production (Previc, 1991).

5.3.3 Motor Manifestations of Laterality in the Prenatal Period

Based on the use of ultrasound, thumb sucking was observed in human foetuses beginning in the 15th week of pregnancy. Interestingly, it was found that the right hand was preferred (Hepper, Shahidullah, & White, 1991). However, subsequent studies focusing on the connection between hand preference (thumb sucking) and the position of the foetus in utero, conducted from the 32nd to the 38th week of pregnancy, did not confirm any significant relationship. In contrast, this motor manifestation of laterality in the form of thumb sucking strongly correlated with head turning in newborns tested shortly after birth. The head was oriented to the same side as the preferred hand during thumb sucking (Hopkins, Lems, Janssen, & Butterworth, 1987).

The most discussed issue is the question of whether the position of the foetus in utero influences prenatal asymmetry. Monitoring was conducted during the last trimester of pregnancy, especially in the last month. Three-quarters of foetuses were in the position with the head in the caudal direction and the back oriented to the left side of the mother. The left arm is in the position against the mother’s pelvis and spine. The right arm is oriented to the outer part of the uterus. These facts lead to the conclusion that such asymmetric positions of the foetus are important for pre-dominance of right-handedness in the human population (Hellige, 2001). The foetus has more freedom for activity of the right arm, which is in a more independent position than the left arm (Corballis, 1991).

However, current studies confirm that this is only an indirect fact. In addition to determining pre-dominance of handedness depending on the position of the foetus in utero, the development of hemispheric specialization for postural functions and motor control has also been studied. The position of the foetus and the pressure caused by the mother's walk develop an otolith (an organ inside the ear maintaining balance) and, particularly, neural pathways leading to the brain. In most individuals, this development leads to the dominance of the left otolith, which is essential to emphasizing the fact that in the postural position a large part of the population looks for support in the left side of the body. Therefore, the right side of the body, controlled by the left hemisphere, becomes dominant for the control of motor behaviour.

5.3.4 Postnatal Development of Motor Manifestations of Laterality

The seeds of motor manifestations of laterality can be observed very soon after birth. When turned on the abdomen, the newborn shows a preference to lie with its head oriented to one side. Research has shown that 70% of children turn their heads to the right. In order to improve accuracy, this research was conducted with a modified position of the newborn on its back. The results of both studies were almost identical. In four months, most infants exhibit right-hand preference – in pointing to objects and touching them. The left hand usually only holds objects in a passive way (Cornwell, Harris, & Fitzgerald, 1991; Young, Segatowitz, Misek, Alp, & Boulet, 1983;). Other studies were conducted in the area of cognitive perception asymmetry in three-month infants. Individuals had to identify photos of their mothers shown to them in the right and left visual field. Infants exhibited preference fixation time with the photograph placed on the left side. This result thus showed stronger activation of their right hemisphere (Molfese, & Segalowitz, 1988).

After infants reach one year of age, gradual upper limb preferences for various types of activities are observed. Between the first and the third year, there is not a substantial difference in capabilities of both upper limbs, and preference of one of them is not clearly apparent. Therefore, it is not suitable to assess handedness for such small children using motor tests. However, there are studies that have dealt with cognitive perception asymmetries between the first and the second year of age using tactile tests of eye–hand co-ordination. Based on palpation, individuals examined a three-dimensional object that they did not see. Different pictures of objects were gradually shown on the screen, and their task was to identify the picture that represented the object (Witelson, 1985). It is not possible to determine motor manifestations of lower limb laterality in this age, mainly because of the postural system formation. A wide range of handedness is gradually finalized in the third year of age. The proportion between left-handed and right-handed individuals almost reflects the proportion in the adult population. This finalization of handedness is tested using motor tests, e.g., peg tests (speed test of putting pegs into holes) (Annett, 1985). The process of lower limb lateralization is only gradual. Children aged four to eight years exhibited weak low limb preference finalization, and they were more ambidextrous (Gentry, & Gabbard, 1995). This fact is supported by the idea that footedness is less subject to right-sided social pressure (Chapman, Chapman, & Allen, 1987). Slow low limb preference finalization was found only in the age categories of eight to 11 years. Current studies suggest that the age range from five to 11 years contains a turning point in the development of limb preference (Oeztuerk, Durmazlar, Ural, Karaagaoglu, Yalaz, & Anlar, 1999; Mori, Iteya, & Kimura, 2004). According to the authors, laterality levels off after the fifth year of age, based on the corpus callosum myelination, which subsequently causes effective communication between the dominant and non-dominant cerebral hemisphere (Barnea-Goraly et al., 2005). Upper limb and eye laterality, manifested by reading and writing, is also associated with speech stabilization, which should end around the 11th year of age. Individual differences in cognitive development can be understood in the relationship between the level of behaviour refinement and level of laterality (brain laterality in children).

However, the process of lateralization is not only observed in comparing different age categories, but also within groups. Individuals may differ from one another not only in the degree of lateralization, but also in the pace of preference finalization (Zebrowská, 1987).

5.3.5 Corpus Callosum and Hemispheric Specialization

An important role in interhemispheric communication is played by the corpus callosum, which most likely contributes to hemispheric specialization (Witelson, 1985). The corpus callosum is the largest cerebral commissure that contains 200 to 300 million nerve fibres. It connects the cortex of the opposite frontal, parietal, and occipital lobes. With regard to the temporal lobe, it only connects auditory areas; the other temporal areas are connected in the anterior commissure (Franz, & Fandy, 2007; Fix, 2002). The corpus callosum forms an integral part of the neural network that is involved in the support of higher cognitive functions (Roessner, Banaschewski, Uebel, Becker, & Rothenberger, 2004). It begins to develop in the prenatal period, between the 10th and

24th week of foetal development (Giedd et al., 1999). It was already presented by Trevarthen (1974) that the corpus callosum matures between the fifth and the 10th year of age (Trevarthen, 1974). Fagard et al. (2001) found that the link between cerebral hemispheres matures during the first 10 years of age (Fagard, Hardy, Kervella, & Marks, 2001). Kalat (1995) thought that the corpus callosum begins to mature during the period from the third to the fifth year of age (Kalat, 1995). These findings indicate that the maturation of the corpus callosum corresponds to the development of limb preference during childhood, from insufficient communication to specialized communication between the hemispheres (Mori, Iteya, & Kimura, 2004). Interesting results were presented in a study by De Bellis et al. (2001), which states that myelination and the corpus callosum development process is not the same in boys and girls aged six to 18 years. The boys exhibited significantly greater size of corpus callosum and longer anterior region (genu) (De Bellis et al., 2001). Studies dealing with research in this area conclude that the relationship between the maturation of the corpus callosum limb preference finalization can answer the question of the nature of permanent sidedness (right-handedness, left-handedness) or ambilaterality. The basic idea is that the stronger lateralized individual is less variable in hemispheric specialization, and shows more distinct functional asymmetries, than ambilateral individuals (Iteya, 1998). Based on the differences in motor co-ordination, i.e., inconsistent laterality (ambilateral individuals) and consistent laterality (right-handers, left-handers) in children of pre-school age, it was concluded that the question concerning the extent of individuals' lateralization depends on the maturation of the corpus callosum between the right and left hemisphere. This means that interhemispheric communication is stronger in children with consistent preference of one limb than in individuals with inconsistent preference (Kalat, 1995). Sigmundsson and Whitting (2002) pointed out the relationship between motor co-ordination and interhemispheric communication. They believed that unskilful and other motor handicapped children usually have a problem with hand–eye co-ordination (Sigmundsson, & Whitting, 2002). Other research using magnetic resonance imaging found that dyslexic children had a significantly smaller anterior region (genu) of the corpus callosum (Hynd et al., 1995).

The next chapter deals with the diagnosis of motor manifestations of laterality. It provides information on the most widely used instruments and their development, relationships and shortcomings, which should serve as guidelines for the construction of new test batteries.

6. DIAGNOSTICS OF FUNCTIONAL MOTOR LATERALITY MANIFESTATION

Research into laterality in relation to the functional asymmetry of brain hemispheres and its diagnosis has been conducted by experts for almost 200 years. During this period, a number of studies regarding the relationship between laterality, mental disorders, functional asymmetry, and cerebral dominance have been written (Musálek, & Štochl, 2010). The diagnosis of laterality is particularly associated with neurology and psychology, especially in the diagnosis of specific disorders (Johnson, 2005).

The first major study dealing with the diagnosis of laterality emerged in the medical field. In the second half of the 19th century, autopsies were performed on stroke patients paralyzed in one half of the body in the sagittal plane that found a cross-lateral brain function. The presumption that the right half of the body is motorically controlled by the left cerebral hemisphere and vice versa was published by the French anthropologist and anatomist Paul Broca in 1867 (McManus, 2002). Along with this discovery, the speech centre, “Broca’s area”, was also localized in the brain; in right-handed individuals, it was almost always located in the left hemisphere. This hypothesis was then confirmed, particularly by a study presented by Liepmann, which showed, based on 83 patients affected by apraxia, that voluntary movements are controlled from the contralateral hemisphere (Liepmann, 1908). At that time, left-handedness was still considered a pathological phenomenon. In the 1930s, S.T. Orton, a leading speech pathologist, published the monograph *Reading, Writing and Speech Problems in Children: A Presentation of Certain Types of Disorders in the Development of the Language Faculty*, in which he pointed out the relationship between insufficient dominance of one of the cerebral hemispheres and disorders of speech and writing in children (Orton, 1937). Studies, which followed on from medical and psychometric research, looked at the relationships and diagnosis of laterality of motor and sensory organs (Green, Satz, Smith, & Nelson, 1989; Kimura, 1964; Nagae, 1983). The results of this work showed that the issue of functional laterality and its diagnosis is very important in addressing the causes of specific disorders of children, pathological phenomena in psychiatric fields (schizophrenia), neurology, and professional diagnosis (Taylor, Dalton, & Fleminger, 1980). Manifestations of laterality were thus also examined in the area of neuropsychology: the issue was, for example, dealt with by the leading Soviet neuropsychologist Alexander Luria in relation to mental disorders (Luria, 1962; Luria, 1976). The relationship of laterality and speech is a long and intensely discussed issue in the area of laterality. This relationship is currently being addressed primarily using magnetic and functional magnetic resonance imaging (Vikingstad, George, Johnson, & Cao, 2000; Sommer, Ramsey, & Kahn, 2001; Binder, Frost, Hammeke, Cox, Rao, & Prieto, 1997).

In the former Czechoslovakia, the issue of laterality and its diagnosis was addressed most intently by Sovák (1962). His studies focused mainly on mental disorders of naturally left-handed children who had been forcibly retrained (Sovák, 1962). The issue of retrained children and children with specific disorders related to manifestations of laterality was also dealt with by Synek, (Synek, 1991). Another view on laterality was presented by Drnková and Syllabová (1983). Their study discusses the very concept of laterality, various types of laterality, and their diagnosis in relation to cross-laterality (different preference of upper and lower limbs or upper limbs and eyes) and speech (Drnková & Syllabová, 1983). In the field of neurology, laterality was dealt with in the first half of the 20th century by Henner, who outlined a possible relationship between cerebellar function and the motor manifestations of laterality in his work (Henner, 1927). Currently, with regard to the neurological-neurodegenerative view, laterality in the context of left-handedness and right-handedness is being addressed by Koukolík, (Koukolík, 2008). The issue of motor manifestations of laterality is also discussed in a study presented by Štochl, who verified the structure of motor symptoms of Parkinson’s disease using motor tests focused on upper limb performance (Štochl, 2008).

6.1 Diagnostic Tools

The current literature does not contain uniform fixed terms for concepts in the assessment of preference and performance in motor limb activity. This chapter presents two basic views on the assessment of motor manifestations of laterality:

- determining the level of preference using the preference task method or self-assessment preference questionnaires,
- assessing different performance of motor organs using performance tests.

6.1.1 Preference Tasks

A number of motor tasks have been created in order to determine upper and lower limb preference, but, surprisingly, not all authors consider them to be reliable predictors in determining individual laterality (Annett, 1970). Others question the creation and use of motor tasks, citing the (unsubstantiated) higher validity and reliability of self-assessment questionnaires, as well as the time needed for processing (Bryden, Mandal, & Ida, 2000; Oldfield, 1971; Sharman, & Kulhavy, 1976). Preference tasks are motor activities given by the examiner to the subject. The result is thus an immediate spontaneous response to a command. Items in the form of motor tasks are mostly scored dichotomously, according to whether the individual performs the task with the right limb or with the left limb.

The simplest tasks that were used at the beginning of research into this area identified laterality of the subject based on determining the preferred hand in unimanual writing or drawing task (Gordon, 1920; Haefner, 1929). Very simple procedures were also used to determine lateral preference (left-sidedness and right-sidedness). According to the Rife test battery (1940), which contained 10 unimanual tasks, everyone who used the left hand in at least one task was considered left-handed (Rife, 1940).

To this day, one of the world's best known batteries that include motor tasks that determine motor and sensory manifestations of laterality is the Harris Test of Lateral Dominance (Harris, 1958). It is a set of preference motor tasks determining motor manifestations of laterality. According to the author, motor tasks are suitable to diagnose population older than seven years of age, where writing ability is assumed. The motor-task part includes items that are instrumental in nature and that determine hand preference using unimanual and bimanual tasks. The battery contains items where the subject shows, for example, hand preference in writing, drawing, or cutting with scissors.

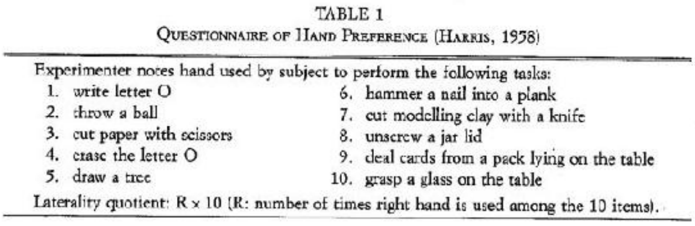


TABLE 1

Questionnaire of Hand Preference (Harris, 1958)

Experimenter notes hand used by subject to perform the following tasks:

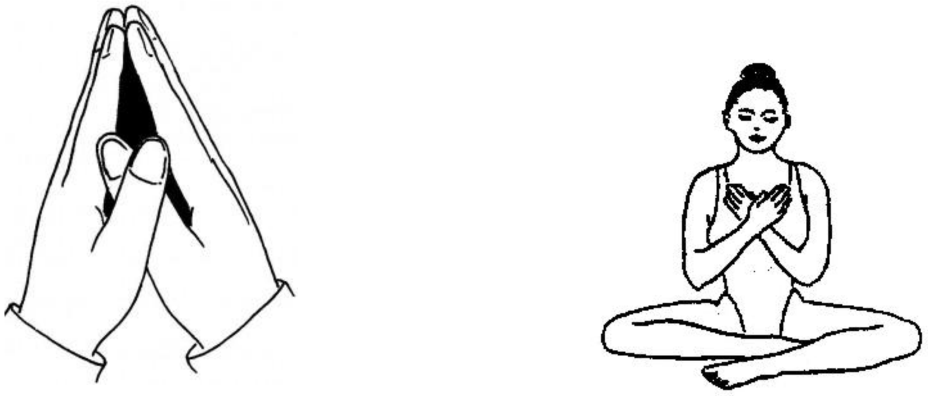
1. write letter O
2. throw a ball
3. cut paper with scissors
4. erase the letter O
5. draw a tree
6. hammer a nail into a plank
7. cut modelling clay with a knife
8. unscrew a jar lid
9. deal cards from a pack lying on the table
10. grasp a glass on the table

Laterality quotient: R × 10 (R: number of times right hand is used among the 10 items).

Fig. 5 Motor preference tasks for hand preference from „Harris test for lateral dominance“ (Harris, 1958). Figure is take over from study of Rigal (1992), (Rigal, 1992 p. 853).

The battery includes monocular and binocular tasks in order to determine ocular dominance. The author extended preference tasks with performance tests, which determine different writing ability of the right and left hand, and performance tests, which examine different performance in upper limb tapping and different hand grip strength. The author is convinced that all items are sufficiently valid in terms of the content, even though they are only based on intuition and logical validity. With regard to this battery, numerical representation of validity of individual indicators was not prepared. The observed reliability of the items to determine hand preference using the test-retest method ranged from 0.75 to 0.83 (Harris, 1958). Expression of the degree of laterality was calculated using the formula $LQ = \frac{(R-L)}{(R+L)} * 100$ (where LQ is the laterality quotient in per cent, R is the number of tasks performed by the right hand, and L is the number of tasks performed by the left hand). This study does not discuss the constructs of hand preference, performance, and ocular dominance in detail. It neither creates nor determines any diagnostic tool structure, and it does not contain the expression of several important aspects of diagnostic quality, such as the factorial validity of indicators and the generic reliability of constructs.

Another well-known preference task battery is that presented by Humphrey (1951) comprising 45 items determining upper and lower limb preference and ocular dominance, which is determined using the result of the monocular task. Thirty items from this battery are designed to determine hand preference. The items are of unimanual and bimanual nature, largely of instrumental type. Some of the indicators are very specific, and not every subject has the opportunity to perform the activity (e.g., holding a golf club or a cricket bat). In addition, the battery includes tasks of simple spontaneous activity, such as folding the arms or lacing fingers together. In these items, the preferred limb is the one whose part (finger, part of arm) is on top.



Prerequisite of left-hand preference Prerequisite of right-hand preference

Fig. 6 Examples of tasks which assess spontaneous hand preference

The calculation of lateral tendency is based on the formula $LQ = \frac{(R-L)}{(R+L)} * 100$ (Humphrey,1951). However, not even this study discusses sufficiently the issue of manifestations of functional laterality in relation to hemispheric asymmetry that would lead to the creation of an acceptable structure of the whole tool. Basic characteristics of individual psychometric indicators are unavailable.

In determining lower limb preference, the most frequently used motor tasks include kicking a ball or moving an object (Bryden, 2000). A more complete picture of motor tasks to determine lateral lower limb preference is shown by the test battery derived from the Waterloo Footedness Questionnaire, which was originally compiled by Bryden (1977) in the form of a questionnaire (Bryden, 1977). The battery contains nine motor tasks with repetition which are scored dichotomously each time. Upon completion of a motor task in a given number of repetitions, the total score achieved is recorded (Elias, & Bryden 1998).

Motor tasks to determine motor and sensory manifestations of laterality were created by a number of Czech (Czechoslovak) experts (Sovák, 1962; Kučera, 1961; Matějček & Žlab, 1972; Zaháněl & Vaverka, 1990). The best-known set of such motor tasks is Matějček and Žlab's “Laterality Test” (1972). Based on motor preference tasks, this diagnostic tool determines upper limb, lower limb, and eye laterality, in both children and adults. It contains a total of 18 preference tasks. Twelve items assess upper limb preference, four items determine lower limb preference, and two items assess ocular dominance using the observation (sighting) factor. Since preference tasks are designed to make the subject repeat the task several times, all items are scored polytomically (in contrast to previous studies) – right, left, absence of preference. The examiner monitors whether the individual performed the task using the right limb, left limb, or whether the individual alternates both limbs in the repeated execution of the same task. With regard to ocular dominance, it is determined which eye is preferred in monocular activity. The calculation of lateral tendency is based on the above formula $LQ = \frac{(R-L)}{(R+L)} * 100$. The authors used the formula presented in Harris's study or, more precisely, Humphrey's study (1951) to calculate the laterality quotient. The authors chose those tasks that were considered particularly valid by the literature. However, these motor tasks were created solely to reflect the needs of clinical practice, and they were not properly validated. Individual items have both unimanual and bimanual character.

However, due to the nature of most motor tasks used in the previous batteries, it is very difficult to diagnose the population younger than seven years in terms of ontogeny of motor activity. Therefore, researchers are currently focussing on the population of younger children, particularly those aged four–six years, for whom they seek to validate mainly hand preference tasks. Krombholz (1993) and Tirash et al. (1999) proposed methods for observing children's spontaneous daily activities using video recordings. Based on the analysis of the video footage, it would be possible, using a certain process of hand preference coding in motor activity, to determine the lateral tendency of the child (Krombholz, 1993; Tirosh, Stein, Harel, & Scher, 1999). In the studies carried out by Pryde et al. (2000) and Fagard and Marks (2000), the authors even focused on the possible standardization of these proposed procedures using video technology (Fagard, & Marks, 2000; Pryde, Bryden, & Roy, 2000). However, these procedures faced the problem of identification and differentiation of hand preference in the motor activities of children, as well as enormous time demands concerning the analysis of movements.

Bryden et al. (2007) attempted to create a comprehensive approach to the diagnosis of upper limb preference in children: the WatHand Cabinet Test (WHCT).

The WHCT uses a cabinet on which and into which various objects can be placed; it is also possible to handle the objects around the cabinet. The child is instructed as to exactly what to do by the examiner. The manipulative items predominantly have the character of unimanual activities. Lateral preference is then expressed using three scores:
1) skilled performance score, which has the same mathematical expression as the previous battery: $LQ = \frac{(R-L)}{(R+L)} * 100$
2) internal consistency score, which measures the average of how many times the child opened the cabinet using the right hand
3) bimanual performance score, which focuses on the activity where the child has to take something from the cabinet after opening it. It assesses whether the same hand that opened the cabinet is used or not
(Bryden, Roy, & Spence, 2007)

Using composite scores, this diagnostic tool has been correlated with the pegboard performance test, 0.563 (Annett, 1976), and the Waterloo Handedness Questionnaire (WHQ), 0.853 (Bryden, 1977). In both cases, the author shows significant correlations of the WHCT vs. the pegboard = 0.563, and the WHCT vs. the WHQ = 0.853 (Bryden, Roy, & Spence, 2007). The study does not explain whether the interpretation was based on adequate polychoric correlations or not. The WHCT itself does not have a verified structure including diagnostic quality in terms of reliability.

Another battery of 16 motor tasks determining upper limb preference in the population of children aged four–six years was created by Kastner-Koller et al. (2007). This diagnostic tool has a four-dimensional structure according model Steenhuis and Bryden (1989) that divides upper limb motor activity into proximal movements; distal movements; spontaneous picking-up movements; and handling movements. Each dimension contains four motor tasks. In addition, individual dimensions have been further divided into groups according to whether the movement is accurate or automatic. Each of the tasks is performed by the child three times (Kastner-Koller, Reimann, & Bruckner, 2007). Apart from the expression of specific reliability of individual tasks, the battery does not have an interpreted structure with quantified relations between indicators and constructs, or between individual constructs.

A very interesting procedure for estimating upper limb preference – the "reaching the card task" – was employed by Connolly and Bishop (1992). Seven coloured cards are placed in front of the child, i.e., in the half-circle with a diameter in the direction from the child's left hand to its right hand. The child is asked to hold a card of a certain colour and move it to the prepared box. The aim is to determine whether the child will take the cards using the same hand, even if it has to take a card across the body axis (Bishop, Ross, Daniels, & Bright, 1996; Connolly, & Bishop, 1992). Doyen and Carlier (2002) attempted to validate this motor task. In their study, Doyen and Carlier correlated the results of Bishop's reaching card task with the results of a questionnaire survey determining upper limb preference and with the results of Annett's peg moving test (1985) identifying the difference in the performance of upper limbs. However, the conclusion of this research did not confirm a relationship between preference and performance, and the authors recommend using both preference unimanual tasks and the reaching task in examining motor manifestations of laterality (Doyen, & Carlier, 2002). This research only used manifest variables in the form of tasks, questionnaire items, and tests. The study did not differentiate the character of the data, i.e., whether it dealt with ordinal or interval data; therefore, the correlations were only expressed using Pearson's correlation coefficient. However, this coefficient can only be used for interval data. The study did not determine polyserial correlations, which was necessary in this case. In addition, the manifest variables in the form of a motor task, test, and questionnaire items were not related to the dimension determining handedness, so in this case the entire diagnosis of handedness lacks any more detailed expression of the structure of this characteristic and relations within it.

In other studies, Calvert and Bishop (1998) focused on the modification of this motor task. The child examined was first asked to point at the card, and then it was instructed to take the card and place it in a box. A certain percentage of probands pointed at the card ipsilaterally, but the relocation was performed contralaterally using the upper limb across the body axis. The results of this research showed that, in addition to the construct of preference for relocating an object (card), there also seems to be a construct for hand preference in pointing to an object. This finding was explained by the need to distinguish between the difficulty of the task (handling an object) and a mere act of pointing to an object (Calvert, & Bishop, 1998). A study by Bryden et al. (2003) modified this type of motor task into a form where everyday tools (pen, toothbrush, hammer, paint brush, spoon) were placed in the half-circle instead of the cards.

Assessment of this procedure was then performed in the adult population. The subjects were first asked to lift an object and mime the relevant activity with it. The result of the study was the finding that upper limb preference is stronger in motor tasks that include demonstration of activity (Bryden, Roy, & Mamolo, 2003). This assumption was supported by another study Mamolo et al.(2004). Results showed direct link between hand manipulation with subjects and space comformity (Mamolo, Roy, & Bryden, 2004). In addition to manipulative activities, diagnosis of preference in the use of upper limbs in motor tasks also focused on determining the feeling of comfort that subjects experience in handling. Mark et al. (1997) conducted research in which the subjects were asked to move small cubes, based on the instructions provided. The movement was first limited to the arm area only. Then the task was repeated, but the probands could also turn and bow their trunk. In addition to determining the subjects' upper limb preference, the degree of comfort was also assessed using the three-point Likert scale (1 – comfortable movement, 2 – uncomfortable movement, 3 – very uncomfortable or even impossible movement). The result of the research showed a connection between the spatial arrangement of objects and limb preference (Mark et al., 1997). A finer distinction of comfort using a continuous 100-point scale, the Comfort Rating Scale, was performed by Mamolo et al. (2006). Interestingly, this study found a significant relationship between the determination of the degree of comfort and the non-preferred hand (Mamolo, Roy, Rohr, & Bryden, 2006).

However, motor preference tasks only show an individual's side tendency; they do not express, in a more precise context, the individual's degree of lateralization. In addition, at present no adequate validation study has been conducted that meets both methodological and psychometric requirements.

6.1.2 Preference Self-reported Questionnaires

Self-assessment questionnaires are designed primarily to determine upper and lower limb preference in motor activity without the possibility of comparing the degree of lateralization. It is only in exceptional cases, e.g., in a diagnostic tool presented by Bryden (1977), that the item determining whether the individual was retrained in the course of development is included. The latent variable which, in this case, represents lateral preference of motor organs or dominance of sensory organs is generally regarded as a continuous variable (Annett, 1970; Annett, 2002; Bryden, 1977; Nettle, 2003; Oldfield, 1971, Sharman, & Kulhavy, 1976). According to Dragovic, this approach is also chosen because it is almost impossible to statistically normalize nonparametric distribution of lateral preference (Dragovic, 2007). Most preference questionnaires currently used have been compiled from the results of questionnaires for the adult population. The questions in the questionnaires focus on motor tasks that usually display unimanual nature, i.e., when responding, the individual only decides between the left and right limb. In scoring the responses, three types of lateral preference are often distinguished, depending on whether the activity is performed with the right limb, left limb, or both with the right and left limb (Annett, 1970 a); Coren, & Porac 1978; Oldfield, 1971). Each of these options has its value in the questionnaire: +1 for the right limb, -1 for the left limb; if the subject does not exhibit any preferred limb for the activity, the response is marked with 0. Laterality quotient, calculated using the formula $LQ = \frac{(R-L)}{(R+L)} * 100$, and given in percentage, is most often used for the subsequent interpretation of the results of the subject's lateral preference (Barut, Murat, Ozdemir, Mustafa, & Yunten, 2007; Chapman, 1987; Oldfield, 1971; Rackowitz, 1974; and others). Other authors, such as Coren and Porac, calculate right-sidedness and left-sidedness in their itemized questionnaire by adding up individual values. Therefore, if the result of an eight-item questionnaire is positive, the subject is considered to be right-sided (Coren, & Porac, 1978). The right-sided individual is the person who reaches the score from +1 to +8 in the questionnaire.

In some studies, the authors work with five response options. Besides the three above-mentioned responses, there are more options: I usually perform the activity using the right limb, I usually perform the activity using the left limb (Bryden, 1977; Sharman, & Kulhavy, 1976). However, the meaning of the word usually is not clearly defined. Some questionnaires even offer the response options rarely or slightly.

Bishop, Ross, Daniels, and Brigit (1996) argue that there is no "gold standard" for determining the lateral preference of motor organs, not even handedness (Bishop, Ross, Daniels, & Bright, 1996; Dragovic, 2007). In addition, different researchers use different items or questionnaires and, in almost all cases, they make arbitrary decisions about how they call sub-groups expressing lateral preference and how they are divided (Annett, 2002; Dragovic, 2007; Peters, 1995). Some of these diagnostic tools also contain items that determine laterality of sensory organs – eyedness and earedness (Coren, 1993). Ocular dominance (eyedness) is mostly determined in the questionnaire survey with questions focusing only on monocular activities (see chapter 5.1.5

Eyedness). Determination of ear dominance is one of the less diagnosed areas in the questionnaires. Ear dominance is typically determined by questions relating to listening to both non-speech and speech stimuli (listening to a watch, listening to the radio) (Coren, 1993; Coren, & Porac, 1978;). Determination of both eye and ear dominance in the questionnaire survey may only represent approximate output, due to the complexity of sensory organ laterality. Yet some authors, e.g., Bourassa et al. (1996), consider questionnaire items to be a better diagnostic tool for measuring eyedness than preference motor tasks (Bourassa, McManus, & Bryden, 1996).

At present, the best known globally used questionnaires determining lateral preference of motor limbs include the Annett Hand Preference Questionnaire (AHPQ) (Annett, 1967), the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971), and the Waterloo Handedness Questionnaire (WHQ) (Bryden, 1977).

The AHQP only assesses hand preference, and includes 12 items that form a combination of unimanual and bimanual everyday activities (in the form of questions). The entire questionnaire is divided into two parts. The first six questions are considered the primary items that strongly correlate with hand preference. The second six questions are considered secondary by Annett, and their correlation with hand preference is not as strong. The items are scored on the three-point Likert scale, and the interpretation of the overall laterality quotient is expressed by the formula $LQ = \frac{(R-L)}{(R+L)} * 100$. In her study, Annett also proposes to divide lateral preferences of the hand into eight different categories, ranging from extremely left-handed individuals to extremely right-handed individuals. The questionnaire does not lack an item determining hand preference in writing (Annett, 1967). However, this indicator is considered to be misleading by some authors due to the social pressure that generally prefers right-handed writing (Riehl, 2010). The first study attempting to approximate the specific reliability of all AHPQ indicators was conducted as late as 1975 by McMeekan and Lishman. On average, it was around the value of 0.75 (McMeekan & Lishman 1975). Dragovic (2007) performed both the latent class analysis and confirmatory factor analysis, including generic reliability approximation, of the AHPQ. The latent class analysis showed that the proposed eight categories of upper limb lateral preference cannot be accepted for the 12-item model in the AHPQ. However, the confirmatory factor analysis found satisfactory psychometric properties and a good model fit of the 12 items of the AHPQ.

Despite this, Dragovic proposed eliminating some items that create the multidimensional nature of the entire diagnostic tool (Dragovic, 2007).

The most frequently cited and most widely used questionnaire designed for the diagnosis of human lateral preference is the EHI, created by R. C. Oldfield (1971). Oldfield argues that the conclusions of previous studies showed insufficient differentiation of upper limb laterality using performance tests. Therefore, the inventory method, which sufficiently distinguishes the level of hand preference, is used for the diagnosis of upper limb laterality. Low time and economic requirements constitute another reason for favouring the inventory method.

The author of the EHI selected 20 items from Humphrey's battery (1951), which assesses hand preference in the adult population. The items subsequently underwent item analysis. The final version of the EHI contains 10 essential items examining hand preference that, according to the results of the item analysis, exhibited the strongest correlation. Furthermore, the questionnaire includes an additional question about lower limb preference and a question assessing ocular dominance based on monocular activity. This questionnaire also uses the formula $LQ = \frac{(R-L)}{(R+L)} * 100$ to calculate the individual's lateral preference. In individual items, test subjects express their upper limb preference by placing a cross, or crosses, in the appropriate column behind the question. The left column represents the left hand; the right column represents the right hand. Two crosses in one column indicate strong preference in the given activity; one cross indicates weak preference. If the person tested does not exhibit a preferred upper limb for an item, one cross is written in each column. Like Annett, R.C. Oldfield views handedness as a continuous variable, i.e., a variable that displays certain degrees, ranging from extremely right-handed individuals to extremely left-handed individuals (Oldfield, 1971). The results of the EHI take the form of ordinal data marked by the author on the five-point Likert scale. Dragovic (2004) also conducted a confirmatory factor analysis of the EHI, which showed that three out of the 10 questionnaire items are redundant. These were two items of bimanual nature that disrupted the unidimensionality of the EHI, and one item of unimanual nature (which hand do you use for drawing) that showed strong collinearity with the item determining hand preference in writing (Dragovic, 2004).

The original version of the Waterloo Handedness Questionnaire by Bryden (1977) comprises 32 items that form a combination of unimanual and bimanual activities of instrumental nature, both skilled and unskilled. The questionnaire also includes an item that determines whether the individual was retrained. In order to determine lateral preference, the items in this study are scored on the five-point Likert scale, depending on whether the person always uses the right upper limb, usually uses the right upper limb, has no preferred upper limb, usually uses the left upper limb, or always uses the left upper limb to perform an activity. The author explains the difference between the terms always and usually by stating that if the person uses one limb in 95% or more cases to perform the activity, the response is always. If the person uses one limb in approximately 75% of cases to perform the activity, the response is usually. The question is whether the subject is able to express percentage for activities that are not so familiar and automatic.

The calculation of lateral preference is based on the same formula that is used in the previous two diagnostic tools: $LQ = \frac{(R-L)}{(R+L)} * 100$. In order to determine the structure of the WHQ, Steenhuis and Bryden (1989) conducted an analysis using the principal component method. The authors state that the WHQ is based on a three-factor structure. The first factor contains items of a skilled nature, the second factor contains items of an unskilled (spontaneous) nature, and the third factor is related to bimanual activities. In addition to the proposed structure, it was found that activities of a skilled nature have a closer relationship to hand preference than those of an unskilled nature (Steenhuis, & Bryden, 1989). Using the principal component method, the structure of the WHQ was also verified by Obrzut et al. (1992). However, the research set consisted of individuals with specific learning disabilities. The three-factor structure was also confirmed, but there were different loads expressing relations of items to hand preference. Research carried out by Oberutz et al. showed that, compared to the results of the previous study, the items of unskilled nature have a closer relationship to the expression of upper limb lateral preference in this specific population. Therefore, this finding indicates instability of validity concerning some items in specific populations (Obrzut, Dalby, Boliek, & Cannon, 1992). In order to obtain a fuller picture of motor organ lateral preference, Bryden (1977) also created the Waterloo Footedness Questionnaire (WFQ). The methodological basis of the WFQ is the same as in the WHQ. The WFQ contains 10 items determining lower limb lateral preference, both in instrumental and spontaneous activity (Bryden, 1977).

The most commonly used questions in the questionnaires:

Which hand do you use to hold a writing instrument for writing?
Which hand do you use to hold a writing instrument for drawing?
Which hand do you use to hold a toothbrush?
Which hand do you use to hold a knife when cutting bread?
Which hand do you use to hold scissors when cutting?
Which hand do you use to throw a ball?
Which hand do you use to hammer a nail into wood?
Which hand do you use to hold a spoon when eating?
Which foot do you use to kick a ball?
Which eye do you use when looking down a telescope?

(Annett, 1967; Barut et al., 2007; Bryden, 1977; Coren, 1993; Crovitz, & Zener, 1962; Chapman, & Chapman, 1987; Hatta et al., 2005; Kovac, 1973; Oldfield, 1971; Porac, & Coren, 1978; Raczkowski et al., 1974; Van Strien, 2002; and others)

However, according to some authors, diagnosis of motor manifestations of laterality using questionnaires implies several pitfalls. According to Nisbett and Wilson (1977), as well as Bryden (2000) Brown et al. (2006), self-assessment questionnaires are affected by the subjective opinions of individuals, unlike spontaneous responses observable by another person (Brown, Roy, Rohr, & Bryden, 2006; Bryden, 2000; Nisbett, & Wilson, 1977). In addition, simple questionnaire questions that were developed based on hypotheses about a connection of handedness with footedness and earedness certainly cannot determine ear dominance very well.

In the course of the 1970s, additional questionnaires were created (Kovac, 1973; Rackowitz, 1974; Sharman, Kulhavy, 1976), but since they simply duplicate the EHI, AHQP, and WHQ (Oldfield, 1971) they are almost never used.

6.1.2.1 Methodological and psychometric shortcomings of the most frequently cited diagnostic tool, the Edinburgh Handedness Inventory

The author Oldfield (1971) states that the purpose was to create a simple diagnostic tool to determine handedness, which could be used in experimental and clinical studies.

The EHI consists of indicators that examine hand preference by asking the following questions: Which hand do you use to:

1. Write?
2. Draw?
3. Throw?
4. Cut with scissors?
5. Brush your teeth?
6. Cut with a knife?
7. Eat with a spoon?
8. Sweep with a broom?
9. Strike a match?
10. Open a box?

Additional questions:

i. Which foot do you prefer to kick with?
ii. Which eye do you use when using only one?
(Oldfield, 1971)

Methodological shortcomings

The fact that no reference to a scientific source dealing with scientific and standardisation studies, methods, and procedures is mentioned is the cause of the essential imperfection of the study. The problems of the research are therefore not specified sufficiently: The laterality of the so-called behavioural domain, which is considered to be a super-construct and which needs to be examined on the basis of scientific theory, and its inner relations need to be explained (Štochl, & Musálek, 2010). The study is not grounded in other studies on the actual determination of handedness and does not explain basic concepts such as hemispheric domination, laterality, its types and possible development in the course of human life. The main construct – handedness, i.e., an indirectly observable variable – is not analysed (Blahuš, 1985). Possible sub-constructs are not specified, as is the case with their relations to the main construct, e.g., fine or rough motor of upper limb, skill/tool or non-skill/spontaneous manifestation of hand preference (Bryden, Mandal, & Ida, 2000) or the distinction of preference according to muscle engagement: proximal movements – of arm and shoulder; or distal movements – of the fingers and hand (Steenhuis, & Bryden, 1989).

The study thus uses only a general concept of handedness, which is intended to express the common examined character of the whole diagnostic tool.

