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Trunk asymmetry and handedness in 8245 school children

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Abstract
The aim of this report is the appraisal of a possible correlation of trunk asymmetry assessed with a scoliometer and lateralization of the brain as expressed by handedness in a school aged population. Many (8245) students (4173 girls and 4072 boys), 6–18 years of age were examined. A checklist was completed for each student including handedness and trunk asymmetry. The standing forward bending test was performed using the Pruijs scoliometer and examined children were divided into three groups for each of the three examined regions (mid-thoracic, thoracolumbar and lumbar) according to the recorded asymmetry (no asymmetry, 2–7° and $\geq$7°). Ninety-one per cent of children were right-handed, while 9% were left-handed. A significant statistical correlation of trunk asymmetry and handedness was found both in boys and girls in the group of asymmetry 2–7° at mid-thoracic ($p < 0.038$) but not at thoracolumbar and at lumbar region. These findings show that there is significant correlation of mild mid-thoracic asymmetry and the dominant brain hemisphere in terms of handedness, in children who are entitled at risk of developing scoliosis. These findings are implicating the possible aetiopathogenic role of cerebral cortex function in the determination of the thoracic surface morphology of the trunk.

Keywords: *Handedness, trunk asymmetry, trunk rotation, scoliosis, scoliosis aetiology, scoliosis school screening*

Introduction

The rib or loin hump reflecting trunk rotation is an indication that there may be a scoliotic curve, although minor trunk asymmetry is not truly a variety of scoliosis and younger individuals with minor asymmetries do not show a higher rate of scoliosis than the wider 'normal' population, but they are still relevant to the broader picture of aetiology [1].

The role of rib asymmetry [2–4] and the importance of the rib cage in the aetiology of idiopathic scoliosis [5–10] has previously been examined. Lumbar asymmetry is an expression of trunk rotation [11,12] or is attributed to leg length inequality or pelvic asymmetry [13], which are also related to scoliotic curves at the lumbar spine [14,15].

Handedness, one of the behavioural markers of early neurodevelopment, may be defined as preference or hand-differences in task performance [16,17]. Hand preference is an expression of motor cortex asymmetry of the brain and is well documented [16,18–20]. A positive association between laterality of the curve in scoliotic children and handedness is reported [21,22], although this issue remains unresolved [17,23]. By reviewing the literature, no clear evidence was found concerning correlation between laterality of trunk asymmetry and handedness in the general population and not only in the scoliotic children. Burwell et al. [24], reported no relation in a sample of healthy schoolchildren. Goldberg and Dowling [25] found a positive correlation in a small group of girls with minor asymmetry.

The above issues stimulated the search for the existence of a possible positive correlation between trunk asymmetry as it is examined by the use of a scoliometer during the forward bending test and the handedness in schoolmates who were screened at school for scoliosis. A possible positive correlation implicates cerebral cortex function as an aetiopathogenic factor for the development of surface trunk asymmetry.

Materials and method

The examined children

Many (8245) students (4173 girls and 4072 boys), 6–18 years of age (mean age 12.5 years old) were examined during the school-screening programme for scoliosis.

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The measurements

A protocol with a checklist was filled in for each child, where handedness and trunk asymmetry were included.

The children's hand preference was documented by just asking the child which hand they prefer for everyday activities, especially writing, eating, throwing an object or performing fine motor skills. For those children where hand preference for performing different types of manual tasks varied, hand preference was determined by the number of performed tasks by each hand. Thus, the examiner had a clear picture of each child's hand preference and no demonstration was needed. Each child was classified objectively as right or left-handed.

Trunk asymmetry was recorded for mid-thoracic (T4–T8), thoracolumbar (T12–L1) and lumbar (L2–L5) region by performing standing forward bending test using the Pruijs scoliometer which was supplied by Orthomet-Surgeyplant B.V. (Waalwijl, Netherlands). The student was asked to bend forward, looking down, keeping the feet ~15 cm apart, knees braced back, shoulders loose and hands positioned in front of knees or shins with elbows straight and palms opposed. Any leg length inequality was not corrected. The side of the hump determined laterality of trunk rotation. Trunk asymmetry (hump) to the right side was defined as right asymmetry and to the left was defined as left asymmetry in each of the three mentioned regions and recorded in degrees.

