REVIEW

Laterality in children: cerebellar dominance, handedness, footedness and hair whorl

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Submitted: 2008-05-21 *Accepted: 2008-06-09*

Key words: **cerebellar dominance, handedness, footedness, hair whorl, ocular and vestibular dominance**

Act Nerv Super Rediviva 2009; **51**(1-2): 9–20 **PII:** ANSR51129R02

Abstract

The purpose of our study was to ascertain the degree of correlation between handedness and physiological neocerebellar extinction syndrome demonstrable on the side contra lateral to the dominant upper extremity. Using the Edinburgh questionnaire and other tests for "handedness", we examined 221 healthy 9–11-year old schoolchildren for hand-use preference. To test their handedness the following 6 mutually indistinguishable tests (p<0.001) were found the most reliable: writing, drawing, holding a knife, scissors, and spoon and striking a match. Congruent response or test outcomes were used for the definition of pure (100%) right-handers (n=166) and pure (100%) left-handers (n=13); the rest were rated as ambidexters (n=42). Cerebellar dominance was ascertained clinically by means of palpation and aspection; by the presence of physiological muscle hypotonia in the extremities contra lateral to the dominant upper extremity in right-handers and in left-handers. In addition to these signs of laterality, we have studied also other questions and tests (totally 34) of handedness and footedness, recorded the hair whorl form, ocular dominance and the direction of turning while standing or walking.

Our findings: 1) Enhanced mirror movements in the non-dominant upper extremity while walking and greater passivity in the wrist, elbow, knee and ankle. 2) For one-foot skipping and for ball kicking the percentage of foot preference was approaching that of hand preference; half the pure right-handers used the left foot for take-off, half the pure left-handers used the right foot for take-off. 3) Physiological hypotonia was also found in the take-off foot for jump-over with what is known as crossed dominance of foot and hand ($p < 0.05$), thus proving that "neocerebellar dominance" manifests itself in accordance with hand dominance. 4) The ocular dominance depends on handedness (by eye preference at looking into a key-hole or a monoskope). 5) Trunk rotation to the left in right-handers and to the right in left-handers lacked statistical consistence. 6) The hair whorl direction was not in agreement with right-handedness or cerebellar dominance associated with it.

1. Introduction

Laterality may be denoting as the asymmetry in the degree of physiological involvement of the left or right cerebral hemispheres in all sorts of activities, mainly in language and symbolic functions. Right- or left-handedness, i.e., preference for one of the upper limbs as used in everyday life in comparison with the "language dominant hemisphere" has been a subject of keen interest of generations of anthropologists, physicians, psychologists, pedagogues, geneticians and other natural scientists.

Standing at the peak of the evolution of species, man has a unique cerebral make-up for abstract thought, speech and for the preferential use of one of the two upper limbs in handling tools. The origin of human handedness remain unknown (Vuoksimaa *et al* 2009). Motor preference of one limb exist in animals (Halpern *et al* 2005; Tommasi 2009). Ever since the days of the founders of aphasiology (Broca 1865; Wernicke 1874), the problem of laterality has been studied by countless individuals and research teams. All seem to share the general view that – relative to the number of right-handers, left-handers and ambidexters – the mechanisms of language and associated symbolic functions are localized in the cortico-subcortical structures of the left cerebral hemisphere in 90–95% of individuals of any ethnicity. In a large proportion of healthy persons, left-handedness – as much as right-handedness – is known to be associated with the left hemispheric localization of language structures and functions (McManus 1999; Khedr *et al* 2002; Szaflarski *et al* 2002). Pure left-handers may have their language centres in the right hemisphere at a rate of 27% (Knecht *et al* 2000) or even higher (up to 69%) (Isaacs *et al* 2006). A small proportion of right-handers may have their language centres in the right hemisphere (Provins 1997; Chee & Caplan 2002; Chee *et al* 1998; Knecht *et al* 2000). Not all sinistrality has a pathological basis (Leiber & Axelrod 1981). The relatively rare condition of crossed aphasia (Marien *et al* 2004) has been studied in at least 166 communications.

Heritability of laterality has been studied in many papers (Annet 1998; 1999; 2008). The genetic factor and language centre localization have been studied by Geschwind and Galaburda (1985), Sicotte *et al.* (1999), Geschwind *et al.* (2002), McManus (1999), Laland *et al.* (1995) and Bishop (2001). The evolution of species during millions of years has been discussed by Corballis (2003; 2006), Wohlschlager & Bekkering (2002), Arbib (2005), Gentilucci & Corballis (2006). The presence of laterality in vertebrates and intervertebrates has been described by Tommasi (2009), Halpern *et al.* (2005).

Handedness independence of language lateralization was demonstrated by Wood *et al.* (2004), Isaacs *et al.* (2006). According to Lindell (2006) the right hemisphere is not completely lacking linguistic ability. The phenotype of handedness is different in different geographical regions (Leask & Beaton 2007; Holder & Kateeba 2004). Socioeconomic relations and handedness were studied by Faurie *et al.* (2008), Cheyne *et al.* (2009). The complexity of interhemispheric coordination relative to musicality, speech and its symbols, prosody, absolute pitch and melody, musical memory or skills in playing musical instruments have been studied by many authors (e.g. Limb 2006; Gaab *et al* 2006; Kostalova *et al* 2006; Tichy 1995; 2006a; Brancucci *et al* 2009).

Hatta (2007) compared the results of authors studying human "handedness" using neuroimaging methods over the past 12 years in an effort to find an agreement between anatomical and functional findings. He found inconsistence in the degree of handedness in left- and right-handers, and differences between genetic and environmentally-modulated models. Somesthetic asymmetry and the degree of handedness have been studied by Illingworth and Bishop (2009), Vingerhoets and Sarrechia (2009). The relation between handedness, footedness, ocular and auditory dominance in India has been studied by Suar *et al.* (2007). Kang and Harris (2000) have reported about handedness-footedness in students. Handedness and footedness were studied electrophysiologically by Hanley (2002). Switched pattern of handedness and footedness were reported by Martin and Porac (2007). In our present study we refrained from exploring the localization of speech centres. For data on crossed cerebro-cerebellar dominance as, for instance, for speech, we refer to Leiner *et al.* (1991), Pillai *et al.* (2003), Jansen *et al.* (2005).

