Measurement of Body Posture using Multivariate Statistical Techniques

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This research arose out of a need to find a well-defined measure of kyphosis and its companion lordodis, two defects of human body posture. In the course of measuring body posture by means of digitised photographs , it was noticed that the digitised data were in a form usable by Principal Component Analysis (PCA) . PCA is a process for finding the source of variability in measurements and identifying the source in terms of a linear combination of measured variables . In the measurements being studied one cause of variability would be body posture , that is , the kyphosis and lordosis of the subjects being photographed. It seemed likely that the application of PCA to data from appropriately marked , photographed and digitised subjects would yield an index of kyphosis /lordosis as a linear combination of certain measurements The search for an index was successful. It also appears that kyphosis and lordosis merely represent extreme values of the same condition , although they have different clinical causes , and so should be regarded as different pathologies. This index generates a scale which truly reflects small changes in posture, thus establishing normal values. It also has the asset of being non-invasive and is obtainable in a well defined , easily repeatable objective manner.

1. Introduction

The ideal posture was described by Kendall *et al.* Given a view from the front and back , the line representing the sagittal plane and coinciding with the middle of the body, begins midway between the heels and extends upward midway between the lower extremities . This line passes through the middle of the pelvis and, spine and sternum and skull . Clearly this assumes that both halves of the body are symmetrical and counterbalance. From the side view the vertical line of reference represents the lateral plane which divides the body into front and back sections of equal weight. These sections , however , are not symmetrical. The line passes through the lobe of the ear , through the shoulder joint , then approximately midway between the back and the abdomen , approximately through the greater trochanter of the femur , slightly anterior to the midline, through the knee and slightly anterior to the lateral malleolus . Any marked deviation from these lines is a postural fault. The problem is that this would apply to most individuals . Kendall and Boynton appear to be describing an individual who is young fit and possibly has had military training. What is sought is a measure which will pick up a spinal defect which is away from the norm of the average human.

Farady (1983) measures lateral curvature of the spine with x-rays. Lines are drawn from the superior end of the cephalad and most caudal vertebrae , parallel to the face of each on the sagittal plane. The intersection of the two lines forms an angle called the COBB angle. It may happen that the two lines do not intersect on the film. In this case, intersecting lines are drawn perpendicular to the vertebrae to form an equivalent angle. The Cobb angle remains the most popular method of measuring spinal curvature at present. Other methods have involved the Flexicurve (Berryman ,1990), DeBrunner's

Kyphometer (Ohlen *et al*, 1988) and the Arcometer (D'Osualdo *et al* 1997). The Flexicurve involves the moulding of a flexible engineer's curve onto the spine and measuring the resulting curve. This is a measure of thoracic kyphosis. This method is a modified approach to the COBB angle method. The Kyphometer and Arcometer are compass-type instruments with an attached protractor. The instrument is applied to the back and a measure of the COBB angle is obtained. These methods have reported some problems with interobserver and intraobserver errors . Also subject size is a factor as well. Difficulties have been reported when tall subjects have been used.

The most popular method being investigated is the method of digitising the spinal landmarks necessary for measuring kyphosis/lordosis. Bryant *et al* (1989) outline the steps to achieve this. Essentially, selected vertebrae are palpated and skin markers are placed on these vertebrae. A photograph is taken and x and y coordinates are assigned to these landmarks . In this case a cubic spline was fitted to these points to look at the curvature.

2. PCA-Reduction of Dimensionality.

Suppose we have n variables :

$$x^T = \{x_1, x_2 \ldots\ldots x_n\}$$

Principal Component Analysis makes n linear combinations of the variables (called principal components)

P =A x

The columns of the transpose of A contain the coefficients of each principal component. The eigenvalues are chosen to capture as much of the variation in **x** as possible while simultaneously ensuring that each eigenvector is orthogonal to its predecessors. This ensures that the components will be uncorrelated.

