STANDARDISED TRUNK ASYMMETRY SCORES

A STUDY OF BACK CONTOUR IN HEALTHY SCHOOLCHILDREN

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This paper reports a new method for expressing numerically asymmetry of the contour of the back in a forward-bending position. Information is given at three spinal levels (T8, T12 and L3) for 636 schoolchildren aged 8 to 15 years. Rib-hump and lumbar-hump scores were standardised to create trunk asymmetry scores (TASs) making comparison possible between children of different age, size and sex. Two groups of children were defined: those with clinically straight spines (585 children); and those with clinical evidence of lateral spinal curves (51 children). In the children with clinically straight spines the main findings were: about 1:4 had objectively detectable rib and lumbar humps; female-to-male ratios were 1.2:1 for the thoracic region and 1.4:1 for the lumbar region; right humps were about 10 times more common than left; TASs in the boys and girls at each spinal level had normal distributions about means to the right of zero (where zero represents perfect symmetry); at T8 and T12, a wider scatter of TASs in girls than in boys; at L3, larger TASs in girls than in boys; a relation between shortening of one lower limb and a contralateral hump on the back; and no relation to age (except at L3), stature (corrected for age) or handedness. The findings are discussed in relation to possible causes of back contour asymmetry, early diagnosis of scoliosis by screening, sexual dimorphism and significance for the pathogenesis of idiopathic scoliosis. Ten children with clinically straight spines and larger TASs, and 42 out of 51 children with clinical evidence of lateral spinal curves in the forward-bending position attended for radiographic examination. Twelve children had "scoliosis curves" of 11 degrees or more as defined by the Scoliosis Research Society. The results are reported in relation to TASs, spinal curve angle (Cobb) and vertebral rotation.

In the last decade school screening for scoliosis, to ensure early treatment and prevention, has burgeoned throughout North America and elsewhere (Brooks et al. 1975; Lonstein 1977; Rogala, Drummond and Gurr 1978; Zorab and Siegler 1980; Lancet 1981; Journal of Bone and Joint Surgery 1982; Lonstein et al. 1982). The "one minute" screening test involves examining the child while standing and bending forward. The observer looks for evidence of asymmetric trunk topography and particularly for a prominence due to rotation (Adams 1865). In the British Isles, findings of some preliminary studies have been published (O'Brien and Van Akkerveeken 1977; Dickson et al. 1980; Goldberg et al. 1980; O'Brien 1980; Owen et al. 1980).

It is axiomatic that any screening procedure for abnormality is based on a knowledge of normality. Yet we were unable to find an objective study of posterior trunk asymmetry in healthy schoolchildren. Recently, in Japan, Takemitsu (1981) defined the limits of back contour asymmetry in schoolchildren using a "hump-meter"—devised by Götze (1973, 1975).

In this paper we report a subjective (qualitative) and objective (quantitative) appraisal of posterior trunk asymmetry in healthy schoolchildren aged 8 to 15 years. A new method is described for quantifying such asymmetry in each child as rib and lumbar hump scores, referred to collectively as trunk asymmetry scores (TASs).

MATERIALS AND METHODS

The subjects
The 636 schoolchildren included all those aged 8 to 11 years attending one primary school and volunteers aged 12 to 15 years attending two comprehensive schools in Nottingham. All were examined and measured by one observer (RGB) (see Appendix, Table 1*). One child was known to have juvenile idiopathic scoliosis and was attending hospital for treatment.

* All the tables referred to in the text are in the appendix.
**Subjective assessment**

The presence or absence of the following asymmetries observed with the child standing erect were recorded: shoulder height, scapular level, chest and hip prominence, and postural scoliosis (using a plumb line). The child was then asked to bend forward looking at the floor, keeping feet together, knees braced back, shoulders loose and hands positioned between knees or shins with elbows straight and palms opposed (Fig. 1). A subjective assessment of asymmetry of the upper chest, mid-chest and lower chest, the lumbar region and sacrum was made in this position. The presence or absence of a structural lateral spinal curvature ("clinical evidence of structural scoliosis") was recorded; observation was facilitated by dotting the centre of each spinous process with a felt-tipped pen. When a slight lumbar scoliosis, associated with a short lower limb, was corrected by an appropriate block under the foot of the short leg, the scoliosis was considered to be compensatory. Handedness was established by asking the child to write his or her name. Intra-observer error was assessed by re-examining 40 boys within two weeks.

**Objective assessment**

With the child in the standard forward-bending position, the vertebra prominens was located. After counting down the spine, skin marks were made over the centre of each spinous process. The outline of the back at T4, T8, T12, L3 and S2 was determined using a "formulator body-contour tracer" (Fig. 2). To ensure that the transverse beam of the apparatus was horizontal, a spirit level was placed upon it. The rods of the apparatus were aligned on a flat horizontal surface, after which they were applied to the child’s back. In positioning the apparatus at each level, the centrally marked rod was placed exactly over the skin mark on each spinous process. The rods were released and moved under gravity into positions determined by the contours of the back. The rods were locked into place; then the apparatus was removed from the back and placed horizontally on a piece of paper. Using a sharp pencil, the following lines were drawn at each spinal level (Fig. 3): the contour of the back as determined by the rods; the position of the centrally

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**Figure 1**

The standard forward-bending position used to assess back contour asymmetry subjectively and objectively.