Countless works have so far been undertaken to document the growing structural asymmetry of the brain and the specialization and differentiation of its constituent areas in both ontogenetic and phylogenetic development. It is only of late that cerebellar hemispheric dominance for cognitive, emotional and other "memory"-related functions has received increased attention (Allen *et al* 2005; Sens & de Almeida 2007; Hu *et al* 2008; Baillieaux *et al* 2008; Hautzel *et al* 2009).

Thanks to Kamil Henner (1927), Czech neurology can boast detailed clinical diagnostics of paleocerebellar regulatory "extinction" functions (asynergy, astasia, ataxia in standing and walking) as well as neocerebellar control functions taking the form of dysmetria and ataxia due to hypermetria, dysdiadochokinesia-adiadochokinesia and increased passivity (cerebellar muscle hypotonia). These symptoms are ipsilateral to the hypo functional cerebellar hemisphere. The dominant cerebellar hemisphere is situated on the side contra lateral to the dominant hemisphere of the forebrain. A minor physiological neocerebellar "extinction" syndrome can be diagnosed in the non-dominant extremities, i.e., left-sided limbs in right-handers and vice versa (Henner 1927; Cernacek 1977; Tichy 2006b). A close co-activation between dorsolateral prefrontal cortex and contra lateral neocerebellum was described by Diamond (2000).

We have described in Tichy and Belacek (2007; 2008) the physiological neocerebellar extinction syndrome as taking the form of clinically identifiable minor muscle hypotonia and moderate passivity also in the cross-preferred lower extremity. We wondered how strong the correlation was between handedness (ascertained with the Edinburgh questionnaire together with other tests and other manifestations of laterality such as footedness, hair whorl, ocular and vestibular dominance) and cerebellar dominance in 9–11-year old healthy children.

2. Material and methods

2.1 Participants

In co-operation with a number of primary schools in Prague we compiled a modified Edinburgh questionnaire for parents and children to complete. Having consulted the Ethics Commission of General University Hospital in Prague, who had endorsed this research plan, we examined 221 9–11 year old children (114 girls, 107 boys) attending forms III, IV and V.

2.2 Examination

The Edinburgh questionnaire (Oldfield, 1971) contains ten questions pertaining to preference for either upper extremity in performing more or less specialized activities (R01 = writing, R02 = drawing, R03 = throwing, R04 = using scissors, R05 = using a toothbrush, R06 = using a knife, R07 = using a spoon, R08 = upper hand in holding a broomstick or some other handle, R09 = striking a match, R10 = holding the lid or top in opening a box). Six more questions were added to the E-questionnaire: R11 = using a key, R12 = thread holding in threading a needle, R13 = the leading hand in tying a knot or necktie, R14 = using a comb, R15 = foot preference in ball kicking, R16 = eye preference for looking into a monoskope. We also added ten more tests or findings such as hair whorl direction (R17), upper limb mirror movements in walking (R18), tests for greater passivity in upper and lower extremities (R19-R22) examined clinically by means of palpation and aspection, take-off and skipping foot preference (R23-R24) and direction of turning while standing or walking (R25–R26). We also tested selected questions against their actual execution (R27-R34). A summary of the 34 items under study is given in ***Tab. 1***.

2.3 Statistical Methods

In order to establish the phenomenon of handedness in a cohort of schoolchildren and to formally identify it in the simplest possible way, we compared a number of different sequences of answers to questions R01-R16. The following six questions proved to be the most effective: R01 = writing, R02 = drawing, R04 = using scissors, R06 = using a knife, R07 = using a spoon and R09 = striking a match. Congruent answers to those questions were used for the definition of pure 100% right-handers (all

Table.1: Modified Edinburgh Inventory test
Please indicate your preferences in the use of hands in the following activities. If you are really indifferent, select "Either."

	When:	Which hand do you prefer?		
R01	WRITING	L	R	Either
R02	DRAWING	L	R	Either
R03	THROWING	L	R	Either
R04	USING SCISSORS	L	R	Either
R05	USING A TOOTHBRUSH	L	R	Either
R06	USING A KNIFE (without fork)	L	R	Either
R07	USING A SPOON	L	R	Either
R08	USING A BROOM (upper hand)	L	R	Either
R09	STRIKING A MATCH	L	R	Either
R10	OPENING A BOX (LID)	L	R	Either
	Additional questions			
R11	USING A KEY (by opening)	L	R	Either
R12	THREADING A NEEDLE	L	R	Either
R13	TYING A KNOT	L	R	Either
R14	USING A COMB	L	R	Either
R15	KICKING A BALL (by leg)	L	R	Either
R16	LOOKING INTO A MONOSCOPE (by eye)	L	R	Either
	Testing the handedness or corresponding cranial dominance			
R17	HAIR WHORL	Clock-wise	Counter-clock-wise	Irregular
R18	HAND'S SYNKINESES	L	R	Either
R19	PASSIVITY OF WRIST	L	R	Either
R20	PASSIVITY OF ELBOW	L	R	Either
R21	PASSIVITY OF KNEE	L	R	Either
R22	PASSIVITY OF ANKLE	L	R	Either
R23	TAKE-OFF FOOT	L	R	Either
R24	SKIPPING LEG	L	R	Either
R25	TURNING (STANDING)	L	R	Either
R26	TURNING (WALKING)	L	R	Either
	Additional testing the handedness (by selected questions)			
R27	OPENING A BOX /test/	L	R	Either
R28	USING A KEY /test/	L	R	Either
R29	STRIKING A MATCH /test/	L	R	Either
R30	USING A BROOM /test/	L	R	Either
R31	TYING A KNOT /test/	L	R	Either
R32	THREADING A NEEDLE /test/	L	R	Either
R33	LOOKING INTO A MONOSCOPE /test/	L	R	Either
R34	KICKING A BALL /test for N=56/	L	R	Either

Note: *The questions R01-R10 correspond to original E-questionnaire* six answers "R" for n=166) and pure 100% left-handers (all six answers "L" for n = 13), the rest were included in the "group of ambidexters"(variable combinations of answers "R" and "L" or "Either" for n= 42).

Subsequent statistical processing made use of (a) ordering all 34 answers/tests by the "measure of laterality", and (b) χ^2 tests of independence and/or homogeneity of the percent structures of each of the 34 items of R01 up to R34 rated against "handedness"(i.e., against the aggregation variable of the "six tests" to identify 100% right-handers, the "group of ambidexters" and 100% left-handers in keeping with the above definition). Where the hypothesis of homogeneity was rejected, i.e., where the χ^2 statistics had exceeded the critical value of $\chi 2$ (4) at the 95% level of reliability, with 4 denoting the degrees of freedom of the pertinent test in 3x3 tables, an extra formal statistical assessment was made of deviations of each cell (per cent) of the given contingence table by means of adjusted residua (see SPSS, 2007).

