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

Jiri Tichy ¹ and Jaromir Belacek ²

¹ Department of Neurology, ² Institute of Biophysics and Informatics, 1st Faculty of Medicine, Charles University, Prague, Czech Republic.

Correspondence to:
Prof. MUDr. Jiri Tichy, DrSc. (Emer. Head of Department of Neurology and Emer. Dean of 1st FM); 1st Faculty of Medicine, Charles University, Kateřinská 30, 128 00 Prague 2; PHONE: +420 22496 5570; jtíchy@lf1.cuni.cz; RNDr. Jaromir Belacek, CSc. (Senior Researcher - Statistician on IBI of 1st FM); 1st Faculty of Medicine, General University Hospital, Salmovská 1, 128 00 Prague 2; PHONE: +420 22496 5706; jaromir.belacek@lf1.cuni.cz.

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

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

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-handness, 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, geneticists 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 (Vuoksima 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 (Provis 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.


Handedness independence of language localization 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; Baillieux et al 2008; Hautzel et al 2009).

Thanks to Kamil Henner (1927), Czech neurology can boast detailed clinical diagnostics of paleocerebellar regulatory “extinction” functions (asynery, 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 Table 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>
<thead>
<tr>
<th>When:</th>
<th>Which hand do you prefer?</th>
</tr>
</thead>
<tbody>
<tr>
<td>R01 WRITING</td>
<td>L R Either</td>
</tr>
<tr>
<td>R02 DRAWING</td>
<td>L R Either</td>
</tr>
<tr>
<td>R03 THROWING</td>
<td>L R Either</td>
</tr>
<tr>
<td>R04 USING SCISSORS</td>
<td>L R Either</td>
</tr>
<tr>
<td>R05 USING A TOOTHBRUSH</td>
<td>L R Either</td>
</tr>
<tr>
<td>R06 USING A KNIFE (without fork)</td>
<td>L R Either</td>
</tr>
<tr>
<td>R07 USING A SPOON</td>
<td>L R Either</td>
</tr>
<tr>
<td>R08 USING A BROOM (upper hand)</td>
<td>L R Either</td>
</tr>
<tr>
<td>R09 STRIKING A MATCH</td>
<td>L R Either</td>
</tr>
<tr>
<td>R10 OPENING A BOX (LID)</td>
<td>L R Either</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional questions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R11 USING A KEY (by opening)</td>
<td>L R Either</td>
</tr>
<tr>
<td>R12 THREADING A NEEDLE</td>
<td>L R Either</td>
</tr>
<tr>
<td>R13 TYING A KNOT</td>
<td>L R Either</td>
</tr>
<tr>
<td>R14 USING A COMB</td>
<td>L R Either</td>
</tr>
<tr>
<td>R15 KICKING A BALL (by leg)</td>
<td>L R Either</td>
</tr>
<tr>
<td>R16 LOOKING INTO A MONOSCOPE (by eye)</td>
<td>L R Either</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing the handedness or corresponding cranial dominance</th>
<th>Clockwise</th>
<th>Counter-clockwise</th>
<th>Irregular</th>
</tr>
</thead>
<tbody>
<tr>
<td>R17 HAIR WHORL</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R18 HAND’S SYNKINESES</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R19 PASSIVITY OF WRIST</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R20 PASSIVITY OF ELBOW</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R21 PASSIVITY OF KNEE</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R22 PASSIVITY OF ANKLE</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R23 TAKE-OFF FOOT</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R24 SKIPPING LEG</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R25 TURNING (STANDING)</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R26 TURNING (WALKING)</td>
<td>L R Either</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional testing the handedness (by selected questions)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R27 OPENING A BOX /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R28 USING A KEY /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R29 STRIKING A MATCH /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R30 USING A BROOM /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R31 TYING A KNOT /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R32 THREADING A NEEDLE /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R33 LOOKING INTO A MONOSCOPE /test/</td>
<td>L R Either</td>
</tr>
<tr>
<td>R34 KICKING A BALL /test for N=56/</td>
<td>L R Either</td>
</tr>
</tbody>
</table>

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) $\chi^2$ 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 $\chi^2$ statistics had exceeded the critical value of $\chi^2$ 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 contingency 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 $\chi^2$ 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:

$$MRL(\%) = (\% \text{Right} + 0.5 \times \% \text{Either}),$$

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

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).
(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.
“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.
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 counterclockwise 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 counterclockwise 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 counterclockwise 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 & Krentsky 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...
Laterality in children: cerebellar dominance, handedness, footedness and hair whorl

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; Diet-
erich & 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 cerebral 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 sophisticated 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 χ² 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).

REFERENCES


Vingerhoest G & Sarrechia I (2009). Individual differences in degree of handedness and somesthetic asymmetry predict individual differences in left-right confusion. \textit{Behav Brain Res.} Ahead of print..