It is easy to show that

$$\sum Var(P_i) = \sum Var(x_i)$$

Thus if the first ,say, k, eigenvalues account for , say, 90% of the total variation ($k < n$) then the variability is describable in terms of k variables.
We thus hope to apply this technique to the vertebrae of the spine and demonstrate that the variability can be explained in as few variables as possible. Principal Component Analysis is well explained in Jackson (1991).

3. Data Manipulation.

Data has been difficult to obtain. The first set of such data which enabled study on the spine consisted of 40 individuals of whom 20 were elite bicycle riders and 20 who did not ride at all. It was postulated that due to the hunched position of the bicycle riders , they might display a greater degree of curvature in the spine than those who did not ride (Ashcroft , 1992). X and Y coordinates were taken for the landmarks:

C7 T4 T8 T12 L3 L5 on the spine.

The right profile was observed. The first necessary objective was to remove any effect due to height and positioning of the feet. This was achieved by :

(a) Translating L5 to (0,0)

(b) Rotating the resultant figure so that C7 lies Y-axis.

(c) Scale the resulting figure so that it lies between (0,0)and (0.1) i.e.C7 is at (0,0) and L5 is at (0.1)

The reason for the above is that morphometrical data always seems to produce a "general" component when PCA is applied , which merely says that size is the major contributing factor to overall variability.

4. Application of PCA.

The reader should note that we now have only 4 landmarks to work with-C7 and L5 are constant and display no variability. Actually there are 8 variables –the x and y coordinate of each landmark.
We apply PCA to the correlation matrix of the data. The covariance matrix can be used but each landmark is regarded as equally important and this is achieved by the use of the correlation matrix.
To ascertain how many components we need a SCREE plot is drawn. This is just a plot of the ordered eigenvalues.

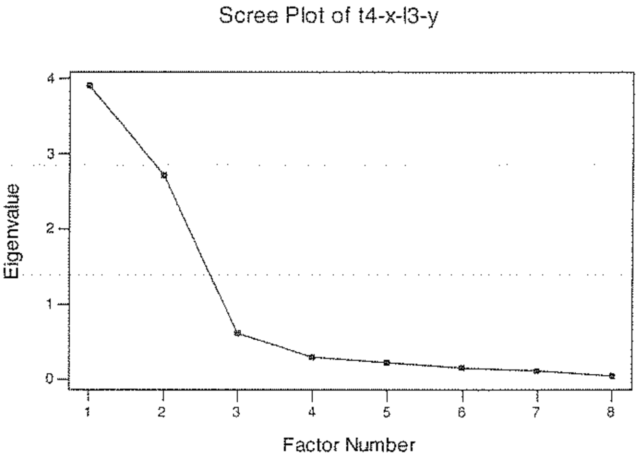

Fig 1 Scree Plot

The plot suggests retaining two components , at most . These two account for 83% of the total variation of the data. (2 latent variables are accounting for the full set of 8)
The remaining 6 are regarded as "scree" or "rubble"- they probably differ by only sampling error. We now "rotate" these components using an orthogonal scheme. This allows easier interpretation of what the latent variables are trying to tell us while ensuring that the components are still uncorrelated. (Factor Analysis , a technique which does much the same thing as PCA, usually uses an oblique rotation-

this loses the independence property of the factors)
The reader will note that "factor" is used in the graphs employed by the statistical software. This is because PCA is often the default for factor Analysis.

Looking at the coefficients of the two retained components:

Table 1. Coefficients of Factors

Variable	Factor 1	Factor 2
T4-X	0.772	0.004
T4-Y	-0.288	0.861
T8-X	0.903	-0.272
T8-Y	-0.249	0.875
T12-X	0.899	-0.363
T12-Y	0.027	0.950
L3-X	0.911	-0.071
L3-Y	0.569	0.683

The first factor has heavy loadings on all the x-coordinates. This can be interpreted as a factor of kyphosis/lordosis . The second factor has heavy loadings on all the y-coordinates. This can be interpreted as the factor of spinal vertebrae heights and shows that a main source of variation is the height of the landmarks of the spine.
Graphically