The results concerning the measure of right laterality (MRL) were presented on line graphs, the adjusted residua departures from "expected values", given the validity of the null hypothesis (independence and/ or homogeneity) were represented by means of ring graphs. The critical values of χ^2 distribution were also used for sex-related homogeneity tests of all 34 items and for assessing the congruence of selected 8 answers to the questionnaire rated against control items R27-R34 (in the last case using McNemar´s tests).

3. Results

Fig. 1 shows the percentage of all 34 activities performed by the right hand, either hands or left hand alone or by leg, eye and form of hair whorl. The first 16 answers to the modified Edinburgh questionnaire document the preponderance of right-handedness in all the activities representing more than 80% of right-sided laterality (with the exception of threading a needle with the leading hand holding the thread – R12 and R32 – and ocular preference – R16). A mirror image of this can be seen in the 5 tests for cerebellar dominance (R18–R22) where, except for upper limb mirror movements in walking, all tests again make up more than 80% of left-sided laterality consistent with the image of "right-handedness".

There is a notable 50% preference for the take-off foot in the "long jump" and a growing tendency toward congruent foot and hand laterality in the more differentiated (demanding) motor activities such as one-foot skipping (R24) and ball kicking (R15 and R34). Turning while standing (R25) was to the left in more than 60%; however, nearly 60% of the schoolchildren would turn to the left as much as to the right while walking. The other tests show right-sided predominance, albeit mostly less conspicuous than in the first 16 items.

Item R17 represents the shape and direction of the hair whorl: 71.9% – clockwise, 8.6% – counter clockwise, 19.5% – irregular or undeterminable hair whorl. Photographs of the three main forms and orientation of the hair whorl in the parieto-occipital region are shown in ***Fig.2a,b,c***. The pie chart (***Fig.3a,b***) represents the sex-related percent distribution of the particular hair whorl forms. There is a striking difference between the boys and the girls since already at the age of 10 the latter give their hair greater care than boys. In 30% of the girls the whorl is beyond reliable assessment. While right-handed boys exhibit a conspicuous predominance of the clockwise form, this is in no statistically significant way dependent on right-handedness (see below).

The measure of laterality (MRL %) for each particular question or test was quantified as follows:

$$\mathbf{MRL(\%) = (\%\ Right + 0{,}5 * \%Either)},$$

where MRL(%) stands for the percent measure of "right-sided" laterality, and %Right %Left and %Either for the distribution percentage given in Fig.1. With regard to answers R01–R34 (see ***Fig.4a***), the MRL values obviously emphasize the "degree of right-handedness" in items R01–R14 and its "mirror image" in those findings which document cerebellar dominance (R18–R22).

Fig.4b presents the same MRL data arranged in ascending order to demonstrate that some groups of responses (particularly the first 26 items from up to down; and part-wise R23; R25–R26; R18 and R21–R22; R19–R20) show no statistically significant difference in terms of MRL values ($p<0.05$). Nevertheless, the formally calculated %MRL +/-SE values as used in Fig.4a,b are designed to demonstrate the sufficiency of the sample size (n=211) rather than exact confidence intervals as MLR percentage based on trinomial distribution of responses. We found the physiological hypotonia and passivity in lower extremities preferred for long-jump" (in this "crossed footedness") also on the side contra lateral to the preferred upper extremity.

The measure of "right-sided" laterality relative to membership of the groups of 100% right-handers, 100% left-handers and the ambidexters is shown in ***Fig.5*** (the items are again arranged according to the bracketed overall %MRL values). Ambidexters were found to have a more than 75% preference for right upper-limb voluntary movement in the first five items (downward), nearly 75% was also found in questions R09 – striking a match, R05 – toothbrush holding, R14 – comb holding, R11 – key holding for unlocking. In some tasks it is impossible to tell right-handers from left-handers or ambidexters. This applies to the take-off foot (in half the right-handers as well as left-handers, the outcome of the R23 test was on the side contra lateral to the dominant hand) but also to the way of turning (R25, R26), to one-foot skipping (R24) and to the hair whorl (R17).

The distinguish graphs in ***Fig.6*** show values (percentage by laterality groups) which are consistent with the diagnosed greater passivity and hypotonia of the muscles enveloping the joints under study: shoulder