However, information on the development of laterality in the child and on different cultural perceptions of laterality (today distorted by immigration) is lacking. When choosing a method of handedness determination, Oldfield decided to apply the method of inventory for the reason of insufficient differentiation of hand preference by performing tasks (Oldfield, 1971). The EHI study does not contain any evaluation of possible questionnaire problems, e.g., sensitivity. For example, a study by McMeekan and Lishman (1975) discovered, during an approximation of the reliability of the EHI by the test-retest method, that tested individuals often changed the intensity of preference for specific answers when completing the questionnaire repeatedly (McMeekac, & Lishman, 1975). According to Bishop et al. (1996), the self-assessing EHI thus has neither a sufficient theoretical basis nor empirical validity and overlooks the important issue of the dimensionality of the handedness construct (Bishop, Ross, Daniels, & Bright, 1996).

When selecting specific indicators, the method of content validity was not used either. Oldfield only states that the basic set of items for the EHI consisted of 20 indicators that he had used for his previous study, the aim of which was to find left-handed musicians (Oldfield, 1969). These items were originally used in a hand preference questionnaire by Humphrey (1951). However, he does not mention the diagnostic quality of this tool, i.e., generic and specific reliability, construct validity, or the validity of specific indicators. Its possible limitations are not mentioned either.

Quote: *"As to the choice of items, it seems probable that no selection could be exempt from criticism. The present set of questions, however, proved capable of answer by a very high percentage of undergraduate subjects."* (Oldfield, 1971 p. 99) The process of selecting specific items therefore remains unfounded.

Based on his previous experience, the author admits that he is not able to respond to essential methodological questions: whether all the items should be given equal weight, or how to work with indicators between which there is such a high correlation that the presence of both of them is superfluous and may thus cause false overvaluation of the diagnostic tool. He points out that the main role of the EHI is as a general screening tool that does not attempt to describe the development of laterality in the individual.

In the part of the study titled Method, Procedure, Subject, the author describes the selection of the observed file. (Quote) *"Copies of the inventory were sent to departments of psychology in several English and Scottish Universities."* (Oldfield, 1971 p. 99) Yet the aspects or the process of selecting the observed file are not stated. At the same time, the study does not deal with the issues of random or intentional selection; nor does it explain the basic differences between these two approaches. A critical work by McMeekan & Lishman (1975) points out a serious problem: The observed file for the creation of the EHI was not based on intentional selection and its results cannot therefore be generalised to the whole population. Among other things, an emphasis was placed upon the selection of left-handed individuals from the London psychiatric registry. The observed file consisted of 1,128 undergraduates (394 M, 734 F). The work does not offer substantiation of the size of the file connected to the standardisation of the diagnostic tool; moreover, it fails to offer a reason for the age category of subjects. The mean age of subjects of both sexes was higher than 20 years. The author merely states that handedness is stabilised by the age of 20. However, he does not describe the development of handedness with regard to the ontogenesis of the individual (McMeekan, & Lishman, 1975).

Psychometric shortcomings

During the filling out the EHI with appropriate crosses and subsequent calculation of the LQ, the results can be easily misinterpreted. If a subject makes only one cross for each of the 10 items, which means that he or she expresses weak preference for a given act, he or she will obtain the same result (according to the mathematic formula of the level of lateral preference of the LQ: $LQ = (R - L)/(R + L)*100)$ as a subject that made two crosses for each of the 10 items as an expression of strong preference (Bryden et al., 2000). The data obtained thereby may therefore eliminate one of the characteristics of the test: that is its ability to discriminate – to tell the difference between specific levels of a given feature (Bryden, Mandal, & Ida, 2000; Schachter, Ransil, & Geschwind, 1987). However, there is no reason to scale strong preference as the double size of weak preference just because it is noted by two crosses instead of one (Williams, 1986).

Later studies dealing with the diagnostic quality of the EHI assessed its validity, reliability and unidimensionality (conceptual homogeneity). They discovered that the EHI is not unidimensional; that means that not all indicators are the function of the same feature (Furr, & Bacharach, 2008). Specific EHI indicators thus do not assess only one common characteristic. The multidimensionality of this diagnostic tool is affirmed by the item “holding a broom” – which is a bimanual act with a weak relation to other indicators (Bryden, 1977). Other studies dealing with these issues suggest deleting those items from the EHI that have only a weak connection to the factor of handedness; along with the mentioned “holding a broom” indicator, the item “box opening” should also be deleted in order to secure unidimensionality (Williams, 1986). The results of the study by Büsch et al. (2010), in which the dimensionality of the EHI was determined by mix Rasch-model IRT (Item Response Theory), imply that the EHI is not unidimensional. The structure of two classes, right-handed and left-handed type – with qualitative differences between individuals – seems to be the best model. Ambilateral individuals do not appear to be an independent group and their interpretation should be considered (Büsch, Hagemann, & Bender, 2010).

The selection of a model for data analysis is a quite problematic and not very clarified part of the study. As handedness in general has an asymmetrical bimodal character (Briggs, & Nebes, 1975; Dellatolas, Annesi, Jallon, Chavance, & Lellouch, 1990), data cannot be analysed by using parametric models. The set of items in the EHI was analysed using a method of item analysis in which all items have the same weight (McFarland, & Anderson, 1980). These authors suggest putting the EHI to a procedure that would find out the weights of specific items with regard to the handedness factor. By eliminating the weakest indicators, the overall validity of the EHI would increase. However, this method was never implemented. Dragovic (2004) tried to explain in his analysis whether all the EHI indicators should have the same value or not. He claims that the study by R.C. Oldfield describes the scoring in the EHI by composite scoring. It is determined by the overall sum of specific items and based on the assumption that all items have the same weight when explaining one common characteristic. In this case, the EHI explains the whole construct of handedness, which is expressed by hand preference in different acts. A single-factor congeneric model of confirmative factor analysis, where the same true-scores with different singularity and indicator error are generated, was used in the analysis (Jöreskog, 1971). Dragovic discovered that two items “sweeping with a broom” and “opening a box” have higher dispersion error and the lowest factor validity *(sweeping with a broom 0.43, opening a box 0.35).* Dragovic subsequently eliminated the item “drawing” from the EHI, as its factor validity was *0.96,* while the item “writing”, with a factor validity of *0.98,* was considered redundant.

This selection consequently led to better inner consistency of the whole diagnostic tool (Dragovic, 2004).

6.1.3 Performance Tests

Motor performance compare the performance and execution quality between the same two motor organs within one motor test. These tests represent motor activities given to the subject by the examiner. They thus focus on immediate spontaneous responses to commands. According to the creators of the tests, performance is directly connected to preference. This is expressed by the fact that the preferred hand is usually also the hand that is more powerful and skilled (Ward, Milliken, & Stafford, 1993). The result of a performance test is the difference in the achieved test score between the right and left limb. The data exhibit an interval nature. Performance tests are usually designed to assess different performance of upper limbs. Given the complexity of movement control, an assumption was made about the multidimensionality of performance, just as in preference. A performance model was designed as far back as in the 1960s, dividing upper limb movements into movements of distal and proximal parts (Lawrence, & Kuypers, 1968). This study was later developed by, for example, Bryden and Steenhuis (1989), who said that the distal part of the upper limb is apparently controlled in a different way than the proximal part (Steenhuis, & Bryden, 1989). In his study dealing with the diagnosis of motor manifestations of laterality using performance tests, Rigal (1992) discovered two basic areas of these tests with four factors. The first area is represented by performance tests, primarily focused on identifying differences in neuromuscular activity performance/speed or neuromuscular activity/strength without placing a demand on the fine motor skills. These tests include various forms of tapping, i.e., a dot-filling test without space constraints from study Peters and Surrfing (1978), grip strength (which is one of the static performance tests), or static targeting (which hand exhibits greater stability) (Peters, & Surfing, 1978). The second area is represented by skill performance tests of fine-motor nature that are focused on movement accuracy (Rigal, 1992). What is assessed here is the number of errors made, the time needed, or both (Borod, Caron, & Koff, 1984a)). The best known tests include the pegboard test (Tiffin, & Asher, 1948), Purdue test (modification of the pegboard test with a specific shape of the peg) (Annett, 1970 b)), dot-filling test (Tapley & Bryden, 1985), and others (Bishop, 1990; Borod, Koff, & Caron, 1984 b)). The pegboard test was first created by Tiffin and Asher (1948). The tool is a board with small holes for pegs. The subject's task is to insert as many pegs into the holes as possible within a specified time, first with the preferred hand and then with the non-preferred hand (Tiffin, & Asher, 1948). The test was later expanded by Marion Annett, who increased the difficulty of this test by introducing pegs and holes with certain shapes so it was not possible just to insert a peg into a hole in any way (Annett, 1970 b)). However, examiners sometimes face a problem of imitation and short-term transfer in this performance test. This is one of the factors of motor learning, especially in the adult population. Transfer generally implies positive transmission of learned and proved activities in the process of motor learning. It is based on the effect of abilities, skills, and knowledge gained in one activity being used in another activity. Motor transfer has two basic components: a motor part and an emotional part.

- Motor part of transfer – after the subject performs the action with the preferred upper limb, the movement pattern is temporarily kept in the memory within the central nervous system, due to the process of sensorimotor learning; based on self-reflection, the central nervous system specifies the parameters for further performance of the action.
- Emotional part of transfer – the motivation factor is the most significant factor in this part; it is very closely related to the learning process, and affects the level of effort to reach or even improve on the previous performance.

(Schmidt, & Lee, 2011; Schmidt, & Wrisberg, 2000)

Based on these facts, the adult subjects did not always show substantively significant differences in the number of pegs inserted with the preferred and non-preferred hand, not even after instruction. Moreover, due to demands on the fine motor activity of fingers, this type of test is not entirely suitable for the children category. Another fine motor performance hand test used is the “modified dot-filling test” (dot circles). The main objective is to mark a dot into each circle with a diameter from 3 mm to 8 mm using a pencil. This motor test is again performed with the preferred and non-preferred hand (Tapley, & Bryden, 1985). With regard to the diagnosis of laterality by means of performance tests, especially in children, part of Ozeretsky’s test that diagnoses the maturity of the nervous system in children is also sometimes used. The entire battery consists of six basic parts determining the level of co-ordination of upper and lower limbs and right-left orientation. The battery also includes a test determining dynamic co-ordination of upper limbs (the child throws a ball), as well as motor speed and precision (the child moves and assembles objects) (Ozeretzky, 1931). General characteristics and definition of handedness fine motor performance in children were dealt with by Gabbard (Gabbard, Iteya, & Rabb, 1997).

In the Czech Republic, the assessment of different performance was performed by Fremelová and Blahutková (2004). They created an instrument for assessing hand fine motor perfromance and lower limb gross motor performance in the form of tapping (Fremelová, & Blahutková, 2004).

A very interesting finding relating to the diagnosis of motor manifestations of laterality and performance was a strong correlations between the pegboard test and the preference task of hammering a nail, or the dot-filling test and the drawing task. This finding supported the view that performance apparently have a complex multi-dimensional structure; this is also the reason that the performance component is neglected in the test batteries used (Elliot, & Roy, 1996). However, some studies point to time demands, as well as the generally weak relationship between the constructs of preference and performance (Porac, & Coren, 1981). Therefore, experts dealing with the diagnosis of motor manifestations of laterality still do not want to fully accept performance tests, and many studies supporting the preference questionnaire method point out their uselessness. On the other hand, according to Peters, the assumption that preference and performance are closely related is correct. He states that emphasis should primarily be placed on the relationship between preference and performance (quality and performance of motor organs) (Peters, 1998; Wachter, Cong, Staude, & Wolf, 2008). In addition, the work of Elliot and Roy (1996) highlights the advantage of monitoring a proband when performing a task, which ensures increased objectivity in the diagnosis of laterality, compared to subjective statements in questionnaire responses. According to Elliot and Roy, the test battery containing valid gross and fine motor tests would enable more comprehensive diagnosis of motor manifestations of laterality (Elliot & Roy, 1996).

An interesting view was presented by Van Strien (2002), who compared all three methods (preference tasks, self-assessment questionnaires, and performance tests) for the diagnosis of motor manifestations of laterality with an emphasis on the assessment of upper limb laterality. Based on research, the author states that the best method is to use a questionnaire whose items exhibit the highest reliability (Van Strien, 2003). However, the study does not deal with issues such as collinearity of items and artificial overestimation of diagnostic quality, which is probably caused by including specific instrument items adapted to the needs of right-sided society.

Within the multifactorial issue of motor manifestations of laterality, gross motor performance and fine motor performance are as yet not fully elucidated. The authors are particularly faced with the problem of determining which of the dimensions is the most important for the diagnosis of motor manifestations and why (Elliot, & Roy 1996).

6.2 Evaluation of Cerebrall Dominance, New Approach for Approximation of Hemispheric Superiority

In addition to the aforementioned traditional approaches to the assessment of motor manifestations of laterality, which are often used to determine the dominant cerebral hemisphere, this section of the thesis outlines a possible new approach. It is the determination of cerebellar dominance, which, according to Professor Henner's hypothesis, should be directly related to motor manifestations of laterality or hemispheric superiority.

The cerebellum is one of the most important areas of the brain, playing a key role in motor control. The cerebellum itself does not initiate movement, but decides about and contributes to the co-ordination, precision, accuracy, and timing of movement. The cerebellum receives inputs from the sensory system and from other parts of the brain and spinal cord. This is information from muscles concerning corticospinal activity and almost simultaneously also information from proprioreceptors concerning the resultant muscle movements. The cerebellum then compares this information with information coming from the eye, ear, and tactile receptors, and integrates the inputs into the final motor activity (Barlow, 2002). It is very interesting that the cerebellum itself contains more synapses than the rest of the brain together (Llinas, Walton, & Lang, 2004).

As mentioned in section 2.2, the cerebellum is composed of three basic functional parts. The oldest and the smallest is archicerebellum, which forms the flocculonodular lobe. This part processes information from the vestibular organ and controls posture. Its removal would result in an inability to maintain upright stance, as well as gait disorders. The medial part of the anterior and posterior lobe of the cerebellum forms paleocerebellum, which processes tactile, proprioceptive, visual, and auditory input signals coming from the spinal cord and from both the auditory and visual system. Fibres from the paleocerebellum lead to both the cortex and the brainstem. This part of the cerebellum activates the descending inhibitory system of the reticular formation, and is responsible for maintaining muscle tone and limb movements. The lateral zone contains the youngest part, the neocerebellum, which is connected with motor areas. The neocerebellum particularly receives inputs from the cortex of the parietal lobe. Outputs are then sent mainly to the ventral part of the thalamus to the contact motor area – the premotor and primary motor areas. All three parts of the cerebellum (the archicerebellum, the paleocerebellum, and the neocerebellum) work as one functional unit (Fine, Ionita, & Lohr, 2002).

Similarly to the telencephalon, the cerebellum consists of two hemispheres. Each cerebellar hemisphere is in contact with the contralateral cerebral hemisphere. Since the motor cortex of the brain controls movements of the opposite half of the body through the pyramidal tract, double crossing occurs (in the pyramidal tract and in the superior cerebellar peduncle). Therefore, either cerebellar hemisphere controls voluntary movements on the ipsilateral side of the body (Čihák, 2001; Fine, Ionita, & Lohr, 2002). During intentional targeted movements, the cerebellum integrates information about the plan, initiation, course, and aim of the movement. Based on this information, together with close co-operation with the extrapyramidal system, the cerebellum continuously performs fine control of muscle tension. In addition, the cerebellum is particularly involved in the control of eye movements (Prsa, 2010). It was discovered that the cerebellum also contains “memory circuits” that seem to be responsible for recalling events, i.e., previously performed motor patterns (Barlow, 2002). Subsequent research has also shown that memory circuits are related to the motor and cognitive subregions of the cerebellum (Ding, Qin, Jiang, Zhang, & Yu, 2012). Therefore, within the movement control, the cerebellum is also involved in the process of motor learning. In this research, which is currently producing hypotheses on the possible structure and principles of motor learning, adaptation to changes in sensorimotor relations is one of the best known types of learning. This learning process is explained by the term “synaptic plasticity within the cerebellum”. This hypothesis of synaptic plasticity is referred to as the Marr-Albus theory (Ito, 1982; Sanger, 2003). Destruction or removal of the cerebellar area does not lead to a complete physical paralysis of an individual, but results in inability with regard to motor learning, fine motor activity, and balance (Wolf, Rapoport , & Schweizer, 2009). With regard to motor activity, such an individual is not able to perform, for example, continuous limb movement in space (Schmahmann, 2004).

Interestingly, removal of only one cerebellar hemisphere does not result in permanent and irreversible loss of the complex function of the cerebellum, but in gradual compensation and significant improvement in functional manifestation. In the event of damage to the cerebellar hemispheres, wide base gait, also called “drunken gait”, with considerable accompanying upper limb movement, can be observed (Tichý et al., 1997). Dysarthria, i.e., apraxia of speech, where only basic gross movements of speech organs are preserved, is another symptom of cerebellar disorders, especially in lesions.

The connection between the function of the cerebellum and motor manifestations of laterality was first assumed by Professor Kamil Henner. Given that the neocerebellum is responsible for the control of muscle tone, Henner (1927) points out “neocerebellar extinction syndrome”. As a result of cerebellar hypotonia of one of the cerebellar hemispheres, neocerebellar extinction syndrome manifests itself in increased muscle hypotonia, passivity, and increased joint extensibility. The cerebellar hypotonia can be observed in humans during walking, and it is manifested by a more noticeable accompanying arm movement on one side of the body. According to Henner, the neocerebellar syndrome should be well detectable in joints. Based on these findings, he pointed out the existence of physiological extinction syndrome (Henner, 1927). Subsequently, he identified slight left-sided neocerebellar extinction syndrome in right-handed individuals in his clinical studies (Henner, 1936). Since the pathways from the motor centres of the cerebral cortex lead to the cerebellum contralaterally, a model was proposed that considers the cerebellar hemisphere which is on the ipsilateral side of the preferred upper limb as dominant (Henner, 1927; Tichý et al., 1997; Tichý, & Běláček, 2009). Apart from the assumption about the relationship between cerebellar dominance and upper limb preference, Tichý and Běláček (2008) attempted to reveal the relationship between cerebellar dominance and lower limb preference. However, no significant relationship was found, probably also due to the selection of the tests (Tichý, & Běláček, 2008). Nonetheless, diagnosis of cerebellar dominance could help in the assessment of natural hemispheric dominance without the influence of the right-sided world phenomenon.

7. EMPIRICAL RESEARCH

The aim of this study is to contribute to the standardization of the new diagnostic tools assessing the motor manifestations of laterality in adults and children aged 8 to 10 years, both in terms of determining the theoretical concept and the selection of appropriate items, and the verification of structural hypotheses concerning the design of acceptable models, including the diagnostic quality of individual parts of the test battery. Moreover in this study we try to suggest new approach in assessing of motor laterality manifestation by means of relationship between cerebellar dominance and hand performance. In order to fulfil this objective it was essential to determine in detail the area of motor manifestations of laterality. Therefore, it was necessary to base the study on extensive theoretical knowledge that shows motor manifestations of laterality as a multidisciplinary concept.

The conclusions of this thesis should become the basis for the completion of the diagnostic tools necessary for a wide range of disciplines (neurology, psychology, kinanthropology, special education, phoniatrics).

In the past, the diagnosis of motor manifestations of laterality was most often associated with the determination of hand preference. Any potential case of determined left-handedness represented a deviation and implied a certain disorder. Until recently, left-handedness was a serious social handicap, and there was a tendency to retrain the left-handed individuals to become right-handed. This trend did not appear only in this country, but also abroad (Annett, 2002; Beaton, 2004; Porac, & Martin, 2007). In some societies, this phenomenon is quite common even today (Bryden, Mandal, & Ida, 2000).

If innate laterality is retrained, entire structures can be moved in the brain, which may lead to a variety of specific disorders (Robinson, & Downhill, 1995). It may result, for example, in a decline in intellectual performance. Studies in psychodiagnostics also suggest that, apart from retraining, other environmental factors may change relations in the cerebral architecture (Annett, 2002). Research also shows that people also differ in speed and intensity of the lateralization process. Especially with regard to children, apart from early and highly lateralized individuals, those displaying slow lateralization and weak intensity were also observed. There is a risk of disorders of speech, reading, and concentration (Gabbard, 1992; Medland, Perelle, De Monte, & Ehrman, 2004; Żebrowska, 1987).

In the former Czechoslovakia, the issue of laterality and its diagnostics was dealt with in the second half of the 20th century by studies focusing on mental disorders as a result of the retraining of naturally left-handed individuals (Sovák, 1958; Sovák, 1962).

As stated in section 6.1.2, the most common tools used in the world to diagnose motor manifestations of laterality are questionnaires, which are primarily intended for the adult population. The best known questionnaires include the Edinburgh Handedness Inventory (Oldfield, 1971), the Waterloo Handedness Questionnaire (Bryden, 1977), and the Annett Handedness Questionnaire (Annett, 1970). Preference questionnaires were also created by other authors (Coren, 1993; Dean, 1988; Elias, 1998; Kovac, 1973; Porac & Coren, 1981; Raczkowski, 1974; Sharman, Kulhavy, 1976;and others).

In the Czech Republic, the best-known diagnostic tool is a set of preference tasks called "Zkouška laterality" (Laterality Test) (Matějček, & Žlab, 1972), created in the early 1970s, which measures upper and lower limb laterality and ocular dominance in both children and adults.

However, most of the aforementioned diagnostic tools are only designed to detect preference (Donaldson, & Johnson, 2006). When a more detailed analysis of these diagnostic tools was conducted, some basic methodological and psychometrics problems were discovered (Musálek, 2011).

With respect to field research, the aforementioned diagnostic tools have been used almost unchanged since the 1970s.

Disciplines such as psychodiagnostics, kinanthropology, psychology, and neuroscience indicate the need for innovation and completion of diagnostic tools to determine laterality. Currently, there are tests that are fragmented, incomplete, and created exclusively for the needs of clinical practice. Moreover, tests to diagnose motor manifestations of laterality in the Czech Republic have not been honed for many years. With respect to the risk population of children aged 7 to 12 years, diagnostic tools have not been created that would adequately differentiate individuals' lateralization. Thus, the development and standardization of tests for the diagnosis of motor manifestations of laterality has long been neglected in the Czech Republic.

The standardization process will be based on existing questionnaires and preference tasks intended to diagnose preference, as well as on motor performance tests, even non-validated. The set of items will be enriched by other assessable indicators focused on the field of task preference and test performance. An indicator for estimating cerebellar dominance will also be created. Based on the implementation of this indicator in the test battery, the hypothesis concerning the relationship between cerebellar dominance and motor manifestations of upper limb laterality will be subsequently tested. The verification of this hypothesis could help identify natural hemispheric dominance.

We expect that this broad concept of laterality examination will be beneficial:

a) to conducting a comprehensive diagnosis of motor manifestations of laterality in children, including the diagnosis of retrained individuals and unsuccessful individuals with good and above-average abilities (Beaton, 2004; Mori, Iteya & Gabbard, 2006; Synek, 1991);

b) to diagnosing conditions after neurosurgical interventions, and to diagnosing other manifestations related to hemispheric dysfunctions (McManus, 2002; Nobuyuki, 2005);

c) to facilitating the selection of candidates for demanding professions and sports disciplines (Carlstedt, 2001).

8. RESEARCH QUESTIONS

The previous studies dealing with the development of diagnostic tools to assess the motor manifestations of laterality did not always choose adequate methodology. In addition, the statistical procedures used to express the structure and dimensionality of these instruments are now obsolete. Within the test battery construction, very few studies dealt with the connection of larger units of laterality diagnosis and the creation of a multi-level diagnostic tool. With respect to the finding of the link between cerebellar dominance and motor manifestations of laterality, there are only sporadic attempts that do not offer a broader interpretation. Therefore, the following scientific questions are addressed:

- What is the diagnostic quality of all items (both existing and newly created) used to diagnose motor manifestations of laterality?

- Which empirical indicators should be chosen to determine the individual constructs of handedness and footedness using motor performance tests?

- Does it exist significant relationship between hand performance and cerebellar dominance?

9. HYPOTHESES

H1: At least 75% of the items in both final forms of the test batteries (for adult and child populations) will exhibit the factor validity of at least 0.6, based on the structural equation modelling method.

H2: The best models of the individual parts of the test battery for both the child and adult populations will exhibit multidimensionality.

H3: The generic reliability of individual constructs will be at least 0.75.

H4: The factor loading of the indicator assessing cerebellar dominance in relation to the upper limb performance factor will be significant in both test batteries, reaching the level of $p < 0.001$.

H5: Statistically significant relationship to the assessment of upper limb preference in the child population reaching the level of $p < 0.001$ will be represented by indicators in which the subjects will also have to work across the natural axis of the body.

The individual values of the coefficients in the hypotheses were chosen based both on previous research (Dragovic, 2004; Dragovic, & Hammond, 2007) and on accepted standards of validation studies and structural equation modelling (Kline, 2011).

10. METHODS

The entire chapter (including all the subchapters) deals with the issue of the standardization study, or more precisely with the parts that are used in this thesis. We will focus on the definition of the theoretical concept, the selection of items and research sample, and the expression of the diagnostic quality of individual parts of the test battery. Given the scope of the thesis, the issue of the creation of standards is not discussed here.

Based on their character, standardization studies fall into “tightly structured research”. They come mostly from the field of quantitative research, which firmly determines the structure of the research plan with clear and specific research questions, clear conceptual framework, and structured scheme (Punch, 2008). In this case, the actual design of the research plan is the most critical point of the entire research process (Brink, & Wood, 1994).

In order to form the test batteries within the standardization procedure, we used the principles of psychometry, which is a theoretical and interdisciplinary tool for creating high-quality diagnostic methods (Michell, 1997).

10.1 Definition of Theoretical Concept

The theoretical concept represents an indirectly measurable characteristic that determines the field and objective of investigation. The theoretical concept is sometimes also called a “hypothetical construct” or “behavioural domain” (Furr, & Bacharach, 2008). Within the standardization process, the definition of the theoretical concept, i.e., the exact demarcation of the field of research, is probably the most important part. In order to determine the theoretical concept, analyses and syntheses of scientific theories concerning the given field are used. Definitions and classifications concerning the issue are reviewed (Anderson, & Gerbing, 1982; Štochl, & Musálek, 2009). It is also important to determine the possible structure of the theoretical concept, i.e., to determine which specific concepts (empirical attributes) of indirectly measurable smaller units the theoretical concept is composed of (Cronbach, & Meehl, 1955; Takane, 2007). This is based on the analysis of the current diagnostic tools used to evaluate the theoretical concept. This has to be complemented with the specification of the tools, i.e., which population they are intended for, and what psychometric properties they exhibit (validity, reliability). After reviewing the theories related to the research problem, defining the parts of the theoretical concepts and diagnostic tools that are suitable for our research, and identifying the research design, it is possible to conduct high-quality specification of the theoretical concept. The theoretical concept, even if only indirectly measurable, must be defined by the researcher in an operationalized way as a latent variable representing the objective of investigation (Byrne, 2001; Štochl & Musálek, 2009).

Based on the study of the theoretical foundations, in order to define the theoretical concept, we first determined the most important concepts – the cerebral hemispheres, the activity of the central nervous system, motion control, motor pathways, muscular activity, laterality, the preferred use of a motor organ, skill, accuracy. The theoretical concept represents the field of research concerning neuromuscular activity controlled by the brain and projected in motor organs. During the biological development of the individual, the neuromuscular activity exhibits a certain development which particularly depends on the maturation of the central nervous system. The projection of the motor activity displays a noticeable difference in the use of the motor organ, i.e., preference. In addition, it is also possible to observe a different quality of performing the movement by both paired motor organs, i.e., performance in gross motor and performance in fine motor activity. In order to specify the basic structure of the theoretical concept, we determined two subfields – preference and performance. The entire field of the theoretical concept is currently being measured by different types of diagnostic tools. These include questionnaires, preference tasks, and performance tests (see sections 6.1.1, 6.1.2, 6.1.3), focusing especially on the motor activity of motor organs. In order to demarcate the theoretical concept, we only used those tools that displayed diagnostic quality. Based on all the aforementioned information, we have defined the theoretical concept: “motor manifestations of laterality”.

10.2 Determination of Specific Theoretical Concepts

With respect to the empirical research, it is necessary that data in the form of manifest variables is directly related to the concepts, and that this connection is tight, logical, and consistent. It is very common that a set of manifest variables (tests, items, tasks) reflects more than one attribute within a theoretical concept. In this case, the theoretical concept consists of a number of specific concepts, and the structure of the theoretical concept defined by us displays a multidimensional nature. Within the multidimensional structure, the indicators (tests, tasks, items) are not directly related to the theoretical concept as a general attribute. In this case, it is necessary to determine the specific concepts that are directly related to the indicators and that the general attribute consists of. The combination of the indicators and the theoretical concept (general attribute) is then indirect – through specific concepts (Punch, 2008).

As mentioned in section 10.1 (Definition of the theoretical concept), two specific concepts of preference and performance were initially established for motor manifestations of laterality. Each of these specific concepts was then further divided into two areas that will be directly related to the observable variables – indicators. In total, the theoretical concept has thus been divided into four specific concepts:

- upper limb preference
- lower limb preference
- upper limb performance
- lower limb performance

The assessment of ocular dominance using the sighting factor forms a separate part which will be conducted through a single indicator.

Based on the findings of the theoretical part, all specific concepts were determined to be latent variables that are continuous in nature, i.e., they allow the assessment of different levels of the investigated trait. In our case, this trait is represented by sidedness – right-sidedness or left-sidedness. The assessment of motor manifestations of laterality is thus based on the continuum from the strong left-sidedness to the strong right-sidedness.

10.3 Determination of Structure of Diagnostic Tool

On the basis of the definition of the theoretical concept and specific concepts, the concept of the diagnostic tool is subsequently determined. This concept is always based on currently accepted hypotheses and the nature of the created diagnostic tools. In determining the concept of the future diagnostic tool, the shortcomings of the previous tools and proposals for new procedures are particularly taken into account for the assessment of the attribute (Butcher, Graham, Haynes, & Nelson, 1995).

In this thesis, we determined the concept of two test batteries for both the adult and child populations. The concept of both test batteries has the same basis, i.e., an assessment of preference and performance of motor organs with the quantification of ocular dominance. Based on the ontogeny of cognitive functions and human motor activity, with respect to the adult population, we decided to use a test battery that would assess the motor manifestations of laterality in three ways. The first part of the test battery, which will display the screening nature, will form a short questionnaire (containing no more than ten items) determining upper and lower limb preference. This part should identify the basic lateral trend of adult individuals.

The second part of the test battery will consist of up to eight motor tasks determining upper and lower limb preference. The tasks (in the form of spontaneous motor activity) should specify the lateral trend of preference. This part of the test battery will also determine ocular dominance using a motor task.

The third part will include performance tests that will assess differences in the performance of both upper and lower limbs. It will contain up to eight indicators. An indicator determining cerebellar dominance will also be implemented in this part of the test battery. The test battery for the diagnosis of motor manifestations of laterality in the adult population will not contain more than 26 indicators. Based on the consultation with the Institute of Pedagogical and Psychological Counselling, the time of diagnosis should not exceed 20 minutes.

Due to the lower levels of self-perception with respect to lateral manifestations, the test battery designed for the child population aged 8–12 years will not contain the questionnaire part and will assess motor manifestations of laterality in two ways.

The first part of the test battery will consist of up to twelve motor tasks for assessing upper and lower limb preference. Based on the motor task focused on the eye sighting factor, ocular dominance will be determined.

The second part of the battery will include performance tests that will assess differences in performance of both upper and lower limbs. This part will contain up to eight indicators, including an indicator determining cerebellar dominance. The entire test battery for the diagnosis of motor manifestations of laterality in the adult population will not contain more than 20 indicators. Based on the consultation with the Institute of Pedagogical and Psychological Counselling, the time of diagnosis should not exceed 15 minutes.

10.4 Creating a Complete List of Relevant Items

The most important step is the selection of appropriate indicators (manifest variables) for the measurement of individual specific concepts (Loevinger, 1957). It is very important that each specific concept is measured using a sufficient number of manifest variables (Clark, & Watson, 1995). The selection of indicators already used in the diagnosis is performed according to the results of already standardized tests whose validity and reliability are known. In addition to the indicators selected in this way, the list should also contain newly created indicators. New approaches to the evaluation of the theoretical concept should be based on the currently accepted scientific theory of the issue studied. With respect to the selection and creation of new items, it is very important to take into account which population the diagnostic tool is intended for (Štochl, & Musálek, 2009).

The creation of a list of relevant items was based on the batteries and individual indicators already standardized, as well as on the ontogeny of human motor activity and maturation of the human central nervous system.

The test battery designed for the adult population.

The list of relevant items for the creation of the questionnaire part of the test battery primarily consists of indicators that display the nature of unimanual tool questions. These are items that reflect the motor activity of common everyday activities.

The preferential tasks for upper and lower limbs represent activities of a unimanual nature. It is not necessary that the subjects have experience of the activities.

When selecting preferential tasks, particular emphasis was laid on the simplicity and low material requirements of the motor tasks.

In order to determine the different performance of upper and lower limbs, performance tests are based on both gross and fine motor activity. In order to determine the level of the upper limb fine motor activity, tests for separate involvement of the distal part as well as for the joint involvement of proximal and distal parts have been used and developed.

The indicator for determining cerebellar dominance is based on the determination of the level of articular passivity in the wrist.

The test battery designed for the child population.

Preferential tasks for upper and lower limbs focus on motor activity of a unimanual nature. Relevant indicators for the upper limb in the part containing preference tasks are primarily focused on motor activity where the proband will work across the natural body axis. During the selection and creation of preference tasks, particular emphasis was laid on the simplicity and low material requirements of the motor tasks.

In order to determine the different performance of upper and lower limbs, performance tests are based on both gross and fine motor activity. In order to determine the level of the upper limb fine motor activity, tests for separate involvement of the distal part as well as for the joint involvement of proximal and distal parts have been used and developed.

The indicator for determining cerebellar dominance is based on the determination of the level of articular passivity in the wrist.

The complete list of relevant items for the creation of the test battery for the adult population contained 75 indicators assessing motor manifestations of upper limb laterality, 34 indicators assessing motor manifestations of lower limb laterality, and 1 indicator assessing the sighting factor of ocular dominance. The list of relevant items for the creation of the test battery for the child population contained 51 indicators assessing motor manifestations of upper limb laterality, 22 indicators assessing motor manifestations of lower limb laterality, and 1 indicator assessing the sighting factor of ocular dominance.

10.5 Content Validity

Content validity of indicators determines to what extent these indicators are likely to reflect, by their importance and content, the indirectly measurable and specific theoretical concept (Carmines, & Zeller, 1991; Ebel, & Frisbie, 1991). In other words, content validity is the extent to which individual elements (tests, items) of a diagnostic tool are relevant for assessing the intended concept (trait), for a specific purpose (Polit, & Beck, 2004; Wynd, Schmidt, & Schaefer, 2003). It is essential to realize that the relevance of the diagnostic tool may vary depending on the function of the assessment (Messick, 1993). According to some authors, the phrase “to which extent” in defining “content validity” is an indicator that content validity has a quantitative basis (Haynes, Richard, & Kubany, 1995; Lennon, 1956). According to McDonald (1999), in assessing the content of individual indicators, it is important to conduct a conceptual analysis, which is an important prerequisite for acceptable validity of manifest variables. The semantic content of these directly measurable variables should correspond with the general attribute and specific concepts that form the conceptual framework of the entire diagnostic tool and that are objectives of our research (McDonald, 1999).

The assessment of the content validity of indicators is conducted using the “expert survey” (Lawshe, 1975; Lynn, 1986; Mastaglia, Toye, & Kristjanson, 2003). One of the frequently used methods for determining the content validity of indicators is C.H. Lawshe’s. This method is based on the agreement between independent panellists (experts) who, based on their knowledge of the issue, decide the extent of the fundamental importance that a certain item has for the reflection of the construct (Lawshe, 1975). In his study, Lynn (1986) suggests ensuring at least three independent experts. These panellists should form a heterogeneous group, each of them seeing the issue from a different perspective (Štochl, & Musálek, 2009). The panellists are first asked whether a certain indicator measures the specified trait. Their second task is to assess the extent to which this indicator is essential to express the concept. This can be achieved by using a scale (mostly the Likert scale) whose selected values describe the strength of the content relationship between the indicator and the concept (Clark, & Watson, 1995; Štochl, & Musálek, 2009;). In his study, Lawshe notes that the more panellists determine an item as essential and having a strong relationship to the expression of the theoretical concept, the greater content validity the item has. Lawshe expressed this dependence mathematically:

$$CVR = \frac{(n_e - \frac{N}{2})}{(\frac{N}{2})}$$

CVR ....content validity

n_e ....number of panellists that viewed the item as essential

N ....total number of panellists

Based on this mathematical expression for determining the content validity of indicators, the following table with recommended values of panellists' conformity was proposed:

Table 1

Reccommended values of panelists conformity

Number of Panelists	Minimum Value
5	.99
6	.99
7	.99
8	.85
9	.78
10	.62
11	.59
12	.56
13	.54
14	.51
15	.49
20	.42
25	.37
30	.33
35	.31
40	.29

(Lawshe, 1975, p. 568)

When creating a scale assessing the content validity of indicators, two types of scales were considered: a scale with an even number of options and scale with an odd number of options. According to Davis (1992), it is generally advisable to have an ordinal scale with 4 categories. The researcher thus prevents a situation where the expert notes that the item displays a neutral character of relevance towards the construct (from the character 1 – not acceptable, to the character 4 – highly relevant). Based on the results, the indicators are selected from categories 3 and 4 (Davis, 1992).