In the present study children are divided into three groups according to the recorded trunk asymmetry (Table I). The first group (group O) comprised children with no or trunk asymmetry of 1°. In the second group (group A), children with trunk asymmetry 2–7° were included and in the third group (group B) with trunk asymmetry ≥7°. Each group was further divided into three sub-groups according to the examining region (sub-group 1 for the mid-thoracic, sub-group 2 for thoracolumbar and sub-group 3 for lumbar region). Children of group A are considered as normal variations that have a potential risk of development a spinal deformity. Children of group B are at high risk of either having or may develop scoliosis and were recommended for further clinical and radiological assessment at hospital [26].

Reliability study

Scoliometer readings on mid-thoracic, thoracolumbar and lumbar region of 10 randomly selected children aged within the range of study population were used. Asymmetry was measured twice by the same observer (TBG) on each child and intra-observer error was calculated within 95% confidence limits using the formula: error = SD × $2/\sqrt{2}$, where SD is standard deviation. The inter-observer error was calculated using the first readings of TBG and those of a second observer (EV), using the same formula.

Table I. The three groups of examined children and their sub-groups according to the examined region and the amount of recorded asymmetry.

	Mid-thoracic (T4–T8)	Thoracolumbar (T12–L1)	Lumbar (L2–L5)
Group O (no asymmetry)	O1	O2	O3
Group A (asymmetry 2–7°)	A1	A2	A3
Group B (asymmetry ≥7°)	B1	B2	B3

Statistical analysis

Statistical techniques used for the study of the sample of children included Shapiro-Wilk, Shapiro–Francia, chi-square goodness of fit, tests for skewness and kurtosis including the one sample Kolmogorov-Smirnov test, two sample Wilcoxon rank–sum (Mann-Whitney) test and chi-square cross-tabs, using the SPSS v.11 package.

Results

The statistical analysis revealed that there is no statistical difference for handedness between boys and girls. Therefore, the correlation between handedness and trunk asymmetry was performed for both sexes together.

In the first group (group O) there are 5783 (71.7%) children with no trunk asymmetry in the mid-thoracic region (sub-group O1), 5407 (67%) children with no asymmetry in the thoracolumbar region (sub-group O2) and 5557 (68.9%) children with no asymmetry in the lumbar region (sub-group O3) (Table II). The different number of children that were recorded as symmetric in the three examined regions reveals that symmetry in one region might be accompanied by asymmetry in another.

In the second group (group A) there are 2144 (26.6%) children with trunk asymmetry 2–7° in the mid-thoracic region (sub-group A1), 2423 (30%) children with trunk asymmetry 2–7° in the thoracolumbar region (sub-group A2) and 2292 (28.4%) children with trunk asymmetry 2–7° in the lumbar region (sub-group A3). Mid-thoracic asymmetry was recorded as right in 1348 (62.9%) children and as left in 796 (37.1%) children, thoracolumbar asymmetry was recorded as right in 1457 (60.1%)

Table II. Frequency of recorded trunk asymmetry in the three examined trunk regions. Left asymmetry is deemed negatively and right asymmetry is deemed positively.

Asymmetry in degrees	Mid-thoracic region (T4–T8)	Thoracolumbar region (T12–L1)	Lumbar region (L2–L5)	
−15	1	3	1	
−13	1		2	
−12	1	1	1	
−11	1	4	4	
−10	6	18	11	
−9	2	9	3	
−8	5	14	12	
−7	19	35	38	
−6	25	37	50	Group B: severe left asymmetry
−5	137	230	221	
−4	131	169	163	
−3	223	271	253	
−2	280	259	198	
−1	13	7	8	Group A: mild left asymmetry
0	5746	5392	5544	
1	24	8	5	
2	399	378	321	Symmetry
3	389	398	381	
4	247	255	241	
5	268	365	398	
6	45	61	66	
7	55	67	72	Group A: mild right asymmetry
8	16	21	18	
9	6	8	10	
10	19	42	34	
11	1	3	2	
12	4	9	4	
13	1			
15	1	2	4	Group B: severe right asymmetry
Missing data	179	179	180	

Table III. Reliability study of recorded asymmetry.