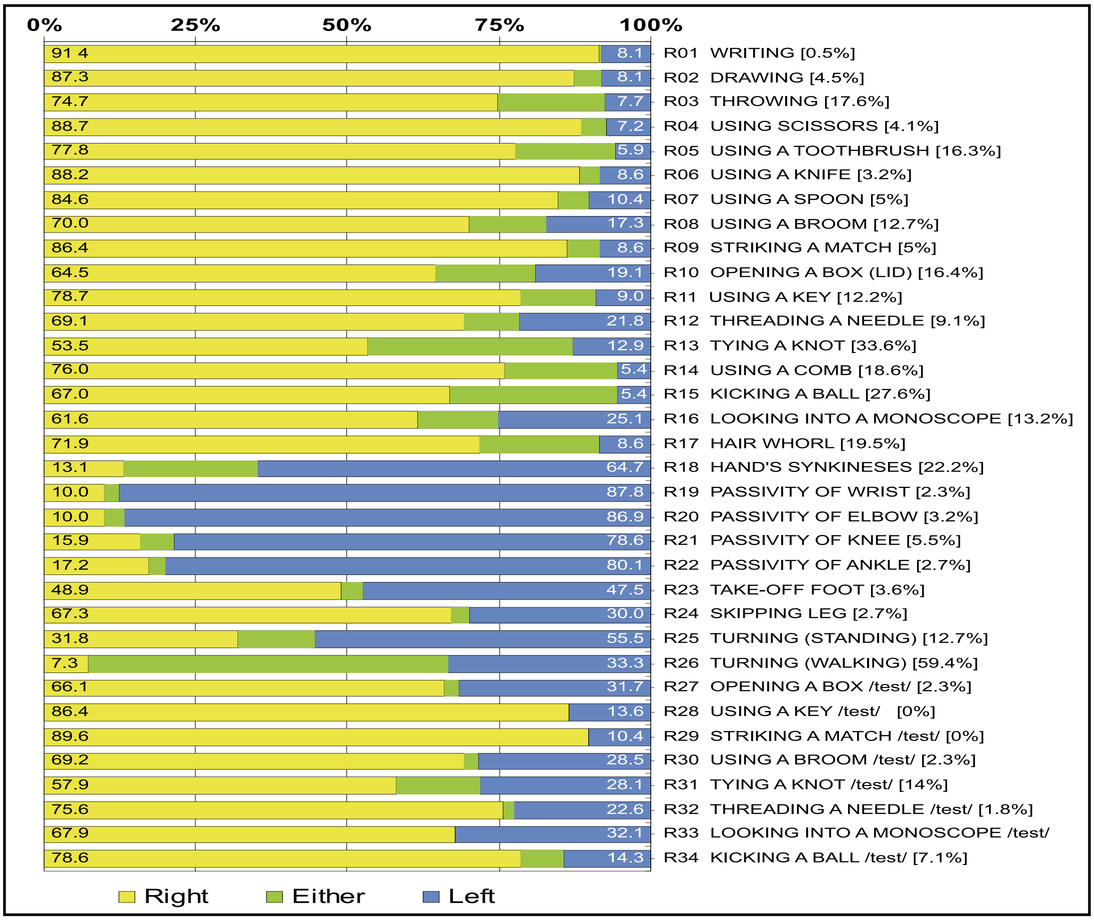


Fig. 1: Structure of Responses to the extended Handedness Questionnaire (%Right, %Left, [%Either]) and additional tests. R17 in our list represents different hair whorls coded as follows: 0% = clockwise, 100% = counterclockwise, 50% = irregular or undeterminable. See Fig.3 for more detailed sex-related hair whorl distribution.

Fig. 2a, b, c: Photo - hair whorl. a) Clockwise, b) Counterclockwise, c) Irregular

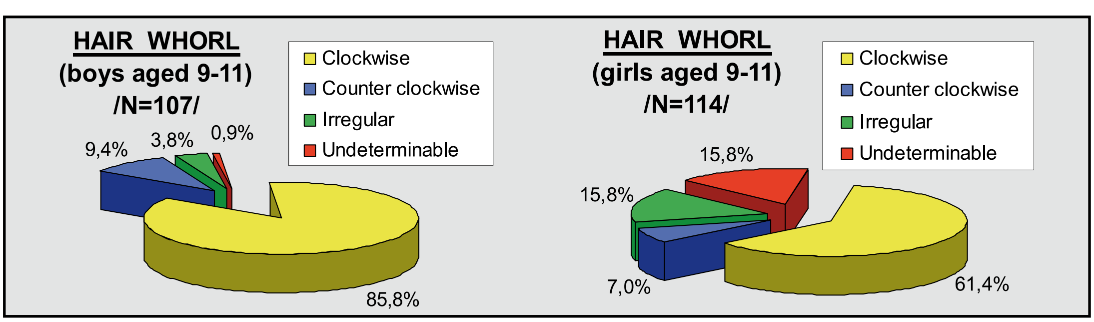


Fig. 3a, b: Hair whorl pie charts. Note the visual correspondence between clockwise hair whorl and right-handedness percent distributions in boys, not in girls. The statistical chi-square test proved the hair-whorl as formally independent of laterality groups (see also Fig. 5).

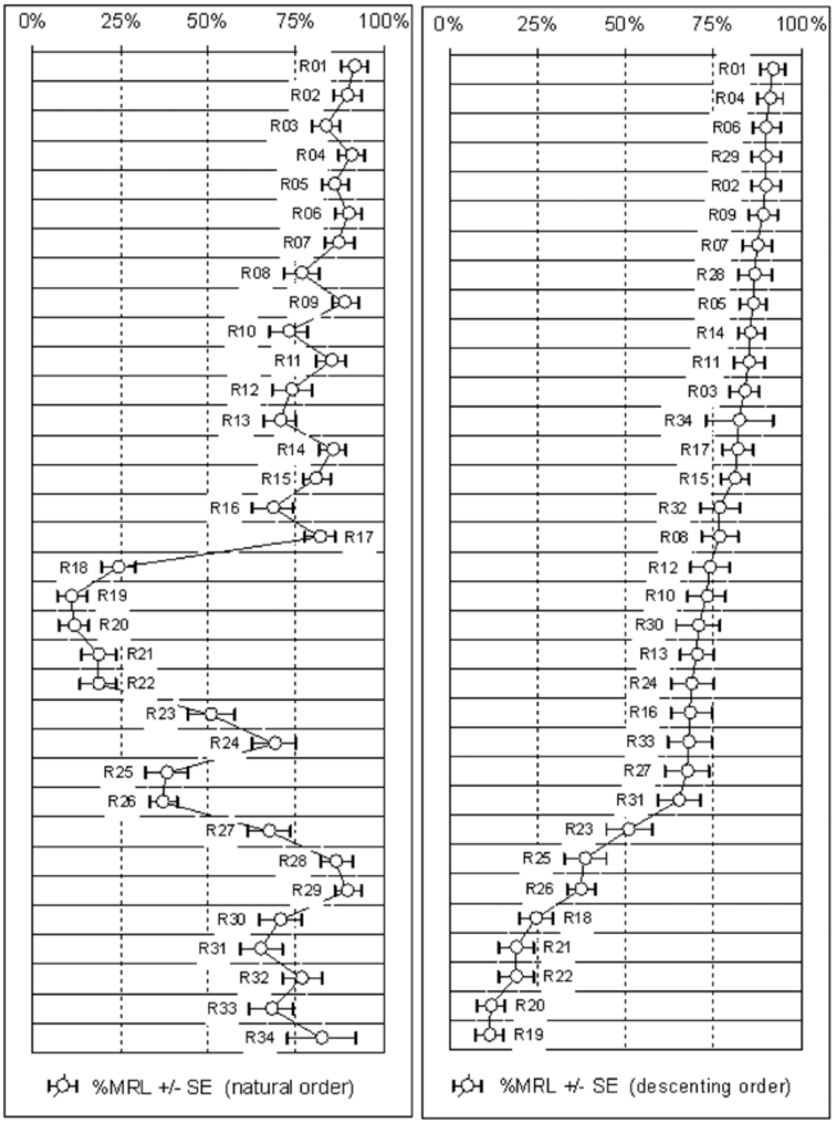


Fig.4a, b: Comparison of responses by Measures of Right Laterality
The Measure of Right Laterality (MRL) is defined as follows:
MRL(%) = (100 + %Right - %Left) / 2 = (%Right + 0.5 * %Either),
where the values for %Right, %Left, %Either come from results presented in Fig.1. Standard Errors (SE) used in Fig.4ab) show the sample size sufficiency (N) rather than exact confidence limits for %MRL.