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**Figure 2**

The formulator body-contour tracer used to take the outline of a child’s back in the thoracic region. Note the spirit level supported on the horizontal beam of the apparatus. The rods have dropped to take up the contour of the child’s back.

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**Figure 3**

Method of tracing and calculating back contour asymmetry at T8 and T12. Note the datum line drawn parallel to the horizontal beam of the apparatus. The trunk asymmetry is summated for five positions on each side of the midline to give the crude rib hump score.
marked rod (the midline); and a datum line drawn parallel to the transverse beam of the apparatus.

**Analysis of back contour asymmetry at T8 and T12 (Fig. 3).** The method used by Thulbourne and Gillespie (1976) was unsuited to our tracings because many of the children did not have a rib hump. Analysis of the tracings was complicated by two factors: the most prominent part of the rib hump lay at different distances from the midline; and lateral chest diameter differed between children. To make the findings comparable the following stages were used to calculate individual rib hump scores and standardise them.

First, each back contour tracing was marked into five divisions on both sides of the midline. The distance between divisions was made equal to five per cent of the corresponding lateral chest diameter. Using this five per cent step size in a child with a lateral chest diameter of 20 centimetres, the first division would be one centimetre from the midline and so on up to five centimetres. The figure of five per cent was chosen because it was found that the fifth division at five per cent included the most prominent part of the thoracic humps.

Secondly, at each of the five divisions, or steps, the distance from the datum line to the back contour line was measured on both sides of the midline; the differences were summated to give **crude rib-hump scores** in millimetres. By using five divisions, the error of the score was reduced by \(\frac{1}{5}\). The convention we adopted was that a positive score denoted a right hump and a negative score a left hump. The tracings were digitised with a Hewlett-Packard 9872A plotter/digitiser connected to a Digital Equipment Corporation MINC-11 computer using a FORTRAN programme to produce crude rib-hump scores.

The crude rib-hump scores were then standardised to a trunk diameter of 21 centimetres. This figure was chosen because it was the overall mean lateral chest diameter for the schoolchildren (Table I).

The calculation of **standardised trunk asymmetry scores** from crude TASs is as follows:

\[
\text{Standardised TAS} = \text{crude TAS} \times \frac{21}{x} \times \frac{5}{s}
\]

Where \(x = \text{lateral chest diameter, or bi-iliac width and } s = \text{step size (five per cent, or four per cent)}\)

**Analysis of back contour asymmetry at L3.** The procedure to compute the standardised hump scores from lumbar tracings was as above, apart from differences in detail, namely: a four per cent step size was used to calculate divisions from the midline—because the fifth division at four per cent included the most prominent part of the lumbar humps; and bi-iliac width was used. The crude lumbar-hump scores were standardised to a five per cent step size and a trunk diameter of 21 centimetres.

The standardised TASs enabled comparisons to be made at different spinal levels in each child, and between one child and another. The findings for tracings at T4 and S2 will be reported elsewhere.

**Mathematical analysis of back contour asymmetry (Fig. 4).** The dependence of trunk asymmetry on the variables discussed above can be demonstrated by the following formula which introduces a further concept; namely, the angle of inclination across the trunk:

\[
H = 1.5 \times \tan i
\]

Where \(H = \text{crude trunk asymmetry score, } x = \text{lateral chest diameter or bi-iliac width, and } i = \text{angle of inclination across the trunk (compare with Takemitsu 1981)}\).

The formula shows the necessity of standardising the TASs to assess the amount or severity of the asymmetry. **Error of the method: its use in detecting humps.** The reproducibility of the method was assessed on 244

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**Diagram to show the effect of lateral chest diameter upon the crude rib-hump score with equal angles of inclination across the posterior chest in the forward-bending position (angle of inclination, \(i = 20 \text{ degrees})\). The standardised rib-hump score for each of the above examples is 114.7 millimetres.**
children. The standard deviation of error was similar at T8, T12 and L3. A child had to have a TAS at any spinal level greater than ± two standard deviations to be recorded as having an objectively detectable hump. This approach excludes children whose TASs fall within 95 per cent of the error of the method.

**Statistical methods.** The information from the children with clinically straight spines was analysed for boys and girls separately as follows: (a) those with TASs outside the 95 per cent confidence limits of the error of the method and thereby having objectively detectable humps; (b) the mean and ± one standard deviation of TASs at each of the spinal level. A variety of statistical methods was used; the details are given in the appendix.

**General anthropometry.** Lateral chest diameters and bi-iliac widths were measured using a Harpenden anthropometer (Holtain Ltd, Dyfed, UK) according to the method of Tanner, Hiernaux and Jarman 1969. Total leg lengths were measured using a tape. Pelvic tilt was assessed visually by determining the distance between the levels of the observer’s thumbs when placed over the anterior superior iliac spines. Conventional clinical examination was used to exclude neuromuscular disease in children attending for radiography.

**Radiographs of the spine.** In 52 children, anteroposterior radiographs of the spine were obtained in the standing position. On each radiograph the following were measured: the angle of the primary spinal curve (Cobb’s method 1948, 1960); the degree of vertebral rotation of the apical vertebra (using Perdriolle’s torsiomètre 1979); and the angle of sacral tilt using the gastric air–fluid level as an intrinsic spirit level (Dickson et al. 1980), which proved possible in all but three subjects. Radiographs of the spine in anteroposterior flexion were obtained in some children later in the study: the subject lay supine, with the hips held symmetrically flexed and abducted to eliminate the lumbar lordosis, taking care to keep the pelvis level during exposure of the film (lordosis elimination radiography).