	Intra-observer error	Inter-observer error
Mid-thoracic (T4–T8)	1.8°	2.6°
Thoracolumbar (T12–L1)	3.2°	3.3°
Lumbar (L2–L5)	4.0°	4.3°

children and as left in 966 (39.9%) children and lumbar asymmetry was recorded as right in 1407 (61.4%) children and as left in 885 (38.6%) children (Table II).

In the third group (group B) there are 139 (1.7%) children with trunk asymmetry ≥7° in the mid-thoracic region (sub-group B1), 236 (3%) children with trunk asymmetry ≥7° in the thoracolumbar region (sub-group B2) and 216 (2.8%) children with trunk asymmetry ≥7° in the lumbar region (sub-group B3). Mid-thoracic asymmetry was recorded as right in 103 (74.1%) children and as left in 36 (25.9%) children, thoracolumbar asymmetry was recorded as right in 152 (64.4%) children and as left in 84 (35.6%) children and lumbar asymmetry was recorded as right in 144 (66.7%) children and as left in 72 (33.3%) children (Table II).

Reliability study revealed that intra-observer error was 1.8°, 3.2° and 4.0° for scoliometer readings at the thoracic, thoracolumbar and lumbar region, respectively. Inter-observer error was 2.6°, 3.3° and 4.3° for scoliometer readings at the mid-thoracic, thoracolumbar and lumbar region, respectively (Table III).

Considering all the examined children for the mid-thoracic region, 5783 (71.8%) were symmetric, 1451 (17.9%) were right asymmetric and 832 (10.3%) were left asymmetric. In the thoracolumbar region 5407 (67.1%) were symmetric, 1609 (19.9%) were right asymmetric and 1050 (13%) were left asymmetric and in the lumbar region 5557 (68.9%) were symmetric, 1551 (19.2%) were right asymmetric and 957 (11.9%) were left asymmetric (Table IV).

Considering handedness in all the three groups, 7332 children (90.9%) were right-handed, while 734 (9.1%) were left-handed (Table V).

In group A, a significant statistical correlation of trunk asymmetry and handedness was found both in boys and girls at mid-thoracic ($p < 0.038$) but not at thoracolumbar ($p < 0.454$) and at the lumbar region ($p < 0.838$) (Table VI).

In group B, no significant statistical correlation of trunk asymmetry and handedness was found

Table IV. Symmetry, right and left asymmetry children in the three studied groups in absolute numbers and in percentages.

		Right asymmetry			Left asymmetry		
	Symmetry	Total	Mild	Severe	Total	Mild	Severe
Mid-thoracic (T4–T8)	5783 (71.8%)	1451 (17.9%)	1348 (16.7%)	103 (1.2%)	832 (10.3%)	796 (9.9%)	36 (0.4%)
Thoraco-lumbar (T12–L1)	5407 (67.1%)	1609 (19.9%)	1457 (18.1%)	152 (1.8%)	1050 (13%)	966 (12%)	84 (1%)
Lumbar (L2–L5)	5557 (68.9%)	1551 (19.2%)	1407 (17.4%)	144 (1.8%)	957 (11.9%)	885 (11%)	72 (0.9%)

Table V. Handedness in absolute numbers and in percentage for each of the studied sub-groups.

Sub-group	Right-handed	Left-handed
O1	5242 (90.6%)	541 (9.4%)
O2	4904 (90.7%)	503 (9.3%)
O3	5052 (90.9%)	505 (9.1%)
A1	1962 (91.5%)	182 (8.5%)
A2	2213 (91.3%)	210 (8.7%)
A3	2089 (91.1%)	204 (8.9%)
B1	128 (92.1%)	11 (7.9%)
B2	215 (91.1%)	21 (8.9%)
B3	191 (88.4%)	25 (11.6%)
All groups	7332 (90.9%)	734 (9.1%)

Table VI. Right and left asymmetry in absolute numbers and in percentage and their correlation (p value) to handedness for each of the studied sub-groups.

Sub-group	Right asymmetry	Left asymmetry	p
A1	1348 (62.9%)	796 (37.1%)	< 0.038
A2	1457 (60.1%)	966 (39.9%)	NSS
A3	1407 (61.4%)	885 (38.6%)	NSS
B1	103 (74.1%)	36 (25.9%)	NSS
B2	152 (64.4%)	84 (35.6%)	NSS
B3	144 (66.7%)	72 (33.3%)	NSS

NSS, Non-statistically significant.

either in boys and girls at the mid-thoracic ($p < 0.546$), thoracolumbar ($p < 0.297$) and at the lumbar region ($p < 0.134$) (Table VI).