(R18), wrist (R19), elbow (R20), knee (R21) and ankle (R22) demonstrating a lower significance of major upper-limb mirror movements rated against a greater passivity of the hand, elbow, knee or foot in the "no dominant" extremities. As for pure left-handers (inner rings in graphs) the %MRL results cannot be told from the 50% limit.

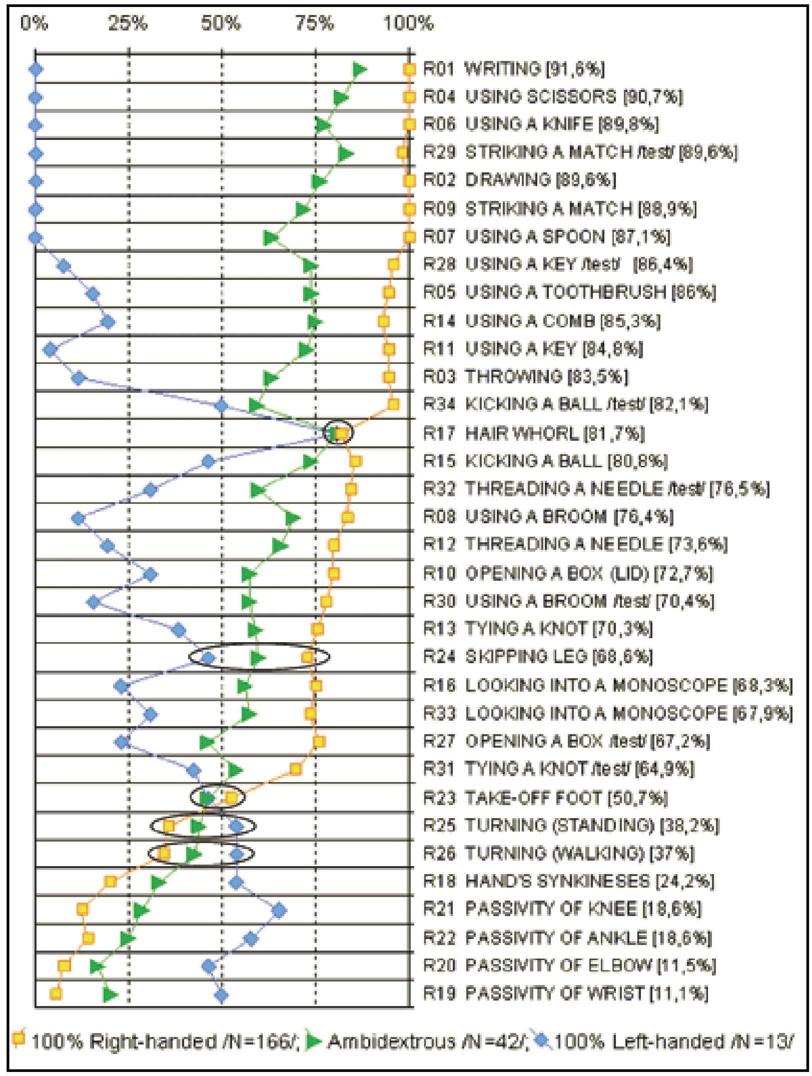
The ***Fig.7*** ring graph shows the rate of foot preference as growing in agreement with handedness all the way from the test for the long-jump take-off foot (R23), one-foot skipping (R24) up to the ball-kicking test (item R15, test R34). The graphs clearly indicate a growing share of departures from the hypothesis of independence of the laterality groups. Neither attempts at vestibular dominance assessment using tests for turning behaviour (R25 – standing, R26 – walking) proved any statistically significant dependence on "handedness". Even relative to %MLR calculated by membership of laterality groups (rings in ***Fig.8***) the percent values given in Fig.8 will be very similar in both tests.

Fig.9 carries a comparison between answers to the question of which eye the subject uses to look into a keyhole or a monoskope (R16) and the more cogent test of looking into a monoskope (R33), again by laterality groups. There, too, is a marked congruence between the questionnaire and the rest results leading to %MRL. In this case, however, the null hypothesis of independence of laterality groups is rejected on both items (p<0.01).

The differences between boys and girls, while the overwhelming majority of tests showed no marked intersex differences are presented in a graph (***Fig.10***), namely, the position of the upper (dominant) hand in R08 – using a broomstick, shovel holder. Ice hockey players holding the stick so that it points leftward are mistaken for "left-handers". Surprisingly enough, a significant difference was found in knot tying (R13) and between boys and girls in test R25 – turning while standing. The anticipated connection between leftward turning and right-handedness was more expressed in boys. Statistically significant deviations at the 95% level of reliability in Fig.10 are marked with little rings.

The last graph (***Fig.11***) illustrates the testing of differences between answers to the questionnaire and the tests performed. Judged by the McNemar's test, the answers were not always congruent with the tests. The hypothesis of "congruence" was not rejected between the following questions and tests: striking a match (R09 versus R29), using a key (R11 versus R28), threading a needle (R12 versus R32 – see Fig. 11), looking into a "keyhole" (R16 versus the monoskope test R33). In contrast, the McNemar's test did reveal significant differences between pairs (question versus test): lid opening (R10 versus R27; p=0.008), handle holding – "dominant" hand in the upper position (R08 versus R30; p=0.001) and tying a knot (R13 versus R312; p=0,004 – see Fig. 11). Answers to the questionnaire tended to "mention the right hand" as distinct from the outcome of the test

Fig. 5: Measures of laterality in 221 children according to hand preference (ordered by %MRL used in Fig. 4b)
Six questions from the top corresponding to the Edinburgh Questionnaire (R01, R02, R04, R06, R07, R09) were characteristic of pure handedness. Note the ellipses collecting the MRLs for the following tests: R17=hair whorl, R24=skipping leg, R23=take-off foot, R25=turning-standing, R26=turning-walking. The chi-square homogeneity tests do not reject the null hypothesis concordant with independence of left- or right-handedness at p>0.05



"realized by the left hand". Discrepancies like these might be put down to the parents´ over schematic or over abbreviated completion of the questionnaire. Or else the explanation might support Keane's view (2008) that some tests in the popular Edinburgh Questionnaire may fall short of consistent differentiation, e.g. that of opening a lid.