**RESULTS**

Two groups of children were defined as viewed in the standing forward-bending position: those with clinically straight spines (585 children, 92 per cent); and those with clinical evidence of lateral spinal curves—after correcting for any identified inequality in leg lengths (51 children, eight per cent). The findings of these two clinical groups of children were analysed separately.

**Children with clinically straight spines**

**Subjective assessment (Tables II and III).** On forward bending, asymmetry with prominence of the right thoracic region was observed in about half the children; in the lumbar region it was found on the right in a quarter to a third of the children. Prominence on the left was less common: in the thoracic region it was seen in 9 to 10 per cent of the children; and in the lumbar region in 7 to 10 per cent.

**Objective assessment.** By eliminating those children whose TASs were within ± two standard deviations of the error of the method, the number with objectively detectable humps was determined (Table IV). The mean and standard deviation of the TASs at each of the three spinal levels are shown in Figure 5, separately for boys and girls.

![Fig. 5](image)

**Trunk Asymmetry Score (mm)**

Mean ± one standard deviation of standardised trunk asymmetry scores in millimetres at each of the three spinal levels for boys and girls with clinically straight spines. At T8 the means for boys and girls are similar and all to the right of zero (zero = perfect symmetry); the girls have a larger standard deviation, or scatter of scores, than the boys. At T12 the means for boys and girls are again similar but are even further to the right of zero: the standard deviation for girls is larger than that for boys—as at T8. At L3, the mean of the boys is similar to that at T8; the mean for the girls is significantly larger than that for the boys and is similar to that for the girls at T12.

The main findings were as follows (Fig. 6): (1) about one child in four had objectively detectable rib and lumbar humps; (2) female-to-male ratios were 1.2:1 for the thoracic region and 1.4:1 for the lumbar region; (3) right humps were about 10 times more common than left humps—like the usual right thoracic curves, but unlike the usual left lumbar curves of juvenile and adolescent idiopathic scoliosis; (4) TASs in the boys and girls at each spinal level had normal (Gaussian) distributions about means to the right of zero (where zero represents perfect symmetry); (5) at T8 and T12, a wider scatter of TASs in girls than in boys; (6) at L3, but not at T8 and T12, larger TASs in girls than in boys; (7) a relation between shortening of one lower limb and a contralateral hump on the back; and (8) no relation to age (except at L3), to stature (corrected for age) or to handedness.

**Inequalities in leg length.** Inequalities in leg length in the range 1.2 to 3.4 centimetres (which were outside 95 per cent of the error of the measuring technique; Burwell, Vernon and Dangerfield 1980), were found in 15 boys and 18 girls; shortening on the right was less common in boys (8 out of 15) than in girls (14 out of 18).

**Radiographs of the spine.** Ten children with large TASs...
had radiographs of the spine in the standing position (five boys and five girls; range of TASs −42 to +54 millimetres). Of four children with right or left rib humps one had a thoracic curve of eight degrees and three had thoracolumbar curves of two, 10 and 11 degrees respectively; the convexity of the spinal curve and the vertebral rotation corresponded with the rib hump; the thoracic curve corrected fully in the flexion radiograph; the other children did not have such films. Three children had right rib humps and left thoracolumbar curves of four, six and 12 degrees without vertebral rotation in erect films—they may have postural scoliosis. Two children with left humps had left thoracic and left thoracolumbar curves of eight and 17 degrees respectively, each without vertebral rotation; the curve in each child corrected fully in flexion radiographs (Figs 7 and 8); they were considered to have postural scoliosis. One boy with right thoracic and lumbar humps had shortening of the left lower limb measured clinically as 3.4 centimetres and by scanogram as 3.0 centimetres; after complete correction of the leg length inequality (as confirmed by the angle of sacral tilt), a left lumbar curve of 18 degrees reduced to four degrees (Figs 9 and 10). It was considered to be compensatory.

**Children with clinical evidence of structural scoliosis**

There were 51 children who showed clinical evidence of structural scoliosis in the forward-bending position (19 boys and 32 girls; see Table I and Figures 11 and 12). Forty-two of these children attended hospital for radiography of the spine. With one exception they had minimal lateral spinal curves of 19 degrees or less, mostly thoracolumbar or lumbar in site. In the boys, there were eight spinal curves convex to the left and eight convex to the right. In the girls, there were 11 spinal curves convex to the left and 15 convex to the right. There were eight children with spinal curves of 11 degrees or more (three boys and five girls). The findings are in contrast to the right thoracic curves of 20 degrees or more commonly seen in girls attending scoliosis clinics.

The majority of the radiological curves had also been identified by clinical examination: these were termed concordant. Only one curve had been diagnosed previously (the girl with the thoracic spinal curve). The side of the spinal curve observed clinically in the forward-bending position was not confirmed radiographically in the standing (erect) position in seven children (two boys and five girls); these were termed discordant; all were radiographically convex to the left and may have been postural. Flexion films, obtained for three subjects, showed the following: in one boy a lumbar curve which became more evident; in another boy a lumbar curve observed clinically but not seen in the erect film was revealed; and in one girl a discordant left thoracolumbar curve converted to a concordant right thoracolumbar curve.