In our case, in order to assess the content validity of indicators, we finally decided to create the five-point Likert scale which did not contain a neutral option and, simultaneously, displayed a fine distinction between individual degrees of the indicators' content validity with regard to the defined theoretical concept:

1. the indicator does not measure the theoretical concept at all
2. the indicator measures the theoretical concept weakly
3. the indicator measures the theoretical concept
4. the indicator measures the theoretical concept strongly
5. the indicator measures the theoretical concept very strongly

In order to assess content validity, the lists of relevant indicators for both the adult and child populations were sent to six experts from different disciplines related to the motor manifestations of laterality. The following disciplines were used: special education, neurology, psychiatry, anthropomotorics, kinesiology, and neurophysiology. All experts were informed of the aim of this thesis, and in addition to the assessment of the indicators' content validity, the experts were asked to specify whether the indicator is appropriate in the form of the question in the questionnaire, motor task, or motor test. This specification was conducted by the experts by assigning shortcuts to the indicators:

Q	question in the questionnaire
PT	preference task
PET	performance test

When assessing the content validity, the fact whether the indicator represents a spontaneous activity or activity that is currently subject to social pressure was also taken into account. The lists of items were sent to the experts repeatedly, three times in total. The lists were always re-sent to the experts 14 days after returning the previous assessment. In order to determine the most appropriate content items, we used the method of conformity developed by Lawshe (1975). The calculation of conformity was carried out according to the formula $CVR = \frac{(n_e - \frac{N}{2})}{(\frac{N}{2})}$ (Lawshe, 1975). Subsequently, we selected the indicators where all experts repeatedly agreed on the value of 5. Then we incorporated the indicators where more than half of experts agreed on the value of 5, but other panellist(s) assigned the value of 4 to this item. The last part of the indicators included in the creation of the test batteries was represented by items to which all the panellists assigned the value 4.

10.6 First Version of Test Batteries

Based on the results of the previous section (10.5), the first version of the entire diagnostic tool was created. It contains all the indicators that in the process of content validity were identified as relevant and essential with respect to the assessment of the defined theoretical concept. At this stage of the creation of the diagnostic tool, it is necessary to have a sufficiently large number of indicators for the assessment of the attribute and its specific parts. Within the standardization procedure, it is very likely that, based on statistical techniques, their number will be reduced (Štochl, & Musálek, 2009). With respect to the items that display the character of a question in the questionnaire, it is necessary to decide which scale the answers will be scored on, i.e., whether, for example, the Likert scale will be used, and how many points it will have. Along with this, it is also important to determine whether the scale will have an odd or even number of points, and verify, based on a scientific theory, whether the respondents from the selected population are able to distinguish between different levels of response options (Furr, & Bacharach, 2008).

In the test battery for the diagnosis of motor manifestations of laterality in the adult population, the following numbers of indicators were selected, based on the results of content validity: 15 indicators for the questionnaire part, 16 indicators for the part containing preference motor tasks, and 15 indicators of performance tests. In total, 46 indicators were selected.

In the test battery for the diagnosis of motor manifestations of laterality in the child population, the following numbers of indicators were selected, based on the results of the content validity: 22 for the part containing preference motor tasks and 14 performance tests. In total, 36 indicators were selected.

In order to answer the questions in the questionnaire part of the test battery for the adult population, the five-point Likert scale was created. With respect to the question assessing upper or lower limb preference, the respondents selected from the following options:

1 = I always use my left upper/lower limb.
2 = I prefer to use my left upper/lower limb.
3 = I don’t have a preferred limb for this activity.
4 = I prefer to use my right upper/lower limb.
5 = I always use my right upper/lower limb.

Many authors use this five-point scale (Bryden, 1977; Oldfield, 1971; Sharman & Kulhavy, 1976), but only Bryden (1977) dealt with the instructions to differentiate between individual degrees in a more detailed way. Bryden (1977) attempted to separate the degrees of preference in terms of percentage, i.e., if a person uses one limb in 95% or more of the activities, he/she selects the option “always”; if a person uses the limb at about 75% of the activities, he/she selects the option “usually” (Bryden, 1977). The question is whether the proband is able to determine the percentage in activities that are not so familiar and automatic. Since we believe that probands are not able to determine exactly the percentage of their limb use, we conceived this division of individual degrees of preference differently. First, we did not use the word “usually”, but rephrased the option using the expression “prefer”. This means that the proband has encountered a situation in regular activity when he/she used the non-preferred limb spontaneously (except for situations involving injury and inability to use the preferred limb). However, the involvement of the non-preferred limb is isolated, and the use of the preferred limb to perform the activity is more natural. The answer “I don’t have a preferred limb for this activity” means that the proband spontaneously uses both paired limbs in the activity. It is natural to use both the right limb and the left limb to perform the activity, and the performance exhibits the same quality in both cases. Instructions specified in this way differ from the current concept, and they try to explain degrees of preference to the respondent individual. Each of the answers in this part of the test battery is a directly observable variable that takes the form of ordinal data.

Motor tasks assessing upper and lower limb preference in both the adult and child populations are directly observable variables that are scored dichotomously (whether the individual performs the activity using the right or left limb). Since in this study they have the character of latent variables of continuous nature, the dichotomously scored, directly observable variables can be considered ordinal data (McDonald, 1999; Muthén, 1984). In order to express the degree of preference, some motor tasks include more repetition (e.g., repeated throwing or kicking at a target). In this case, despite the dichotomous scoring of individual attempts, the data are polytomous in the overall view. Using these three attempts, the individual can achieve more than two different scores.

Performance tests are continuous, directly observable variables the results of which are data of an interval nature. Motor performance tests are divided into two types in this thesis. The first type includes the tests in which time represents a constant (e.g., the test is performed for 30 seconds). In indicators where time was used as a constant, the duration of the test had to be determined. The second type includes tests where time is not a constant (e.g., the test is performed until it is completed, based on the specified rules). The resultant scores in individual tests that expressed the degree of laterality were obtained from the calculation of the difference in the performance of the right limb and the left limb.

10.7 Verification of Intelligibility of Items

The aim of this part of the standardization procedure is to verify the clarity of the indicators (questions, tasks or tests) in their text form for the intended population. It includes, for example, the wording of a question in the questionnaire or a request to perform motor activity. The verification of clarity is performed using a pilot sample of the population. A sufficient sample is represented by 20 individuals. The participants in the pilot study are first asked to express their opinions on the individual items of the first version of the diagnostic tool, in terms of clarity, difficulty or simplicity of an item or a technical solution, including feelings during performance (Štochl, & Musálek, 2009). The verification procedure concerning the items' clarity may be repeated several times with independent pilot samples (Moore, & Benbasat, 1991).

The clarity of the items in the first version of the test battery was assessed in both the adult and child population in the pilot set containing 25 representatives of the adult population and 25 representatives of the child population. The pilot set for the adult population consisted of the students of the master's degree programme at the Faculty of Physical Education and Sport, Charles University, field of study Physical Education and Sport. The pilot set for the child population consisted of the students of the Albrechtická Primary School in Kbely, Prague 9.

The adult population displayed problems with the clarity of the questionnaire part where the probands were not able to clearly distinguish between the 5th and the 4th option, and the 1st and the 2nd option. The most significant problem in the clarity was found in the pilot samples of both populations in the performance test part. Apart from the problems with understanding the assignment and subsequent execution of motor activity, shortcomings were identified in the objectivity of the test assessment, especially in fine motor activity of the lower limb in children. Based on the feedback and analysis of these shortcomings, the instructions in the questionnaire part of the test battery designed for the adult population were modified. The instructions and requirements of the problematic indicators in the performance tests, in both test batteries, were also modified.

10.8 The Research Sample and Its Size

The size and specification of the research sample is one of the fundamental questions of standardization studies (Peers, 1996).

In order to determine the research sample size it is important to specify the margins of error of the items that are the most important for the evaluation of the theoretical concept (Cochran, 1977). In quantitative types of research, a hypothesis is generally accepted that a 5% margin of error for categorical data and a 3% margin of error for continuous data is acceptable (Krejcie, & Morgan, 1970). A very difficult part of determining the research sample size is an estimate of the variance in the most important variables. Some of the other ways of determining the research sample size include the use of the results of studies with the same or a similar number of probands

(Cochran, 1977), or compliance with the recommended minimum values of research sample sizes given in the table from the study by Bartlett, Kotrlik, and Higgins (2001), which contains values for both continuous and categorical variables (Bartlett, Kotrlik, & Higgins, 2001).

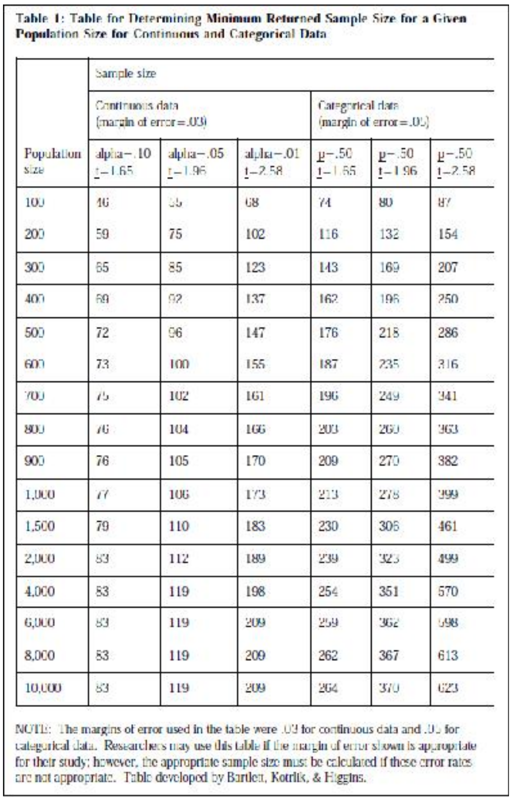


Table 1: Table for Determining Minimum Returned Sample Size for a Given Population Size for Continuous and Categorical Data

	Sample size					
	Continuous data (margin of error=.03)			Categorical data (margin of error=.05)		
Population size	alpha=.10 t=1.65	alpha=.05 t=1.96	alpha=.01 t=2.58	p=.50 t=1.65	p=.50 t=1.96	p=.50 t=2.58
100	46	55	68	74	80	87
200	59	75	102	116	132	154
300	65	85	123	143	169	207
400	69	92	137	162	196	250
500	72	96	147	176	218	286
600	73	100	155	187	235	316
700	75	102	161	196	249	341
800	76	104	166	203	260	363
900	76	105	170	209	270	382
1,000	77	106	173	213	278	399
1,500	79	110	183	230	306	461
2,000	83	112	189	239	323	499
4,000	83	119	198	254	351	570
6,000	83	119	209	259	362	598
8,000	83	119	209	262	367	613
10,000	83	119	209	264	370	623

NOTE: The margins of error used in the table were .03 for continuous data and .05 for categorical data. Researchers may use this table if the margin of error shown is appropriate for their study; however, the appropriate sample size must be calculated if these error rates are not appropriate. Table developed by Bartlett, Kotrlik, & Higgins.

Fig. 7 Recommended values of research sample size (Bartlett, Kotrlik, & Higgins, 2001, p. 48)

One of the accepted standards in standardization studies, where methods such as structural equation modelling are used for data analysis, is to test one item by at least fifteen independent measurements (Loehlin, 2004; Hair, Anderson, Tatham, & Black, 1995). Some authors suggest that for a quick estimate of the research sample size it is necessary to have at least 50 probands more than eight times the variables used (Kaplan, 2009). Barrett (2007) emphasizes, apart from the minimum research sample size (which should contain more than 200 individuals according to him), the homogeneity of the research sample that should be ensured based on a scientific theory from the demarcated area of the theoretical concept (Barrett, 2007).

The specification of the research samples was based on two fundamental aspects:

The first was the need for diagnosis, especially in the child population, which could reveal the cause of possible specific disorders.

The second was the practical aspect of availability of the research sample. The selection area of our research sample was the City of Prague. We based the selection on the results of studies which suggest that the ratio of left-sided and right-sided normally developing individuals in many populations is 1:9. Therefore, we do not assume that this ratio would be currently different in different parts of the Czech Republic. The first research sample consisted of children aged 8 to 10 years. At this age, the lateralization process is still at the fixing phase, and it is a period with a very high occurrence of a variety of specific disorders. The second research sample was represented by young people aged 17 to 19 years. At this age, the lateralization process is already completed, and the test battery can be used to diagnose adults. The probands representing the child population were individuals from state primary schools of the City of Prague which had no specific specialization (arts, technology, sports, languages), and their classes contained no integrated children. The probands representing the adult category were students of Prague general upper secondary schools without a specific specialization (arts, technology, sports, languages). When determining the sample size, the procedure proposed by Kaplan (2009), i.e., eight times the indicators used plus 50 probands, was used as the basic estimation (Kaplan, 2009).

Adult population:

$ss = (48 * 8) + 50$

$ss = 434$

Child population:

$ss = (36 * 8) + 50$

$ss = 338$

As both interval and ordinal data occur in the assessment in both test batteries, we compared the calculated values with the table presented by Bartlett et al. (2001), based on the 3% margin of error for interval data and the 5% margin of error for ordinal data. The research sample size we specified in the confidence interval of 95% in the table ($p = 0.05$) was consistent with the previous calculation. The final research sample size for the adult population was set at 440 probands. Due to availability, the research sample size of the child population was eventually adjusted to 400 probands.

In order to support the selection, we used a complete list of primary schools and four-year and multiple-year general upper secondary schools from the City of Prague which we obtained at the Institute of Educational and Psychological Counselling. With respect to the complexity of a randomized selection of probands from Prague schools and accurate definition of the area of the City of Prague, we decided to obtain both research samples based on the method of purposive sampling which met the following conditions. In co-operation with the Institute of Educational and Psychological Counselling, both secondary and primary schools from each district of the city were selected. As we set the number of the tested individuals at one school to 40, only those schools that were attended by at least 50 individuals of the given age were selected. Out of these schools, a list was created from which one primary school and one secondary school were randomly selected from each district of Prague. In total, 10 primary schools and 11 secondary schools were selected. Due to the large number of items in both test batteries, we subsequently decided to divide both research samples into two halves. Each part of the research sample of the adult population included 220 individuals. Each part of the research sample of the child population included 200 probands. Furthermore, two versions of the test battery were also created for each population. Several of the strongest identical indicators, chosen based on the results of the content validity, were incorporated in both versions. Other indicators were different in both versions.

10.9 Final versions of Test Batteries Before Collecting the Data

A) ADULT POPULATION:

Questionnaire:

Based on the results of the content validity, the following 4 strongest indicators were selected for both versions of the test battery:

- Which hand do you use to hold a writing instrument for drawing?
- Which hand do you use to hammer a nail into wood?

- Which hand do you use to hold a knife when cutting bread?
- Which foot do you use to kick a ball?

The remaining 11 items of the questionnaire part were divided: 6 items were added to the first version, and 5 items were added to the second version, i.e. one version of the test battery contained 10 items in the questionnaire part, and the second version of the test battery contained 9 items.

Preference motor tasks:

Based on the results of the content validity, the following 3 strongest indicators were selected for both versions of the test battery:

- Throw the ball at the target.
- Erase the drawn line.
- Demonstrate how you would write the letter T on the floor using one of your feet.

The remaining 13 motor tasks were divided: the groups of 7 items were added to both versions of the test battery, to the 3 strongest indicators. One version of the test battery contained 10 items in the peference tasks part, and the second version of the test battery contained 9 items.

Performance tests:

Based on the results of the content validity, the following 4 strongest indicators were selected for both versions of the test battery – two for the upper limb and two for the lower limb:

- Tracing the spiral
- Dot-filling fine motor test
- Lower limb tapping
- Slalom with a ball between obstacles

Subsequently, the item for the diagnosis of cerebellar dominance was implemented into these tests (into both versions of the test battery).

Of the remaining 11 performance tests, 5 were added to one version and 6 to another version, i.e. one version of the test battery contained 9 indicators in the performance test part, and the second version of the test battery contained 10 indicators.

The first version of the test battery for the adult population

The questionnaire part:

- Which hand do you use to hold a writing instrument for drawing?
- Which hand do you use to hammer a nail into wood?
- Which hand do you use to hold a knife when cutting bread?
- Which hand do you use to hold a toothbrush when brushing your teeth?
- Which hand do you use to hold a rubber when erasing?
- Which hand do you use to hold a key when unlocking the door?
- Which hand do you use to hold a glass if you want to drink?
- Which foot do you use to kick a ball?
- Which foot do you place on the first step when walking upstairs?
- While standing, which of your lower limbs do you place forward when you want to slide without the support of your hands?

Preference task part:

- Throw the ball at the target.
- Erase the line.
- Demonstrate how you would comb your hair.
- Use the pointer to point at the following object.
- Demonstrate how you would spread butter on bread.
- Demonstrate how you would write the letter T on the floor using one of your feet.
- Perform standing on one leg.
- Kick the ball at the target.
- Move the cube on the floor using one of your feet.
- Demonstrate a long jump.

Use the tube to look at the object.

Performance test part:

- Tracing the spiral
- Dot-filling fine motor test
- Grip strength using a dynamometer
- Arranging matches within the limited area using tweezers
- Moving beads from one box into another using tweezers
- Measuring articular passivity in order to diagnose cerebellar dominance
- Lower limb tapping
- While standing, slalom with a ball between obstacles using a foot
- While sitting on a chair, rolling a ball on the track in the shape of the number eight between two points using a lower limb
- While sitting on a chair, moving small cubes from place to place using a foot

The second version of the test battery for the adult population

The questionnaire part:

- Which hand do you use to hold a writing instrument for writing?
- Which hand do you use to hammer a nail into wood?
- Which hand do you use to hold a knife when cutting bread?
- Which hand do you use to hold a plate when drying it?
- Which hand do you use to hold a match when lighting it?
- Which hand do you use to hold a spoon when eating?
- Which foot do you use to kick a ball?
- Which lower limb do you use to stand on one leg?
- Which foot do you put a shoe on first?

Preference task part

- Throw the ball at the target.
- Erase the lines.
- Ring the bell.
- Use the pointer to point at the following objects.
- Clap your hands.
- Demonstrate how you would write the letter T on the floor using one of your feet.
- Kick the ball at the target.
- Perform jumps forward using one leg.

- Perform the basic (starting) position, and then step forward.
- Make a 360-degree turn

Use the tube to look at the object.

Performance test part:
- Tracing the spiral
- Dot-filling fine motor test
- Pegboard test
- Threading beads on a metal wire
- Collecting toothpicks (matches)
- Measuring articular passivity in order to diagnose cerebellar dominance
- Lower limb tapping
- While standing, slalom with a ball between obstacles using a foot
- While sitting on a chair, moving a cube in the “maze” provided
- While sitting on a chair, taking off a knitted sock from one foot using the other foot

B) CHILD POPULATION

Preference motor tasks:

Based on the results of the content validity, the following 4 strongest indicators were selected for both versions of the test battery:
- Draw a leaf according to the model.
- Ring the bell.
- Throw the ball at the target.
- Kick the ball at the target.

The remaining 18 motor tasks were divided: 9 tasks were added to each version, to the strongest indicators, i.e. the preference motor task part contained 13 indicators in both versions of the test battery.

Performance tests:
Based on the results of the content validity, the following 4 strongest indicators were selected for both versions of the test battery – two for the upper limb and two for the lower limb:

- Tracing the spiral
- Dot-filling fine motor test
- Lower limb tapping
- Slalom with a ball between obstacles

Of the remaining 10 tests, 6 were added to each version of the test battery to the 4 strongest indicators. In the performance test part, each version contained 10 indicators.

Subsequently, the item for the diagnosis of cerebellar dominance was implemented into these tests (into both versions of the test battery).

The first version of the test battery for the child population

Preference task part:

- Draw a leaf according to the model.
- Take the bell in one hand and ring it.
- Take the ball in one hand and throw it at the target.
- According to the instructions, turn the cards of the given colours placed on the sheet of paper.
- Create a line in the marked space using matches.
- Show how many points you can roll with the dice on three attempts.
- Demonstrate how you brush your teeth.
- Open the box.
- Kick the ball placed on the floor at the target.
- Using one foot, tap the rhythm that I am clapping.
- While standing, demonstrate how you slide without the support of your hands.
- Stretch your arms sideways and make a 360-degree turn around your axis.
- Move the cube along the line on the floor using one of your feet.

Use the tube to look at the object.

Performance test part:

- Tracing the spiral
- Dot-filling fine motor test
- Moving beads from one box into another using tweezers
- Turning a box alternately with the front and the rear side on the table
- Threading beads on a metal wire
- Moving matches using a hand
- Measuring articular passivity in order to diagnose cerebellar dominance
- Lower limb tapping
- Slalom with a ball between obstacles
- Kicking a ball against the wall

The second version of the test battery for the child population

Preference task part:

- Draw a leaf according to the model.
- Take the bell in one hand and ring it.
- Take the ball in one hand and throw it at the target.
- Erase the line.
- Show me the following objects using one hand.
- Demonstrate how you stir with a teaspoon in a cup.
- Press number 5 on the calculator.
- Show me how you comb your hair.
- Kick the ball placed on the floor at the target.
- Show me jumps forward on one leg.
- Start running and make a long jump.
- Demonstrate how you would write the letter T on the floor using one of your feet.
- Step on the platform.

Use the tube to look at the object.

Performance test part:

- Tracing the spiral
- Dot-filling fine motor test
- Screwing a nut on a bolt

- Pegboard
- Turning a card between fingers
- Measuring articular passivity in order to diagnose cerebellar dominance
- Lower limb tapping
- Slalom with a ball between obstacles
- While standing, moving a cube in the “maze” provided
- While sitting on a chair, moving small cubes from place to place using a foot

10.10 Data Analysis, Evaluation of Structure

Following the data collection procedure, the final selection of items and determination of the structure and diagnostic quality of the entire test battery are conducted in this part of the standardization procedure. In order to determine the final structure of the diagnostic tool that is designed to assess the pre-defined theoretical concept, currently the most frequently used methods are structural equation modelling methods (SEM), specifically the confirmatory approach. This approach quantifies, in a reflective manner, relations between indicators and specific concepts which make up the general attribute – the theoretical concept (see more in sections 11.1 and 11.2.1). Based on SEM methods, models of the diagnostic tool structure are verified whose quality and appropriateness for the data are expressed through model fit indices. In addition, possible collinearity (strong correlation of two indicators in one dimension) is determined, using the correlations between the individual indicators. In order to compare the quality of the individual models, a residual matrix of indicators is also used that points out unexplained correlations of individual indicators within the model. Based on the results of SEM, the final number of specific concepts (dimensions) and relations between them are determined.

10.11 Approximation of Reliability

Reliability is an indirectly observable character of test scores determining their diagnostic quality (Blahuš, 2008). The conceptual basis of reliability and features of the main procedures for the approximation of reliability are defined, for example, by the Classical Test Theory (CTT), which represents a theory of measurement (Gulliksen, 1950; Magnusson, 1967). According to the CTT, test reliability reflects the range of differences in the test scores of the respondents affected by a certain error of measurement from the actual values (true scores) (Blahuš, 2008; Lord, & Novick, 1968; Thompson, 2003). In terms of reliability, the CTT implies one important assumption for measurement errors. Specifically, it is assumed that the error is accidental and has no dependence on the actual values, i.e., errors and actual values are uncorrelated with each other. In practical research, researchers are more specific, saying that measurement errors tend to cancel each other within the entire number of respondents. This means that some respondents' observed results, expressed by the measured value, are improved by these errors and other respondents' observed results are worsened. The above facts imply the most common mathematical expression of the diagnostic procedure reliability as a proportion of the variance of the actual values and the observed values (McDonald, 1999).

$$\mathrm{Re}\,l = \frac{S^2\tau}{S^2 x}$$

Reliability is generally divided into two basic types: specific and generic. Approximation of specific reliability determines the diagnostic error of a manifest variable (item, task or test). Subject to certain conditions (unidimensionality, parallel form of tests), this approximation is usually carried out by the test-retest method.

Generic reliability means the reliability of the entire concept – an indirectly measurable variable that expresses the diagnostic error of the determined property. The best known coefficients used to approximate generic reliability are Cronbach's α and McDonald's ω. However, Cronbach's α coefficient is not a direct approximation of generic reliability, but it determines the bottom limit (Maydeu-Olivares, & McArdle, 2005).

In order to determine the optimal design of the diagnostic tool to achieve an acceptable level of accuracy – low diagnostic error (reliability), the generalizability theory is also used (Brennan, 2001; Cronbach, Rajaratnam, & Gleser, 1963; Shavelson, & Webb, 1991). This theory implies that the theoretical concept can be assessed using an infinite universe of indicators. These theoretically measure the attribute with absolute precision. Errors in the measurement of the concept using a common diagnostic tool are thus caused by a limited number of indicators that should represent the concept. The generalizability theory implies one important assumption, namely homogeneity or unidimensionality of indicators (Brennan, 2001). Unidimensionality means that all the indicators in a particular area of research measure the same attribute (McDonald, 1999; Blahuš, 1985).

In this study, we have focused on the approximation of generic reliability. For each construct, it has been estimated using McDonald's ω coefficient, which is also the generalizability coefficient.

$$\omega = \frac{\left(\sum \lambda_j\right)^2}{\left[\left(\sum \lambda_j\right)^2 + \sum \psi_j{}^2\right]}$$

ω .... reliability McDonald coefficient

λ_j .... factor loading

ψ_j .... uniqueness

(Blahuš, 1991; McDonald, 1999)

The reliability coefficient is always shown only in models that met the eligibility conditions of the diagnostic quality.

11. STRUCTURAL EQUATION MODELING (SEM)

11.1 Introduction

Structural equation modelling (SEM) is a statistical technique used to verify structural theories of a certain attribute. The concept of SEM or casual modelling is not only one statistical method used to assess the diagnostic quality of a certain tool, but contains a variety of procedures. SEM works with two types of variables.

Directly observable (manifest) variables represent individual items, tests or tasks. These variables can have the nature of categorical, ordinal or continuous data.

The second type of variables includes latent variables that represent operationalized, indirectly measurable specific concepts. The basic assumption is that the latent variables in SEM must be continuous. Directly observable variables that indirectly measure the concept are also called indicators or items (Kline, 2011). Latent variables in SEM are called factors (Bollen, 2002).

The basic statistical term in SEM is covariance, which is defined for two continuous, directly observable variables by the relationship:

$$\mathrm{cov}_{xy} = r_{xy}\ SD_x\ SD_y$$

r_{xy} ......correlation between variables

SD_x ....standard deviation of one variable

SD_y ....standard deviation of the second variable

The SEM analysis has two main objectives:

- to understand covariances between individual indicators,
- to explain their variance as much as possible using a selected model.

(Kline, 2011)

The basic task of SEM is to determine relations between latent and directly observable variables, which differentiates SEM from other statistical techniques, such as ANOVA or multiple regression (MR). These techniques only allow us to analyze directly measurable variables. Another major difference between SEM and ANOVA or MR is that in SEM it is possible to separate measurement errors from true scores of attributes. This is what allows SEM to model latent variables directly (Yuan, & Bentler, 2007). Measurement errors, called non-reliability, are directly related to measurable variables, and constitute a part of unexplained variance – residue. This residue represents variance which was not explained for the indicator relating to the identified factor (Kline, 2011).

The SEM analysis consists of two parts: the measurement model and the structural model.

- The measurement model represents a regression model which, using linear regressions, describes the relations between the directly observable variables (indicators) and latent variables (factors).
- The structural model describes, using multivariate regressions, three types of relations:
    a. between factors and indicators,
    b. between indicators,
    c. between factors and those indicators that are not related to the identified factor.

(Jöreskog, & Sörbom, 1979; Muthén, 1984)

Based on the statistical analysis, it is decided whether the proposed model can be accepted or not.

If it is revealed, based on the results of SEM, that the proposed model is not consistent with the data, i.e., that the model fit is inadequate, the model is rejected. However, if the quality of the model based on the data expressed by the model fit is acceptable, the proposed model may be accepted (Marsh, Hau, & Grayson, 2005).

11.2 Types of SEM models

As suggested in the previous section, SEM is not just a statistical method, but an umbrella term for more specific statistical procedures. The basic concept of SEM distinguishes three basic analyses:

1) The path analysis represents the oldest of a series of structural models designed for directly observable variables. The structural model represents the hypothesis about the effect of a certain variable. The aim of the path analysis is the separation of direct and indirect relations between variables (Duncan, 1966;

Loehlin, 2004). Although the path analysis is not considered by some authors as a typical SEM model, its creation was a very important step for the further development of SEM (Štochl, 2008).

2) Factor analyses – the confirmatory approach (CFA) is a technique aimed at determining the relations between factors and indicators that are explicitly specified (see section 11.3 for more information on CFA).
3) Structural regression models – structural regression models (SRM), sometimes also called "full LISREL models", represent the most general SEM model. The structural regression model is a synthesis of the structural model and the measurement model. As with the path analysis, the SRM allows us to test the hypothesis regarding the direct and indirect causal effects of variables. However, unlike the path analysis, these effects may also be related to factors (latent variables) in the SRM, because the SRM includes measurement components that represent the relationship between directly observable variables (indicators) and the factors identified as in CFA.

(Kaplan, 2009; Kline, 2011)

11.3 Confirmatory Factor Analysis (CFA)

CFA is one of the techniques of SEM used to test or verify structural theories and to test the validity of a certain tool (McDonald, 1999). This statistical technique requires sufficient knowledge of the scientific theory of the subject by the researcher, who, prior to CFA, explicitly specifies both factors and indicators (Morrison, 1990). Since CFA only focuses on explaining the relations between factors and indicators, it represents a measurement model within SEM (Thompson, 2004; Vandenberg, & Lance, 2000). Statistical estimates of the relations between indicators and factors are called factor loadings, and they are generally interpreted as regression coefficients that can be both in the standardized and non-standardized form. CFA indicators are continuous variables. As mentioned in section 11.1, it is an important prerequisite that the factor is also a continuous latent variable.

The basic mathematical expression for the general factor model:

$$x = \Lambda f + \varepsilon$$

x… is a directly observable response (answer in the questionnaire, performance in the test)

Λ… (λjk) is (p x m) matrix of factor loadings (e.g., regression weights of j observable variable on k factor for j = 1, ..., p and k = 1, ...m)

f… is (m x 1) random vector of factors

ε… is a random vector of the uniquenesses of variables

An important assumption is that uniquenesses do not correlate with factors. These uniquenesses are thus specified as independent.

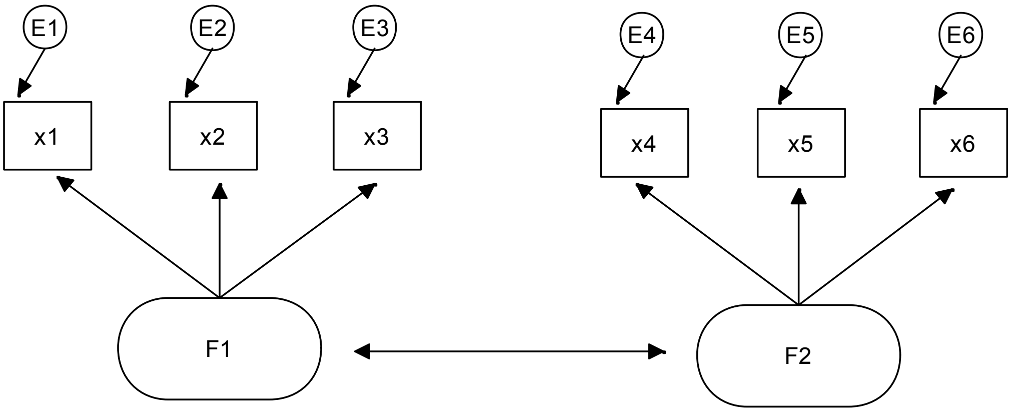


Fig. 8 Example of CFA model, independent clusters (Kline, 2011, p. 112)

Ovals F1 a F2…. Latent variables mathematically called factors faktory

Squares x1 - x6…Manifest variables called indicators indikátory

Circles E1 - E6…Uniqueness

When using CFA in standard models, it is essential to follow the rules of model identification. In the one-factor CFA model, in order to identify the model, it is necessary that the factor includes at least three indicators. In this case, we use the "just-identified" model, in which the number of observations equals the number of parameters. However, the number of degrees of freedom (df) = 0. Although the model is identified in this case, this just-identified model is not sufficient in SEM for its zero degree of freedom. When using CFA, it is thus always necessary to ensure the "over-identified" model, in which the number of observations exceeds the number of parameters. For a one-factor model, it is necessary to have at least four indicators. The simplest example of the two-factor over-identified CFA model is a model where each of the two factors contains at least two indicators (Kline, 2011; Ullman, 2006).

The prerequisite for the use of SEM – CFA in this case – for the interval data analysis is multivariate normality, which is a generalization of one-dimensional (univariate) normal distribution (Stein, 1981). Every case of a one-dimensional (univariate) normal distribution exhibits a normal character. Each variable has a normal distribution for each value of every other variable (Kline, 2011). This assumption is particularly important for the estimation of parameters with the maximum likelihood (ML) method used for continuous data type (Hoogland, 1999). Multivariate normality can be determined, for example, using a statistical test such as the Cox-Small Test (Cox, & Small, 1978). In other estimation methods, e.g., weighted least mean square of variance, the assumption of multivariate normality is not required (Muthén & Muthén, 2010). Another requirement is linearity, which assumes linear relations between indicators and factors, as well as mutual relations between factors (Bollen, & Lennox, 1991). Apart from another requirement in the form of a sufficiently large research sample, which was described in section 10.9, it is necessary to prevent multicollinearity between indicators in CFA. In model testing, multicollinearity is a very strong relationship of two or more independent variables measuring a certain attribute. Among these variables, the correlation coefficient is close to –1 or 1. In such a case, it is likely that the covariance matrices are singular, and the model cannot be identified (Grewal, Cote, & Baumgartner, 2004).

In this study, in order to determine the structure of motor manifestations of laterality in indicators of continuous nature, we decided to use CFA. It was a part of the test battery that determined motor manifestations of laterality using performance tests in which data display interval character. To verify the multivariate normality we used Cox-Small Test. In all four parts of performance tests (two versions for the child population and two versions for the adult population), possible multicollinearity was first investigated using correlation matrices. Multicollinearity was subsequently excluded, based on the results. When determining the model itself, a two-factor structure was always set as a basis, i.e., in all versions of the test battery, in the performance test part. One factor formed hand performance, and the second factor formed foot performance.

11.4 Categorical Variables and SEM

Fundamentally, categorical variables are of two types:

- dichotomous (binary) variables contain two response options that estimate the degree of the determined characteristic (Brown, 2006; Muthén, 1984);
- polytomous ordinal variables include at least three response options (categories). These options have a natural order which reflects the level of the determined characteristic or trait through the selection of categories in individual observable variables (Andrich, 1978; McDonald, 1999; Muthén & Asparouhov, 2002).

An important feature of ordinal variables is that even though their categories define different levels of determined characteristics, exact distances are not known in this order between determined degrees in the form of categories. Therefore, we cannot talk about the average or variance (Furr, & Bacharach, 2008; Mellenbergh, 1995). Against this background, it is appropriate to use different techniques that are based on the general factor model for the ordinal data analysis (Lubke, & Neale, 2008).

As in continuous data, a general one-factor model has been derived for binary variables.

$$x = \Lambda f + \varepsilon$$

x… is a directly observable response (answer in the questionnaire, performance in the test)

Λ… (λjk) is (p x m) matrix of factor loadings (e.g., regression weights of j observable variable on k factor for j = 1, ..., p and k = 1, ...m)

f… is (m x 1) random vector of factors

ε… is a random vector of the uniquenesses of variables

The regression equation represents the probability of a certain answer of the proband with a certain value of the level of the characteristic *f*. This means that the regression equation is a functional equation of conditional probability (McDonald, 1999).

However, this general model of a linear function of conditional probability has three main limitations:

1) If *f* is too small, the result is negative probability; if *f* is too large, the probability of a response is greater than 1.
2) We must assume that the indicator uniqueness variance is independent of the latent variable.
3) Estimation error of the factor score is constant for all values of the latent variable.

These restrictions can be eliminated by normal ogive model (Christofferson, 1975; Muthén, 1978) which is derived from factor analytic framework. Within this framework, it is assumed that a latent response variable *yi** underlies each observed categorical response variable *yi*. The latent response *yi** are related to the latent traits η via a standard factor analytic model.

$$\mathrm{yi}* = \beta_i'\eta + \varepsilon_i$$

$\beta'_i\eta$……….is a 1x *p* vector of factor loadings
ε…………..is a measurement error

Since in this model is assumption that latent traits and measurement errors are normally distributed so that latent response variables are also normally distributed. On the other side, the latent response variables are related to the observed categorical responses through a threshold relation,

$$y_i = k \text{ if } \alpha_{i,k} < y_i* < \alpha_{i,k} + 1$$

where $\alpha_{i0} = -\infty$ and $\alpha_{i,m-1} = +\infty$. That is, under this model, a respondent chooses a response alternative based on her location on the response variable y_i* relative to a set of m - 1 item threshold parameters, $\alpha_{i,k}$. Response alternative k will be endorsed when the respondent's latent response value y_i* lies between thresholds $\alpha_{i,k}$ and $\alpha_{i,k+1}$.

In this technique are using tetrachoric correlations for categorical binary data, and polychoric ordinal correlations for categorical polytomous data. This procedure is called categorical confirmatory factor analysis (CCFA). CCFA is a statistical technique that, by its nature, falls into Item Response Theory (IRT) (Forero, & Maydeu-Olivares, 2009).

An important advantage of IRT is that it is based on the item and its characteristic. Otherwise it is CTT that deals with items almost exclusively in the context of a particular test, and thus it is not separable from the test (Hambleton, Swaminathan, & Rogers, 1991). IRT is used for both dichotomous and polytomous categorical data to model the relationship between the indirectly observable variables that are always continuous in nature, usually conceptualized as the capacity of the proband and the probability of a certain response (e.g., the correct answers of the proband to individual items in the test battery or test). The core of IRT lies in the psychometric approach, which emphasizes the fact that an individual's response to individual items in the test is affected by the level of the individual's skills or qualities and the character of the item (e.g., difficulty or discrimination). In CCFA parameter of difficulty is the same as threshold and parameter of discrimination represent factor loading. IRT also displays an equivalent of the unidimensionality requirement, known as the principle of local independence (Lord, & Novick, 1968; Wright, 1999). This assumption implies that the probability of a correct or a specific answer by the proband (obtained from the one-dimensional model) is not affected by the performance or a decision in other items of the test. The assumption of local independence in the one-dimensional model means that the probability of any response by the proband is determined by the probability amount related to the correct or wrong answers to the test items. The main advantage of IRT is that both persons and indicators are assessed on the same scale – a continuum expressing capability levels and the probability of correct answers (Ayala, 2009; Hambleton, Swaminathan, & Rogers, 1991;). CCFA thus represents a suitable method for modelling ordinal categorical data even data have multidimensional character (Mislevy, 1986; Forero, & Maydeu-Olivares, 2009).

Both CCFA and CFA require a continuous character of the latent variable (Yuan, & Bentler, 2007).