4. Discussion

4.1 Maturity of brain functions

Notwithstanding individual differences, what is known as **hemispheric dominance** and related mechanisms of speech and other motor and sensory-sensitive functions appear to be more or less fixed in the well established anatomical structures of the brain already round the age of ten years (Gaillard *et al* 2000; 2003; Bryden *et al* 2007; Corballis *et al* 2008). Hence our decision to study healthy 9–11-year old children for preference of the upper or lower extremities i.e., for handedness, for footedness and cerebellar hemispheric crossed dominance follows. Surprisingly enough we found a 50% preference as a crossed foot preference. Given a more sophisticated voluntary foot movements – one foot skipping, ball kicking and – to our preliminary results- using a wheel for writing a number/letter on the floor (Tichy, Belacek – unpublished results) the preference of the foot was approaching that of the hand. This dominance takes the form of a minor "physiological neocerebellar extinction syndrome" diagnosable by lower muscle tone in the non-dominant extremities, i.e., left-sided in right-handers and right-sided in left-handers.

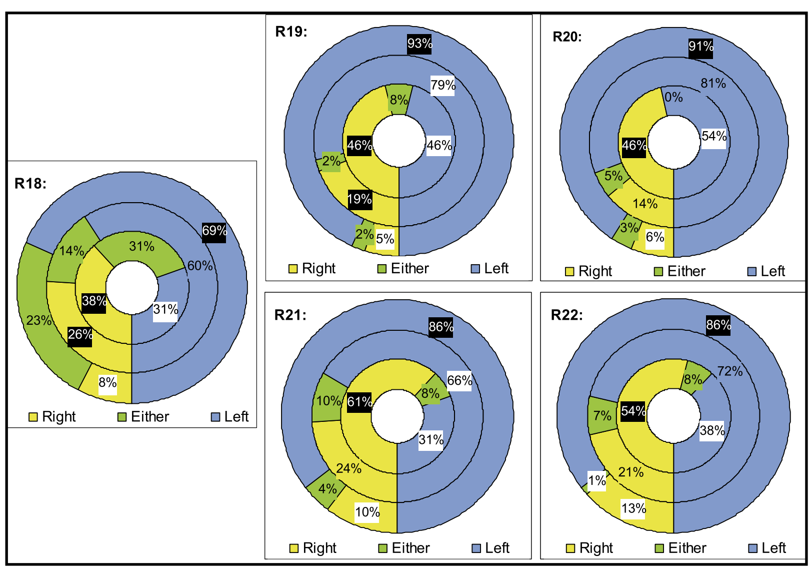


Fig. 6: Cerebellar physiological hypotonia in non-dominant limbs according to hand preference (R18=hands synkinesis during walking (shoulder passivity), R19=passivity of wrist, R20=passivity of elbow, R21=passivity of knee, R22=passivity of ankle). The inner ring in this graph corresponds to 100% left-handedness, the outer ring to 100% right-handedness. Black/white areas/percentage demonstrate significant deviations from expected values correponding to presumed homogeneity .

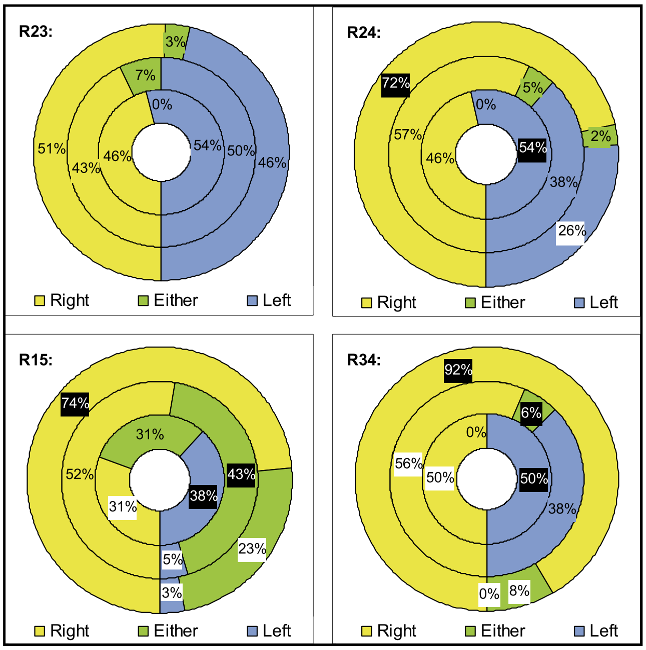


Fig. 7: Testing of simple jumping according to hand preference (R23= take-off foot, R24=skipping leg, R15=ball kicking leg /questionnaire/, R34=ball kicking leg /test/). The inner ring in this graph corresponds to 100% left-handedness, the outer ring to 100% right-handedness. Black/white areas/per cents demonstrate significant deviations from expected values correponding to presumed homogeneity .

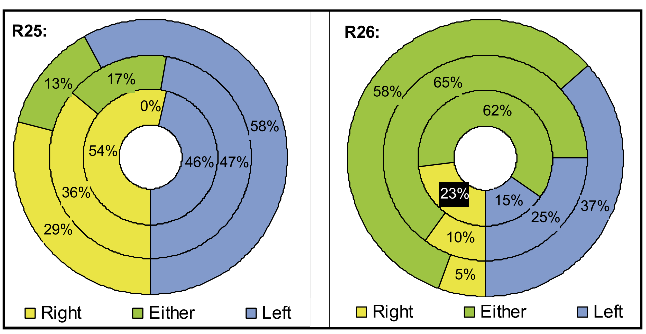


Fig.8*:* Vestibular dominance testing according to hand preference (R25=turning-standing; R26=turning-walking). The inner ring of this graph corresponds to 100% left-handedness, the outer ring to 100% right-handedness. Black areas/per cent demonstrate significant deviation from expected values correponding to presumed homogeneity .