Some lumbar curves were considered to be compensatory to a sacral tilt (where the magnitude and side of the spinal curve equalled almost twice the angle of sacral tilt; Dickson et al. 1980).

**Interrelation of TASs and the radiographic variables.** In this analysis, children considered to have postural scoliosis and the girl with juvenile idiopathic scoliosis were excluded. There was a statistically significant correlation between TASs measured nearest the apical vertebra of the primary spinal curve and: (1) Cobb spinal curve angle \( r = 0.42, P = 0.02, n = 34 \); and (2) vertebral rotation \( r = 0.35, 0.02 < P < 0.05, n = 34 \). The Cobb angle correlated with the degree of apical vertebral rotation \( r = 0.89, P < 0.001, n = 34 \).

**Leg-length inequality.** There were four girls and one boy with significant leg-length inequalities. All were in the range 1.5 to 2 centimetres. There was no apparent relation to the spinal curvature.

**DISCUSSION**

**Clinical significance of asymmetry—definition of a “scoliosis curve”.** The criteria used by Brooks et al. (1975) to diagnose structural scoliosis were the presence of at least one positive physical sign—a rib hump, lumbar hump, spinal imbalance, or discrepancy in shoulder height—and radiographic evidence of a spinal curve of at least five degrees. Brooks et al. (1975) applied these criteria to a population of 3492 children aged 12 to 14 years. The incidence of scoliosis was found to be 13.6 per cent. In other series, the “scoliosis prevalence” has varied greatly, but only 0.3 per cent required treatment (Lonstein 1977). It has been estimated that the prevalence of spinal curves of 20 degrees or more is five per 1000 (Kane 1977).

Taylor, Bushell and Ghosh (1978 a, b) pleaded for commonsense to prevail in order to avoid excessive investigation and unnecessary treatment. They hoped that “a measureable laboratory parameter” would emerge to aid prognosis and rationalise treatment. In a subsequent paper, Brooks (1980) reported that the Prevalence Committee of the Scoliosis Research Society defined a “scoliosis curve” as one of 11 degrees or more; such curves were found in two per cent of subjects between the ages of 12 and 16 years.

In the 52 children radiographed in the present study, 1.9 per cent had curves of 11 degrees or more (six boys and six girls); only one child (the girl with juvenile idiopathic scoliosis) had a curve greater than 20 degrees. Few, if any, of the others are likely to progress beyond 20 degrees.

Of the 584 children who did not have spinal radiographs, it cannot be known how many had a “scoliosis curve”. It is possible that one or more may develop progressive idiopathic scoliosis; this is under investigation as part of a longitudinal study.

Leaving aside the boy with 3 centimetres inequality of leg length, six children had flexion radiographs; in each, a change in the spinal curve angle was found (Figs 7 and 8). Such radiographs may help in identifying postural scoliosis and therefore have prognostic value.
Further work is being undertaken to evaluate the method and appraise its significance for the definition of a "scoliosis curve".

**Early diagnosis—a possible new approach.** The Swedish experience reported by Torell, Nordwall and Nachemson (1981) showed that early diagnosis and bracing of children with juvenile and adolescent idiopathic scoliosis had the following effects: spinal curves were less severe when diagnosed; fewer spinal curves progressed to 40 degrees; and less surgical operations were performed. There was, however, a fivefold increase in the number of patients referred to hospital for an orthopaedic opinion.

**Forward Bending Position**

![Diagram](image)

**Fig. 6**

Diagram to summarise the findings for back contour asymmetry in the standard forward-bending position for the 585 children with clinically straight spines. There was no relation to age (except at L3), stature or handedness. (TAS = trunk asymmetry score, R = right, L = left, RH = rib hump, LH = lumbar hump.)

**Fig. 7**

Radiographs of the spine of a boy aged 15 years with a clinically straight spine and a left rib hump in the standard forward-bending position (TAS at T8 = +30 millimetres, at T12 = +12 millimetres, and at L3 = -6 millimetres). Figure 7—Radiograph standing erect. Note the left thoracolumbar curve of 17 degrees (curve limits T9 to L3, apical vertebra T12, vertebral rotation five degrees). Figure 8—Radiograph when flexed. Note that the spine is almost straight with a residual left curve of two degrees. The curve of 17 degrees is considered to be a postural scoliosis. To measure rotation of the apical vertebra using Perdrillo's method (1979), two crosses have been made on the edges of the vertebral bodies as datum points and the vertical diameter of the pedicle on the convexity has been marked by a line: the torsiométre is superimposed and the rotation read off in degrees.

**Fig. 8**

**Fig. 9**

Radiographs of the spine of a boy aged 15 years with a short left lower limb with and without correction of leg-length inequality (TAS at T8 = +28 millimetres, at T12 = +54 millimetres, and at L3 = +34 millimetres without correction). A scanogram showed 3.0 centimetres of shortening of the left lower limb; the thoracic and lumbar humps were on the right. Figure 9—Radiograph in the standing (erect) position. Note that the pelvis on the left is lower and there is a left lumbar curve of 18 degrees (curve limits L1 to S, apical vertebra L3, vertebral rotation 15 degrees). Figure 10—Radiograph in the erect position after correcting the leg length inequality by a three-centimetre raise under the left foot. Note that the pelvis is level and there is a residual left lumbar curve of four degrees.
These observations, and those of Lonstein et al. (1982), suggest that while early diagnosis is beneficial, many children are being referred to hospital unnecessarily (Leaver, Alvik and Warren 1982). It could be argued that this is a price to be paid by the many to treat the few. In our opinion this view is acceptable only if methods currently used to detect early idiopathic scoliosis cannot be improved.