The relationship between the probability of certain responses and the level of the determined latent variable of the trait, measured using a certain universe of test items, is expressed by a mathematical function which, in the graphical form, forms the "characteristic curve" (von Davier, & Carstensen, 2007). IRT thus provides higher model strength for a comprehensive assessment, and, unlike CTT, does not follow the creation of parallel forms of tests using the same tasks (Lord, 1962; Wang, Bradlow, & Wainer, 2002).

The proposed versions of the test batteries contain both ordinal categorical data (questionnaire part in the test battery for the adult population) and dichotomous categorical data (preference task part). In order to verify the structural theory for these types of data we decided to use "Categorical Confirmation Factor Analysis" (CCFA).

11.5 Types of Parameters Used in SEM Method for Parameters Estimation

Our objective is to achieve the maximum fit of the estimated covariance matrix with the covariance matrix formed from the results of directly observable variables, using statistical techniques SEM and CCFA. This process is called parameter estimation, and it is obtained by minimizing the discrepant function between the data and the model (Yuan, & Bentler, 2007). When using the discrepant feature, it is very important to consider what type of data is used in modelling. Muthén (1984) described the diversity of approaches when working with continuous and categorical data, which he summarized in the continuous/categorical variable methodology (CVM) (Muthén, 1984). In a situation where the data is categorical, the relations between variables are estimated using tetrachoric and polychoric correlations.

The most common features include:

- Maximum Likelihood (ML) – due to its complexity, this function is called the "full information method", and it is used in cases of multivariate normal distribution of indicator results (endogenous variables) in the population. ML is most often used for interval data type in CFA (Ferron & Hess, 2007);
- Robust Maximum Likelihood (RML) – this function is used in cases of violation of multivariate normal distribution. Just as ML, it is used for interval data type (Yuan, & Bentler, 2007);

- Weighted Least Square Mean Variance (WLSMV) – this function is used for categorical data of both dichotomous and polytomous character. WLSMV is thus suitable for the CCFA technique. The asymptotic correlation matrix is used here. In dichotomously scored data, the estimated matrix is a tetrachoric correlation matrix; in ordinal categorical data, the estimated matrix is based on a polychoric correlation matrix. This function is also suitable for the sample analysis $n \geq 200$ (Muthén et al., 1997; Swygert, McLeod, & Thissen, 2001).

The indicators compiled in the test battery have the character of both continuous and categorical variables. After verifying the multivariate normality of data using the Cox-Small text, we decided to use the ML function for continuous, directly observable variables. For the model with categorical data of dichotomous and ordinal nature, we decided to use the WLSMV function in this research, based on consultation with and adopting the recommendations of Professor Bengt Muthén.

11.6 Model Testing Fit Evaluation

The main objective in SEM is to test certain theories using the selected models that are conceptualized according to currently accepted hypotheses in the field. These conceptualized models represent a prediction of this theory between operationalized latent variables that are measured using appropriate indicators (Hayduk, Cummings, Boadu Pazderka-Robinson, & Boulianne, 2007). When testing a model, it is important to realize whether the model analyses in SEM solve the researcher's theoretical questions, regardless of whether the model is preserved that was created based on the theory (Millsap, 2007). Since statistical models are only estimate tools, it often happens in model testing in SEM that there is not only one model whose fit (i.e., how well the model captures the determined data) would lead to its absolute acceptance. In addition, research is conducted using various samples that do not constitute basic population samples, but only their parts. Therefore, research with the same models, tested in the same population but with different samples, determine different model fits, and sometimes even structures of the entire theoretical concept. The crucial question then is how to proceed if there are multiple models that even in different structure alternatives fit data equally well or very similarly. The researcher can only perform the interpretation and make the final decision based on knowing the theoretical concept that was defined in the research (Raykov, & Marcoulides, 2000). This decision is, of course, based on the subjective level of knowing and understanding the connections within the theoretical concept (Kirk, 1996).

In order to determine the quality of a model, model fit indices are used. Model fit indicates how well the proposed model fits the data obtained from measurements using selected indicators in the research sample (Kline, 2011). A very important role in the interpretation of fit indices is played by the research sample size. If the research sample size is not sufficiently large, there is a danger that the fix index will not reflect the real applicability of the model for its generalization to the population (Barrett, 2007). Another requirement for the applicability of fit indices is to fulfil the assumption of the over-identified model type (see 11.3). In SEM, more fit indices are generally used to express the quality of a model. The use of at least three fit indices is considered the gold standard by some authors.

Due to the type of indicators, we decided to use the following indices which were considered suitable by McDonald & Marsh and Hu & Bentler to assess the model fit (Hu & Bentler, 1999; McDonald & Marsh, 1990).

A) Basic index

- **Chi-square:** It is the basic and probably the most widely used model test statistics, and, like asymptotic chi-square statistics, it expresses model discrepancy. With its numerical expression, this fit index shows a “wrong fit”, i.e., the higher the chi-square value, the worse the model fit. Along with this, the significance of the difference between the covariance structure model and covariance matrix of directly observable variables is tested. The significance level of chi-square is usually set at $p > 0.05$. If p is less than 0.05, the considered model should be rejected (Marsh, Hau & Grayson, 2005).

B) Index approximating error

- **Root Mean Square Error of Approximation (RMSEA):** This index represents standardized measurement of empirical discrepancy (Browne, & Cudeck 1993). RMSEA does not approximate the central chi-square distribution. RMSEA follows the non-central chi-square distribution where the non-centralized parameter allows for discrepancies between the proposed model and the covariances of directly observable variables (Steiger, 1990). The lower the value of RMSEA, the better the model fit. Some authors have proposed approximate values for expressing the fit quality using RMSEA. Values ≥ 0.10 show a poor model fit; values ranging from 0.08 to 0.10 show an average model fit; values ranging from 0.05 to 0.08 show a good model fit; and values ≤ 0.05 show a very good model fit (McDonald & Ho, 2002; Steiger 1990).

- **Standardized Root Mean Square Residual (SRMR):** This fit index is based on comparing the differences between covariance residuals, specifically on the differences between the observed covariances (from directly observed variables) and the predicted covariances (of the model). The SRMR fit index ranges in the closed interval from 0 to 1; the closer the values are to zero, the better the model fit. It is generally accepted that values ≤ 0.08 show an acceptable model fit (Kline, 2011).
- **Weighted Root Mean Square Residual (WRMR):** WRMR is based on a similar principle to SRMR, i.e., on comparing differences in residual covariances, namely on differences between observed covariances (from directly observed variables) and the predicted covariances (of the model). However, this index is set for assessing the model fit using categorical dichotomous or ordinal data, or in cases where data lose normality. WRMR does not only show values in the closed interval from 0 to 1, but can also show values greater than 1. The closer the values are to zero, the better the model fit. Only values ≤ 1 are considered to be acceptable for this index (Muthén & Muthén, 2010).

C) Incremental (progressive) index unmodified for model complexity

- **Comparative Fit Index (CFI):** CFI is an index that measures the relative improvement of the fit in the proposed model compared with the baseline model (Bentler, 1990). The CFI index is also a rescaled standardized version of the Relative Noncentrality Index (RNI) (McDonald & Marsh, 1990). CFI depends on the same distribution assumptions as the RMSEA index (Kline, 2011). CFI index values are in the closed interval from 0 to 1, with values close to one indicating a good model fit. According to Hu & Bentler (1999), the recommended acceptable CFI index value is 0.95.

D) Incremental (progressive) index modified for model complexity

- **Tucker-Lewis (TLI):** TLI represents a non-standardized fit index whose values are not only in the closed interval from 0 to 1, but can also be greater than 1. The recommended acceptable value of this fit index was set at 0.95 (Hu & Bentler, 1998).

11.7 Residuals

Residuals represent the differences between the model correlation and directly observed determined correlation. Residual correlations are standardized covariance residuals that represent the differences between directly observed and expected modelled covariances (Kline, 2011). When assessing the residual correlation matrix for categorical data, the value up to 0.10 is generally considered an acceptable limit of unexplained correlations. Values in the residual correlation matrix > 0.10 indicate that the model does not explain well the directly observable correlations (Bollen, 1989). Cases of residual matrices for interval data mostly involve standardized covariance residuals. In this case, a hypothesis is tested whether the residual covariance of the population equals zero. If these residuals have values greater than 2.58, which corresponds to the confidence interval of 0.01, they are considered high (Jöreskog & Sörbom, 1993). Some authors even recommend regarding standardized values in the residual matrix greater than 1.96 as high residuals, which corresponds to the confidence interval of 0.05 (Kline, 2011).

12. RESULTS

The aim of this thesis is to determine the structure and the diagnostic quality of the test batteries for diagnosing motor manifestations of laterality. One of the test batteries is intended for the adult population and one for the child population. Both test batteries contain the part with motor preference tasks and the part with performance tests. The test battery for the adult population also includes the questionnaire part, determining the preference in the use of upper and lower limbs in everyday activities.

In order to determine the structure, the SEM method and the confirmatory approach were used for the continuous data type. For categorical data, of both dichotomous and polytomous ordinal nature, the categorical confirmatory factor analysis (CCFA) was used. For the interval data type, the confirmatory factor analysis (CFA) was used. All of data for both baterries were analyse in statistical software M-plus version 6 (Muthén & Muthén, 2010). The approximation of reliability of all parts of both test batteries was determined by calculating McDonald's ω coefficient.

The actual results are divided into two basic areas:

- sample characteristics and structural models of the test battery and their parts for the adult population
- sample characteristics and structural models of the test battery and their parts for the child population

12.1 Test Battery for Adult Population

Sample characteristics and structural models of the test battery and their parts for the adult population

A total of 440 probands participated in the research (212 men and 228 women) aged 17–19 years (average age 18.2 years). They were students of Prague general upper secondary schools without a specific specialization (arts, technology, sports, languages). The entire research sample was divided into two subgroups, each containing 220 probands. The first subset marked as A consisted of 104 men and 116 women. The second subset marked as B consisted of 108 men and 112 women.

The subset A was diagnosed with the first version of the test battery, and the subset B was diagnosed with the second version of the test battery.

12.1.1 Questionnaire

The data in both versions of the questionnaire part was scored on the five-point Likert scale. It is thus a categorical data of polytomous character. Due to the categorical data type, the WLSMV method was used as a parameter estimation.

The items of the questionnaire part of the first version of the test battery:

- Which hand do you use to hold a writing instrument for drawing? **HD**
- Which hand do you use to hammer a nail into wood? **NA**[1]
- Which hand do you use to hold a knife when cutting bread? **KC**
- Which hand do you use to hold a toothbrush when brushing your teeth? **THB**
- Which hand do you use to hold a rubber when erasing? **ER**
- Which hand do you use to hold a key when unlocking the door? **UNL**
- Which hand do you use to hold a glass if you want to drink? **GD**
- Which foot do you use to kick a ball? **KB**
- Which foot do you place on the first step when walking upstairs? **ST**
- While standing, which of your lower limbs do you place forward when you want to slide without the support of your hands? **SLI**

We first tested the model where we divided the upper and lower limb preference into two dimensions.

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[1] This item is scored reversely therefore, the analysis contains a negative loading for this item. The person being tested is not deliberately asked about the preferred upper limb but about the non-preferred upper limb in order to hold the attention of the persons being tested

Table 2

Fit of the 2-factor model questionnaire 1. version of test battery (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	57.51	0.0071	34	0.99	0.99	0.056	0.532

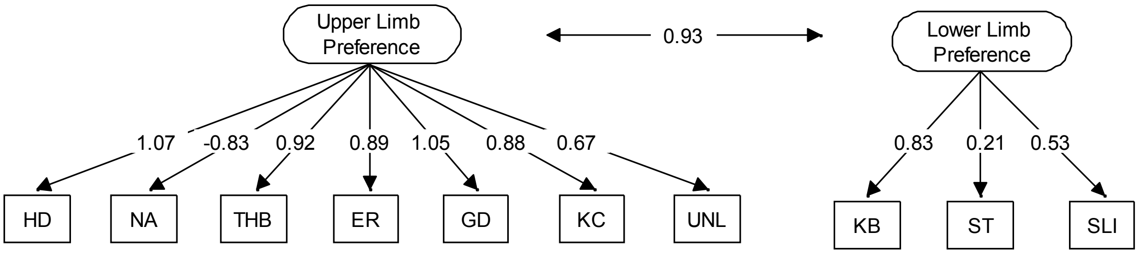


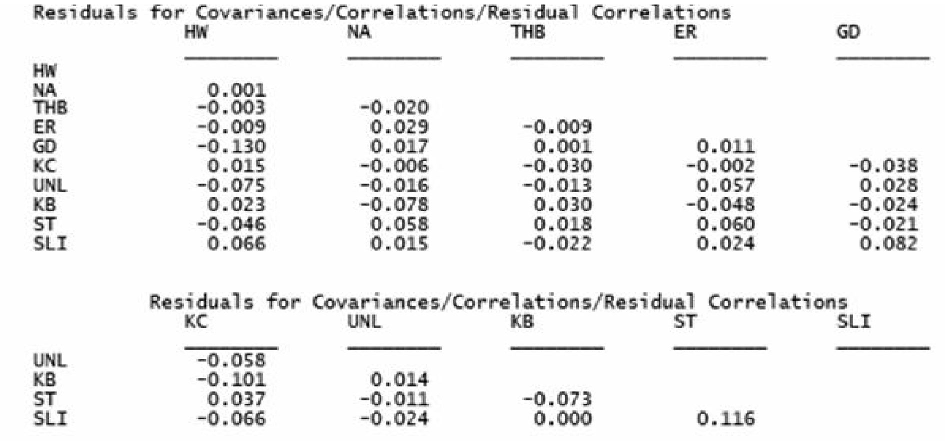
Fig. 9 Path diagram of 2-factor model questionnaire 1. version of test battery (adult population)

The proposal of this structure displayed what is called a Heywood case, when the covariance matrix it is not positively defined. The HD item (Which hand do you use to hold a writing instrument for drawing?) and the GD item (Which hand do you use to hold a glass if you want to drink?) for the “Upper Limb Preference” factor showed a factor loading greater than 1, which led to the negative variance of uniqueness, and, therefore, this model was rejected. In addition to problems with items whose loadings exceeded the value of 1, a very weak correlation of the ST item (Which foot do you place on the first step when walking upstairs?) to the “Lower Limb Preference” factor, ST = 0.21, was found in this model. It is, therefore, possible that this item will be removed in further analyses. An interesting finding is also the strong correlation between both factors (0.93), which indicates that the questionnaire part may show a one-factor structure.

With respect to the Heywood case, the results of the residual matrix are not very decisive, but it is clear that the problems in this model were associated with the GD item (holding a glass) and the KB item (Which foot do you use to kick a ball), whose residuals are higher than the value of 0.100.

Table 3

Residual matrix 2-factor model questionnaire 1. version of test battery (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
                HW            NA            THB           ER            GD
              ________      ________      ________      ________      ________
HW
NA               0.001
THB             -0.003        -0.020
ER              -0.009         0.029        -0.009
GD              -0.130         0.017         0.001         0.011
KC               0.015        -0.006        -0.030        -0.002        -0.038
UNL             -0.075        -0.016        -0.013         0.057         0.028
KB               0.023        -0.078         0.030        -0.048        -0.024
ST              -0.046         0.058         0.018         0.060        -0.021
SLI              0.066         0.015        -0.022         0.024         0.082

           Residuals for Covariances/Correlations/Residual Correlations
                KC            UNL           KB            ST            SLI
              ________      ________      ________      ________      ________
UNL             -0.058
KB              -0.101         0.014
ST               0.037        -0.011        -0.073
SLI             -0.066        -0.024         0.000         0.116
```

For further analysis of the two-factor model, we decided to remove the HD item and GD item from the model.

Table 4

Fit of the 2-factor model questionnaire 1. version of test battery withou items HD and GD (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	26.68	0.1122	19	0.99	0.99	0.045	0.454

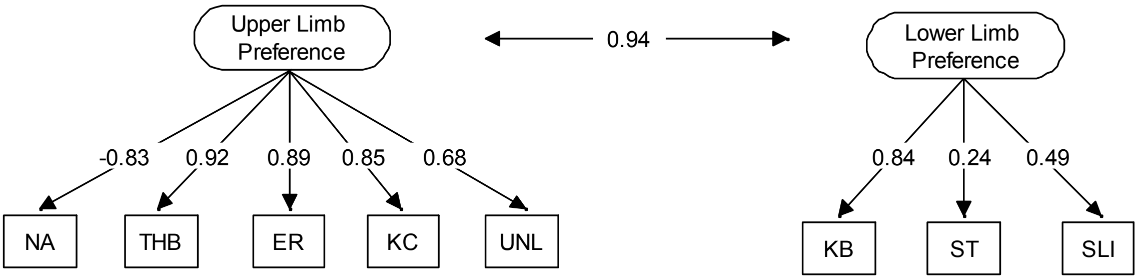
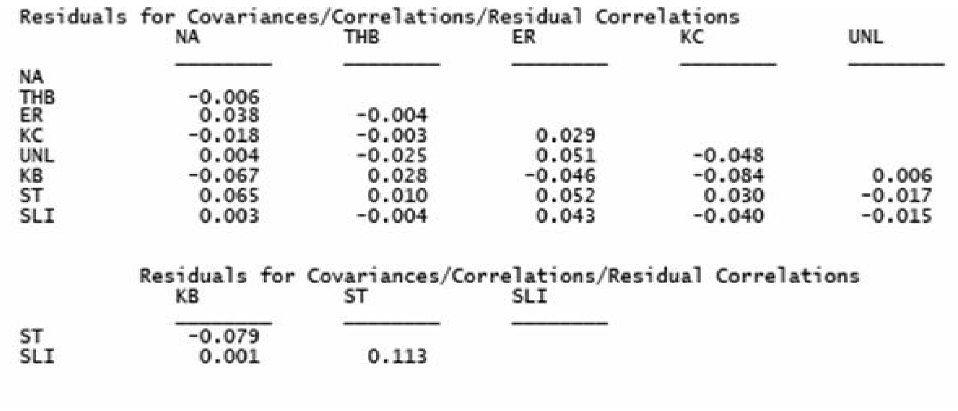


Fig. 10 Path diagram of 2-factor model questionnaire 1. version of test battery without items HD and GD (adult population)

After removing the problematic items, we achieved an acceptable model fit, including acceptable levels of P-value. The "Lower Limb Preference" factor again displayed ST (0.24) (Which foot do you place on the first step when walking upstairs?) as the weakest item; it probably measures a different attribute than lower limb preference. In addition, despite the presence of this weak item, the correlation between the two factors is still strong, and it is thus likely that after removing the ST item, this correlation would be even stronger. Therefore, this model was also rejected. The results of the residual matrix were better in this model, but the SLI item (While standing, which of your lower limbs do you place forward when you want to slide without the support of your hands?) still displayed a higher residual than generally accepted, i.e., greater than 0.100.

Table 5

Residual matrix 2-factor questionnaire 1. version of test battery without items HD and GD (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
              NA            THB           ER            KC            UNL
              ________      ________      ________      ________      ________
NA
THB           -0.006
ER             0.038        -0.004
KC            -0.018        -0.003         0.029
UNL            0.004        -0.025         0.051        -0.048
KB            -0.067         0.028        -0.046        -0.084         0.006
ST             0.065         0.010         0.052         0.030        -0.017
SLI            0.003        -0.004         0.043        -0.040        -0.015

         Residuals for Covariances/Correlations/Residual Correlations
              KB            ST            SLI
              ________      ________      ________
ST            -0.079
SLI            0.001         0.113
```

In the next design of the questionnaire structure, we decided to remove the ST item in the "Lower Limb Preference" factor, and added the remaining items of this factor to the items determining upper limb preference. We then called the whole factor "Preference of Locomotive Organs".

Table 6

Fit of the 1-factor model questionnaire 1. version of test battery without items HD, GD and ST (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	16.25	0.29	14	0.99	0.99	0.028	0.381

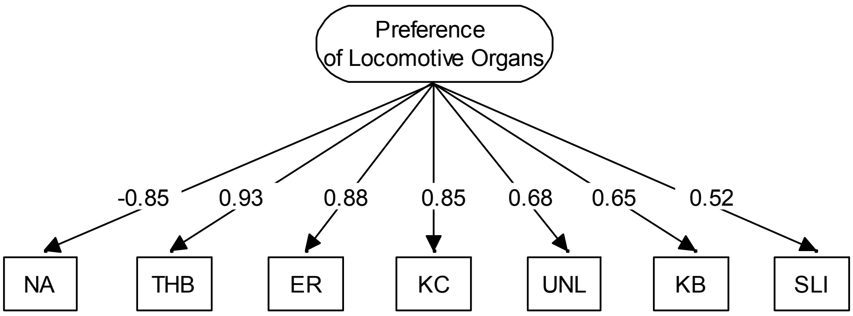
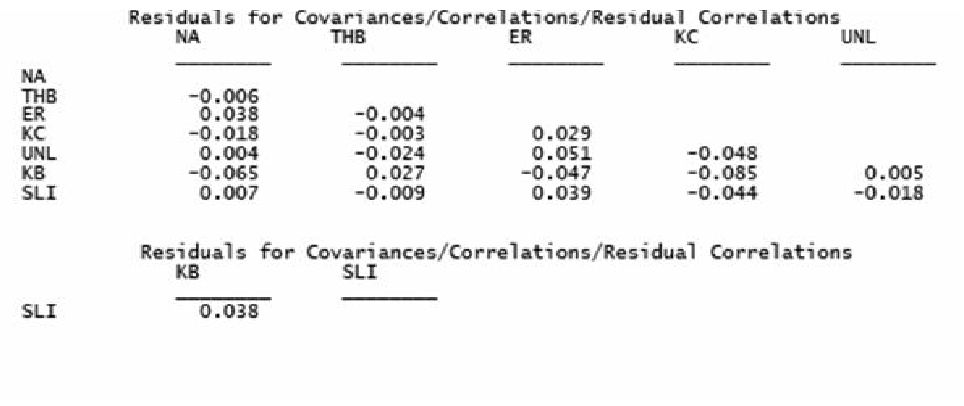


Fig. 11 Path diagram of 1-factor model questionnaire 1. version of test battery without items HD, GD and ST (adult population)

This one-factor structure of the questionnaire part proved to be the most appropriate in the first version of the test battery. All fit index values showed a very good model fit. The residual matrix did not contain any residual values that would be unacceptable in the model.

Table 7

Residual matrix 1-factor model questionnaire 1. version of test battery without items HD, GD and ST (adult population)



```
            Residuals for Covariances/Correlations/Residual Correlations
              NA            THB           ER            KC            UNL
              ________      ________      ________      ________      ________
 NA
 THB           -0.006
 ER             0.038        -0.004
 KC            -0.018        -0.003         0.029
 UNL            0.004        -0.024         0.051        -0.048
 KB            -0.065         0.027        -0.047        -0.085         0.005
 SLI            0.007        -0.009         0.039        -0.044        -0.018


            Residuals for Covariances/Correlations/Residual Correlations
              KB            SLI
              ________      ________
 SLI            0.038
```

Table 8

Generic reliability – questionnaire part 1. version (adult population)

Name of the factor	McDonald ω
Preference of Locomotive Organs	0.90

Based on the determined quality of this proposed structure, this model was adopted. During the analysis of the questionnaire part, very strong factor loadings were clearly identified in the instrumental-skill items related to upper limb preference NA (-Which hand do you use to hammer a nail into wood?) NA = -0.85, THB (Which hand do you use to hold a toothbrush when brushing your teeth?) THB = 0.93, ER (Which hand do you use to hold a rubber when erasing?) Er = 0.88 a KC (Which hand do you use to hold a knife when cutting bread?) KC = 0.85 that apparently display possible influence of motor expression of laterality through imitation or socially-culture environment.

The questionnaire part items of the second version of the test battery:

- Which hand do you use to hold a writing instrument for drawing? **HD**
- Which hand do you use to hammer a nail into wood? **NA**[2]
- Which hand do you use to hold a match when lighting it? **MAT**
- Which hand do you use to hold a spoon when eating? **HS**
- Which hand do you use to hold a plate when drying it? **WE**[3]
- Which hand do you use to hold a knife when cutting bread? **KC**
- Which foot do you use to kick a ball? **KB**
- Which lower limb do you use to stand on one leg? **STA**
- Which foot do you put a shoe on first? **SHO**

In next step we analysed questionnaire part in second version of test battery for adult apopulation.

Based on the results of the previous modelling in the questionnaire part of the first version of the test battery, we verified the one-factor structure.

[2, 3] These items are scored reversely therefore, the analysis contains a negative loading for these items. The person being tested is not deliberately asked about the preferred upper limb but about the non-preferred upper limb in order to hold the attention of the persons being tested

Table 9

Fit of the 1-factor model questionnaire 2. version of test battery (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	96.82	<0.0000	36	0.98	0.97	0.113	0.936

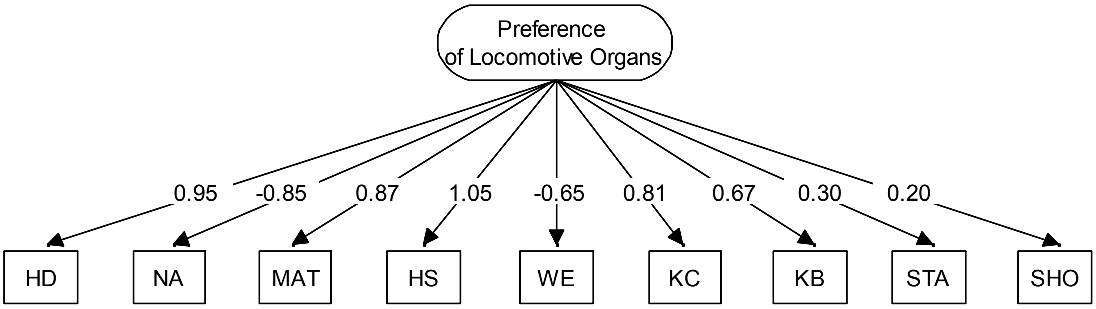


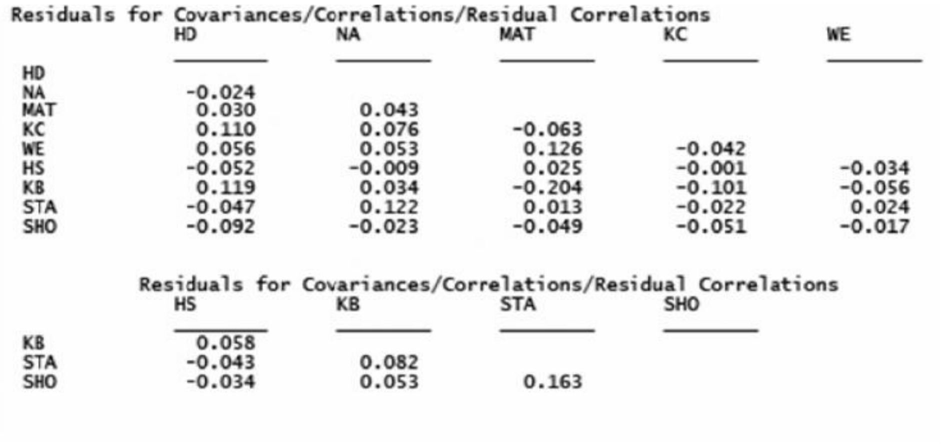
Fig 12 Path diagram 1-factor model questionnaire 2. version of test battery (adult population)

The one-factor model in the questionnaire part of the second version of the test battery again showed a Heywood case. The HS item (Which hand do you use to hold a spoon when eating?) displayed a factor loading greater than 1, causing a negative variance of uniqueness, and therefore this model was rejected. In addition, the model also exhibited very weak factor loadings of the STA item (Which lower limb do you use to stand on one leg?) and the SHO item (Which foot do you put a shoe on first?).

The results of the residual correlation matrix show that this model contains a large amount of unexplained residuals whose value is greater than 0.100.

Table 10

Residual matrix 1-factor model questionnaire 2. version of test battery (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
             HD            NA            MAT           KC            WE
           ________      ________      ________      ________      ________
 HD
 NA         -0.024
 MAT         0.030         0.043
 KC          0.110         0.076        -0.063
 WE          0.056         0.053         0.126        -0.042
 HS         -0.052        -0.009         0.025        -0.001        -0.034
 KB          0.119         0.034        -0.204        -0.101        -0.056
 STA        -0.047         0.122         0.013        -0.022         0.024
 SHO        -0.092        -0.023        -0.049        -0.051        -0.017

          Residuals for Covariances/Correlations/Residual Correlations
             HS            KB            STA           SHO
           ________      ________      ________      ________
 KB          0.058
 STA        -0.043         0.082
 SHO        -0.034         0.053         0.163
```

When analyzing collinearity, it was found that the HS item displays strong collinearity with HD, NA ,and MAT; therefore, we decided to remove this item from further modelling. We again tested the one-factor model, but without the HS item.

Table 11

Fit of the 1-factor model questionnaire 2. version of test battery without item HS (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	55.95	<0.0000	20	0.98	0.97	0.095	0.798

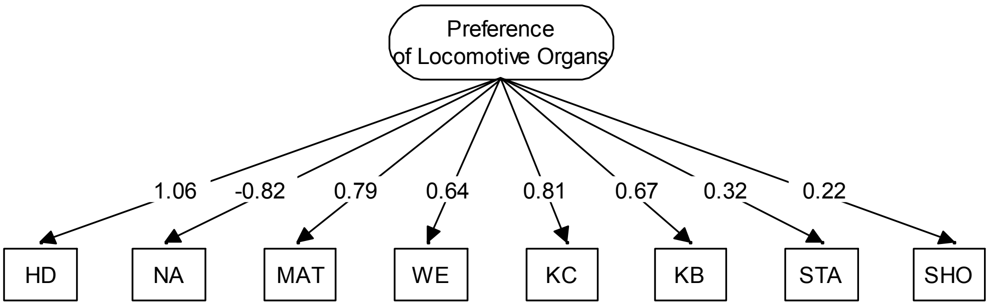


Fig. 13 Path diagram 1-factor model questionnaire 2. version of test battery without item HS (adult population)

Even after removing the HS item, however, the second one-factor structure exhibited a Heywood case. As in the questionnaire part in the first version of the test battery, it was the HD item (Which hand do you use to hold a writing instrument for drawing?). Therefore, this model also had to be rejected. The results of the residual correlation matrix showed no improvement in this case.

When analyzing the content and character of both items whose factor loadings in the proposed models exceeded the value of 1, it was concluded that these results may result from the social pressure to which these activities are subjected within society.

The proposed models revealed that, in the one-factor structure under the umbrella name "Preference of Locomotive Organs", STA and SHO display the weakest factor loadings. Based on their character and content, they were related to the determination of lower limb preference. Therefore, with respect to further analysis, it was decided to divide the one-factor structure into two factors: 1. "Upper Limb Preference", 2. "Lower Limb Preference".

Table 12

Fit of the 2-factor model questionnaire 2. version of test battery without items HS and HD (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	26.04	0.016	13	0.98	0.97	0.071	0.573

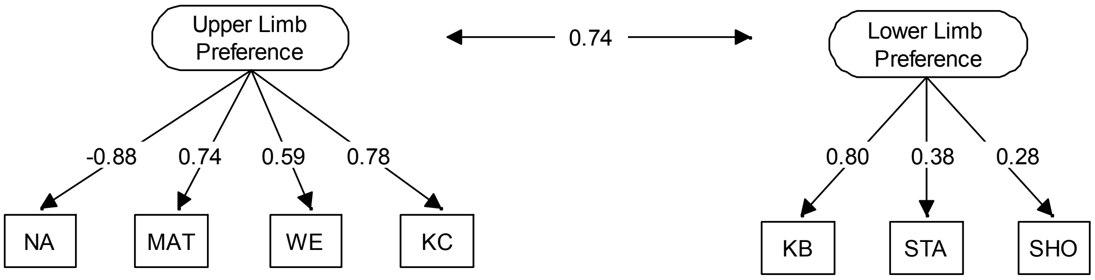
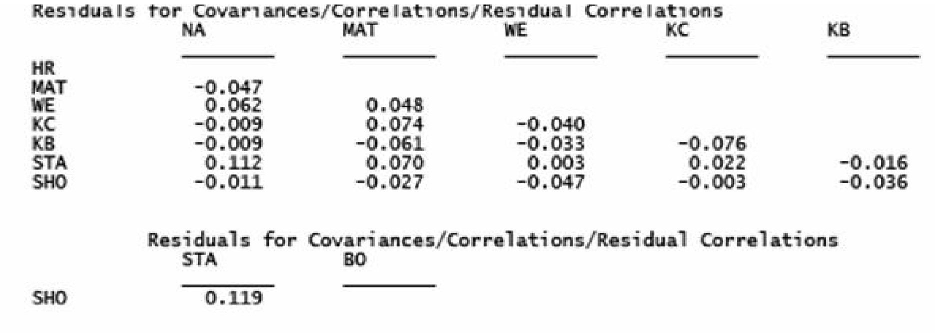


Fig. 14 Path diagram 2-factor model questionnaire 2. version of test battery without items HS and HD (adult population)

This two-factor model in the questionnaire part of the second version of the test battery finally showed the best model fit. However, this proposed structure did not achieve a level of diagnostic quality like the resulting structure of the questionnaire part of the first version of the test battery, which is evident from the values in the residual matrix.

Table 13

Residual matrix 2-factor model questionnaire 2. version of test battery without items HS and HD (adult population



```
Residuals for Covariances/Correlations/Residual Correlations
              NA          MAT         WE          KC          KB
           ________    ________    ________    ________    ________
HR
MAT         -0.047
WE           0.062       0.048
KC          -0.009       0.074      -0.040
KB          -0.009      -0.061      -0.033      -0.076
STA          0.112       0.070       0.003       0.022      -0.016
SHO         -0.011      -0.027      -0.047      -0.003      -0.036

          Residuals for Covariances/Correlations/Residual Correlations
              STA         BO
           ________    ________
SHO          0.119
```

Table 14

Generic reliability – questionnaire part 2. version (adult population)

Name of the factor	McDonald ω
Upper Limb Preference	0.83
Lower Limb Preference	0.51

The generic reliability value in the “Lower Limb Preference” factor, McDonald ω = 0.51, was also unacceptable.

This two-factor model in the questionnaire part of the second version of the test battery finally showed the best model fit. However, this proposed structure did not achieve a level of diagnostic quality like the resulting structure of the questionnaire part of the first version of the test battery, which is evident from the values in the residual matrix.

Summary:

The final form of the questionnaire consists of a one-factor structure from the first version of the test battery which met all the assumptions of diagnostic quality of the model acceptability. The CCFA results of the questionnaire parts also suggest that the items of skilled character for assessing the level of preference for both upper and lower limbs represent more of a unidimensional structure. This assumption is supported by the very nature of the testing. The questionnaire determining the degree of preference of upper and lower limbs has a self-assessment nature, so it is likely that the respondents' answers may be influenced by subjective opinions. Another possible explanation is the very nature of the items. Since the tested individuals could choose from five options in each item, the questions in the questionnaire had to be related to standard activities known by everybody from everyday life, so every individual is able to determine the degree of preference in the activity. However, the questions with such a focus in the self-assessment questionnaire usually display the nature of activities subject to imitation or social pressure. In the actual result of the modelling of the questionnaire parts, support for this assumption can be found in the form of weaker factor loadings in activities that are not subject to the current right-sided world.

The UNL item (Which hand do you use to hold a key when unlocking the door?) is based on a non-skilled activity, and perhaps for this reason the factor loading is not so strong. The weakest item in this part of the test battery is SLI (While standing, which of your lower limbs do you place forward when you want to slide without the support of your hands?). The character of this item shows the spontaneous activity that is probably also related to the rotation attribute. However, after removing this item, there was a significant deterioration of the entire model fit, including the P-value.

12.1.2 Preference Tasks

The data in this part of the test battery is scored dichotomously; therefore, the WLSMV method was used as a parameter estimation.

Research points out differences between upper and lower limbs (Sahyoun, 2004); therefore, we decided to use the two-factor model:

- "Upper Limb Preference",
- "Lower Limb Preference".

The motor task **LT** “Use the tube to look at the object”, which is included in both versions of the test batteries, was not used in the structural equation modelling method. In order to express the relationship between this indicator and motor manifestations of laterality, using the tetrachoric correlation, the LT indicator was correlated with the final indicators that formed the most suitable model of preference tasks in the test battery designed for the adult population.

Preference task items of the first version of the test battery:

- Throw the ball at the target. **THR**
- Erase the line. **ER**
- Demonstrate how you would comb your hair. **CO**
- Use the pointer to point at the following object. **PO**
- Demonstrate how you would spread butter on bread. **SPR**
- Demonstrate how you would write the letter T on the floor using one of your feet. **WT**
- Perform standing on one leg. **ST**
- Kick the ball at the target. **KB**
- Move the cube on the floor using one of your feet. **MC**
- Demonstrate a long jump. **LJ**

Use the tube to look at the object. **LT**

Table 15

Fit of the 2-factor model preference tasks 1. version of test battery (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	83.31	0.0002	34	0.98	0.98	0.069	0.856

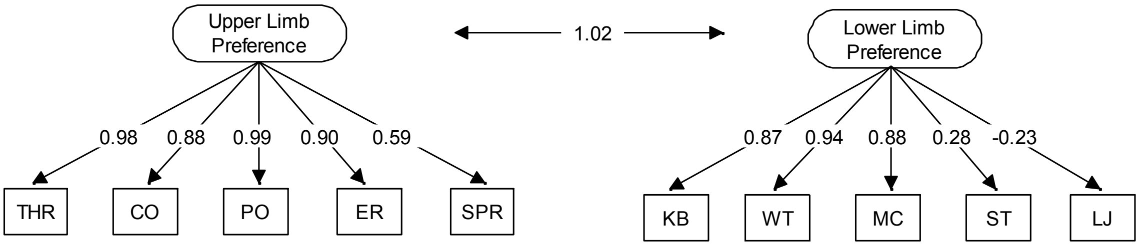


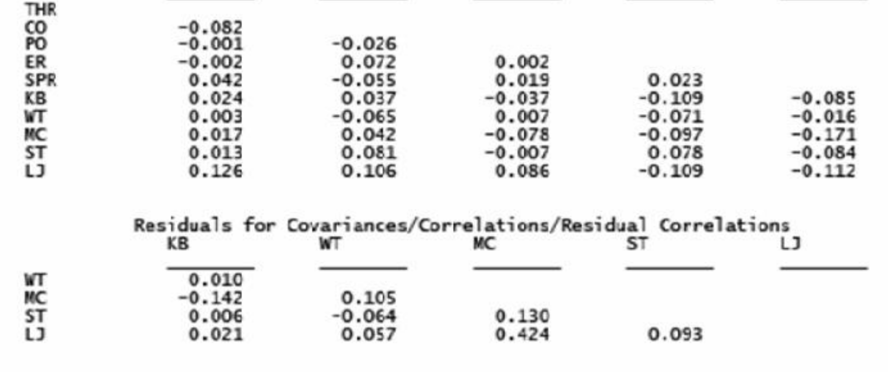
Fig. 15 Path diagram 2-factor model preference tasks 1. version of test battery (adult population)

This model also displayed a Heywood case in the form of a negatively defined covariance matrix. This time, a correlation greater than 1 was found between upper and lower limb preference factors. Therefore, this structure proposal was rejected. The model also reveals collinearity of the indicators THR (Throw the ball at the target) and PO (Use the pointer to point at the following object) whose regression coefficient, with respect to the upper limb preference factor, is almost 1. In the lower limb preference factor, collinearity between KB (Kick the ball at the target) and MC (Move the cube on the floor using one of your feet) was found. In addition, a weak loading of the LJ item (Demonstrate a long jump) was found, LJ = -0.23.

Particularly in the indicators determining lower limb preference, the residual matrix contains very high values, greater than 0.100.

Table 16

Residual matrix 2-factor model preference tasks 1. version of test battery (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
              THR          CO           PO           ER           SPR
            ________     ________     ________     ________     ________
THR
CO           -0.082
PO           -0.001       -0.026
ER           -0.002        0.072        0.002
SPR           0.042       -0.055        0.019        0.023
KB            0.024        0.037       -0.037       -0.109       -0.085
WT            0.003       -0.065        0.007       -0.071       -0.016
MC            0.017        0.042       -0.078       -0.097       -0.171
ST            0.013        0.081       -0.007        0.078       -0.084
LJ            0.126        0.106        0.086       -0.109       -0.112

           Residuals for Covariances/Correlations/Residual Correlations
              KB           WT           MC           ST           LJ
            ________     ________     ________     ________     ________
WT            0.010
MC           -0.142        0.105
ST            0.006       -0.064        0.130
LJ            0.021        0.057        0.424        0.093
```

In further modelling, we kept the two-factor structure, but we decided to remove the PO item, which showed strong collinearity, from the "Upper Limb Preference" factor. We also removed the MC task, which showed collinearity with the KB task, and the weakest indicator, the LJ motor task, from the factor.