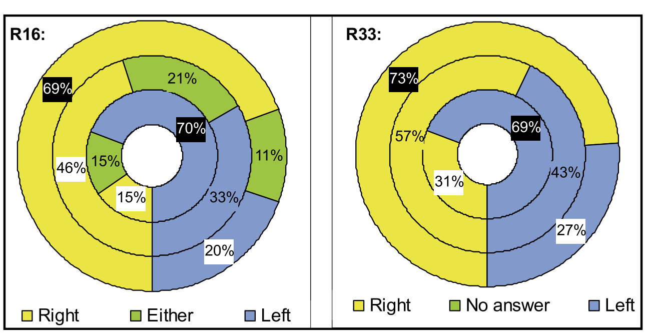


Fig. 9*:* Ocular dominance testing according to hand preferences (R16=looking into a monoscope, R33= looking into a monoscope /test/). The inner ring corresponds to 100% lefthanders,the outer to right-handers with black/white areas demonstrating significant deviations from expected values correponding to presumed homogeneity .

4.2 The hair whorl

The hair whorl is one of the signs of laterality-asymmetry worth discussing. The commonly shared view is that in the overwhelming majority of individuals of all races (except Afro-Americans with their very dense hair follicles – Wunderlich & Herrema 1975) the clockwise whorl is situated in the capilitium over the right half of the skull with a single centre in the parieto-occipital region. According to Klar (2003; 2005) the counter-clockwise hair whorl is found in 10% of the Caucasian population, about one half of them being left-handers, revealed a strong correlation between right-handedness, clockwise whorl and language dominance. While Jansen *et al.* (2007) or Perelle *et al.* (2008) found no connection between clockwise or counter clockwise hair whorls or right- or left-handedness, Weber *et al.* (2006) found a congruence between the clockwise hair whorl and speech localization in the left hemisphere. As for the counter clockwise variety they found atypical speech laterality as did Schmidt *et al.* (2008).

In our own cohort, with boys and girls assessed separately, we had 15% of the girls with hair whorls unavailable because of their hairdo. Only two of the boys had two centres each – one was a right-hander, the other an ambidexter (Tichy & Belacek 2008). **We found no statistically significant correlation between handedness and hair whorl orientation.** Irregular and atypically localized hair whorls were found twice as often in individuals with diverse, even developmental, anomalies (Scott *et al* 2005). In agreement with our results some other authors reported the girls´ hair whorl to be less regular (Selakovic & Gavrilovic 1989; Ziering & Krenitsky 2003). Similar results were published in newborns (Bernard *et al* 1976). The development of hair and its anomalies has been studied by a number of authors (Samlaska *et al* 1989; Furdon & Clark 2003; Schmidt *et al* 2008). The more detailed genetic and clinical analyses of hair whorl orientation, handedness and language dominance have been contributed by Hatfield (2006) and Jansen *et al.* (2007). **No-one has so far taken up the subject of correlation between cerebellar dominance and hair whorl.**

4.3 Cerebellar dominance

In our own study we found a highly significant congruence ($p < 0.001$) between handedness and the "physiological cerebellar extinction syndrome". As mentioned before, the Kamil Henner's Czech school of neurology explored cerebellar symptomatology including cerebellar dominance repeatedly. Cerebellar hypotonia manifests itself in reduced muscle resistance on palpation or during passive manipulation, and is due to inhibition of gamma- and alpha-motoneuronal activities, e.g., while testing for the pendular patellar reflex (Adams & Victor 1993). In the present study we were not able to arrange quite exact recording of relative muscular hyper/hypotonia because the children were examined in their school area. Experienced neurologist should have no problem

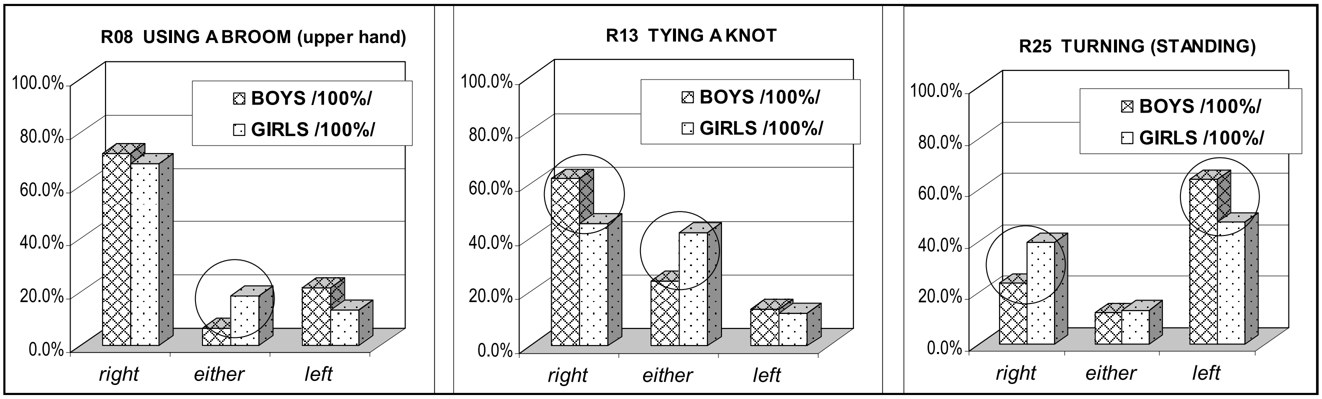


Fig. 10: Sex differences. Only three activities were significantly different in boys as distinct from girls. In R08 (= using a broom) this was because most girls would use both hands, in R13 (= tying a knot) due to the predominance of right-handed boys; and in R13 (= turning-standing) because of the preference for leftward turns. The connection with the right-side vestibular system is more expressed in boys than in girls.