Apart from the work of Takemitsu (1981) there is no published numerical data on back contour asymmetry for a normal sample of schoolchildren. Takemitsu used a humpmeter on 3819 healthy children and defined abnormal asymmetry as 7 to 10 millimetres of hump; the larger figure was for adolescent boys. By using this clinical threshold, he detected 84.5 per cent of spinal curves of 15 degrees or more. The information was not analysed separately for postural and idiopathic scoliosis.

Our findings show that an observed rib or lumbar hump is usually normal. In the children with clinical evidence of lateral spinal curves, the incidence of TASs outside the mean ± three standard deviations at one or more spinal levels was seven times that of those children with clinically straight spines. By non-radiographic measurements of back contour asymmetry and lateral spinal curves using automated instruments, we hope to discriminate which children need orthopaedic care.

**TASs and leg-length inequality—the best position for screening.** Inequality of leg length has been recorded in some children with trunk asymmetry (Dickson et al. 1980; Taylor and Slinger 1980; Papaioannou, Stokes and Kenwright 1982). Our observations confirm these findings. Moreover, shortening of one lower limb was found to be associated with a contralateral hump on the back, not only at L3 but also at T12 and T8. These findings...
indicate that the *standing* forward-bending position used in school screening, while satisfactory for clinical use, should be replaced by a *sitting* forward-bending position when measurements are needed (see Harada, Takemitsu and Imai 1981).

**Vertebral rotation and vertebral asymmetry.** It is generally considered that a rib hump implies vertebral rotation and, by implication, a lateral spinal curve (James 1976). This is consistent with the knowledge that in the normal thoracolumbar spine of an adult lateral flexion is always associated with axial rotation (Gregersen and Lucas 1967; see Davis 1959).

In the children with clinically straight spines, the following features were consistent for only four of the 10 children radiographed: side of rib hump (in the forward-bending position); side of the lateral spinal curve; and side of vertebral rotation (on radiographs taken in the erect position). In the other children with large TASs there was no evidence of vertebral rotation. As already discussed, one problem is that the position of vertebrae, one to another, when the spine is flexed may be different from that in the standing position.

Intravertebral asymmetry, without intervertebral rotation, could have caused the large TASs in the children with clinically straight spines who lacked radiographic evidence of vertebral rotation. In this connection, using anatomical specimens, Taylor (1978) observed asymmetry of vertebral arches and their processes more frequently than wedging of vertebral bodies. Subsequently, Taylor (1980 a, b) reported that right midthoracic pedicles were longer than left pedicles in 69 per cent of children under seven years of age; in children over eight years of age, there was a reversal of asymmetry with left pedicles longer than right in 50 per cent of midthoracic vertebrae. This was not so for lumbar vertebrae where in children aged 7 to 13 years, right pedicles were longer; this would explain our finding of a preponderance of right lumbar humps (see below). There is clearly a need to examine pedicle length asymmetry and TASs in patients with normal spines undergoing computerised tomography.

**Handedness and dominance.** Our findings show no relation between handedness and TASs. In the absence of assessment for dominance (laterality) of hands, feet, eyes and ears, we are unable to conclude that cerebral hemispheres are not involved in normal trunk shape distortion. There is electromyographic evidence for the hypothesis that lateral dominance influences asymmetry of axial muscles (Süssová, Pfeiffer and Dušek 1972). However, in the thoracic region of healthy subjects no difference has been found between myoelectric activity on the two sides of the back (Zetterberg, Andersson, Björk and Örtengren 1981). The latter studies need to be evaluated in relation to TASs. Neuromuscular mechanisms do not explain the sexual dimorphism involving trunk asymmetry, although there is evidence of sexual dimorphism in early cerebral hemisphere maturation (Taylor 1969; Smart, Jeffery and Richards 1980); and of cognitive abilities (for speech and spatial tasks) in the adult brain (McGlone 1983).

LATERALITY is used to describe an asymmetrical function (Touwen 1972). Hence it seems inappropriate to apply the term to trunk humps. Although a child's back shows individual characteristics of shape, there is an overall pattern in the sample examined; it is clearly different from the "fluctuating asymmetry" of humeri and teeth observed in rodents subjected to prenatal stress (Siegel and Doyle 1975). It is probable that genetic factors are involved: racial, family and twin studies are clearly indicated. Like the genetic theories of handedness, it is possible that other factors, particularly prenatal and perinatal, may be important (Coren and Porac 1980; Smart et al. 1980; Geschwind and Behan 1982).

**Sexual dimorphisms in the axial skeleton (possible significance for the pathogenesis of idiopathic scoliosis).** Female-to-male ratios for trunk humps of 1:2:1 have been reported by other workers (Brooks et al. 1975); the sex ratio for TASs was significant in our data only for the lumbar region.