Also, when every single child of all groups (O + A + B) was cross-tabulated, a significant statistical correlation of trunk asymmetry and handedness was found both in boys and girls at the mid-thoracic ($p < 0.044$) but not at the thoracolumbar ($p < 0.260$) and at the lumbar region ($p < 0.345$) (Table VII).

Discussion

Brain asymmetry

A number of methods have been described for detecting asymmetry of the brain. Test of vibration and joint position sense [27], studies on somatosensory-evoked potential [28], dichotic listening [29], eye and ear preference are markers of neurodevelopment, which demonstrate the organization of the sensory system [30]. Hand and foot preferences are expressions of cerebral motor cortex asymmetry [19,25]. By defining handedness, the examiner has an objective method of examining motor organization and lateralization of the brain [31,32].

Handedness

The quantification of hand preference is generally performed using specific questionnaires like the Annett Handedness Inventory [33] or Edinburgh Handedness Inventory [34], but these questionnaires are not feasible to be filled in the school setting during the usual school-screening programme. Since preferences for different types of manual tasks may be independently lateralized [16], the correlation between hand preference and performance asymmetry would be increased by measuring asymmetries in multiple manual tasks in day-life activity. Children were classified as right or left handed by evaluating performance asymmetry in a number of manual tasks, without the use of specific preference inventory scores, which was beyond the scope of the present study.

Trunk asymmetry

Several reports are studying trunk asymmetry in children [35–39]. The shape of the back develops mainly during the pubertal growth spurt at ages 12–14 years in girls and boys [40]. The measurement of the back surface asymmetry with the scoliometer is a useful tool in IS assessment [41,42] as it is reported that (a) it correlates well with the skeletal deformity, especially axial rotation [43], (b) the torso asymmetry expressed as a hump shows a strong surface-spine relation in scoliosis, encouraging development of a model to detect scoliosis magnitude and progression from the surface shape with minimal X-ray radiation [44–46] and (c) the measurement of gibbosity provides the clinician with a highly reliable estimation of the Cobb angle [47–49].

Analysing the reliability study for Pruijs's scoliometer measurements, it was observed that maximal variability is shown at the lumbar and minimal at the thoracic region. Scoliometer measurements are reported to have an almost similar variability of $\pm 2^\circ$ to $\pm 4^\circ$ [50–52].

Table VII. Cross-tabulation of handedness by trunk asymmetry less than 7° and ≥7° in the thoracic region. Total $n = 8245$ children. Asymp. Sig. (2-sided) $p < 0.038$.

	No. of children with no trunk asymmetry	No. of children with right trunk asymmetry 2–7° ($p < 0.038$)	No. of children with left trunk asymmetry 2–7° ($p < 0.038$)	No. of children with right trunk asymmetry ≥7° ($p < 0.546$)	No. of children with left trunk asymmetry ≥7° ($p < 0.546$)
Right handed	5242	1221	741	94	34
Left handed	541	127	55	9	2

Missing values = 179.

Asymmetry prevalence in the present study is found to be 28.2% in the mid-thoracic region, 32.9% for the thoracolumbar region and 31.1% for the lumbar region. Scoliosis incidence in Greece (Cobb angle > 10° according to Scoliosis Research Society [53]) is 1.9% (range 1.1–2.9%) [54–58]. Mild trunk asymmetry in the mid-thoracic region was recorded as right in 16.7% of the examined children and as left in 9.9% (Table IV), in opposition to the predominant right convexity of the curve in thoracic idiopathic scoliosis. Mild mid-thoracic trunk asymmetry does not follow the curve pattern of thoracic idiopathic scoliosis. It is apparent that mild mid-thoracic trunk asymmetry does not necessarily mean scoliosis. For severe trunk asymmetry of more than 7° the prevalence in the present study is 1.6% for the mid-thoracic, 2.8% for the thoracolumbar and 2.7% for the lumbar region (Table IV), which correlates well with the recorded scoliosis incidence in the literature, as mentioned above.