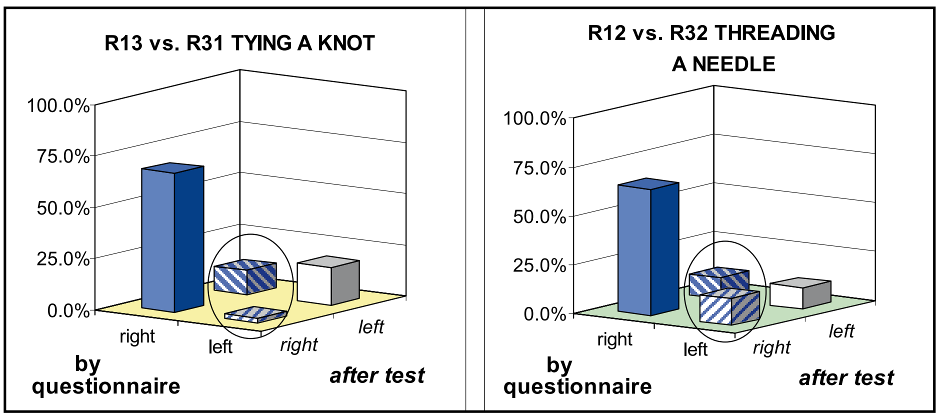


Fig. 11: Comparison between questionnaire answers and test results. Comparisons between the questionnaire results and a number of control tests showed some discrepancies. The disagreement between the declared answers and test results appeared, e.g., in an overestimation of "right-handed" answers to the R13 question (tying a knot) and the actual "left-handed" execution of the task (tested by means of R31). On the contrary, no statistically significant difference was found in testing the thread holding hand while threading a needle (R12 vs. R32). The graph in Fig.11 presents differences, the statistical significance of which was rated by means of the McNemar's test (highlighted with circles).

with the recognition of cerebellar dominance in healthy subjects by means of palpation and joint excursibility determination.

Anatomical interconnections between the cerebellum and many cortical and sub cortical regions of the contra lateral pros encephalic hemisphere have long been well known to serve feedback adaptive responses during motor activity (Barlow 2002). Neuroimaging methods helped to confirm cerebellar involvement in a number of cognitive, emotional, language and memory functions (Schmahmann & Sherman 1998; Gottwald *et al* 2004; Schutter & Van Honk 2005; Allen *et al* 2005; Gordon 2007; Sens & de Almeida 2007; Steinlin 2007; Nagao & Kitazawa 2008; Hu *et al* 2008).

4.4 Ocular dominance

Ocular dominance – Adams, Horton (2009) lay somewhat off the series of laterality functions under scrutiny. As such it remained on the margin of our study of laterality-handedness, a phenomenon associated with cerebellar dominance. Since both eyes are connected to both hemispheres and with regard to the existence of fields of vision (given equal optic properties of both eyes and pathways), ocular dominance appears to be a predominantly functional, dynamic cortical phenomenon. No association between eye dominance in parents and that in their children was found by Dellatotas *et al.* (1998). The formation of ocular columns is seen as an example of modular organization on the basis of afferentation and efferentation in the visual cortex (Yacoub *et al* 2007; 2008). According to others (Adams & Horton 2006; Horton 2006) the function of cortical columns remains in the dark. Healthy right-handers show an 80–90% preference for the right eye. Evans (2007) sees ocular dominance as a continuous adaptive phenomenon.

4.5 Vestibular dominance

Brandt, Dieterich (1999), Dieterich *et al.* (2003) found dominance for vestibular cortical function in the "not speaking" hemisphere, manifests itself in the physiological predominance of either vestibular system, mostly the one on the right temporal-parietal operculum (Fasold *et al* 2002; Schlindwein *et al* 2007; Dieterich & Brandt 2008a; 2008b; Janzen *et al* 2008). In everyday life, in games, dancing, etc., right-handers prefer turning leftward, the left shoulder first (Mohr *et al* 2003; Mohr & Bracha 2004). In another study (Mohr & Livesley 2007), no significant correlations were found between turning behaviour, handedness or footedness. The tendency to rotate to the right in left-handed and ambidextrous children was less pronounced. The small number of left-handed children in our sample limits our conclusions, of course.

4.6 Handedness and cerebellar dominance

Right-handedness is related to the dominance of the right cerebellar hemisphere. This phenotype is connected with corresponding contra lateral left-sided cerebellar hypotonia of limbs. The anatomy and physiology of the cerebellum, as well as the very complicated interrelations between cerebellar hemispheres, visual and balance systems and the cortical network for body scheme has led to the characterization of the cerebellum as an adaptive controller (Barlow 2002), which is fully submissive to the cerebral cortex network. Some recent papers have concentrated on the cognitive, emotional, linguistic and other functions of cerebellar hemispheres (Jansen *et al* 2005; Hu *et al* 2008; Timman & Daum 2007).

4.7 Footedness

The permanent discussion between ”preference and performance” testing seems to have been settled, in the sense that preference is the most important. Surprisingly, 50% the left and/or right-handed children preferred the contra lateral leg for jumping over a virtual distance. We found physiological hypotonia of the recoiling leg to be in agreement with predicted cerebellar dominance based on hand preference. We assume that clinical test of physiological hypotonia of the lower limb is present even on the leg, which was preferred for simple ”long jumping” is in accordance with handedness. The phenomenon of handedness and footedness are not in concordance (Martin & Porac 2007; Kang & Harris 2000). This observation is in agreement with studies about brain activity during unilateral knee, ankle and toes flexion-extension that were more bilateral during movements of the non dominant leg, used mainly for locomotion (Kapreli *et al* 2006).

5. Conclusions

”Laterality” appears to be a structurally arranged complex of physiological phenomena not quite dependent on one another. Laterality in children appears to be stabilized by the age of about 10 years. **In this study, on a smaller number of probands in comparison to some larger-scale studies, we want bring attention to the interesting information about crossed footedness and cerebellar dominance, which is related to handedness. Motor cortex of the left hemisphere, connected with the right cerebellar hemisphere is responsible for handedness and cerebellar dominance.** Handedness and footedness are in concordance only in more sophisticated foot activities (as kicking a ball) or in signs of cerebellar hypotonia (through the passivity on the limbs inverse to handedness). But we found a 50% preference for the contra lateral take-off extremity in the long jump in right-handers as much as in left-handers. The high rate of crossed foot preference compared with hand preference can be put down to considerable automacy of movement in the long jump proceeding at mostly sub cortical and spinal levels. The physiological hypotonia found in the crossed dominant foot as very significant toward handedness proves that **“neocerebellar dominance” manifests itself in accordance with hand dominance**. The ocular dominance depends on handedness (by eye preference at looking into a key-hole or a monoskope). The vestibular dominance (by preference leg by turnings in standing or walking) is independent on handedness. We can assume the more sophistic relations towards activities of verbally not dominant hemisphere than in the case of ocular preference. The hair whorl direction we found independent to handedness (by χ^2 tests of independence and/or homogeneity). The hair whorl is less well identifiable in girls.

Acknowledgment

This paper was supported by Czech Ministry of Education, Youth and Physical Culture to Charles University in Prague (Project – research plan No. MSM 0021620816: *Pathophysiology of neuropsychiatric diseases and its clinical application*).

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