The wider scatter of TASs in girls is consistent with previous observations that the range of variation of size is greater in females than in males, for example in the pelvis of prepubertal children (Reynolds 1945, 1947) and the humerus in white adults (Krahli and Evans 1945). In prepubertal children, skeletal sexual dimorphisms are also described for head shape (Baughan and Demirjian 1978), vertebral body shape (Brandner 1970), pelvic shape (Reynolds 1945, 1947), forearm length, metacarpal and finger length, deciduous teeth (Demirjian 1982) and bone age (see Tanner 1962; Prader 1982).

The reasons for these axial and appendicular skeletal features of sexual dimorphism in healthy children is unknown. There is no evidence that they are due to ligamentous or neuromuscular mechanisms acting postnataally. Some could be sex-linked genetic expressions intrinsic to growing skeletal tissues and determined prenatally. Such an explanation has been offered to explain the reduction of phalangeal number of the fifth toes of adult females (Venning 1956; and see Tanner 1962).

The significance of sexual dimorphisms for the pathogenesis of idiopathic scoliosis is not clear. Three possible mechanisms are: (1) that the physical build of females (such as their vertebral body shape) may facilitate the progression of a spinal curve (see above); (2) that the greater range of variation in trunk asymmetry in girls implies a wider threshold between normality and abnormality (a similar interpretation applies to the higher incidence of idiopathic scoliosis in white, relative to black, subjects; Segil 1974); and (3) that in early embryonic life, developing skeletal primordia of the sexes may be susceptible at different times to genetic or environmental factors or both which create aberrations expressed later in life as a deformity in a way related to age and sex.

**TASs and the early diagnosis of scoliosis.** The purpose of
this study was to provide a basis of normality for evaluating the trunk shape deformity in children with idiopathic scoliosis. The method has enabled us to define extremes of back contour asymmetry in statistical terms, as Kane (1977) did for lateral spinal curves on radiographs. Preliminary observations have suggested that most children with idiopathic structural spinal curves of 20 degrees or more have TASs greater than two standard deviations from the normal mean at one vertebral level, at least. These studies will be the subject of a separate paper.

ADDENDUM

Since this paper was submitted, using a horizontal measuring stick, similar findings of trunk asymmetries for healthy schoolchildren in Belgium have been reported (Vercauteren et al. 1983).

APPENDIX

The sample of schoolchildren (Table I). The "normality" of the sample was evaluated for stature separately for boys and girls from each school. The standard deviation score of stature was calculated for each child using data for the normal British population published by Tanner (1978). No significant differences were found between the three schools for boys or girls (Student's t test); the findings for stature were similar to those published by Tanner (1978). At the two comprehensive schools for the boys and girls separately, there was no significant difference for the numbers of children with and without objectively detectable humps (Mantel-Haenszel test; Breslow and Day 1980).

Subjective assessment of back contour asymmetry. The results are expressed in Tables II and III.

Error of the subjective assessment. A fourfold table of frequencies was set up to represent: (a) the first and second sets of observations, and (b) symmetrical and asymmetrical. This analysis was undertaken separately for the thoracic region (T8 and T12 combined) and the lumbar region. No significant differences were found (thoracic region $\chi^2 = 0.11$, $0.7 < P < 0.8$, lumbar region $\chi^2 = 0$, $P > 0.9$; McNemar test).

Error of the objective assessment. The error was analysed with respect to (a) using the plotter/digitiser, (b) using a plaster model prepared from the trunk of a child with a marked thoracic scoliosis, and (c) 244 children measured twice within two weeks with about equal numbers of boys and girls at each age.

A study of 80 tracings measured twice using the Hewlett-Packard plotter/digitiser, showed that differences between TASs at first and second recordings were $0.21 \pm 0.94$ millimetres (mean and standard deviation). Hence the error due to the plotter/digitiser was minimal. The plaster model was held rigidly in a vice and 10 tracings were made on the posterior aspect of each of the thoracic and lumbar regions. The standard deviations of the differences between tracings were: thoracic region, $\pm 3.5$ millimetres; and lumbar region, $\pm 2.7$ millimetres. In the 244 children, the differences between TASs at the first and the second tracings were calculated. The standard deviations of the error of the method at each level were as follows: at T8 $= \pm 10.3$ millimetres; at T12 $= \pm 10.7$ millimetres; and at L3 $= \pm 10.9$ millimetres. No evidence of skewness was found at any of the spinal levels. In consequence for this observer a child had to have a TAS $\geq \pm 22$ millimetres (mean $\pm 2$ standard deviations) at T8, T12 and L3 to be recorded as having an objectively detectable hump. Hence about one third of the error was due to the observer obtaining and analysing the tracings; two thirds were attributed to postural changes within the subject being examined—due probably to varying trunk rotation superimposed on trunk shape in the standing forward-bending position (compare with Frobin and Hierholzer 1982).

Objectively detectable humps (Table IV). Female-to-male ratios of the number of children with objectively detectable humps were: for T8 and T12 combined, 1:2:1 (0.2 < $P < 0.3$); and at L3, 1:4:1 (0.02 < $P < 0.05$) (2 x 2 contingency table).