Table 17

Fit of the 2-factor model preference tasks 1. version of test battery without items PO, MC and LJ (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	21.34	0.31	19	0.99	0.99	0.025	0.514

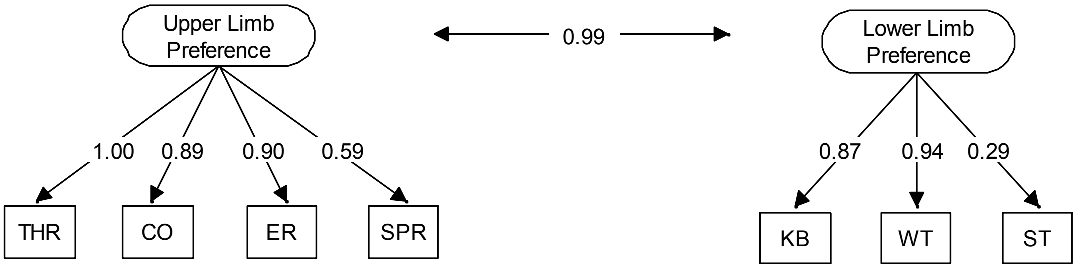
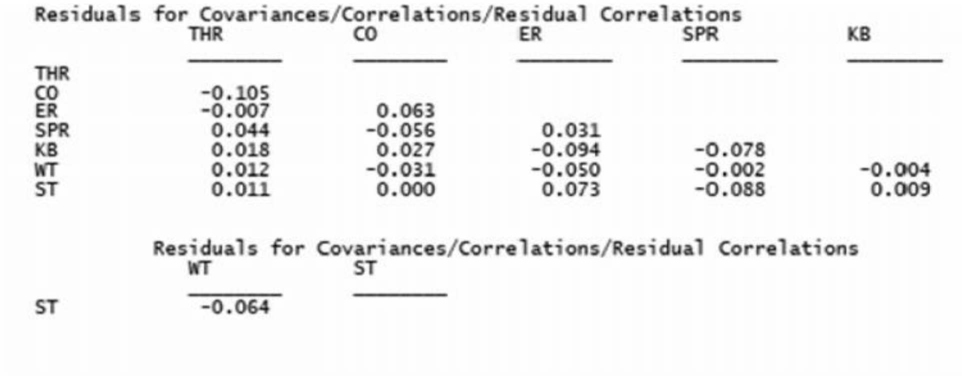


Fig. 16 Path diagram 2-factor model preference tasks 1. version of test battery without items PO, MC and LJ (adult population)

Despite very good model fit index values, this structure was rejected for the following reasons: The THR indicator (Throw the ball at the target.) displayed the absolute factor loading equal to 1 in the "Upper Limb Preference" factor. In this model, a very strong correlation between both factors, r = 0.99, was also found, and the residual correlation matrix in this model also showed some high residuals, greater than 0.100.

Table 18

Residual matrix 2-factor model preference tasks 1. version of test battery without items PO, MC and LJ (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
              THR          CO           ER           SPR          KB
           ________     ________     ________     ________     ________
THR
CO           -0.105
ER           -0.007        0.063
SPR           0.044       -0.056        0.031
KB            0.018        0.027       -0.094       -0.078
WT            0.012       -0.031       -0.050       -0.002       -0.004
ST            0.011        0.000        0.073       -0.088        0.009

           Residuals for Covariances/Correlations/Residual Correlations
              WT           ST
           ________     ________
ST           -0.064
```

In further modelling, we removed the THR indicator whose factor loading was equal to 1, and we decided to verify the most restrictive two-factor structure with three indicators for each.

Table 19

Fit of the 2-factor model preference tasks 1. version of test battery without items PO, MC, LJ a THR (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	13.90	0.38	8	0.99	1.01	0.019	0.491

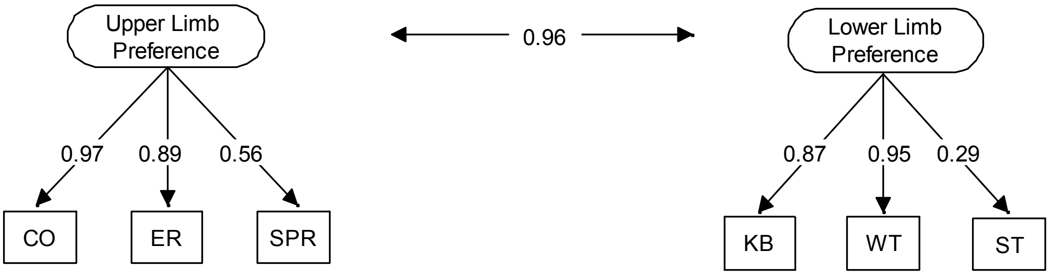
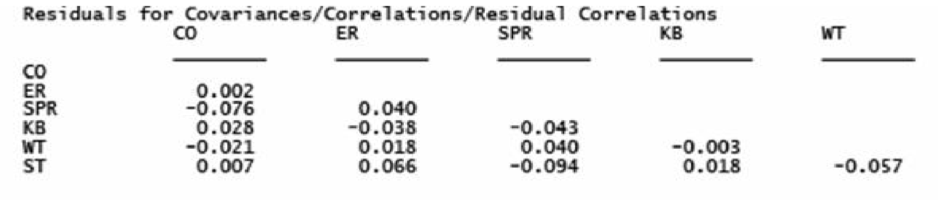


Fig. 17 Path diagram 2-factor model preference tasks 1. version of test battery without items PO, MC, LJ a THR (adult population)

A very strong correlation between both factors, reaching the level of 0.96, was found in this model. It was obvious that the two-factor structure is redundant, so despite the small residuals, we rejected this model.

Table 20

Residual matrix 2-factor model preference tasks 1. version of test battery without items PO, MC, LJ a THR (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
              CO          ER          SPR         KB          WT
              ________    ________    ________    ________    ________
 CO
 ER             0.002
 SPR           -0.076       0.040
 KB             0.028      -0.038      -0.043
 WT            -0.021       0.018       0.040      -0.003
 ST             0.007       0.066      -0.094       0.018      -0.057
```

The last model proposed in this section was the one-factor model with six indicators. The factor in this model was called the same as in the questionnaire part ("Preference of Locomotive Organs"). Despite the fact that this model showed a fit deterioration, the one-factor structure was chosen as more appropriate and easier to interpret for the preference task part in the first version of the test battery. A very interesting finding was also the fact that when we attempted to remove from this structure the ST item (Perform standing on one leg), which displayed the weakest factor loading, ST = 0.27, there was a significant deterioration of the model fit.

Table 21

Fit of the 1-factor model preference tasks 1. version of test battery without items PO, MC, LJ a THR (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	19.29	0.24	9	0.99	0.99	0.026	0.543

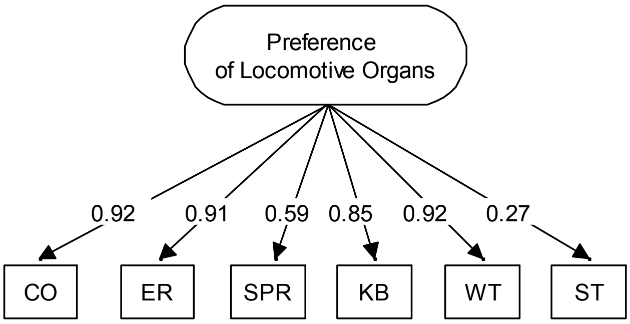
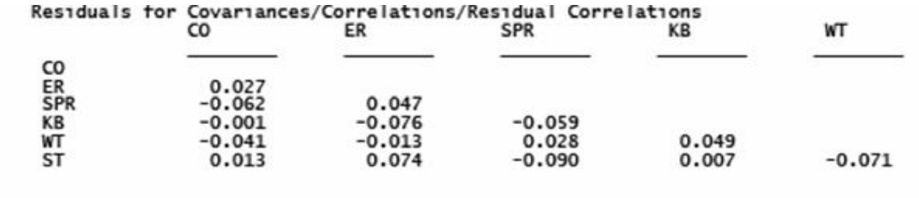


Fig. 18 Path diagram 1-factor model preference tasks 1. version of test battery without items PO, MC, LJ a THR (adult population)

Table 22

Residual matrix 1-factor model preference tasks 1. version of test battery without items PO, MC, LJ a THR (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
              CO           ER           SPR          KB           WT
           ________     ________     ________     ________     ________
 CO
 ER           0.027
 SPR         -0.062        0.047
 KB          -0.001       -0.076       -0.059
 WT          -0.041       -0.013        0.028        0.049
 ST           0.013        0.074       -0.090        0.007       -0.071
```

Table 23

Generic reliability – preference part 1. version (adult population)

Name of the factor	McDonald ω
Preference of Locomotive Organs	0.89

Both in the questionnaire part and in the preference task part of the first version of the test battery, most high factor loadings were observed in the indicators of a skilled nature, both with a tool and without a tool. The weakest indicators in this one-factor structure were SPR (Demonstrate how you would spread butter on bread.) and ST (Perform standing on one leg.). Despite the nature of the task in the form of a skilled activity, the SPR indicator only displayed the factor loading of 0.59. Therefore, we presume that the performance of this task can be affected by the “unenforced” social pressure, i.e., imitation, especially in left-handed individuals. In addition, it is the only task to involve bimanual activity. The preference task ST, which exhibits a factor validity of 0.27, was, after consultation, chosen deliberately as a suitable indicator because of its generality and unskilled nature, with a very low probability of any imitation. Based on the results, it was concluded that this task measures a different attribute, not motor organ preference, i.e., lower limb preference in this case.

Preference task items of the second version of the test battery:

- Throw the ball at the target. **THR**
- Erase the lines. **ER**
- Ring the bell. **RI**
- Use the pointer to point at the following objects. **POC**[4]
- Clap your hands. **CL**
- Demonstrate how you would write the letter T on the floor using one of your feet. **WT**
- Kick the ball at the target. **KB**
- Perform jumps forward using one leg. **HOP**
- Perform the basic (starting) position, and then step forward. **STO**
- Make a 360-degree turn. **TU**

Use the tube to look at the object. **LT**

Based on the results from the preference task part in the first version of the test battery, the one-factor structure “Preference of Locomotive Organs” was first proposed.

Table 24

Fit of the 1-factor model preference tasks 2. version of test battery (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	68.60	0.0007	35	0.96	0.95	0.069	0.933

---

[4] This task is performed across the natural body axis of the individual

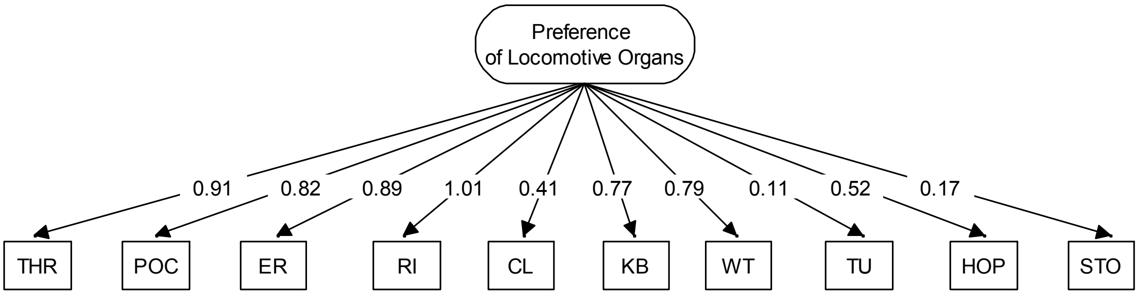
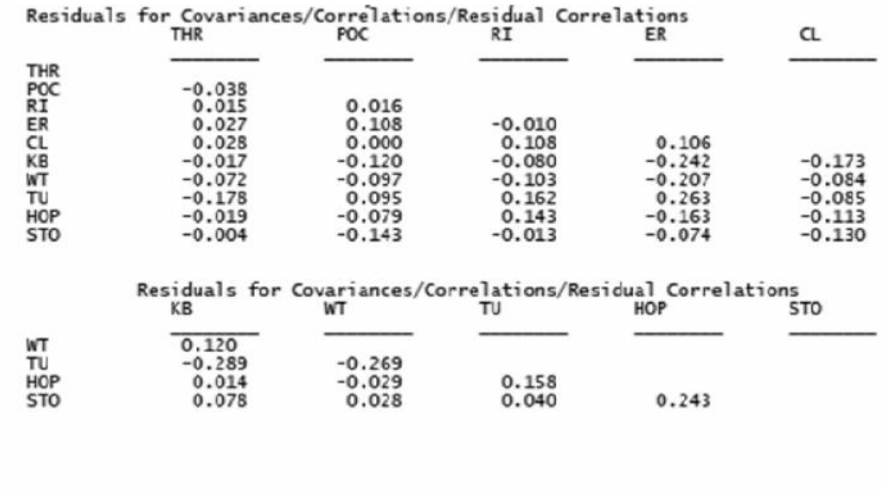


Fig. 19 Path diagram 1-factor model preference tasks 2. version of test battery (adult population)

The proposed model contained a Heywood case. The factor loadings of the RI item (Ring the bell.) was greater than 1. For this reason, this model was rejected, and the RI item was removed from modelling for further analysis. In this one-factor model, weak factor loading of the TU item (Make a 360-degree turn.), TU item = 0.11, and STO item (Perform the basic [starting] position, and then step forward.), STO = 0.17, were also found. The TU item is likely to have a strong relationship with another latent variable, probably to the attribute of rotation. With respect to the STO item, an inappropriate procedure in making motor activity was probably chosen. It is possible that this item is too general to assess preference.

Table 25

Residual matrix 1-factor model preference tasks 2. version of test battery (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
              THR          POC          RI           ER           CL
           ________     ________     ________     ________     ________
THR
POC          -0.038
RI            0.015        0.016
ER            0.027        0.108       -0.010
CL            0.028        0.000        0.108        0.106
KB           -0.017       -0.120       -0.080       -0.242       -0.173
WT           -0.072       -0.097       -0.103       -0.207       -0.084
TU           -0.178        0.095        0.162        0.263       -0.085
HOP          -0.019       -0.079        0.143       -0.163       -0.113
STO          -0.004       -0.143       -0.013       -0.074       -0.130

           Residuals for Covariances/Correlations/Residual Correlations
              KB           WT           TU           HOP          STO
           ________     ________     ________     ________     ________
WT           0.120
TU           -0.289       -0.269
HOP           0.014       -0.029        0.158
STO           0.078        0.028        0.040        0.243
```

In subsequent modelling, RI, TU, and STO were removed from the analysis, and the one-factor structure was again verified using the remaining 7 items.

Table 26

Fit of the 1-factor model preference tasks 2. version of test battery without items RI, TU and STO (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	25.12	0.029	14	0.97	0.96	0.064	0.780

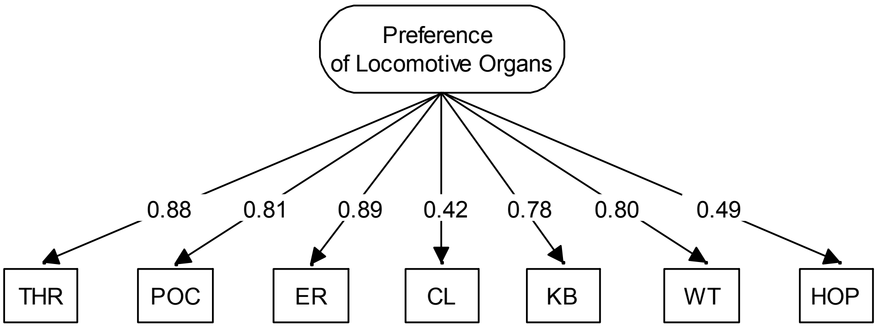


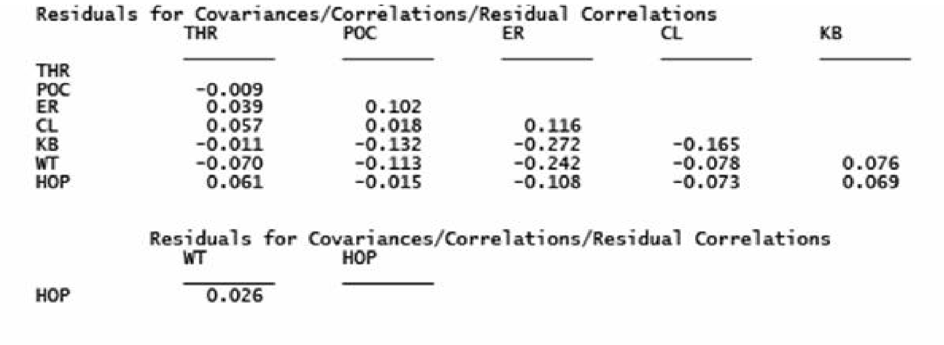
Fig. 20 Path diagram 1-factor model preference tasks 2. version of test battery without items RI, TU and STO (adult population)

After removing the problematic items, the model fit was improved. However, the model signification was weak, not exceeding the value of 0.05. This model was not accepted.

Looking at the residual correlation matrix, we can see that this model contains a number of unexplained residuals that exceed the generally acceptable level of the absence of explanation, i.e., the value of 0.100.

Table 27

Residual matrix 1-factor model preference tasks 2. version of test battery without items RI, TU and STO (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
               THR         POC         ER          CL          KB
             ________    ________    ________    ________    ________
THR
POC           -0.009
ER             0.039       0.102
CL             0.057       0.018       0.116
KB            -0.011      -0.132      -0.272      -0.165
WT            -0.070      -0.113      -0.242      -0.078       0.076
HOP            0.061      -0.015      -0.108      -0.073       0.069

           Residuals for Covariances/Correlations/Residual Correlations
               WT          HOP
             ________    ________
HOP            0.026
```

These high residuals may indicate a poorly selected number of factors, and, therefore, it was decided to divide the items into two factors and model a two-factor structure: 1. “Upper Limb Preference”, 2. “Lower Limb Preference”.

Table 28

Fit of the 2-factor model preference tasks 2. version of test battery without items RI, TU and STO (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	13.13	0.43	13	0.99	1.00	0.017	0.494

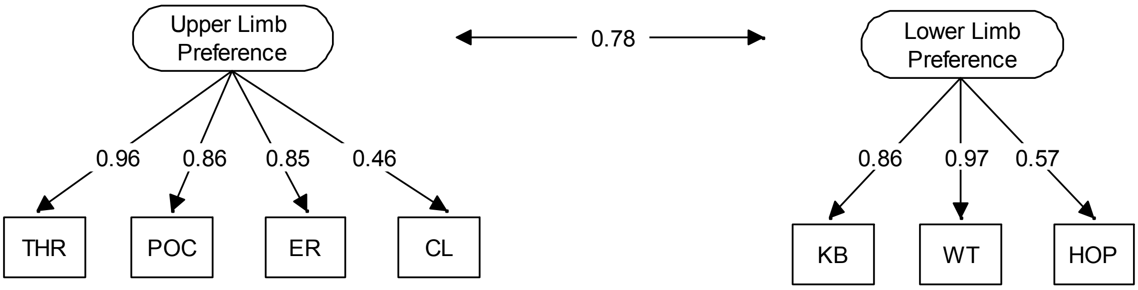
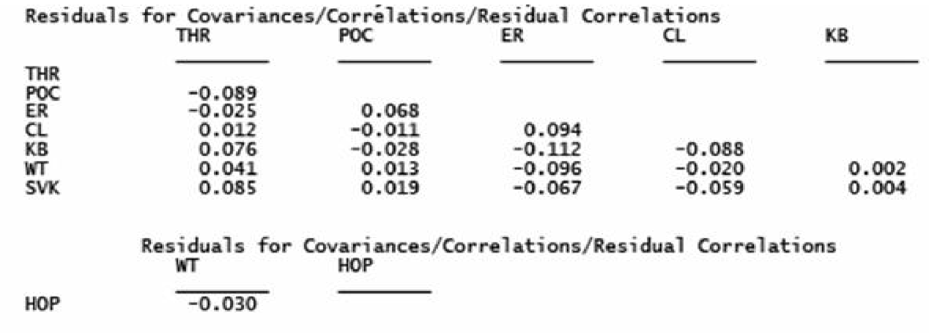


Fig. 21 Path diagram 2-factor model preference tasks 2. version of test battery without items RI, TU and STO (adult population)

The proposed model with two separate factors for upper limb preference and lower limb preference showed a significant improvement of all fit index values, including the model significance expressed by the P-value = 0.43. Moreover, only one value greater than 0.100 (KB – ER) was also identified in the residual correlation matrix.

Table 29

Residual matrix 2-factor model preference tasks 2. version of test battery without items RI, TU and STO (adult population)



```
Residuals for Covariances/Correlations/Residual Correlations
                THR          POC          ER           CL           KB
              ________     ________     ________     ________     ________
THR
POC           -0.089
ER            -0.025        0.068
CL             0.012       -0.011        0.094
KB             0.076       -0.028       -0.112       -0.088
WT             0.041        0.013       -0.096       -0.020        0.002
SVK            0.085        0.019       -0.067       -0.059        0.004

           Residuals for Covariances/Correlations/Residual Correlations
                WT           HOP
              ________     ________
HOP           -0.030
```

Table 30

Generic reliability – preference tasks 2. version (adult population)

Name of the factor	McDonald ω
Upper Limb Preference	0.89
Lower Limb Preference	0.85

The correlation between the factors at r = 0.78 indicated that the entire model should have a bi-factor or hierarchical structure. However, the result of the hierarchical model showed a significant deterioration in the fit of all $p < 0.05$. The bi-factor structure displayed a Heywood case, so these models were both rejected.

Table 31

Fit of the hierarchic model with one general factor without items RI, TU and STO (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
hierarchic	35.59	0.001	14	0.85	0.80	0.097	1.128

The two-factor structure of preference motor tasks proved to be the most appropriate in the second version of the test battery (see Table 28); therefore, this model was accepted for determining the degree of preference.

The relationship of eyedness and preference tasks assessing upper and lower limb preference:

Along with motor tasks assessing motor organ preference, ocular dominance was determined in both versions of the test batteries using the LT indicator (Use the tube to look at the object.). Therefore, we correlated the LT indicator with individual preference tasks contained by the two-factor model, adopted from the second version of the test battery.

- Throw the ball at the target. **THR**
- Erase the lines. **ER**
- Use the pointer to point at the following objects. **POC**[5]
- Clap your hands. **CL**
- Demonstrate how you would write the letter T on the floor using one of your feet. **WT**
- Kick the ball at the target. **KB**
- Perform jumps forward using one leg. **HOP**

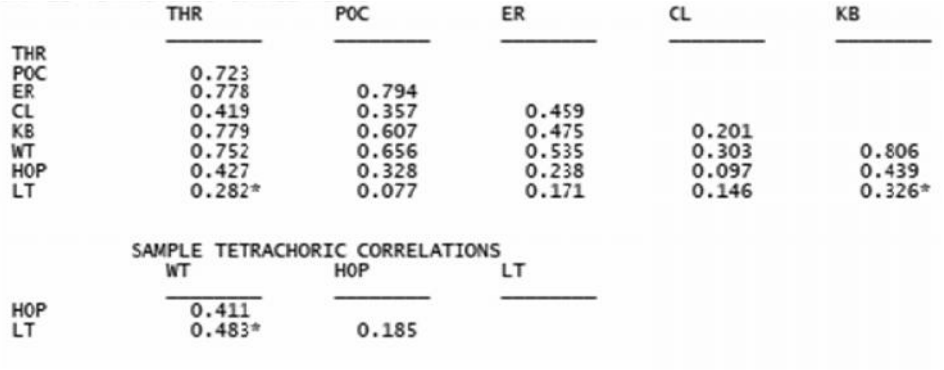
Tetrachoric correlations were used in the matrix. The significance of these correlations was assessed. The significance of the correlations was set at $p < 0.05$.

---

[5] This task is performed across the natural body axis of the individual.

Table 32

Correlation matrix hand preference tasks and eye dominance (adult population)



```
             THR          POC          ER           CL           KB
           ________     ________     ________     ________     ________
THR
POC         0.723
ER          0.778        0.794
CL          0.419        0.357        0.459
KB          0.779        0.607        0.475        0.201
WT          0.752        0.656        0.535        0.303        0.806
HOP         0.427        0.328        0.238        0.097        0.439
LT          0.282*       0.077        0.171        0.146        0.326*

        SAMPLE TETRACHORIC CORRELATIONS
           WT           HOP          LT
           ________     ________     ________
HOP         0.411
LT          0.483*       0.185
```

*significance correlation p<0.05

Surprisingly, the correlation matrix shows that the LT indicator displays two significant correlations with motor tasks assessing lower limb preference KB (Kick the ball at the target**)** and WT (Demonstrate how you would write the letter T on the floor using one of your feet**)** and only one significant correlation with the motor task assessing upper limb preference (THR), although literature reports 80% lateral correspondence of hand preference and ocular dominance (measured by means of the sighting factor) (Bourrasa & McManus, Bryden, 1996).

Summary:

Based on the results of the analysis of the questionnaire part, in the preference task also we expected strong factor loadings in items of an instrumental or skilled nature related to upper and lower limb preference. This assumption was confirmed.

The “Upper Limb Preference” factor contains 4 items, none of them displaying the same course of motor pattern. The character of the motor task THR, based on throwing at the target, activates the entire upper limb in terms of movement, so this task involves the work of both distal and proximal parts of the upper limb. Apart from the motor activation of the entire upper limb, the POC indicator (Use the pointer to point at the following objects pointing across the natural body axis) also includes determination of the spatial advantage of pointing at the object. This motor task assumes that the more varied the upper limb sidedness of the subject is, the higher probability that the person also uses the non-preferred upper limb when pointing at objects across the natural body axis. The motor task ER (Erase the lines) particularly activates the area of the hand and fingers. It is, therefore, an activity that mainly involves the distal part of the upper limb in the movement. The lowest factor loading in this model, in the factor “Upper Limb Preference”, was displayed by the CL indicator (Clap your hands.). This indicator has the character of unskilled motor activity that is not subject to any obvious imitation or pressure of the socially-culture environment. This activity is the only one to display a bimanual nature. The preferred hand is the controlling hand in this task, and the non-preferred hand has a supportive function.

The three indicators determining lower limb preference displayed the strongest factor loadings in the motor task WT (Demonstrate how you would write the letter T on the floor using one of your feet.). This task has the nature of a static skilled activity that places emphasis on the right lower limb movement in the sagittal and frontal plane. The second indicator is KB (Kick the ball at the target.) which represents a skilled task associated with the control and management of the tool that the subject has to set in motion in a certain direction. The motor task HOP (Perform jumps forward using one leg.) places emphasis mainly on the stability of the lower limb in the cyclical jump movement. This involves unskilled activity that had the weakest correlation to the “Lower Limb Preference” factor in this model. Compared to the two remaining indicators, this different tightness of the relationship is probably caused by the unskilled nature of this task, along with a different foundation of the motor pattern.

12.1.3 Performance Tests

The data in this part of the test battery are of an interval nature. Both versions of the draft performance tests included tests with the reverse scoring character. These were the tests in which time was not a constant.

Performance test items of the first version of the test battery:

- Tracing the spiral **SP**[6]
- Dot-filling fine motor test **DO**
- Grip strength using a dynamometer **HGR**
- Arranging matches within a limited area using tweezers **MAC**
- Moving beads from one box into another using tweezers **TW**
- Measuring articular passivity in order to diagnose cerebellar dominance **JO**

---

[6] Time is not a constant in this test, so the factor loading indicates a negative value.

- Lower limb tapping **TA**
- While standing, slalom with a ball between obstacles using a foot **SL**[7]
- While sitting on a chair, rolling a ball on the track in the shape of the number eight between two points using a lower limb **RB**[8]
- While sitting on a chair, moving small cubes from place to place using a foot **CM**[9]

The two-factor model was proposed as the starting model, because the human lower limb is not as adapted to such an extent to fine motor activity as the upper limb.

Factors:

- "Upper Limb Performance",
- "Lower Limb Performance".

With respect to the fact that our data met the condition of multivariate normality, we used the maximum likelihood (ML) method as a parameter estimation.

Table 33

Fit of the 2-factor model performance tests 1. version of test battery (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	66.27	0.0008	34	0.94	0.92	0.069	0.057

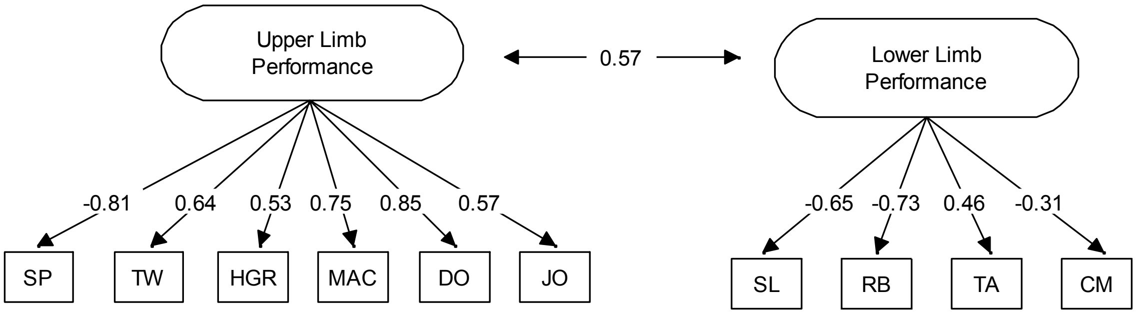


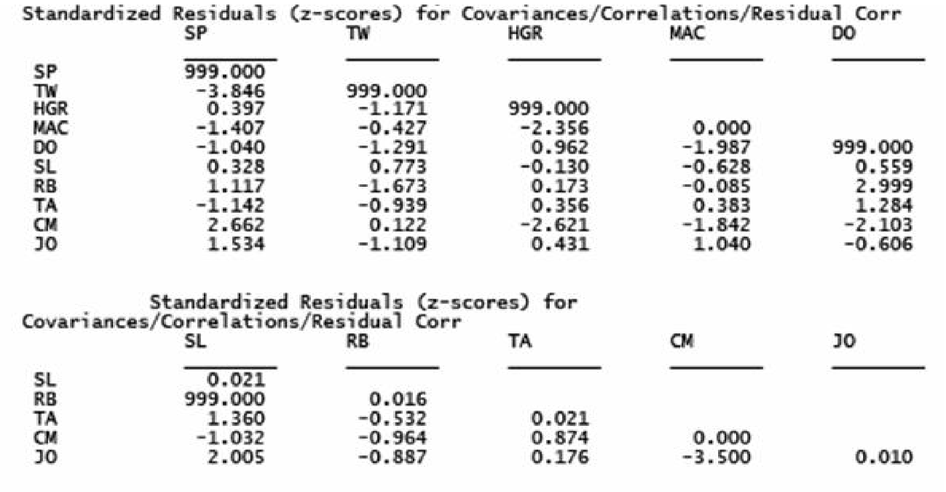
Fig. 22 Path diagram 2-factor model performance tests 1. version of test battery (adult population)

[7, 8, 9] Time is not a constant in these tests, so the factor loading indicates a negative value.

The results of the proposed two-factor structure did not show a satisfactory model fit. Fit indices CFI and TLI were below average, and the model significance ($P < 0.05$) was also unsatisfactory. The residual covariance matrix of this model shows a large amount of unexplained covariances, i.e., values greater than 2.58.

Table 34

Residual matrix 2-factor model performance tests 1. version of test battery (adult population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
              SP          TW          HGR         MAC         DO
              ________    ________    ________    ________    ________
  SP           999.000
  TW            -3.846     999.000
  HGR            0.397      -1.171     999.000
  MAC           -1.407      -0.427      -2.356       0.000
  DO            -1.040      -1.291       0.962      -1.987     999.000
  SL             0.328       0.773      -0.130      -0.628       0.559
  RB             1.117      -1.673       0.173      -0.085       2.999
  TA            -1.142      -0.939       0.356       0.383       1.284
  CM             2.662       0.122      -2.621      -1.842      -2.103
  JO             1.534      -1.109       0.431       1.040      -0.606

          Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
              SL          RB          TA          CM          JO
              ________    ________    ________    ________    ________
  SL             0.021
  RB           999.000       0.016
  TA             1.360      -0.532       0.021
  CM            -1.032      -0.964       0.874       0.000
  JO             2.005      -0.887       0.176      -3.500       0.010
```

The most problematic test was clearly the CM test (While sitting on a chair, moving small cubes from place to place using a foot), whose factor loading is the weakest in this model (CM = 0.31). Another test which, based on the results, is not entirely suitable for this section is the HGR test (Grip strength using a dynamometer); it has the weakest factor validity to the "Upper Limb Performance" factor. The results also show that although the TA test (Lower limb tapping) displayed the 100% consensus of experts in assessing the content validity, it exhibits a weak factor loading (TA = 0.46) in this model.

Based on the results of the two-factor model, it was decided to remove the weakest item from each factor. In the "Upper Limb Performance" factor, it was the

HGR test (Grip strength using a dynamometer) with the factor loading HGR = 0.53. This test assesses the static strength of the hand which does not involve any movement that would express the quality or speed of execution. The second removed test was the CM test (While sitting on a chair, moving small cubes from place to place using a foot) from the "Lower Limb Performance" factor. The CM indicator showed an insufficient distinction of differences in the performance of both lower limbs (*cohen d < 0.3*) already in the course of testing.

Table 35

Fit of the 2-factor model performance tests 1. version of test battery without items HGR and CM (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	36.29	0.0097	19	0.96	0.95	0.068	0.037

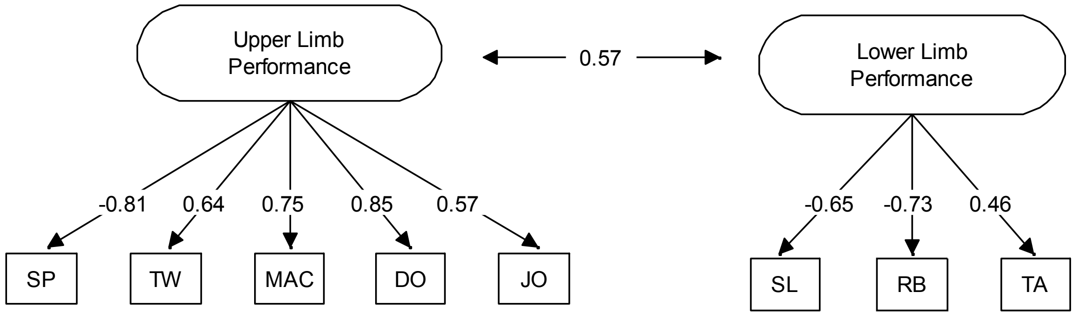
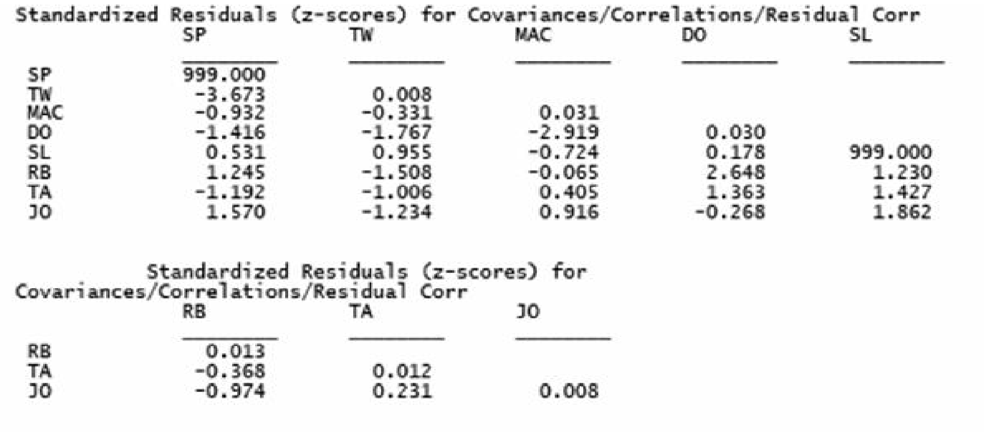


Fig. 23 Path diagram 2-factor model performance tests 1. version of test battery without items HGR and CM (adult population)

After removing the two weakest tests from each factor, the model fit improved, and the values of the fit indices CFI and TLI allowed us to accept the model, but this improvement was not sufficient in the P-value. The residual covariance matrix still displays three values greater than 2.58 (SP – TW, MAC – DO, DO – RB), and there was no substantial improvement in unexplained residuals.