The pattern of spinal asymmetry during normal growth could be explained by the hypothesis of oscillating axial torsion [59], with an early bias to the left and a later bias to the right in the majority of the population. Patterns of back contour asymmetry [24,40] and skeletal limb asymmetry [60–63] could also be explained by the above hypothesis [17].

Spinal curvature is translated into surface asymmetry via the rib cage, spinal muscles, viscera, fat and skin in a manner that is unique to each patient and changes over time as the deformity progresses [44]. Laterality of trunk asymmetry, as measured using the scoliometer could be the surface expression of the asymmetrical action of a ‘composite muscle trunk rotator’ (Nottingham AIS theory) [64–68] and, therefore, the surface expression of cerebral motor cortex function.

Leg length inequality

Leg length inequality may also result in trunk asymmetry. In healthy children, a physiological shortening of one leg (1–2 cm) is associated with a contralateral hump on the back in forward flexion [24] not only at L3 but also at T12 and T8 vertebrae [24]. Ingelmark and Lindstrom [69] reported that the causation of scoliosis is very difficult to establish because it may involve a large number of different mechanisms acting singly or in combination. They suggest that probably the main factor among others is the usually longer right leg in children prior to puberty, although the right leg of adults is usually shorter than the left. Several authors have reported that, in patients with leg length inequality, a short right leg is up to three times more common than a short left leg [69–72]. Badii et al. [13] found that almost twice as many study participants had a smaller right than a smaller left hemipelvis. The typical asymmetric pelvis has also its left half set a little higher and further back than the right [69]. Leg asymmetries in normal children are either equalized during growth or with the contribution of other mechanisms, facilitate the increase of trunk asymmetry and probably play a role in the pathogenesis of idiopathic scoliosis [69]. Considering that most people preferentially use the left leg and the right hand to compensate the body rotation, during the stance phase of gait, left leg longer length could perhaps be ascribed to a growth acceleration induced by the greater working load imposed on it [69] as an expression of Hauter–Volkman’s law. The left foot supports a significantly higher load than the right in right-handed subjects [73,74]. This association of leg length inequality with the side of the dominant hand (or leg) is possible an expression of lateralization of motor cerebral cortex.

A hypothesis

The results of the present study that correlates trunk asymmetry in group A1 (mild mid-thoracic trunk asymmetry 2–7°) with handedness stimulate the hypothesis that cerebral motor cortex function is an initiation factor for the rib cage deformity [8] which may affect the spine in that specific group of children, especially if it acts at the age near the growth spurt [40].

It is also hypothesized that lateralization of cerebral motor cortex function results in an asymmetrical action of trunk muscles and asymmetrical growth of the lower limbs. Both mechanisms may result in specific patterns of mild trunk asymmetry.

Furthermore, handedness may introduce some kind of misbalance of the spine because of asymmetric muscle strength and proprioception, even though whether handedness further cause the formation of asymmetry or curvature is far from known with reference to the previous and current studies. A well established asymmetry >7°, which is caused mainly by the 3-D spinal deformity (scoliosis), does not correlate statistically significantly to handedness in the present study. Cerebral motor cortex function and lateralization of the brain seems to be not the only responsible factor for the progression of the deformity (severe asymmetry), but could play a role in the initiation of the pathology (mild mid-thoracic asymmetry).

The significant positive correlation between laterality of mild mid-thoracic trunk asymmetry and cerebral lateralization is expressed by handedness is not a finding that establishes a cause-effect relationship but suggests that handedness and mild mid-thoracic trunk asymmetry are probably determined by the same mechanism. A similar strong association between scoliosis curve pattern and handedness has been reported by Goldberg and Dowling [21]. Cerebral lateralization shows a strong association not only to curve laterality as seen on radiographs of scoliotic children [21] but also when examined with scoliometer mild mid-thoracic trunk asymmetry of children being at risk for the development of the disease.

A major limitation of this study involved the estimation of leg length inequality among healthy children and its contribution to trunk asymmetry. Minor asymmetry is not always scoliosis [1], especially the lumbar asymmetry that results from anisomelia. A study that would investigate a possible correlation between leg length inequality and surface morphology of the trunk should be conducted.

Conclusion

A significant positive correlation between cerebral lateralization as it is expressed by handedness and mild trunk asymmetry at the mid-thoracic region implicates the possible aetiopathogenic role of cerebral cortex function in the determination of the thoracic surface morphology of the trunk.

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