Right-to-left ratios of the number of children with objectively

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Boys</th>
<th>Lateral chest diameter Bi-iliac width (centimetres)</th>
<th>Girls</th>
<th>Lateral chest diameter Bi-iliac width (centimetres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>29</td>
<td>18.9 ± 1.0</td>
<td>29</td>
<td>18.3 ± 1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.5 ± 1.3</td>
<td></td>
<td>19.9 ± 1.2</td>
</tr>
<tr>
<td>9</td>
<td>29</td>
<td>19.5 ± 1.2</td>
<td>24</td>
<td>19.1 ± 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20.3 ± 1.5</td>
<td></td>
<td>20.9 ± 1.8</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>20.0 ± 1.3</td>
<td>39</td>
<td>19.7 ± 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.3 ± 1.2</td>
<td></td>
<td>21.6 ± 1.7</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>20.7 ± 1.4</td>
<td>23</td>
<td>20.8 ± 1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22.3 ± 1.4</td>
<td></td>
<td>23.4 ± 1.7</td>
</tr>
<tr>
<td>12</td>
<td>51</td>
<td>21.5 ± 1.6</td>
<td>51</td>
<td>21.5 ± 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.0 ± 1.9</td>
<td></td>
<td>24.2 ± 2.0</td>
</tr>
<tr>
<td>13</td>
<td>54</td>
<td>22.2 ± 1.6</td>
<td>52</td>
<td>22.2 ± 1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24.2 ± 1.8</td>
<td></td>
<td>25.7 ± 1.9</td>
</tr>
<tr>
<td>14</td>
<td>51</td>
<td>23.8 ± 1.9</td>
<td>51</td>
<td>22.7 ± 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25.1 ± 1.8</td>
<td></td>
<td>25.9 ± 1.4</td>
</tr>
<tr>
<td>15</td>
<td>53</td>
<td>24.5 ± 2.3</td>
<td>52</td>
<td>22.8 ± 1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25.8 ± 2.1</td>
<td></td>
<td>26.5 ± 1.6</td>
</tr>
<tr>
<td>TOTALS</td>
<td>315</td>
<td>(295)</td>
<td>321</td>
<td>(290)</td>
</tr>
</tbody>
</table>

* Numbers in brackets show the number of children without clinical evidence of structural scoliosis. The calculations for lateral chest diameter and bi-iliac width were made from these children.
Table II. Comparison of subjective with objective assessment of the posterior chest in the forward-bending position in children without clinical evidence of structural scoliosis

<table>
<thead>
<tr>
<th>Subjective assessment of mid-posterior and lower posterior chest</th>
<th>Objective assessment of posterior chest at T8 and T12 combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>Symmetrical</td>
</tr>
<tr>
<td></td>
<td>Per cent</td>
</tr>
<tr>
<td>Symmetrical</td>
<td>Per cent</td>
</tr>
<tr>
<td>Boys</td>
<td>44</td>
</tr>
<tr>
<td>Girls</td>
<td>36</td>
</tr>
<tr>
<td>Right rib hump</td>
<td>Per cent</td>
</tr>
<tr>
<td>Boys</td>
<td>46</td>
</tr>
<tr>
<td>Girls</td>
<td>55</td>
</tr>
<tr>
<td>Left rib hump</td>
<td>Per cent</td>
</tr>
<tr>
<td>Boys</td>
<td>10</td>
</tr>
<tr>
<td>Girls</td>
<td>9</td>
</tr>
</tbody>
</table>

Table III. Comparison of subjective with objective assessment of posterior lumbar region in the forward-bending position in children without clinical evidence of structural scoliosis

<table>
<thead>
<tr>
<th>Subjective assessment of lumbar region</th>
<th>Objective assessment of posterior lumbar region at L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>Symmetrical</td>
</tr>
<tr>
<td></td>
<td>Per cent</td>
</tr>
<tr>
<td>Symmetrical</td>
<td>Per cent</td>
</tr>
<tr>
<td>Boys</td>
<td>66</td>
</tr>
<tr>
<td>Girls</td>
<td>63</td>
</tr>
<tr>
<td>Right lumbar hump</td>
<td>Per cent</td>
</tr>
<tr>
<td>Boys</td>
<td>24</td>
</tr>
<tr>
<td>Girls</td>
<td>30</td>
</tr>
<tr>
<td>Left lumbar hump</td>
<td>Per cent</td>
</tr>
<tr>
<td>Boys</td>
<td>10</td>
</tr>
<tr>
<td>Girls</td>
<td>7</td>
</tr>
</tbody>
</table>

Table IV. Children with objectively detectable trunk asymmetry scores (TASs) in the forward-bending position and without clinical evidence of structural scoliosis

<table>
<thead>
<tr>
<th>Rib humps (T8 and T12 combined)</th>
<th>Total number of children</th>
<th>Rib humps (T8 and T12 combined)</th>
<th>Lumbar humps (L3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right humps (TAS $\geq +22$ millimetres)</td>
<td></td>
<td>Per cent</td>
<td>Number</td>
</tr>
<tr>
<td>Boys</td>
<td>295</td>
<td>24</td>
<td>72</td>
</tr>
<tr>
<td>Girls</td>
<td>290</td>
<td>29</td>
<td>84</td>
</tr>
<tr>
<td>Left humps (TAS $\geq -22$ millimetres)</td>
<td></td>
<td>Per cent</td>
<td>Number</td>
</tr>
<tr>
<td>Boys</td>
<td>295</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Girls</td>
<td>290</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>
detectable humps were: for T8 and T12 combined, boys 10.3 ± 1.0, girls 8.4 ± 0.9; and at L3, boys 11.0 ± 0.1, girls 12.3 ± 0.1. At adjacent spinal levels for the number of boys and girls there was a significant difference for the comparisons T8 with T12 and T12 with L3 (P < 0.001 in each case, 2 x 2 contingency table). At T8 there were 44 boys (39 right, 5 left humps) and 54 girls (48 right, 6 left). At T12, there were 67 boys (62 right, 5 left) and 75 girls (70 right, 5 left). At L3, there were 60 boys (55 right, 5 left) and 80 girls (74 right, 6 left).