Table 36

Residual matrix 2-factor model performance tests 1. version of test battery without items HGR and CM (adult population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
              SP            TW            MAC           DO            SL
              ________      ________      ________      ________      ________
 SP           999.000
 TW            -3.673         0.008
 MAC           -0.932        -0.331         0.031
 DO            -1.416        -1.767        -2.919         0.030
 SL             0.531         0.955        -0.724         0.178       999.000
 RB             1.245        -1.508        -0.065         2.648         1.230
 TA            -1.192        -1.006         0.405         1.363         1.427
 JO             1.570        -1.234         0.916        -0.268         1.862

           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
              RB            TA            JO
              ________      ________      ________
 RB             0.013
 TA            -0.368         0.012
 JO            -0.974         0.231         0.008
```

The “Upper Limb Performance” factor included an innovative indicator, JO (Measuring articular passivity in order to diagnose cerebellar dominance), which had the weakest factor validity (JO = 0.57) in the tested structure. We decided to remove the test from the next model and verify whether the nature of this test does not affect the quality of the whole structure.

Table 37

Fit of the 2-factor model performance tests 1. version of test battery without items HGR, CM and JO (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	22.48	0.048	13	0.97	0.96	0.061	0.034

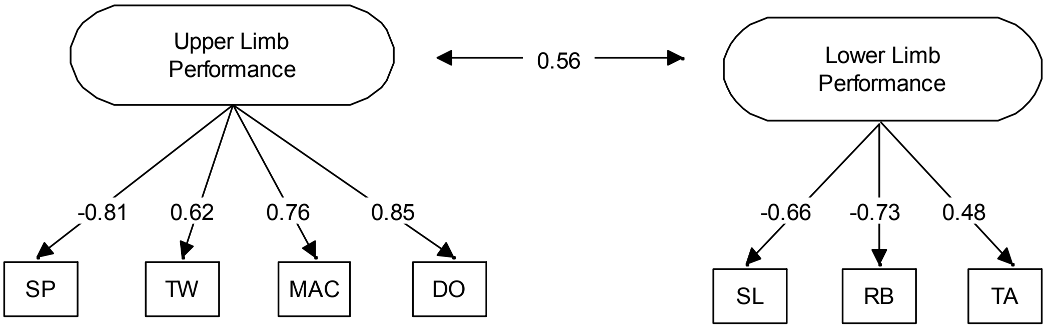
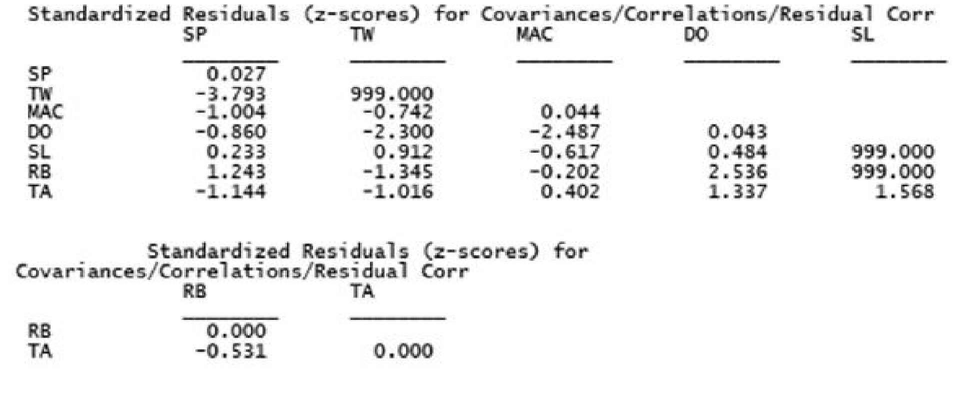


Fig. 24 Path diagram 2-factor model performance tests 1. version of test battery without items HGR, CM and JO (adult population)

However, after removing the JO indicator (Measuring articular passivity in order to diagnose cerebellar dominance), there was no significant improvement in the entire model fit. Moreover, the residual covariance matrix shows that there is one value that greatly exceeds the value of 2.58 (SP – TW) and that there are two other values which are close to the value of 2.58 (MAC – DO and DO – RB). It was revealed, therefore, that this test does not affect the proposed structure.

Table 38

Residual matrix 2-factor model performance tests 1. version of test battery without items HGR, CM and JO (adult population)



```
 Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                SP           TW           MAC          DO           SL
              ________     ________     ________     ________     ________
 SP             0.027
 TW            -3.793      999.000
 MAC           -1.004       -0.742        0.044
 DO            -0.860       -2.300       -2.487        0.043
 SL             0.233        0.912       -0.617        0.484      999.000
 RB             1.243       -1.345       -0.202        2.536      999.000
 TA            -1.144       -1.016        0.402        1.337        1.568


           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                RB           TA
              ________     ________
 RB             0.000
 TA            -0.531        0.000
```

The TW indicator (Moving beads from one box into another using tweezers) was eventually removed due to an insufficient distinction of differences in the performance of both lower limbs, where the substantive significance of this test was below average. In this case, *cohen d = 0.4*. The last model proposed in this section was a two-factor model without the HGR indicator (grip strength using a dynamometer), CM indicator (while sitting on a chair, moving small cubes from place to place using a foot), and TW indicator (Moving beads from one box into another using tweezers).

Table 39

Fit of the 2-factor model performance tests 1. version of test battery without items HGR, CM and TW (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	21.48	0.078	13	0.98	0.97	0.055	0.032

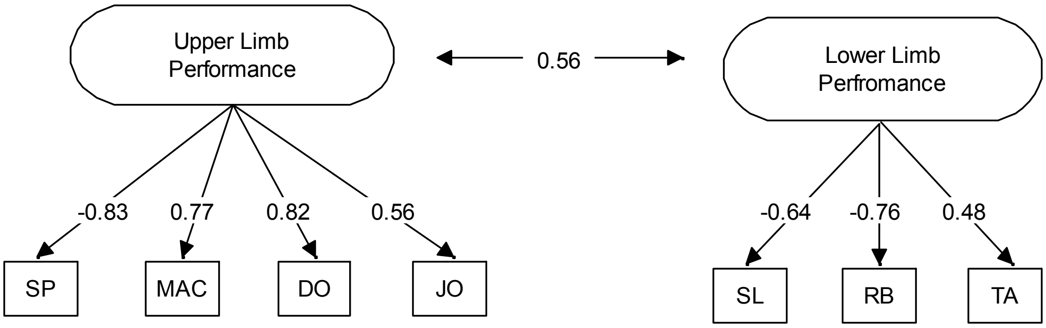
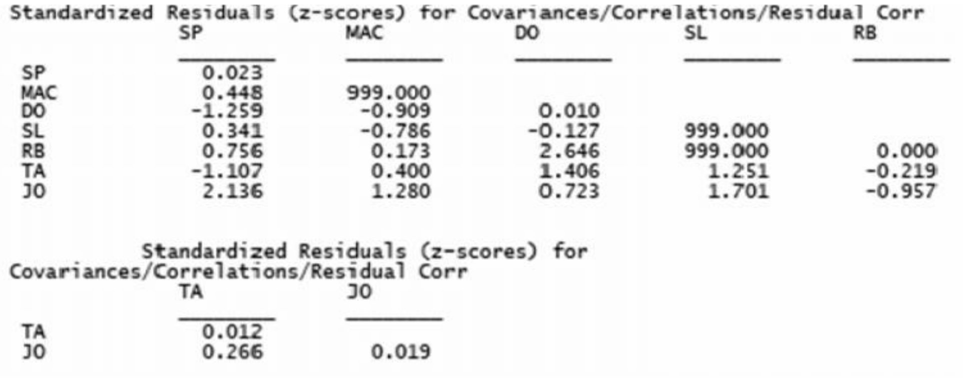


Fig. 25 Path diagram 2-factor model performance tests 1. version of test battery without items HGR, CM and TW (adult population)

This two-factor model without the HGR, CM, and TW indicators, which showed a further slight improvement in the model fit and signification, was finally determined as the most appropriate model in the first version of the test battery. The results of the residual covariance matrix also show that a number of high residuals were reduced in this model – to only one value greater than 2.58 (DO – RB).

Table 40

Residual matrix 2-factor model performance tests 1. version of test battery without items HGR, CM and TW (adult population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                SP           MAC          DO           SL           RB
              ________     ________     ________     ________     ________
 SP             0.023
 MAC            0.448      999.000
 DO            -1.259       -0.909        0.010
 SL             0.341       -0.786       -0.127      999.000
 RB             0.756        0.173        2.646      999.000        0.000
 TA            -1.107        0.400        1.406        1.251       -0.219
 JO             2.136        1.280        0.723        1.701       -0.957

          Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                TA           JO
              ________     ________
 TA             0.012
 JO             0.266        0.019
```

Table 41

Generic reliability – performance tests 1. version (adult population)

Name of the factor	McDonald ω
Upper Limb Performance	0.83
Lower Limb Performance	0.66

The results of the performance tests of the first version of the test battery have shown that the performance of human motor organs is composed of two different dimensions: “Upper Limb Performance” and “Lower Limb Performance”. This finding could be explained by the fact that upper limbs are relaxed, compared to lower limbs, and they are adapted primarily to manipulation, whereas lower limbs primarily perform a support function. The SP indicator (tracing the spiral), MAC indicator (Arranging matches within the limited area using tweezers), and DO indicator (Dot-filling fine motor test) related to the factor “Upper Limb Performance” represent fine motor tests, while the MAC test involves the entire upper limb in the activity. The SP and DO tests mainly involve the hand and fingers. The strength of relations of these indicators to the “Upper Limb Performance” factor confirms the results of the studies (Annett, 2002) which indicate that the more a test is of a fine-motor nature, the more the performance of both limbs differs (Annett, 2002; Brown et al., 2006). In the “Lower Limb Performance” factor, the strongest indicators in this version of the test battery were the tests of a manipulative nature, i.e., SL (While standing, slalom with a ball between obstacles using a foot) and RB (While sitting on a chair, rolling a ball on the track in the shape of the number eight between two points using a lower limb). An interesting result in this part of the first version of the test battery is that the model fit and its significance are lower than in the models in the previous two parts of the test battery. This is probably due to the size of factor loadings of the indicators in the “Lower Limb Performance” factor, in which an unacceptable value of generic reliability (McDonald ω = 0.66) has been found.

As in the previous section, the confirmatory factor analysis for interval data was used for analysing the data from the performance tests of the second version of the test battery. The performance tests included four tests with a reverse scoring nature. These were the indicators SP, SL, MF, and TDS, in which “time” was not a constant.

Performance test items from the second version of the test battery:

- Tracing the spiral: **SP**[10]
- Dot-filling fine motor test: **DO**
- Pegboard test: **PG**
- Threading beads on a metal wire: **STB**
- Collecting toothpicks (matches): **PT**
- Measuring articular passivity in order to diagnose cerebellar dominance: **JO**
- Lower limb tapping: **TA**
- While standing, slalom with a ball between obstacles: **SL**[11]
- While sitting on a chair, moving a cube in the “maze” provided: **MF**[12]
- While sitting on a chair, taking off a knitted sock from one foot using the other foot: **TDS**[13]

[10, 11, 12, 13] Time is not a constant in these tests, so the factor loadings indicates a negative values.

Based on the previous modelling, the two-factor structure was first verified:

Factors:

- "Upper Limb Performance",
- "Lower Limb Performance".

As the data from the second version also met the condition of multivariate normality, we used the maximum likelihood (ML) method as a parameter estimation again.

Table 42

Fit of the 2-factor model performance tests 2. version of test battery (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	142.56	<0.000	34	0.83	0.77	0.126	0.063

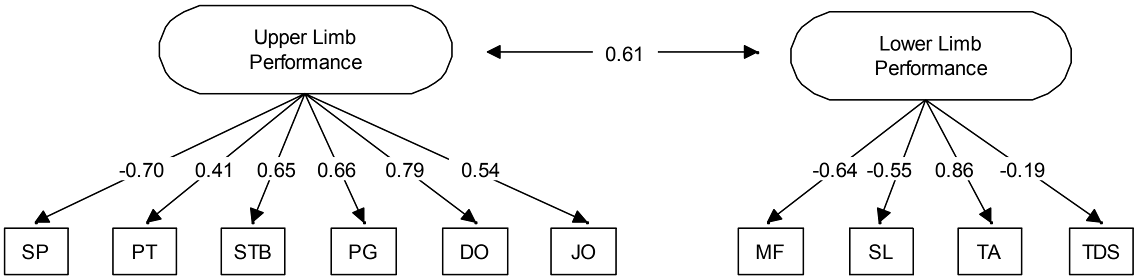
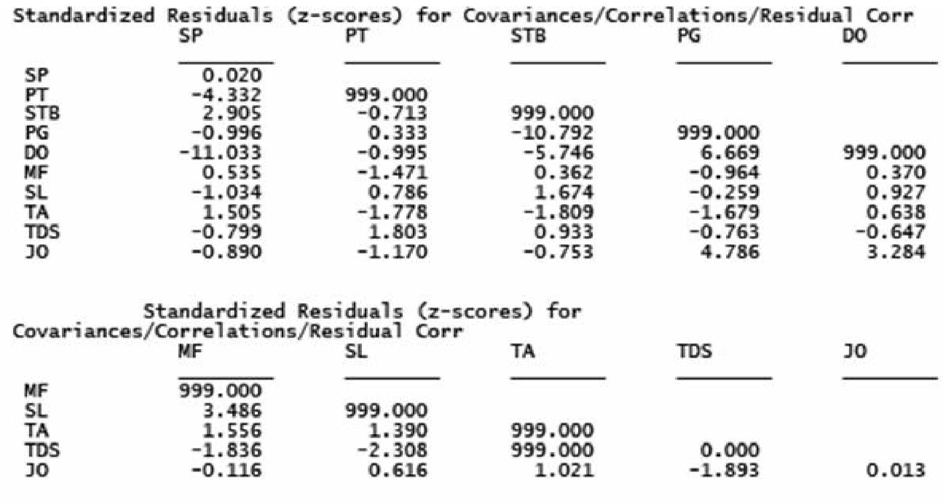


Fig. 26 Path diagram 2-factor model performance tests 2. version of test battery (adult population)

The fit of the two-factor model with all performance tests in the second version of the test battery showed a very poor model fit. All fit indices were significantly below average, which was subsequently also reflected in the values of standardized covariance residuals, which reached extreme values (SP – DO, STB – PG, PG – DO, JO – PG).

Table 43

Residual matrix 2-factor model performance tests 2. version of test battery (adult population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                SP          PT          STB         PG          DO
             ________    ________    ________    ________    ________
 SP             0.020
 PT            -4.332     999.000
 STB            2.905      -0.713     999.000
 PG            -0.996       0.333     -10.792     999.000
 DO           -11.033      -0.995      -5.746       6.669     999.000
 MF             0.535      -1.471       0.362      -0.964       0.370
 SL            -1.034       0.786       1.674      -0.259       0.927
 TA             1.505      -1.778      -1.809      -1.679       0.638
 TDS           -0.799       1.803       0.933      -0.763      -0.647
 JO            -0.890      -1.170      -0.753       4.786       3.284

         Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                MF          SL          TA          TDS         JO
             ________    ________    ________    ________    ________
 MF           999.000
 SL             3.486     999.000
 TA             1.556       1.390     999.000
 TDS           -1.836      -2.308     999.000       0.000
 JO            -0.116       0.616       1.021      -1.893       0.013
```

Very interesting findings were yielded by the results, particularly in the second factor, “Lower Limb Performance”. The strongest factor loading was revealed by the TA test (Lower limb tapping), TA = 0.86, which is a significantly closer relationship of this indicator to the “Lower Limb Performance” factor than in the first version of the test battery. Additional support for the hypothesis about the relationship between cerebellar dominance and motor manifestations of laterality was brought by the JO test (Measuring articular passivity in order to diagnose cerebellar dominance), which also in the second version of the performance tests showed a significant factor validity of JO = 0.54. The weakest factor loading was displayed by the TDS indicator (While sitting on a chair, taking off a knitted sock from one foot using the other foot), TDS = -0.19. In the diagnosis alone, this test showed a strong variability with no clear recognition of differences in the skill of the lower limb, and was, therefore, removed in further modelling. In the factor “Upper Limb Performance”, the weakest factor loading was displayed by the PT test (Collecting toothpicks). This test also showed a very weak sensitivity in determining the difference in the performance between the upper limbs, *cohen d < 0.3*. In further modelling, we removed both of these tests, as they did not measure the latent variable we determined.

Table 44

Fit of the 2-factor model performance tests 2. version of test battery without items PT and TDS (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	99.39	<0.000	19	0.87	0.80	0.118	0.065

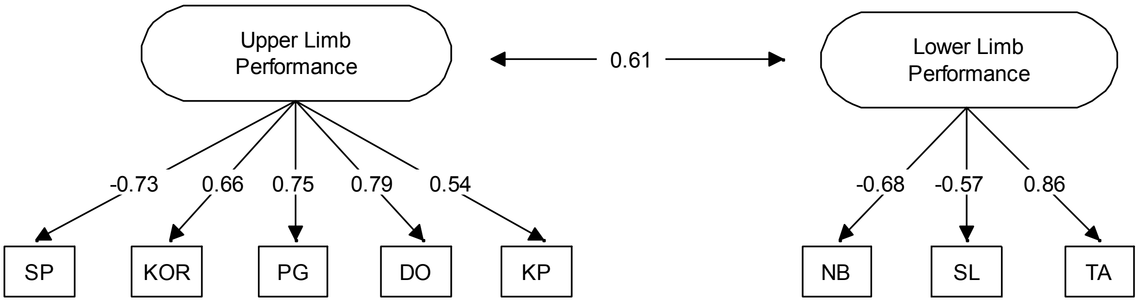
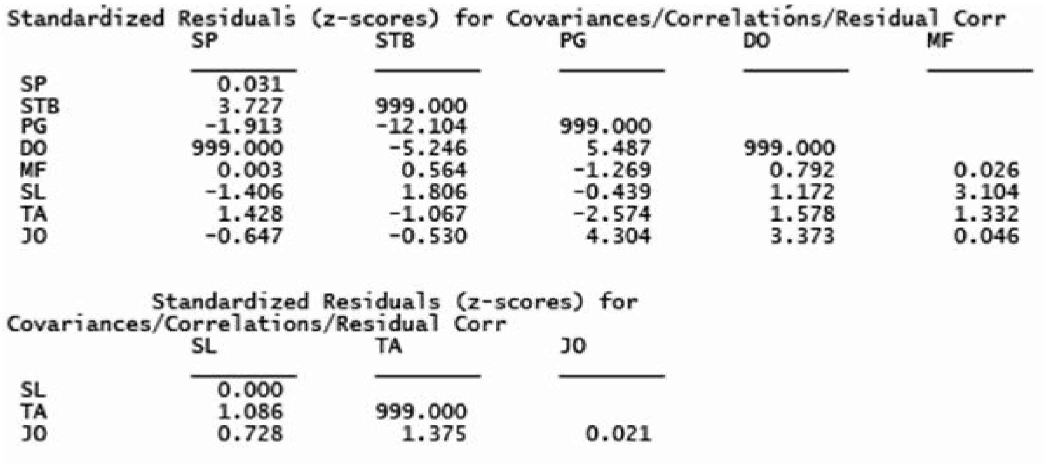


Fig. 27 Path diagram 2-factor model performance tests 2. version of test battery without items PT and TDS (adult population)

However, even after removing the two weakest indicators, PT (Collecting toothpicks) and TDS (While sitting on a chair, taking off a knitted sock from one foot using the other foot), from the previous model, this proposed structure did not display any fit improvement, and all the acquired values were still significantly below average. Likewise, there was no improvement in values in the residual covariance matrix, which still contained a number of extreme values (PG – STB, PG – DO, PG – JO, STB – DO).

Table 45

Residual matrix 2-factor model performance tests 2. version of test battery without items PT and TDS (adult population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                 SP            STB           PG            DO            MF
              ________      ________      ________      ________      ________
 SP              0.031
 STB             3.727       999.000
 PG             -1.913       -12.104       999.000
 DO            999.000        -5.246         5.487       999.000
 MF              0.003         0.564        -1.269         0.792         0.026
 SL             -1.406         1.806        -0.439         1.172         3.104
 TA              1.428        -1.067        -2.574         1.578         1.332
 JO             -0.647        -0.530         4.304         3.373         0.046

          Standardized Residuals (z-scores) for
 Covariances/Correlations/Residual Corr
                 SL            TA            JO
              ________      ________      ________
 SL              0.000
 TA              1.086       999.000
 JO              0.728         1.375         0.021
```

The values in the residual covariance matrix, however, suggest that the PG test (Pegboard test) could be a problematic indicator in the model could. Although it displays a strong factor loading, PG = 0.75, when assessing differences in the performance of both upper limbs, low substantive significance of the difference, *cohen d = 0.5*, was found retrospectively.

In further modelling, we did not remove any indicator with a weak factor loading, but the test which, according to the interpretation of the sensitivity results, did not show a sufficient substantive significance of the difference in the performance of both upper limbs. In addition, this indicator, based on its character, falls into the category of tests in which the proximal part of the upper limb is also strongly activated.

Table 46

Fit of the 2-factor model performance tests 2. version of test battery without items PT, TDS and PG (adult population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	14.13	0.36	13	0.99	0.99	0.021	0.032

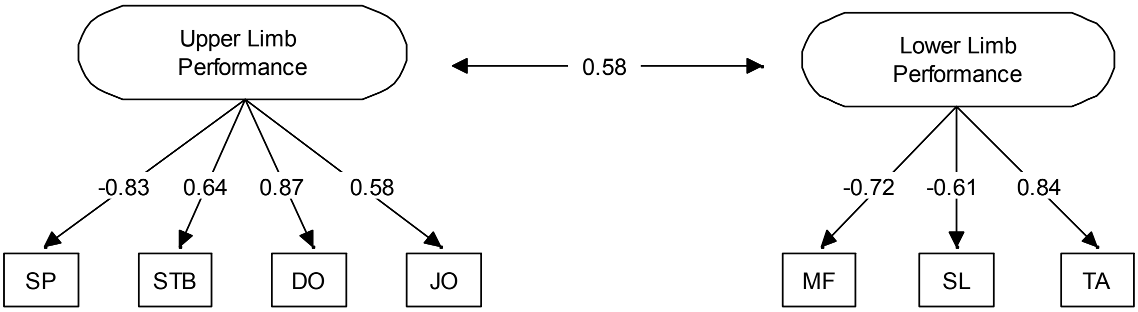
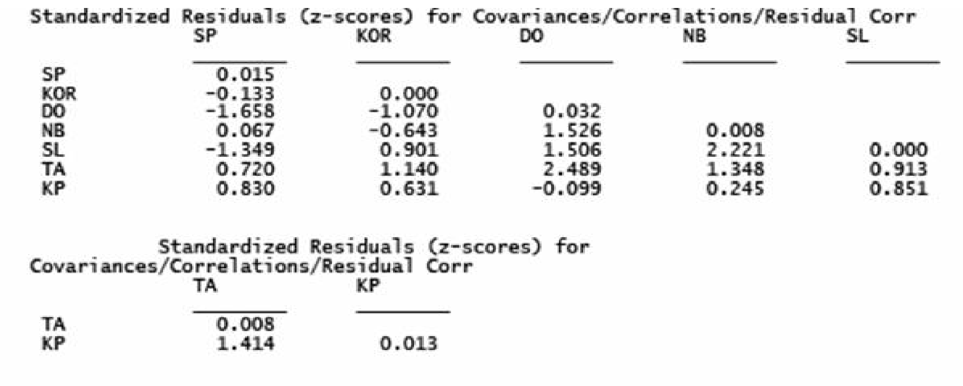


Fig. 28 Path diagram 2-factor model performance tests 2. version of test battery without items PT, TDS and PG (adult population)

The two-factor model without the PG indicator (Pegboard test) showed a significant improvement in all values of fit indices. Moreover, the values of CFI, TLI, and RMSEA reached the level of a very good model fit. The signification of the model P – the value of 0.36 – was also considerable. It was thus confirmed that the character and low sensitivity of the PG test had a profound impact on the quality of the entire model. The removing of the PG test was also reflected in the residual covariance matrix, where the value of the residuals decreased significantly. Only two values in the matrix were greater than 2. Therefore, this two-factor model without the PT, TDS, and PG tests was chosen as the best.

Table 47

Residual matrix 2-factor model performance tests 2. version of test battery without items PT, TDS and PG (adult population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                 SP          KOR          DO          NB          SL
              ________    ________    ________    ________    ________
 SP              0.015
 KOR            -0.133       0.000
 DO             -1.658      -1.070       0.032
 NB              0.067      -0.643       1.526       0.008
 SL             -1.349       0.901       1.506       2.221       0.000
 TA              0.720       1.140       2.489       1.348       0.913
 KP              0.830       0.631      -0.099       0.245       0.851

           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                 TA          KP
              ________    ________
 TA              0.008
 KP              1.414       0.013
```

Table 48

Generic reliability – performance tests 2. version (adult population)

Name of the factor	McDonald ω
Upper Limb Performance	0.82
Lower Limb Performance	0.78

Summary:

In order to diagnose motor manifestations of laterality using performance tests the two-factor model, obtained from the second version of the test battery, was adopted. This model displayed a very good fit with a high diagnostic quality with two different factors. The final form of the adopted model of the performance test part contained seven performance indicators. They were fine motor tests, gross motor tests, and an indicator determining articular passivity. The correlation between the two factors is at r = 0.58, which is a very similar result as in the performance test part in the first version of the test battery. In the second version of the test battery, it is also clear that human motor organ performance consists of two clearly distinct dimensions: "Upper Limb Performance" and "Lower Limb Performance". These findings in both versions of the test battery with some different indicators support the hypothesis of different motor control and control of the upper and lower limb motion in relation to their functional nature in human life.

The SP and DO indicators, as in fine motor tests, displayed a close relation to the factor "Upper Limb Performance". A weaker factor validity was shown by the STB test (Moving beads), STB = 0.64. Although this test was sensitive in distinguishing differences in the performance of both upper limbs, it also exhibited considerable variability, which could be caused by a covariance variable in the form of the amount of sweat on fingers when handling the beads. The last indicator in the "Upper Limb Performance" factor was the JO test (Measuring articular passivity in the wrist). The JO test had the weakest factor validity in this factor, but, with respect the nature of this test, it was understandable. By contrast, a very interesting finding was that the JO indicator retained an almost unchanged factor loading, JO = 0.58, also in the second version of the test battery. This fact suggests a relationship between motor manifestations of laterality and cerebellar dominance. In the "Lower Limb Performance" factor, which includes three tests, the TA test (Lower limb tapping), TA = 0.84, was the strongest indicator. As opposed to the modelling in the first part of the test battery, this was a new finding. The different strength of the relationship of the TA test in both versions could be caused by errors in the calculations of the examiner. According to the study by Fremelová & Blahutková (2004), this indicator should have a strong relationship with the lower limb performance attribute. The remaining two tests of the “Lower Limb Performance” factor, MF (While sitting on a chair, moving a cube in the “maze” provided) and SL (While standing, slalom with a ball between obstacles), had a nature of manipulative activity, and, therefore, both of these indicators showed similar factor loadings. A stronger relationship of the MF test (MF = –0.72) to this factor could be caused by the fact that this test was carried out while sitting. Both lower limbs were relaxed, and only one of them worked in the activity itself. In the SL test (SL = –0.61), which was performed while standing, one lower limb had a leading function – handling the ball, and the other lower limb had a supportive function – ensuring stability. The activity thus involved the co-operation of both lower limbs. In the test, this could result in affecting the outcome, in terms of different capability of stability of each lower limb.

12.2 Test Battery for Child Population

A total of four hundred probands participated in the research (193 boys and 207 girls) aged from 8 to 10 years (average age 9.1 years). They were students of Prague primary schools without a specific specialization (arts, technology, sports, languages). The entire research sample was divided into two subsets, each including 200 probands. The first subset, marked as A, consisted of 96 boys and 104 girls. The second subset, marked as B, consisted of 97 boys and 103 girls.

The subset A was diagnosed using the first version of the test battery; the subset B was diagnosed using the second version of the test battery. Both versions of the test battery contained a preference motor task part and a performance tests part.

12.2.1 Preference Tasks

The data in this part of the test battery is of a categorical nature, and it is scored dichotomously. Indicators were also used where the activity in motor tasks is repeated several times. The WLSMV method was used as a parameter estimation.

The ontogeny of children's motor skills is different in upper and lower limbs. Lower limbs are lateralized later in children. Therefore, it was decided to use the two-factor model:

1. "Upper Limb Preference",
2. "Lower Limb Preference".

The motor task "Use the tube to look at the object. **LT**", which is included in both versions of the test battery, was not used in the structural equation modelling method. In order to express the relationship between this indicator and motor manifestations of laterality, the LT indicator was correlated, using tetrachoric correlations, with the final indicators that formed the most suitable preference task model for the test battery designed for the child population.

Preference task items from the first version of the test battery:

- Draw a leaf according to the model. **DM**
- Take the bell in one hand and ring it. **RI**
- Take the ball in one hand and throw it at the target. **THR**
- According to the instructions, turn the cards of the given colours placed on the sheet of paper. **CAB**[14]
- Create a line in the marked space using matches. **MAR**[15]
- Show how many points you can roll with the dice on three attempts. **CTH**
- Demonstrate how you brush your teeth. **TC**
- Open the box. **OPB**
- Kick the ball placed on the floor at the target. **KB**
- Using one foot, tap the rhythm that I am clapping. **TR**
- While standing, demonstrate how you slide without the support of your hands. **SLI**
- Stretch your arms sideways and make a 360-degree turn around your axis. **TU**
- Move the cube along the line on the floor using one of your feet. **CM**

Use the tube to look at the object. **LT**

[14, 14] These tasks can be performed across the natural body axis of the individual

As in the test battery for the adult population, the relationship of the motor task determining ocular dominance using the sighting factor with the upper limb preferences and lower limb preference factor was also tested for each model.

Table 49

Fit of the 2-factor model preference tasks 1. version of test battery (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	208.54	<0.0000	64	0.95	0.95	0.118	1.535

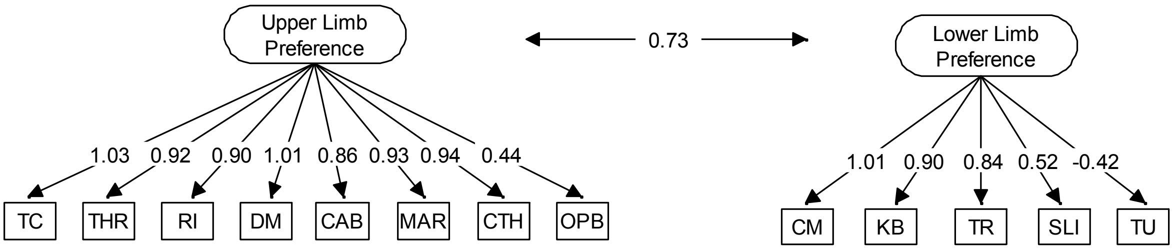
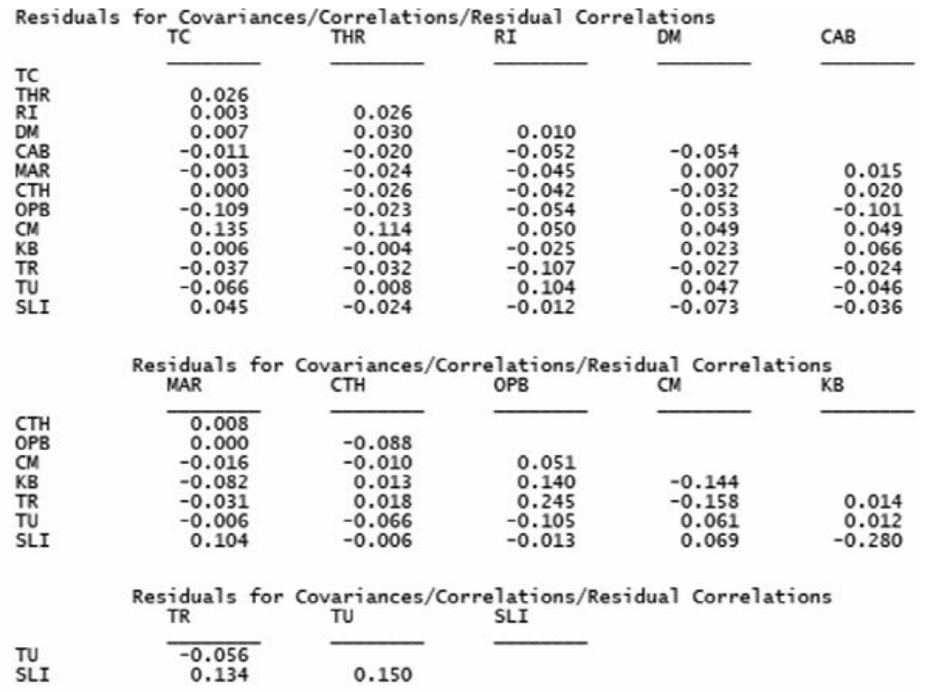


Fig. 29 Path diagram 2-factor model preference tasks 1. version of test battery (child population)

In the first model tested, a Heywood case was found, so this model was rejected. Factor loadings greater than 1 were found in the TC indicator (Demonstrate how you brush your teeth.), DM indicator (Draw a leaf according to the model.), and CM indicator (Move the cube along the line on the floor using one of your feet.). For further analysis, these indicators were removed due to collinearity with other motor tasks. In the “Upper Limb Preference” factor, the OPB task (Open the box.), OPB = 0.44, was the motor task with the weakest factor loading, which could be explained by the nature of this indicator. Unlike other motor tasks, it involves a bimanual activity. In the “Lower Limb Preference” factor, the TU indicator (Stretch your arms sideways and make a 360-degree turn around your axis.), TU = –0.42, was found to be the weakest, which is also associated with the rotation attribute. The results of the residual correlation matrix show a considerable amount of unexplained residuals greater than 0.100.

Table 50

Residual matrix 2-factor model preference tasks 1. version of test battery (child population)



```
Residuals for Covariances/Correlations/Residual Correlations
              TC          THR         RI          DM          CAB
              ________    ________    ________    ________    ________
TC
THR             0.026
RI              0.003       0.026
DM              0.007       0.030       0.010
CAB            -0.011      -0.020      -0.052      -0.054
MAR            -0.003      -0.024      -0.045       0.007       0.015
CTH             0.000      -0.026      -0.042      -0.032       0.020
OPB            -0.109      -0.023      -0.054       0.053      -0.101
CM              0.135       0.114       0.050       0.049       0.049
KB              0.006      -0.004      -0.025       0.023       0.066
TR             -0.037      -0.032      -0.107      -0.027      -0.024
TU             -0.066       0.008       0.104       0.047      -0.046
SLI             0.045      -0.024      -0.012      -0.073      -0.036

         Residuals for Covariances/Correlations/Residual Correlations
              MAR         CTH         OPB         CM          KB
              ________    ________    ________    ________    ________
CTH             0.008
OPB             0.000      -0.088
CM             -0.016      -0.010       0.051
KB             -0.082       0.013       0.140      -0.144
TR             -0.031       0.018       0.245      -0.158       0.014
TU             -0.006      -0.066      -0.105       0.061       0.012
SLI             0.104      -0.006      -0.013       0.069      -0.280

         Residuals for Covariances/Correlations/Residual Correlations
              TR          TU          SLI
              ________    ________    ________
TU             -0.056
SLI             0.134       0.150
```

Another proposed model was the two-factor model without the TC, DM, and CM indicators, which were removed due to collinearity.

Table 51

Fit of the 2-factor model preference tasks 1. version of test battery without items TC, DM and CM (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	49.96	0.038	34	0.98	0.97	0.048	0.630

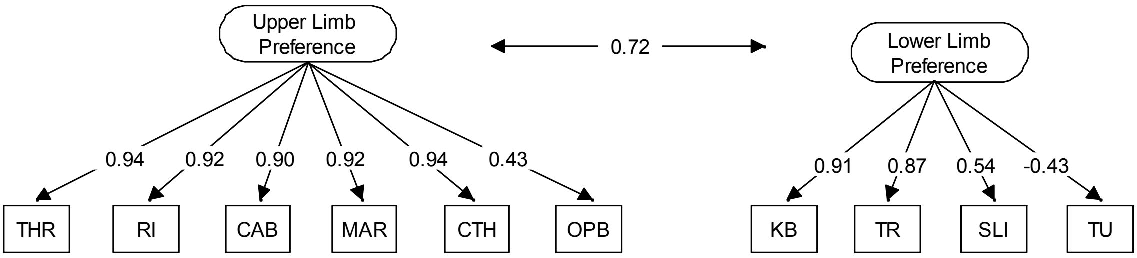
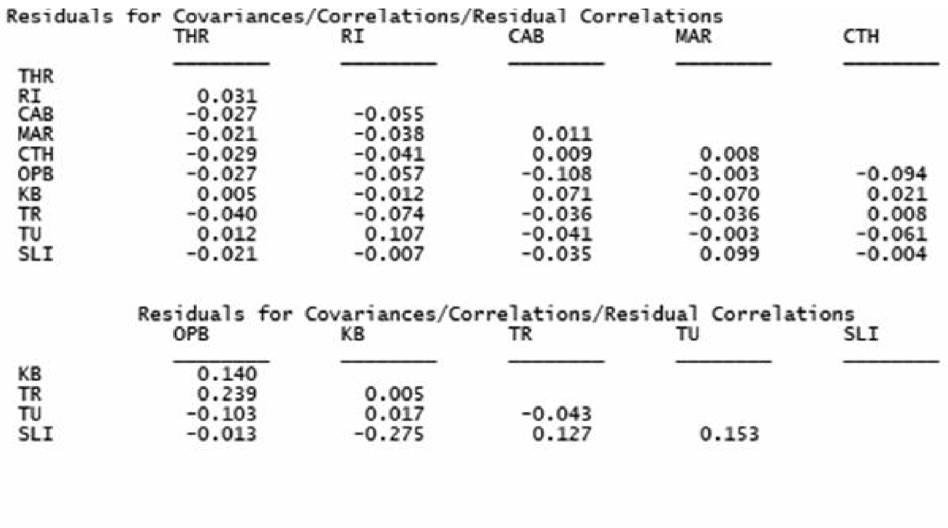


Fig. 30 Path diagram 2-factor model preference tasks 1. version of test battery without items TC, DM and CM (child population)

After removing the problematic indicators, the entire model fit was improved. All fit indices in this two-factor structure showed values that reached a good model fit. The results of the residual matrix displayed some improvement, but the OPB indicator (Open the box.) clearly proved to be problematic. This preference task is of a bimanual nature, and thus could affect the unidimensionality of the "Upper Limb Preference" factor.

Table 52

Residual matrix 2-factor model preference tasks 1. version of test battery without items TC, DM and CM (child population)