**Means and standard deviations of TAs at T8, T12 and L3—relation to side.** See Figure 5 and Table V. Each mean was significantly to the right of zero (P < 0.001) (where zero represents perfect symmetry). No evidence of skewness was detected in the data, except at T12 in boys (g = -0.281, P = 0.05). No evidence of kurtosis was detected except at T8 and T12 in boys (g2, at T8, 1.176, P < 0.001; g2, at T12, 0.628, 0.02 < P < 0.05).

**Table V.** Means and standard deviations of standardised TAS scores of children without clinical evidence of structural scoliosis

<table>
<thead>
<tr>
<th>Spinal level</th>
<th>Standardised trunk asymmetry scores (millimetres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n = 295)</td>
</tr>
<tr>
<td>T8</td>
<td>+9.0 ± 12.4</td>
</tr>
<tr>
<td>T12</td>
<td>+12.0 ± 13.4</td>
</tr>
<tr>
<td>L3</td>
<td>+8.5 ± 14.2</td>
</tr>
</tbody>
</table>

Normal (or Gaussian) distributions of TASs at T8, T12 and L3. The Kolmogorov-Smirnov one-sample test was used to evaluate whether or not the TASs were consistent with a normal distribution. The data were arranged from -4 to +4 SDs about each mean in steps of 0.5 SDs separately for boys and girls and for each spinal level, and the ogives drawn. None of the values of D was above the critical value as given in the table of Neave (1981) (5% level, z2, constant c). Neither was statistical significance found when the data, for boys and girls separately, were analysed cumulatively by 1/n at each observed value; nor by each year of age separately for boys and girls with a step function of 1/n. Hence, there was insufficient evidence to disprove a normal distribution. TASs evaluated with respect to age, sex, site, stature, handedness and inequality of leg length. An analysis of variance showed that there was no significant relation of TASs to chronological age ("crude age") at any spinal level. When corrected for sex, there was no statistically significant difference for age in the thoracic region; there was a weak significance in the lumbar region (at L3, F = 1.75, df = 14:569: 0.02 < P < 0.05).

There was a statistically significant relation to sex as shown by four statistical tests. Female-to-male ratios of the number of children with objectively detectable humps revealed a significant difference for the lumbar, but not for the thoracic, region (see above). A Student's t test showed that at L3 the TASs were significantly larger in girls than in boys (0.01 < P < 0.02). No such difference was found at T8 or T12 (Figure 5, Table V). An analysis of variance confirmed the difference for sex was still present at L3 (F = 5.07, df = 1:583: P < 0.001), but not at T8 or T12. When corrected for age, the statistical significance for sex was still present at L3, but was weaker (F = 2.25, df = 8:569, 0.01 < P < 0.02). Comparing boys with girls using the variance ratio test, F-values were as follows: at T8, F = 1.40; one-sided P = 0.002: two-sided P = 0.004; at T12, F = 1.34, one-sided P = 0.0065; two-sided P = 0.013; at L3, F = 1.11, not significant (df = 289 and 294: personal communication by Neave 1982). The Kolmogorov-Smirnov two-sample test did not show statistically significant differences for sex at any spinal level. This non-parametric test is general and has less power than the t test and an analysis of variance. It does not test for spread as does the variance ratio.

In connection with site, in boys, mean scores were significantly larger at T12 than at T8 and L3 (P < 0.001). In girls, mean scores were significantly larger at T12 and L3 than at T8 (P < 0.001 and 0.01 < P < 0.01 respectively, paired t test).

No relation between stature (expressed as standard deviation scores) and TASs was found for boys or girls (correlation coefficients, r).

The null hypothesis that the TASs were unrelated to the handedness was not rejected statistically (boys T8 0.2 < P < 0.3, others P > 0.5, df = 1, 2 x 2 contingency table). Excluding children with clinical evidence of structural scoliosis, there were 13.2 per cent of left-handed children (boys 41, girls 36; compare with Smart et al. 1980). Yule's correction for continuity was used.

The relation of inequality of leg length to TASs was evaluated using parametric and non-parametric tests. The correlation coefficients (r) were as follows: boys, at T8, 0.14, P = 0.009; at T12, 0.24, P < 0.001; at L3, 0.24, P < 0.001; girls, at T8, 0.12, P = 0.019; at T12, 0.24, P < 0.001; at L3, 0.21, P < 0.001. The Mann-Whitney test was applied to boys and girls combined with leg-length inequalities of 1.2 centimetres or more. At each spinal level, TASs were ranked with respect to two groups: longer or shorter in right lower limb. A significant relation was found between shortening of one leg and a contralateral hump on the back at L3, T12 and T8 (0.001 < P < 0.01, 0.001 < P < 0.01 respectively) (compare with Taylor and Slinger 1980).

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