```
Residuals for Covariances/Correlations/Residual Correlations
            THR          RI           CAB          MAR          CTH

            --------     --------     --------     --------     --------
 THR
 RI            0.031
 CAB          -0.027       -0.055
 MAR          -0.021       -0.038        0.011
 CTH          -0.029       -0.041        0.009        0.008
 OPB          -0.027       -0.057       -0.108       -0.003       -0.094
 KB            0.005       -0.012        0.071       -0.070        0.021
 TR           -0.040       -0.074       -0.036       -0.036        0.008
 TU            0.012        0.107       -0.041       -0.003       -0.061
 SLI          -0.021       -0.007       -0.035        0.099       -0.004

         Residuals for Covariances/Correlations/Residual Correlations
            OPB          KB           TR           TU           SLI

            --------     --------     --------     --------     --------
 KB            0.140
 TR            0.239        0.005
 TU           -0.103        0.017       -0.043
 SLI          -0.013       -0.275        0.127        0.153
```

This model showed an unsatisfactory significance, P-value = 0.038. The correlation between the factors at r = 0.72 indicated that the upper limb preference attribute and lower limb preference attribute probably have a common basis in the background, “motor organ preference”. This common basis, however, has a certain degree of uniqueness in each factor that does not allow us to consider the upper limb preference and lower limb preference diagnosed by motor tasks as unidimensional. It was interesting to find in the “Preference o upper limb” factor strong factor loadings of the CAB indicator (According to the instructions, turn the cards of the given colours placed on the sheet of paper.), CAB = 0.90, and MAR indicator (Create a line in the marked space using matches.), MAR = 0.92, where the emphasis is placed on the activity of upper limbs, even across the natural body axis.

In the following modelling procedure, it was decided to maintain the two-factor structure, from which the bimanual activity character indicator, OPB, was removed. This step was taken in order to maintain the unidimensionality of the “Upper Limb Preference” factor.

Table 53

Fit of the 2-factor model preference tasks 1. version of test battery without items TC, DM, CM and OPB (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	26.71	0.22	26	0.99	0.99	0.034	0.534

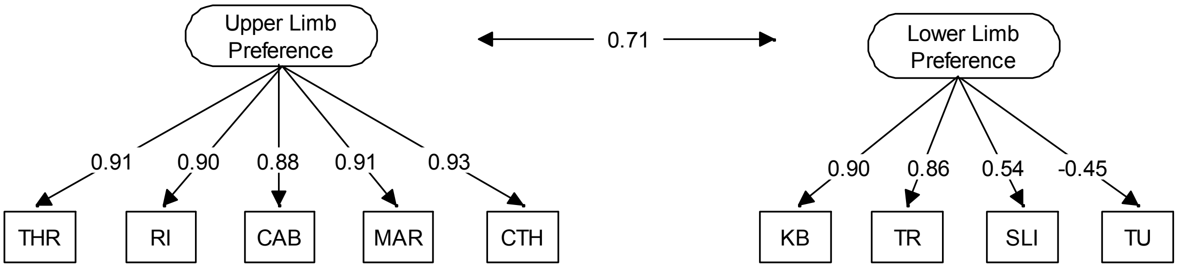


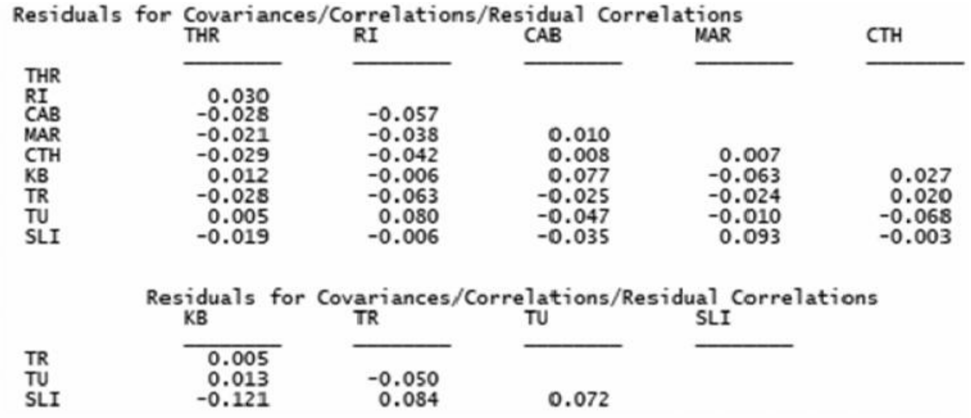
Fig. 31 Path diagram 2-factor model preference tasks 1. version of test battery without items TC, DM, CM and OPB (child population)

By removing the OPB indicator, the entire two-factor model fit was significantly improved, including the value of the P-value, which was at an acceptable level of P-value = 0.22. The assumption that the bimanual motor task OPB may affect the structure by its character proved to be justified.

The residual matrix was also improved; no values greater than 0.100 were detected.

Table 54

Residual matrix 2-factor model preference tasks 1. version of test battery without items TC, DM, CM and OPB (child population)



```
Residuals for Covariances/Correlations/Residual Correlations
              THR          RI           CAB          MAR          CTH
              ________     ________     ________     ________     ________
 THR
 RI            0.030
 CAB          -0.028       -0.057
 MAR          -0.021       -0.038        0.010
 CTH          -0.029       -0.042        0.008        0.007
 KB            0.012       -0.006        0.077       -0.063        0.027
 TR           -0.028       -0.063       -0.025       -0.024        0.020
 TU            0.005        0.080       -0.047       -0.010       -0.068
 SLI          -0.019       -0.006       -0.035        0.093       -0.003

          Residuals for Covariances/Correlations/Residual Correlations
              KB           TR           TU           SLI
              ________     ________     ________     ________
 TR            0.005
 TU            0.013       -0.050
 SLI          -0.121        0.084        0.072
```

Table 55

Generic reliability – preference tasks 1. version (child population)

Name of the factor	McDonald ω
Upper Limb Preference	0.95
Lower Limb Preference	0.81

This two-factor structure with nine motor indicators finally proved to be the most appropriate in this first version of the test battery.

Two indicators in the “Preference of lower limb” factor are more related to the rotation attribute, SLI (While standing, demonstrate how you slide without the support of your hands) and TU (Stretch your arms sideways and make a 360-degree turn around your axis). It was decided to verify how the model fit changes if they are removed. As laterality is not yet fully stabilized in children at this age, we supposed that indicators for assessing upper and lower limb preference could form one dimension. Therefore, the quality of the one-factor model with seven indicators was also verified.

Table 56

Fit of the 1-factor strucutre preference tasks 1. version of test battery without items TC, DM, CM, OPB, SLI and TU (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	51.40	<0.000	14	0.99	0.99	0.114	1.016

The results of the model fit clearly show that the one-factor structure is inappropriate in this case, and the removal of the SLI and TU items results in the loss of important information in the assessment of lower limb preference. Therefore, this model was rejected.

Preference task items from the second version of the test battery:

- Draw a leaf according to the model. **DM**
- Take the bell in one hand and ring it. **RI**
- Take the ball in one hand and throw it at the target. **THR**
- Erase the line. **ER**
- Show me the following objects using one hand. **PO**
- Demonstrate how you stir with a teaspoon in a cup. **SBS**
- Press number 5 on the calculator. **CAL**
- Show me how you comb your hair. **CH**
- Kick the ball placed on the floor at the target. **KB**
- Show me jumps forward on one leg. **HOP**
- Start running and make a long jump. **LJ**

- Demonstrate how you would write the letter T on the floor using one of your feet. **WT**
- Step on the platform. **GOS**

Use the tube to look at the object. **LT**

Based on the results in the preference task part of the first version of the test battery, the two-factor structure was first proposed in the same part of the second version of the test battery for the child population.

Table 57

Fit of the 2-factor model preference tasks 2. version of test battery (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
2-factor	105.73	0.013	64	0.97	0.97	0.054	0.790

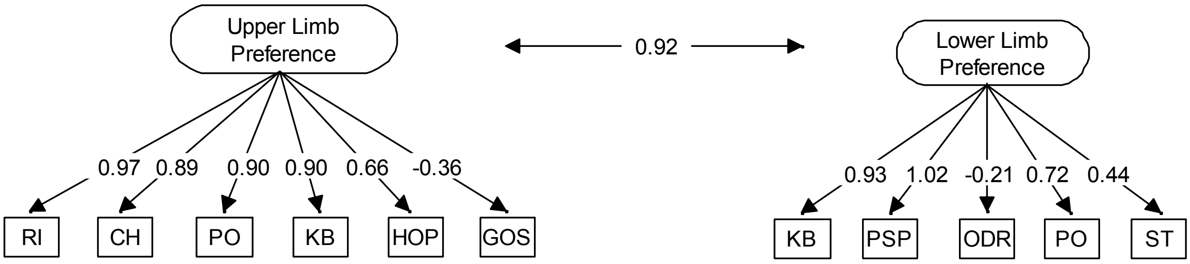
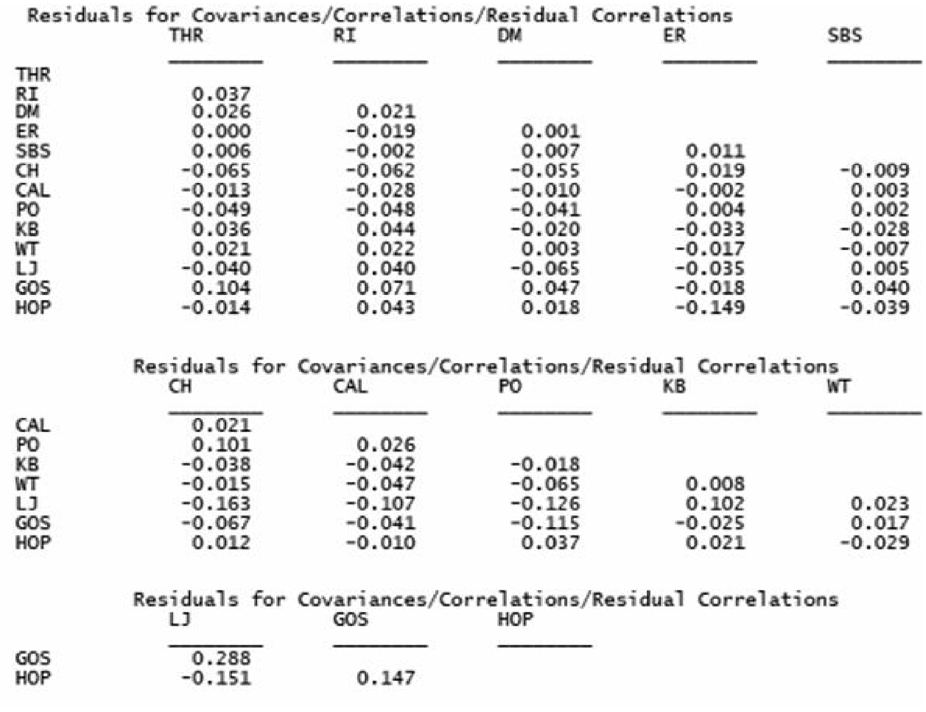


Fig. 32 Path diagram 2-factor model preference tasks 2. version of test battery (child population)

As in the preferential motor task part in the first version of the test battery for the child population, this two-factor model also displayed a Heywood case. Therefore, this model was rejected. The "Upper Limb Preference" factor exhibited a strong multicollinearity of the THR indicator (Take the ball in one hand and throw it at the target.), DM indicator (Draw a leaf according to the model.), ER indicator (Erase the line.), SBS indicator (Demonstrate how you stir with a teaspoon in a cup.), and CAL indicator (Press number 5 on the calculator.). This multicollinearity is probably based on the nature of the items through which a very similar or even identical movement pattern is activated. From this perspective, an assumption has been inferred that these items are redundant in this factor, and they were not selected appropriately. The “Lower Limb Preference” factor displayed collinearity between the KB indicator (Kick the ball placed on the floor at the target.) and WT indicator (Demonstrate how you would write the letter T on the floor using one of your feet.). On the contrary, the LJ item (Demonstrate a long jump.) was the weakest indicator in this factor, LJ = –0.21. During the test itself this item pointed out its inappropriateness of use, due to the incomplete lateralization stabilizing process of the lower limb in jumping activities. This indicator proved to be the most problematic in the residual matrix, where most of the unexplained residuals were related to this motor task.

Table 58

Residual matrix 2-factor model preference tasks 2. version of test battery (child population)



```
 Residuals for Covariances/Correlations/Residual Correlations
              THR           RI            DM            ER            SBS
              ________      ________      ________      ________      ________
 THR
 RI              0.037
 DM              0.026         0.021
 ER              0.000        -0.019         0.001
 SBS             0.006        -0.002         0.007         0.011
 CH             -0.065        -0.062        -0.055         0.019        -0.009
 CAL            -0.013        -0.028        -0.010        -0.002         0.003
 PO             -0.049        -0.048        -0.041         0.004         0.002
 KB              0.036         0.044        -0.020        -0.033        -0.028
 WT              0.021         0.022         0.003        -0.017        -0.007
 LJ             -0.040         0.040        -0.065        -0.035         0.005
 GOS             0.104         0.071         0.047        -0.018         0.040
 HOP            -0.014         0.043         0.018        -0.149        -0.039

              Residuals for Covariances/Correlations/Residual Correlations
              CH            CAL           PO            KB            WT
              ________      ________      ________      ________      ________
 CAL             0.021
 PO              0.101         0.026
 KB             -0.038        -0.042        -0.018
 WT             -0.015        -0.047        -0.065         0.008
 LJ             -0.163        -0.107        -0.126         0.102         0.023
 GOS            -0.067        -0.041        -0.115        -0.025         0.017
 HOP             0.012        -0.010         0.037         0.021        -0.029

              Residuals for Covariances/Correlations/Residual Correlations
              LJ            GOS           HOP
              ________      ________      ________
 GOS             0.288
 HOP            -0.151         0.147
```

The entire model exhibited a strong correlation between the two factors, r = 0.92, which suggests that in this case the indicators used could form a bi-factor structure with a general factor in the background. In the further analysis, all the aforementioned problematic indicators (THR, DM, ER, SBS, CAL, WT), including the LJ indicator, were rejected. A bi-factor structure in which the correlations between the individual factors were fixed to 0 was also tested. The general factor in the background was termed “Preference of Locomotive Organs”.

Table 59

Fit of the bi-factor model preference tasks 2. version of test battery without items THR, DM, ER, SBS, CAL, WT and LJ (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
bi-factor	27.69	0.002	10	0.98	0.96	0.094	0.751

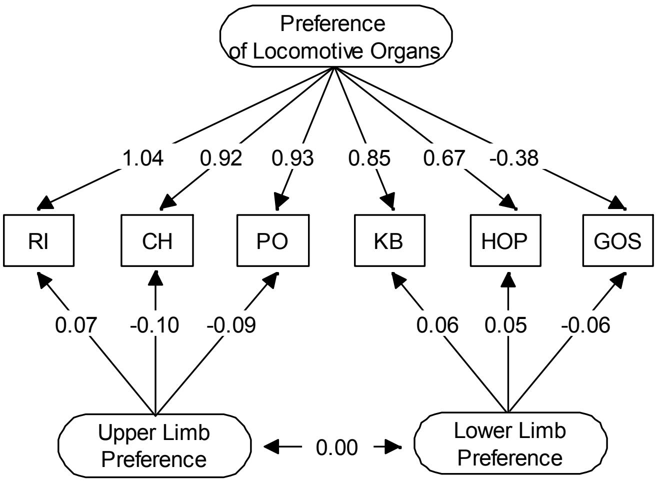


Fig. 33 Path diagram bi-factor model preference tasks 2. version of test battery without items THR, DM, ER, SBS, CAL, WT and LJ (child population)

The RI (Ring the bell) indicator factor loading in this proposed bi-factor structure was greater than 1, which again represented a Heywood case. Therefore, the model was rejected. The results in this model, however, supported the hypothesis that the indicators of preference motor tasks in this version of the test battery probably form a unidimensional structure with the “Preference of Locomotive Organs” factor.

The last proposed structure was the one-factor model with six indicators.

Table 60

Fit of the 1-factor model preference tasks 2. version of test battery without items THR, DM, ER, SBS, CAL, WT and LJ (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	WRMR
1-factor	30.90	0.0057	14	0.96	0.95	0.078	0.883

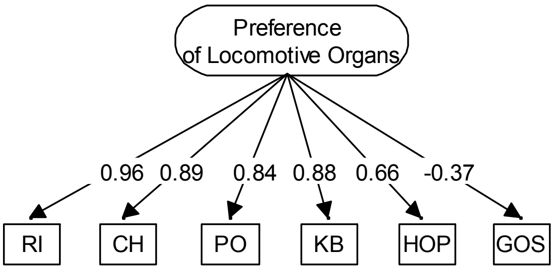


Fig. 34 Path diagram 1-factor model preference tasks 2. version of test battery without items THR, DM, ER, SBS, CAL, WT and LJ (child population)

Although the results of the one-factor model did not show a Heywood case, the quality of the model was not acceptable. In particular, the RMSEA index (RMSEA = 0.078) only displayed an average value, and the same applied to WRMW (WRMW = 0.883). Furthermore, this proposed one-factor structure was below the chosen level of the model signification, 0.05, and the P-value was in this case only 0.0057. We assume that this model is too restrictive for quality assessing preference.

Although the value of generic reliability reached an acceptable level (table 61), this model was for previous reasons rejected.

Table 61

Generic reliability – preference tasks 2. version (child population)

Name of the factor	McDonald ω
Preference of Locomotive Organs	0.88

The relationship between eyedness and preference tasks assessing upper and lower limb preference:

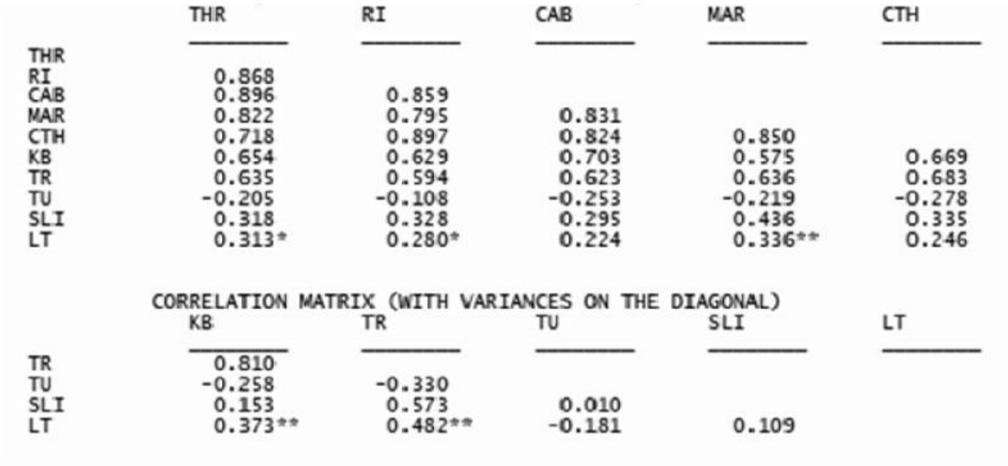
Along with motor tasks assessing motor organ preference, ocular dominance was determined in both versions of the test batteries using the LT indicator (Use the tube to look at the object.). We thus correlated the LT indicator (Use the tube to look at the object.) with the individual preference tasks included in the adopted two-factor model from the first version of the test battery.

- Take the ball in one hand and throw it at the target. **THR**
- Take the bell in one hand and ring it. **RI**
- According to the instructions, turn the cards of the given colours placed on the sheet of paper. **CAB**[16]
- Create a line in the marked space using matches. **MAR**[17]
- Show how many points you can roll with the dice on three attempts. **CTH**
- Kick the ball placed on the floor at the target. **KB**
- Using one foot, tap the rhythm that I am clapping. **TR**
- Stretch your arms sideways and make a 360-degree turn around your axis. **TU**
- While standing, demonstrate how you slide without the support of your hands. **SLI**

[16, 16] These tasks can be performed across the natural body axis of the individual

Table 62

Correlation matrix hand preference tasks and eye dominance (children population)



```
           THR           RI            CAB           MAR           CTH
         --------      --------      --------      --------      --------
THR
RI         0.868
CAB        0.896         0.859
MAR        0.822         0.795         0.831
CTH        0.718         0.897         0.824         0.850
KB         0.654         0.629         0.703         0.575         0.669
TR         0.635         0.594         0.623         0.636         0.683
TU        -0.205        -0.108        -0.253        -0.219        -0.278
SLI        0.318         0.328         0.295         0.436         0.335
LT         0.313*        0.280*        0.224         0.336**       0.246

        CORRELATION MATRIX (WITH VARIANCES ON THE DIAGONAL)
           KB            TR            TU            SLI           LT
         --------      --------      --------      --------      --------
TR         0.810
TU        -0.258        -0.330
SLI        0.153         0.573         0.010
LT         0.373**       0.482**      -0.181         0.109
```

*significance correlation p< 0.05

** significance correlation p< 0.01

The correlation matrix shows that the LT indicator that determines the ocular dominance factor, through the sighting factor, significantly correlates with a total of three motor tasks assessing upper limb preference and two motor tasks assessing lower limb preference. Three of these motor tasks even displayed a significant correlation $p < 0.01$. However, the results show that a stronger relationship is observed between the LT indicator and motor tasks assessing lower limb preference, just as in the correlation matrix for the adult population. The KB (Kick the ball placed on the floor at the target) and TR (Using one foot, tap the rhythm that I am clapping) indicators showed a significant correlation with the LT indicator at the significance level of $p < 0.01$.

Summary:

The final form of the preference motor task part for the child population is composed of a two-factor structure with nine indicators from the first version of the test battery. This structure met all requirements of the diagnostic quality of an acceptable model. The results show that the indicators in the “Upper Limb Preference” factor, where the subjects worked across the natural body axis, CAB (According to the instructions, turn the cards of the given colours placed on the sheet of paper.) and MAR (Create a line in the marked space using matches.) very well indicated the strength of the upper limb preferences. The "Upper Limb Preference" factor also contains three different motor indicators:

- the THR indicator (Throw the ball at the target.), involving both proximal and distal parts of the upper limb in movement,
- the RI indicator (Ring the bell.), involving mainly the distal part of the upper limb in movement,
- the CTH indicator (Show how many points you can roll with the dice on three attempts.), which is a combination of the movements of the two previous motor tasks.

The "Lower Limb Preference" factor contains four indicators. A very strong relationship with this factor was found in the motor tasks KB (Kick the ball at the target.) and TR (Using one foot, tap the rhythm that I am clapping.). While the KB task is a traditional motor task involving both lower limbs in the activity (one has a control function – kicking; the other has a stabilizing function), the TR indicator is designed to allow the subject to have both lower limbs relaxed. This condition is fulfilled by the fact that the subject is sitting on a chair while performing this motor task. The other two indicators, SLI (While standing, demonstrate how you slide without the support of your hands) and TU (Stretch your arms sideways and make a 360-degree turn around your axis), are more related to the assessment of the rotation attribute. However, recent studies show that there is a significant relationship between lower limb preference and rotation (Mohr, Landis, Bracha, & Brugger, 2003; Štochl & ,Croudace, 2012, in press). In performing these tasks, lower limb preference is assessed indirectly.

12.2.2 Performance Tests

The data in this part of the test battery are of an interval nature. Both versions of the proposed performance tests contained tests with the reverse scoring character. These were the tests in which time was not a constant.

Performance test items from the first version of the test battery:

- Tracing the spiral **SP**[18]
- Moving beads from one box into another using tweezers **TW**
- Dot-filling fine motor test **DO**
- Measuring articular passivity in order to diagnose cerebellar dominance **JO**
- Moving matches using a hand **PM**
- Threading beads on a metal wire **STB**
- Turning a box alternately with the front and the rear side on the table **BTW**
- Lower limb tapping **TA**
- Slalom with a ball between obstacles **SL**[19]
- Kicking a ball against the wall **RKB**

In the performance test part, the two-factor model was first tested. Conceptually, this model was based on the theory that, viewed functionally, upper and lower limbs are controlled differently. In addition, it was assumed for the child population that the lower limb would not display such a degree of lateralization due to its slower motor ontogeny. Factors:

- "Upper Limb Performance",
- "Lower Limb Performance".
-

With respect to the fact that our data met the condition of multivariate normality, we used the maximum likelihood (ML) method as a parameter estimation.

Table 63

Fit of the 2-factor model performance tests 1. version of test battery (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	98.93	<0.000	34	0.90	0.87	0.098	0.076

---

[18] Time is not a constant in this test, so the factor loading indicates a negative value

[19] Time is not a constant in this test, so the factor loading indicates a negative value

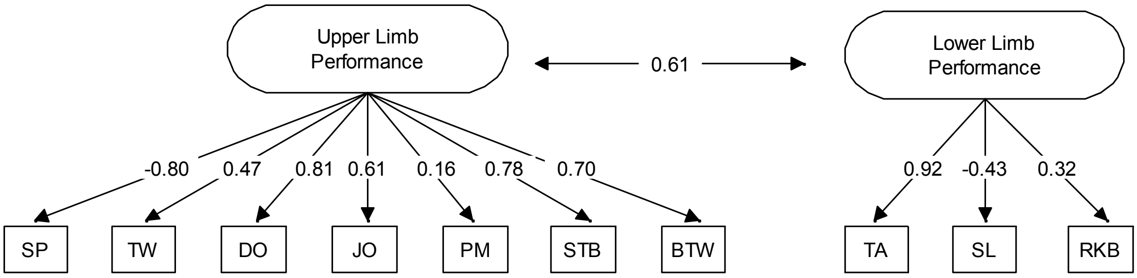


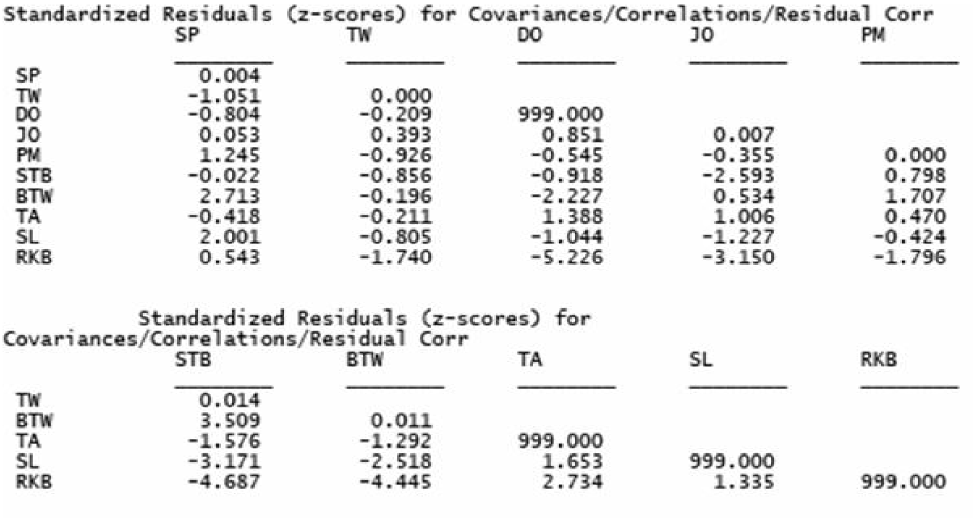
Fig. 35 Path diagram 2-factor model performance tests 1. version of test battery (child population)

Based on all fit indices, the results from this two-factor structure show a weak model fit. Therefore, this model was rejected. The PM test (Moving matches using a hand) (PM = 0.16) proved to be highly problematic in the "Upper Limb Performance" factor. During the actual data collection the PM test already showed very low sensitivity in determining differences in the performance of upper limbs, *cohen d < 0.5*. In addition, in this test, upper limb dexterity often did not correspond with the results of the fine motor tests, SP (Tracing the spiral) and DO (Dot-filling fine motor test). An important finding was the relationship between the "Upper Limb Performance" factor and the JO test (Measuring articular passivity in order to diagnose cerebellar dominance) (JO = 0.61). It was at a very similar level as in the adult population. This result suggests that the upper limb muscle tonus is genetically determined, and, therefore, this indicator has a similarly strong relationship with the "Upper Limb Performance" factor for both children and adults. The test results pertaining to the "Lower Limb Performance" factor displayed a weak relationship between the SL test (Slalom with a ball between obstacles) and RKB test (Kicking a ball against the wall). These tests have a manipulative nature, and it is likely that in these motor activities they showed a weaker lower limb lateralization in children. In the course of performing both tests, stability, balance, and handling problems were observed. This resulted in an unclear determination of the "more skilled" lower limb.

The problems with tests for the lower limb showed that assessing differences in the performance of lower limbs will probably be only possible if the TA performance test (Lower limb tapping), which does not require fine motor skills, is used. The results of the residual covariance matrix display a noticeable amount of unexplained residuals. The critical value of 2.58 was most frequently exceeded in the RKB test.

Table 64

Residual matrix 2-factor model performance tests 1. version of test battery (child population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
              SP            TW            DO            JO            PM
          ________      ________      ________      ________      ________
 SP          0.004
 TW         -1.051         0.000
 DO         -0.804        -0.209       999.000
 JO          0.053         0.393         0.851         0.007
 PM          1.245        -0.926        -0.545        -0.355         0.000
 STB        -0.022        -0.856        -0.918        -2.593         0.798
 BTW         2.713        -0.196        -2.227         0.534         1.707
 TA         -0.418        -0.211         1.388         1.006         0.470
 SL          2.001        -0.805        -1.044        -1.227        -0.424
 RKB         0.543        -1.740        -5.226        -3.150        -1.796

           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
              STB           BTW           TA            SL            RKB
          ________      ________      ________      ________      ________
 TW          0.014
 BTW         3.509         0.011
 TA         -1.576        -1.292       999.000
 SL         -3.171        -2.518         1.653       999.000
 RKB        -4.687        -4.445         2.734         1.335       999.000
```

Based on the previous results, the problematic tests were excluded from further modelling. The PM indicator was removed from the “Upper Limb Performance” factor, and the SL and RKB indicators were removed from the “Lower Limb Performance” factor.

Since two of the three tests were removed from the “Lower Limb Performance” factor, a one-factor model with the “Performance of Locomotive Orans” factor was subsequently tested.

Table 65

Fit of the 1-factor model performance tests 1. version of test battery without tests PM, SL and RKB (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
1-factor	29.86	0.008	14	0.97	0.96	0.075	0.031

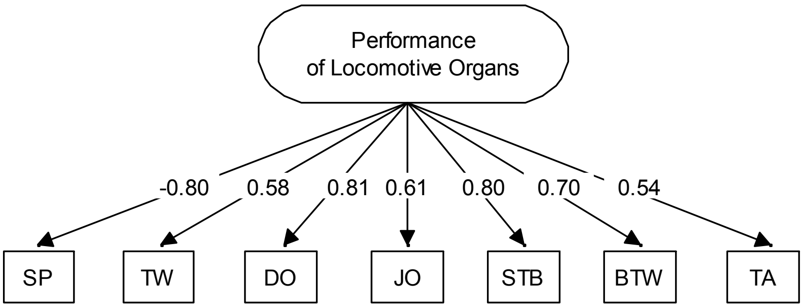
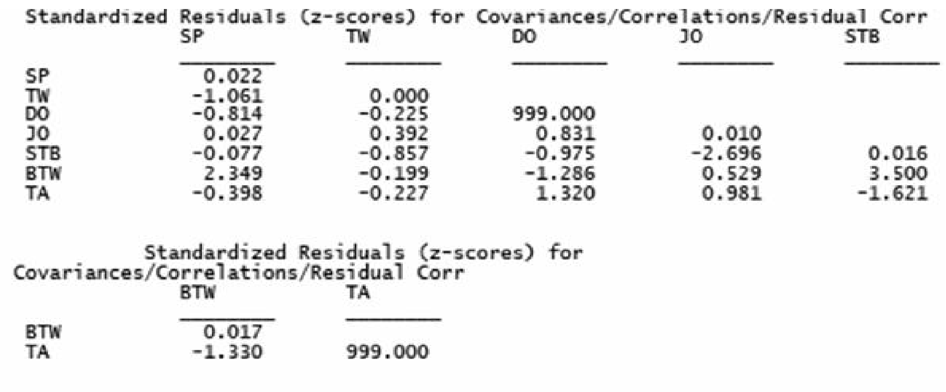


Fig. 36 Path diagram 1-factor model performance tests 1. version of test battery without tests PM, SL and RKB (child population)

The one-factor model showed improvement in all values of fit indices, but the RMSEA index was at the level of the average RMSEA fit (0.075), and the model significance in the form of the P-value was unacceptable. The results of the residual covariance matrix pointed to a possible problem with the STB test (Threading beads on a metal wire). Despite the high factor loading on the "Upper Limb Performance" factor, STB = 0.80, high values greater than 2.58 were found in the residual covariance matrix in this test.

Table 66

Residual matrix 1-factor model performance tests 1. version of test battery without tests PM, SL and RKB (child population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                SP          TW          DO          JO          STB
             ________    ________    ________    ________    ________
 SP             0.022
 TW            -1.061       0.000
 DO            -0.814      -0.225     999.000
 JO             0.027       0.392       0.831       0.010
 STB           -0.077      -0.857      -0.975      -2.696       0.016
 BTW            2.349      -0.199      -1.286       0.529       3.500
 TA            -0.398      -0.227       1.320       0.981      -1.621

           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                BTW         TA
             ________    ________
 BTW            0.017
 TA            -1.330     999.000
```

Therefore, in the final analysis of performance tests in the first version of the test battery, the STB (Threading beads on a metal wire) test was removed, and a one-factor structure with six indicators was proposed.

Table 67

Fit of the 1-factor model performance tests 1. version of test battery without tests PM, SL, RKB and STB (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
1-factor	5.57	0.78	9	0.99	0.99	0.004	0.021

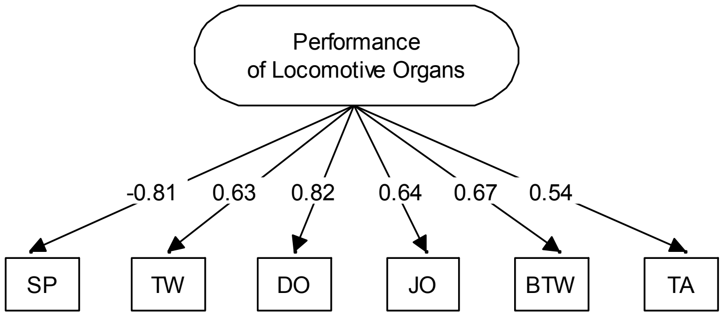
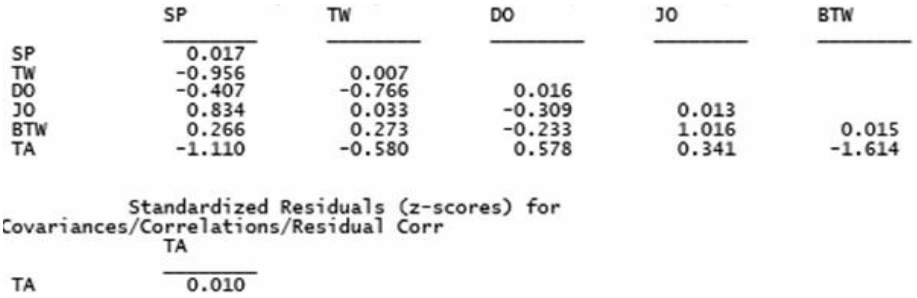


Fig. 37 Path diagram 1-factor model performance tests 1. version of test battery without tests PM, SL, RKB and STB (child population)

Table 68

Residual matrix 1-factor model performance tests 1. version of test battery without tests PM, SL, RKB and STB (child population)



```
              SP          TW          DO          JO          BTW
           ________    ________    ________    ________    ________
SP            0.017
TW           -0.956       0.007
DO           -0.407      -0.766       0.016
JO            0.834       0.033      -0.309       0.013
BTW           0.266       0.273      -0.233       1.016       0.015
TA           -1.110      -0.580       0.578       0.341      -1.614

           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
              TA
           ________
TA            0.010
```

Table 69

Generic reliability – performance testss 1. version (child population)

Name of the factor	McDonald ω
Performance of Locomotive Organs	0.83

The results of the residual matrix show that this one-factor model does not contain any residuals greater than 2.58, and that in previous analyses the STB test was truly the disturbing manifest variable.

This one-factor model with six motor tests in the first version of the test battery met all the conditions of the acceptable model. The values of all fit indices showed a very good fit, including high model significance, P-value = 0.78. Four of the tests assess differences in the performance of upper limbs, and one test, TA (Lower limb tapping, is designed to determine differences in the performance between the lower limbs. The JO test (Measuring articular passivity in order to diagnose cerebellar dominance) measures cerebellar dominance, by means of different muscle tonus in the wrist. The variables determining the lower limb dexterity based on handling objects proved to be unsuitable in the course of testing. None of the tests distinguished well the "dexterity" of both lower limbs. This fact points out the unequal ontogeny of lower and upper limb motor activity in children.

Performance test items test in the second version of the test battery:

- tracing the spiral **SP**[20]
- dot-filling fine motor test **DO**
- screwing a nut on a bolt **SCN**[21]
- pegboard **PG**
- turning a card between fingers **TWC**
- measuring articular passivity in order to diagnose cerebellar dominance **JO**
- lower limb tapping **TA**

[20, 20] Time is not a constant in these tests, so the factor loadings indicates a negative values.

- slalom with a ball between obstacles **SL**[22]
- while standing, moving a cube in the “maze” provided **MF**[23]
- while sitting on a chair, moving small cubes from place to place using a foot **CM**[24]

Table 70

Fit of the 2-factor model performance tests 2. version of test battery (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
2-factor	119.08	<0.0000	34	0.83	0.77	0.112	0.072

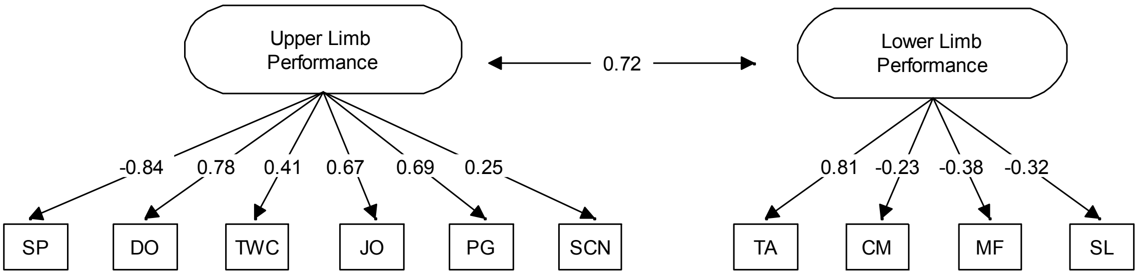


Fig. 38 Path diagram 2-factor model performance tests 2. version of test battery (child population)

The results from this two-factor structure showed a very weak model fit, which was determined in all fit indices; this model was therefore rejected. In the “Upper Limb Performance” factor, the SCN test (Screwing a nut on a bolt) proved to be highly problematic. During the actual data collection the SCN test already showed very low sensitivity in determining differences in the performance of upper limbs. In addition, in this test, upper limb dexterity often did not correspond with the results of the fine motor tests, SP (Tracing the spiral) and DO (Dot-filling fine motor test). These facts are probably reflected in the low factor loading of this test, SCN = 0.25. However, an important result in this analysis of the second version of the test battery was the confirmation of the extent of the relationship between the “Upper Limb Performance”

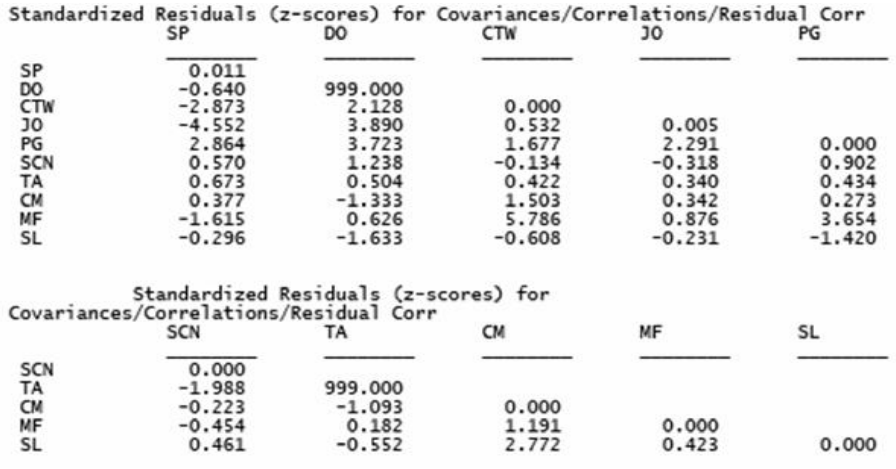
[22, 22, 23] Time is not a constant in these tests, so the factor loadings indicates a negative values.

factor and the JO test (Measuring articular passivity in order to diagnose cerebellar dominance), JO = 0.67, which supported the hypothesis of the existence of the relationship between cerebellar dominance and handedness also in the child population. The “Lower Limb Performance” factor displayed very weak factor loadings of the CM (While sitting on a chair, moving small cubes from place to place using a foot), MF (While standing, moving a cube in the “maze” provided), and SL (Slalom with a ball between obstacles) in all manifest variables that emphasized handling of the object. This finding was supported by the results of the performance tests from the first version of the test battery, where it was suggested that lower limb tests of a manipulative nature are not appropriate for children at this age due to the unstable lower limb lateralization. As in the testing of the first version, the SL test displayed problems with stability, balance, and handling, which resulted in ambiguous determination of the more skilled lower limb. Low sensitivity was also determined in the MF and CM tests that were performed while sitting.

The low quality of the model is also evident from the results of the residual covariance matrix that contains a large number of values greater than 2.58.

Table 71

Residual matrix 2-factor model performance tests 2. version of test battery (child population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                 SP           DO           CTW          JO           PG
              ________     ________     ________     ________     ________
 SP             0.011
 DO            -0.640      999.000
 CTW           -2.873        2.128        0.000
 JO            -4.552        3.890        0.532        0.005
 PG             2.864        3.723        1.677        2.291        0.000
 SCN            0.570        1.238       -0.134       -0.318        0.902
 TA             0.673        0.504        0.422        0.340        0.434
 CM             0.377       -1.333        1.503        0.342        0.273
 MF            -1.615        0.626        5.786        0.876        3.654
 SL            -0.296       -1.633       -0.608       -0.231       -1.420

           Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                 SCN          TA           CM           MF           SL
              ________     ________     ________     ________     ________
 SCN            0.000
 TA            -1.988      999.000
 CM            -0.223       -1.093        0.000
 MF            -0.454        0.182        1.191        0.000
 SL             0.461       -0.552        2.772        0.423        0.000
```

In the course of further modelling, it was decided to exclude the CM, MF, and SL tests which had a very weak relationship to the "Lower Limb Performance" factor. This step led to the design of a one-factor structure from which the SCN test was removed due to its weak relationship to the "Upper Limb Performance" factor. The name of the factor was the same as in the previous case in the first version of the test battery "Performance of Locomotive Organs".

Table 72

Fit of the 1-factor model performance tests 2. version of test battery without tests SCN, CM, MF and SL (child population)

Model	Chi-square	P-value	df	CFI	TLI	RMSEA	SRMR
1-factor	31.90	0.0002	9	0.94	0.91	0.108	0.041

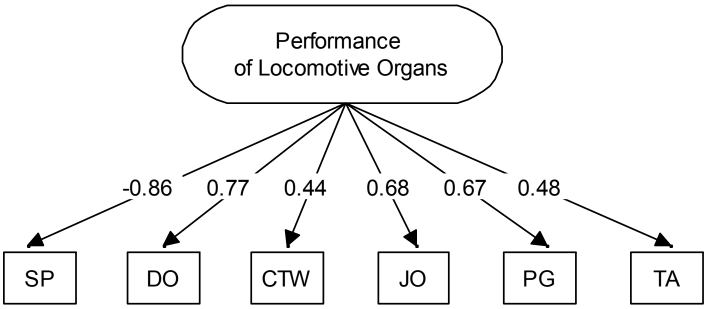
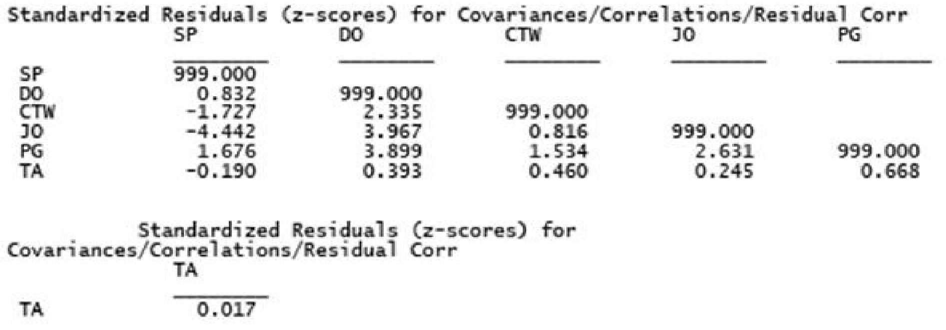


Fig. 39 Path diagram 1-factor model performance tests 2. version of test battery without tests SCN, CM, MF and SL (children population)

This one-factor structure with six indicators did not show satisfactory model fit values. All indices reached below-average values, including model significance. Despite the fact that the quality of this model was low, the approximation of generic reliability (Tab. 74) was the only one to meet the diagnostic quality with it value. However, this model was found unsatisfactory, also based on the results of the residual covariance matrix, which displayed high unexplained residuals; the model was therefore rejected.

Table 73

Residual matrix 1-factor model performance tests 2. version of test battery without tests SCN, CM, MF and SL (child population)



```
Standardized Residuals (z-scores) for Covariances/Correlations/Residual Corr
                SP            DO            CTW           JO            PG
              ________      ________      ________      ________      ________
 SP           999.000
 DO             0.832       999.000
 CTW           -1.727         2.335       999.000
 JO            -4.442         3.967         0.816       999.000
 PG             1.676         3.899         1.534         2.631       999.000
 TA            -0.190         0.393         0.460         0.245         0.668

          Standardized Residuals (z-scores) for
Covariances/Correlations/Residual Corr
                TA
              ________
 TA             0.017
```

Table 74

Generic reliability – performance tests 2. version (child population)

Name of the factor	McDonald ω
Peformance of Locomotive Organs	0.81

Summary:

The model chosen as the best was the one-factor model of performance tests from the first version of the test battery, which met all requirements of diagnostic quality, including the acceptable level of the diagnostic error of the construct approximated by the coefficient McDonald ω = 0.83.

The adopted one-factor structure of performance tests consists of six indicators. The motor tests SP (Tracing the spiral) and DO (Dot-filling fine motor test) are focused on fine motor activity involving mainly the distal part of the upper limb, i.e., hand and fingers. While the SP test emphasizes the rotational movements of the wrist to keep the firmest spiral line, the DO test is focused on controlled flexion and extension in the wrist with the requirements for targeting the tool in small space. The motor test TW (Moving beads from one box into another using tweezers) combines the activity of the distal and proximal parts of the upper limb, the more difficult part being the handling of the tweezers in the hand and grasping the bead. However, in addition to difficulties in grasping the bead with the non-preferred upper limb, an important phenomenon in this test was also the problem of estimating the distance when moving the beads from one box into another. A new approach to assessing the upper limb performance is represented by the BTW test (Turning a box alternately with the front and the rear side on the table), which involves the entire upper limb from the proximal to distal part, while the movement coming from the shoulder joint represents hand pronation and supination. When this test was being performed with the non-preferred limb, greater accompanying movements of the preferred hand that were supposed to be passive were observed in children. The JO test (Measuring articular passivity in order to diagnose cerebellar dominance) was the last indicator related to upper limb performance. Surprisingly, the JO test did not display the weakest factor validity in this case. In both versions for the child population in diagnosing motor manifestations of laterality, the test exhibited a stable strength of the relationship to the "Preference of Locomotive Organs " factor. This fact thus indicates the relationship between motor manifestations of laterality and cerebellar dominance (in the form of the physiological extinction syndrome), proposed by Professor Henner, also in the child population.

The only test that determines the different performance between the lower limbs was the TA test (Lower limb tapping), which displayed the weakest factor loading in the adopted one-factor model. However, given the functional differences of upper and lower limbs, this degree of relationship is understandable. Interestingly, this diversity was not as sharp in the child population as in the adult population. It was already found in the course of the testing that children are able to distinguish very well the preferred lower limb in preference motor tasks. However, the borders were blurred in the manipulative tests determining differences in dexterity between the preferred and non-preferred lower limb. Both lower limbs displayed the same unskilfulness. This fact could be explained by lower requirements concerning the stabilization of the lower limb lateralization in children that subsequently result in the stabilization of both preference and observable proficiency (fine motor activity) of the lower limb. This hypothesis was also supported by the results of analyses which showed that the tests focusing on finer activity of the lower limb or the foot alone showed instability, and thus were not appropriate for the child population.

13. SCORING

Although the scoring of the items in the newly created test batteries is not the primary objective of this thesis, we decided to design a simple scoring for practical use and interpretation of results. We realize that it is necessary to take into account the diversity of weights of individual indicators, as well as the non-linearity of the results, in the precise scoring of categorical items and interval tests. All these aspects go beyond the objectives and possibilities of this thesis; therefore, we believe that the creation of high-quality scales for the precise interpretation of the results obtained from the diagnosis of motor manifestations of laterality is a task for a specialized study.

Questionnaire score sheet (adult population):

Interpretation of results:

We chose for scoring a five-point scale with values 0, 25, 50, 75, and 100. Each of these values represents specific degree of preference. Since the chosen numbers are ordered according to their magnitude from the left to the right, we assign number 0 to each of the items 2 – 7 in case that the subject responds that s/he always uses left limb in given situation. We assign number 25 to each of the items 2 – 7 in case the subject responds that s/he rather uses left limb in given situation. We assign number 50 to each of the items 2 – 7 in case that the subject responds that s/he does not have any preferred limb for given situation. We assign number 75 to each of the items 2 – 7 in case that the subject responds that s/he rather uses right limb in given situation. We assign number 100 to each of the items 2 – 7 in case that the subject responds that s/he always uses right limb in given situation. Since the item is reverse, we assign number 100 in case that the subject responds that s/he always uses left limb; 75 in case s/he rather uses left limb; 50 in case s/he does not have any preferred limb for given situation; 25 in case s/he rather uses rather right limb and 0 in case that the subject always uses right limb in given situation.

The laterality quotient is then the product of number 100 and fraction, where the numerator is the addition of numbers assigned to all items, and the denominator is the addition of maximum achievable values (i.e. 700).

$$LQ = \frac{\sum_{1}^{7} x_i}{700} * 100$$

where x_i is the number assigned to the i-th attempt

Values of LQ are in the interval <0, 100>

If the LQ is in the interval <0, 50), the individual is left-sided and it is true that the more the coefficient approaches values 50, the more the left-side preference of the subject decreases. If the LQ is in the interval (50, 100>, the individual is right-sided. The more the value of the coefficient approaches the value 100, the more the right-side preference of the subject is stronger. If the result for the subject has value 50 in the questionnaire part, the individual is ambilateral with no preference.

Preference tasks:

Interpretation of results:

To asses this part of the test battery, we use essentially the same formula for each factor as in the questionnaire part.

Since the factor of upper limb preference contains indicators with more than one attempt, the laterality quotient (LQ) of these factors must be calculated for *n* attempts partial.

We thus get for given indicators:

$$LQ = \frac{\sum_{1}^{n} x_i}{n * 100} * 100, \text{ where}$$

x_i.......... is the number assigned to the i-th attempt

n........... is number of attempts

The values of the laterality quotients of both factors lie in the interval <0, 100>

The benefit of the preference tasks part is that “partial” LQs, i.e. laterality quotients of indicators with repeated attempts, allow us to better determine the degree of sidedness. The case that LQ = 50, is not possible, i.e. a certain degree of lateralization is always manifested.

If the LQ is in the interval <0, 50), the individual is left-sided and it is true that the closer the coefficient is to the value of 50, the more the left-side preference of the diagnosed person decreases. If the LQ is from the interval (50, 100>, the individual is right-sided. The closer the coefficient is to the value of 100, the more the right-side preference of the diagnosed person increases.

Performance tests:

Interpretation of the results:

The third part of the test battery compares the "skilfulness" of both paired limbs. The individual tests show which of the two limbs is:

1) more efficient within the time provided ....tests of the 1st type
2) faster in the performance of the required quality ....tests of the 2nd type

In the tests of the first type, performance of the left and right limb in a given time is compared, i.e. time is constant. The laterality quotient LQA shows here the share of performance of the right limb in the total, i.e. 100% performance of both limbs. This is determined based on the formula $LQ = \frac{R}{R+L} * 100$, where R is the numerical assessment of the performance of the right limb, and L is the numerical assessment of the performance of the left limb.

In the tests of the second type, the times needed to perform the test in the required quality using either of the paired limbs are compared.

The time of the right limb is denoted as R, the time of the left limb as L, so the expression $\frac{1}{R}$ expresses the part of the test performed in a unit of time (i.e. performance) by the right limb. Likewise, the expression $\frac{1}{L}$ is used. In order to calculate LQ, the formula with the numerical expression of performances is used again:

$$LQ = \frac{\frac{1}{P}}{\frac{1}{P} + \frac{1}{L}} * 100$$

Based on the algebraic adjustment, the result is:

$$LQ = \frac{\frac{1}{P}}{\frac{L+P}{PL}} * 100 = \frac{1}{P} * \frac{PL}{L+P} * 100 = \frac{L}{L+P} * 100$$

$$LQ = \frac{L}{L+P} * 100$$

Interpretation of the indicator "Determination of articular passivity in the wrist"

After measuring the angles in the wrists of both upper limbs, the following relation is used:

Angle α, right wrist ..... R
Angle α‘, left wrist L

(R–L RELATION)

a) if the angle α at the wrist of the right limb R is greater than the angle α‘ at the wrist of the left limb L – R > L, LQ = 100 – estimated dominance of the left cerebral hemisphere for motor activity

b) if the angle α at the wrist of the right limb R is equal to the angle α‘ at the wrist of the left limb L – R = L, LQ = 50 – estimated uncertain dominance of the cerebral hemispheres for motor activity

c) if the angle α at the wrist of the right limb R is less than the angle α‘ at the wrist of the left limb L – R < L, LQ = 0 – estimated dominance of the right cerebral hemisphere for motor activity

14. DISCUSSION

The aim of this study was to contribute to the standardization of new diagnostic tools – test batteries – assessing motor manifestations of laterality in adults and children aged 8–10 years. It included:

determination of the theoretical concept;
selection of appropriate items;
verification of structural hypotheses concerning the proposal of acceptable models;
expression of diagnostic quality of the individual parts of the test batteries.

Similarly to Annett, Oldfield, and Bryden (Annett, 1970; Oldfield, 1971; Bryden, 1977), motor manifestations of laterality were considered to be continuous latent variables.

The discussion is divided into two parts. The first part deals with the test battery for the adult population; the second part deals with the test battery for the child population aged 8–10 years.

a) The test battery for the adult population:

The test battery for the adult population consists of three parts:

questionnaire;
preference task;
performance test.

The questionnaire part of the test battery has a unidimensional nature called "Preference of Locomotive Organs". This is consistent with the results presented by Suar et al. (2007), who, using the CFA, established the one-factor structure of questions assessing upper and lower limb preference as the most suitable (Suar et al., 2007).

The five-point Likert scale that we chose to assess individual levels of preference within the questionnaire proved to be sufficiently precise. We also focused on a clear definition of individual levels of preference and instructions on how to distinguish them. These instructions are not included in most previous studies (Annett, 1970; Oldfield, 1971; Sharman, & Kulhavy1976), so the results can be distorted by the subjective view of the respondent.

The questionnaire does not contain items of a bimanual nature. The CCFA analysis of the questionnaire items showed that the items of a bimanual nature displayed weak factor loadings, and they probably form a different dimension, as opposed to unimanual questions. This finding supports the results of the studies by Dragovic (2004), Büsch (2010), and Bryden and Steenhuis (1989), who point out that the multidimensionality of hand preference depends on the type of activity (Bryden & Steenhuis, 1989; Büsch et al., 2010; Dragovic, 2004).

The final structure of the questionnaire part is consistent with the results of the previous studies, which point out the fact that the strongest indicators are questions of a skilled and instrumental nature (Annett, 1998; McManus, 2002). The structural equation modelling (SEM) of the questionnaire part showed that the traditional questions (which hand do you use to write; which hand do you use to draw; and which hand do you use to hold a spoon while eating) are redundant. Motor activity covered by these questions is likely to be subject to cultural and social pressure. With respect to these indicators, a strong multicollinearity and interference in the structural model was detected. This finding is contrary to the trends of hand preference questionnaires where the aforementioned items are very often used (Annett, 1985; Bryden, 1977; Coren, 1993; Oldfield, 1971; Porac, & Coren, 1978).

When analyzing the data, multicollinearity was also found in some items assessing lower limb preference. The CCFA results showed that the variability of lower limb motion patterns is probably more limited than in upper limbs, based on their function. Therefore, the structure of the questionnaire contains only one question directly determining lower limb preference (kicking the ball). Other questions of this nature (one supporting lower limb, one leading lower limb) were redundant in the models. We could only reveal this fact using the selected statistical techniques. Therefore, our questionnaire was different from the previously compiled questionnaires (Porac, & Coren, 1978; Coren, 1993), which contain more items of this type. The studies by Porac and Coren (1978) only used the test-retest method to determine the stability of responses over time. The questionnaire by Coren (1993) only refers to the results of the exploratory factor analysis presented in a study by Porac and Coren (1981), which identified a cluster of questions suitable for the determination of lower limb preference. The exploratory factor analysis, however, does not show collinearity; in addition, the authors worked with Pearson’s correlation coefficient, which is not suitable for ordinal data type.

An interesting finding is that the best structural model of the questionnaire also includes an item relating to rotation. This item indirectly estimates lower limb preference. It was the first time that its relationship to the concept of motor manifestations of laterality was expressed in a questionnaire. Although this item shows the weakest factor validity in relation to the selected specific concept, it could not be removed, in order to guarantee the most appropriate model. The result indicates that rotation and motor manifestations of laterality are probably closely linked, which would support the hypothesis of the study presented by Mohr et al. (2003) and Štochl & Croudace (2012, in press).

Given the complexity of sensory organs and the differences in experts' opinions regarding their laterality, we believe that it is inappropriate to include items assessing eye and ear dominance in the questionnaire survey, as is the case in the studies by Bourassa and Coren (Bourassa et al., 1996; Coren, 1993).

We are aware that the diagnostic tool in the form of a questionnaire is, to a certain degree, affected by the subjectivity of the respondent, and we therefore agree with the views of Nisbett and Wilson (1977), Bryden (2000), and Brown et al. (2006). Furthermore, we believe that a questionnaire determining motor organ preference using a five-point scale is an appropriate screening tool only for the adult population, based on imagination and the assumption of a certain level of abstraction.

Preference tasks:

Within the test battery, the preference motor task part has a two-factor structure consisting of the "Upper Limb Preference" and "Lower Limb Preference" factors. As in the case of the questionnaire part, this part also confirmed that the strongest indicators are instrumental skilled tasks. This finding supports the hypotheses of those authors who believe that the questions in the questionnaire assess motor organ preference as precisely as motor tasks (Bryden, McManus, & Bulman-Fleming, 1994; Oldfield, 1971; Sharman, & Kulhavy, 1976; Singh, Manjary, & Dellatolas, 2001).

When modelling and selecting the most appropriate preference tasks, it was revealed that the diagnosis should also contain indicators that do not display a skilled instrumental nature. These indicators do not seem to be affected by the possible imitation or targeted learning of the activities. Within the "Upper Limb Preference" factor, it is the CL indicator (Clap your hands), and within the "Lower Limb Preference" factor, it is the HOP indicator (Perform jumps forward using one leg).

We believe that the combination of skilled and unskilled indicators presents a more precise assessment of upper and lower limb preferences.

In our model, the unskilled indicators display the weakest factor validity, so they could probably form a different dimension. This view supports the assumption of Bryden and Steenhuis (1989), who, using the principal component method, determined that the items assessing upper limb preference (questions in the questionnaire and motor preference tasks) can be divided into the skilled factor and the unskilled factor (Bryden, & Steehuis, 1989). Likewise, these views support the assumption of Kalaycioğlu et al. (2008), who, using the exploratory factor analysis, showed that lower limb preference is probably multidimensional in nature and that skilled and unskilled preference activities exist separately (Kalaycıoğlu, Kara, Atbaşoğlu, & Nalçacı, 2008).

Therefore, we believe that the indicators that are not of a skilled nature helped establish the two-factor structure.

The correlation between the factors at the level r = 0.78 shows that both the "Upper Limb Preference" factor and the "Lower Limb Preference" factor measure a similar area of the determined concept. Thus, an interesting finding was that the SEM displayed a significant deterioration in the model fit in designing a bi-factor structure and hierarchical structure. We believe that there is a general factor, "Preference of Locomotive Organs", behind these two factors. Furthermore, we believe that if the preference task part only contained skilled indicators, the structure could have a unidimensional nature with the "Preference of Locomotive Organs in Skilled Activities" factor.

Performance tests:

The performance tests have a two-factor structure with the factors "Upper Limb Performance" and "Lower Limb Performance". In line with other studies (Annett, 2002), our results also showed that if an upper limb test has a more fine motor nature, it reflects the specific concept of performance more strongly (Annett, 2002). The following tests in particular were used: SP (Tracing the spiral) and DO (Dot-filling fine motor test). In the process of SEM, the "pegboard test" had to be excluded from the final version. This is at variance with the fact that this test is described in the literature as particularly relevant to assessing the level of upper limb fine motor activity (Annett, 1985; Brown, Roy, Rohr, & Bryden, 2006; and others). In our view, the aforementioned fact is caused by the low sensitivity of the test. The substantive significance of the difference in the performance of both upper limbs in this test was found to be inadequate. The difference in the performance of both upper limbs averaged 2 pins. Therefore, the question is whether a longer period of time is necessary for testing or whether the test has to be more difficult for the adult population.

By contrast, the JO indicator (Measuring articular passivity in order to diagnose cerebellar dominance), which represents a new approach in the estimation of natural hemispheric dominance, proved suitable in this model. Despite the completely different nature of this indicator, it was found that it is significantly related to motor manifestations of laterality. Its relationship to upper limb performance was significant. This result supports the hypothesis of Professor Henner (1927) and recent studies by Tichý & Běláček (2008) about the connection of the cerebellar extinction physiological syndrome and handedness (Henner, 1927; Tichý & Běláček, 2008). However, we are aware that the execution of the test is purely of a field nature. This test could reflect an examiner's error, resulting from practical (in)experience with the measurement of angles and proportions of the human body. We believe that in order to determine the specific reliability of this test it will be necessary to carry out more extensive measurements, perhaps even by more examiners. It was very interesting to observe that about 30% of left-handed subjects showed a reverse articular passivity, i.e., according to the results of this test, they would have been categorized as right-handers. It is possible that this finding is related to the long-debated question as to the extent to which laterality is determined genetically. The reverse asymmetry of articular passivity observed in some left-handed individuals could indicate the original genetic makeup, according to which these individuals should be right-handed. Due to the environment and stressors, this right-sided tendency could have been changed.

The lower limb tests did not confirm the assumption that if a test has a finer motor nature, it differentiates the performance of both lower limbs better. The strongest test of the "Lower Limb Performance" factor was TA (Lower limb tapping), which is not focused on the quality of movement, but on the speed of movement and balance. In our view, this fact is caused by the functional orientation of lower limbs, which are not free for work and which primarily perform the stabilization and locomotor functions.

The correlation between the factors "Upper Limb Performance" and "Lower Limb Performance" at the level $r = 0.56$ indicates that these factors probably have a common general basis in the form of the assessment of motor organ performance. However, the different functions of both paired motor organs cancel out this correlation, and they probably indicate a different control of the motor activity of upper and lower limbs.

b) Test battery for the child population:

The test battery for the child population consists of only two parts: preference tasks and performance tests. The questionnaire part was deliberately not included due to the undeveloped abstraction and imagination in the self-assessment of the level of preference.

Preference tasks

This part of the test battery has a two-factor structure with the factors "Upper Limb Preference" and "Lower Limb Preference". The results of SEM showed that strong factor loadings are displayed by motor tasks of a manipulative nature (Throwing at the target; Ringing the bell; Kicking the ball). This finding is consistent with the study by Kastner-Koller et al. (2007).

The "Upper Limb Preference" factor also displayed a strong relationship of the reaching tasks – CAB (According to the instructions, turn the cards of the given colours placed on the sheet of paper) and MAR (Create a line in the marked space using matches) – where the subject can repeatedly work across the natural body axis. As in the study by Doyen & Carlier (2002), it has been shown that the tasks in which motor activity is repeated several times are a sensitive indicator of the degree of upper limb preference (Doyen, & Carlier, 2002). We believe that, unlike in traditional unimanual tasks, the perspective of an advantage or disadvantage in handling an object across the body axis is the main indicator of preference in reaching tasks. Therefore, in our view, these tasks should form the basis for determining upper limb preference.

A surprising result was that the "Lower Limb Preference" factor also contained, in the final form, motor tasks related to the rotation attribute – SLI (While standing, demonstrate how you slide without the support of your hands) and TU (Stretch your arms sideways and make a 360-degree turn around your axis). These indicators measured lower limb preference indirectly, and they, of course, displayed the weakest factor loadings in connection with the aforementioned factor; however, these factor loadings were significant. This finding supports the results of the recent study by Štochl and Croudace (2012, in press), who, using structural equation modelling, showed a significant relationship of laterality of motor organs and rotation (Štochl, & Croudace, 2012, in press). The resulting factor loading of the TU item (Stretch your arms sideways and make a 360-degree turn around your axis), TU = –0.45, also supported the results of previous studies (Mohr, Landis, Bracha, & Brugger, 2003). These show that right-sided individuals turn more to the left, i.e., towards their left shoulder.

The correlation between the two factors at the level r = 0.71 again showed a common basis of these two latent variables, which can be called “Preference of Locomotive Organs”. However, the correlation was not as strong as in the preference tasks for the adult population. This finding could possibly be explained by the presence of indicators measuring the rotation attribute, apart from lower limb preference.

Performance tests:

The performance tests have a one-factor structure with the “Performance of Locomotive Organs” factor. The upper limb tests also showed that if a test has a more fine motor nature, it differentiates the performance of both upper limbs better (Annett, 2002). The CFA of the performance tests revealed an evident ontogeny of children’s motor activity, which is also reflected in motor manifestations of laterality.

The upper limbs, which are used to handle objects from an early age, did not show, in comparison with the adult population, significantly worse performance in the fine motor tests – SP (Tracing the spiral) and DO (Dot-filling fine motor test). There are not many studies dealing with the preparation of tests for the determination of performance for the child population. Therefore, these findings could be used as guidelines in further research.

The JO indicator (Measuring articular passivity in order to diagnose cerebellar dominance), which represents a new approach in the estimation of natural hemispheric dominance, as in the test battery for the adult population, also proved to be suitable in this model. The factor loading of this test was even higher than in the test battery for the adult population. As in the first part of the discussion, this result supports the hypothesis of Henner (1927) and recent studies by Tichý & Běláček (2008). Of course, a question arises also in this case as to the extent to which this form of field form of the test is reliable and sensitive. It was very interesting to find that even the child population showed about 25% left-handed individuals who displayed a reverse articular passivity, i.e., according to the results of this test, they would have been categorized as right-handers. This finding further deepened our assumption of the genetic determination of laterality, including cerebellar dominance. As in the case of the results of the adult population, this reverse asymmetry of articular passivity could indicate the original genetic makeup that was changed by environmental stressors.

The tests designed for lower limbs, i.e., limbs which are not used for specific activities in this age, did not show significant differences in the performance of both limbs in the SL test (Slalom with a ball between obstacles) and the MF test (while standing, moving a cube in the "maze" provided). The results in the determination of lower limb performance were very unstable in these cases. The more the activity displayed a fine-motor nature with an emphasis on balance, the less sensitive the test was. The TA test (Lower limb tapping) proved to be the strongest test assessing lower limb performance. Surprisingly, this test was the only appropriate test to assess the difference in the performance of both lower limbs of children aged 8–10 years. In our view, these findings can be explained by the slower fixing of lower limb laterality, which may end as late as after the pubescent period. If the lower limb tests were performed without the need for balance, children might display a better concentration on the activity itself, which could lead to the increased sensitivity of the test.

An additional task when evaluating motor manifestations of laterality was LT (Use the tube to look at the object), which, using the sighting factor, determined eye dominance. The correlation of the results between handedness and this task is reported around 80%. Interestingly, the LT task in this study, in both populations, more strongly correlated with indicators assessing lower limb preference. This result does not support the current hypotheses; on the contrary, we believe that it could indicate that eye dominance and lower limb preference are not affected by social pressure.

The results of the study confirmed the hypothesis H1, which assumed that at least 75% of the final indicators of both versions of the test batteries would have a factor validity of at least 0.6. This assumption was very important in confirming the hypothesis H2, i.e., that generic reliability of individual constructs would be at least 0.75. Generic reliability of all constructs of both test batteries ranged from 0.78 to 0.95. By contrast, the hypothesis H3 was refuted, because not all parts of both test batteries had a multidimensional structure. The questionnaire part for the adult population and performance tests for the child population have a one-factor structure. By determining the factor loadings of the JO indicator (Measuring articular passivity in order to diagnose cerebellar dominance) of both test batteries, the hypothesis H4 was confirmed. Both of these factor loadings of the indicator assessing cerebellar dominance in the performance part were significant in both test batteries, reaching the level of $p < 0.001$. The results also showed that motor tasks in which the subject can work across the natural body axis are very sensitive indicators in assessing the level of upper limb preference. This was shown especially in the child population, and this finding confirmed the hypothesis H5, which had assumed a high significance of these indicators, at the level of $p < 0.001$.

15. CONCLUSION

The result of the thesis is the construction of two test batteries for the diagnosis of motor manifestations of laterality. One is intended for the adult population, and the second for children aged 8–10 years. Both have a clear structure and diagnostic quality. The generic reliability of both test batteries ranges between McDonald ω 0.78 and 0.95.

The test battery for the adult population consists of a questionnaire part, a preference motor task part, and a performance test part; it includes a total of 23 indicators. For the first time, the structure of these three diagnostic methods (which are otherwise used separately) was verified together, using SEM.

As the only part in this test battery, the questionnaire has a unidimensional structure with the "Motor Organ Preference" factor. The generic reliability of the "Preference of Locomotive Organs" factor is McDonald ω = 0.89.

The preference motor tasks have a two-factor structure with the factors "Upper Limb Preference" and "Lower Limb Preference". The generic reliability of the "Upper Limb Preference" factor is McDonald ω = 0.89. The generic reliability of the "Lower Limb Preference" factor is McDonald ω = 0.85.

The performance tests also have a two-factor structure with the factors "Upper Limb Performance" and "Lower Limb Performance". This part of the test battery found a significant relationship between the "Upper Limb Performance" factor and a manifestation of cerebellar dominance in the form of articular passivity in the wrist. The generic reliability of the "Upper Limb Performance" factor is McDonald ω = 0.82. The generic reliability of the "Lower Limb Performance" factor is McDonald ω = 0.78.

The test battery for the child population has two parts, preference motor tasks and performance tests, and it contains 16 indicators. For the first time, the structure of these two diagnostic methods was verified together, using SEM.

The preference motor tasks have a two-factor structure with the factors "Upper Limb Preference" and "Lower Limb Preference". In the "Upper Limb Preference" factor, the indicators where the subjects could work across the natural body axis were first tested. The results showed that these indicators have a high correlation to the given factor, i.e., they are very sensitive indicators in assessing the level of upper limb preference.

The generic reliability of the “Upper Limb Preference” factor is McDonald ω = 0.95. The generic reliability of the “Lower Limb Preference” factor is McDonald ω = 0.81.

The performance tests have a one-factor structure with the “Performance of Locomotive Organs” factor. The child population also displayed a significant relationship between this factor and indicator evaluating cerebellar dominance, JO = 0.64. The generic reliability of the “Performance of Locomotive Organs” factor is McDonald ω = 0.83.

The construction of both test batteries and the results of SEM showed that the long-debated dimensionality of the theoretical concept of motor manifestations of motor organ laterality is different in adults and children, probably due to the ontogeny of human motor activity. The results of the verification of the structural hypotheses also show that the level of dimensionality is based on the different functionality of limbs and their parts, as well as on the character of the indicators that are (in different degrees) subject to socio-cultural pressure. Socio-cultural pressure can apparently affect the human motor control in some socially ingrained unimanual activities, which, in this study, often showed collinearity in the process of SEM. Therefore, we assume that the assessment as well as (primarily) scoring and interpretation of the results of motor manifestations of laterality will remain a challenge for researchers with respect to the understanding of the functional asymmetry of cerebral hemispheres, due to complex genetic, physiological, and social interaction.

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17. APPENDIX

ADULT POPUALTION:

A) Questionnaire part

Name of the item	λ*
Which hand do you use to hammer a nail into wood? **	-.85
Which hand do you use to hold a rubber when erasing?	.88
Which hand do you use to hold a toothbrush when brushing your teeth?	.93
Which hand do you use to hold a knife when cutting bread?	.85
Which hand do you use to hold a key when unlocking the door?	.68
Which foot do you use to kick a ball?	.65
While standing, which of your lower limbs do you place forward when you want to slide without the support of your hands?	.52

* *factor loading*

** this item is scored reversly, the person being tested is not deliberately asked about the preferred upper limb but about the non-preferred upper limb in order to hold the attention of the persons being tested

B) Preference tasks

Name of the item	λ*
Throw the ball at the target	.96
Use the pointer to point at the following objects**	.86
Erase the lines	.85
Clap your hands	.46

* *factor loading*

** *this task is performed across the natural body axis of the individual*

Name of the item	λ*
Kick the ball at the target	.86
Demonstrate how you would write the letter T on the floor using one of your feet	.97
Perform jumps forward using one leg	.57

** factor loading*

Eye dominance

Name of the item
Use the tube to look at the object

C) Performance tests

Name of the item	λ*
tracing the spiral**	-.83
threading beads on a metal wire	.64
dot-filling fine motor test	.87
measuring articular passivity in order to diagnose cerebellar dominance	.58

** factor loading*

*** time is not a constant in this test, so the factor loading indicates a negative value*

Name of the item	λ*
while sitting on a chair, moving a cube in the “maze” provided**	-.72
while standing, slalom with a ball between obstacles**	-.61
lower limb tapping	.84

** factor loading*

*** time is not a constant in these tests, so the factor loadings indicates a negative values*

CHILD POPULATION

A) Preference tasks

Name of the item	λ*
Take the ball in one hand and throw it at the target	.91
Take the bell in one hand and ring it	.90
According to the instructions, turn the cards of the given colours placed on the sheet of paper	.88
Create a line in the marked space using matches	.91
Show how many points you can roll with the dice on three attempts	.93

* *factor loading*

Name of the item	λ*
Kick the ball placed on the floor at the target	.90
Using one foot, tap the rhythm that I am clapping	.86
While standing, demonstrate how you slide without the support of your hands	.54
Stretch your arms sideways and make a 360-degree turn around your axis	-.45

* *factor loading*

Eye dominance

Name of the item
Use the tube to look at the object

B) Performance tests

Name of the item	λ*
tracing the spiral**	-.81
moving beads from one box into another using tweezers	.63
dot-filling fine motor test	.82
measuring articular passivity in order to diagnose cerebellar dominance	.64
turning a box alternately with the front and the rear side on the table	.67
lower limb tapping	.54

* *factor loading*

** *time is not a constant in this test, so the factor loading indicates a negative value*