Fig 2. Plot of Coefficients

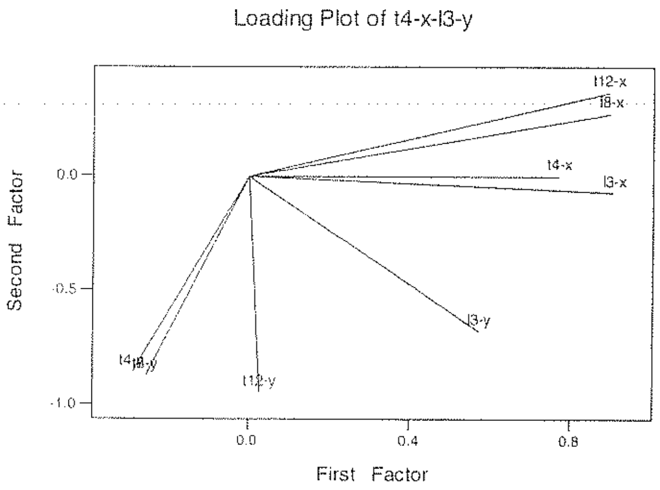

Fig 2. Coefficient plot

The reader will notice a relatively high value for L3-Y and the somewhat "out of place" position on the loading plot. The reason appears to be that L3 moves in sympathy with the other vertebrae so that as the x-coordinates are moving to the right , L3 appears to be moving upward.

This set of data was replicated by another examiner and the same experiment was repeated . the 2 sets of results showed a 0.997 correlation thus confirming reliability of the palpation and subsequent measurements.

5. The Index of Kyphosis/Lordosis

Having ascertained that the first factor was the one we were searching for , a score could be given to every subject which would ascertain the degree of kyphotic/lordotic tendency that each had. The coefficients were scaled so as to give a range of scores which had a mean of zero and a standard deviation of unity. The scores range from −1.87 to 3.24. Looking at the distribution of the scoresthey appear to have a normal distribution and indeed a normality test does not reject the hypothesis of normality.

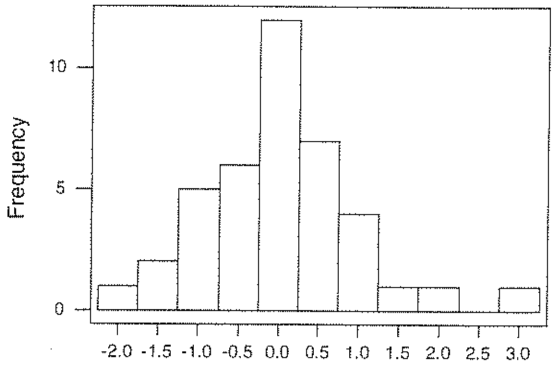

Fig 3 factor 1 scores

The validity of the scores can be demonstrated by looking at the spinal shapes for differing scores. It will be observed that a large negative score indicates kyphosis and a large positive score indicates lordosis. A near zero score indicates a normal spine.

It must be noted that these subjects were regarded as normal primarily. Therefore any extreme scores must be viewed as an extremity of the normal bounds of spinal curvature. If the score was calculated for a person with ,say, extreme kyphosis using these coefficients , then we would expect to get a very large negative score. As things stand we have a measure of normality on a standard normal scale.

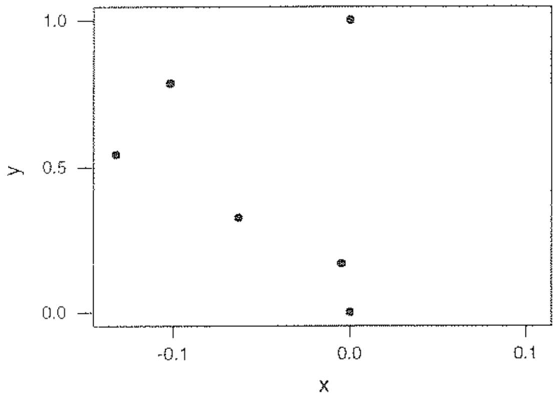

Fig 4 . Score = -1.87

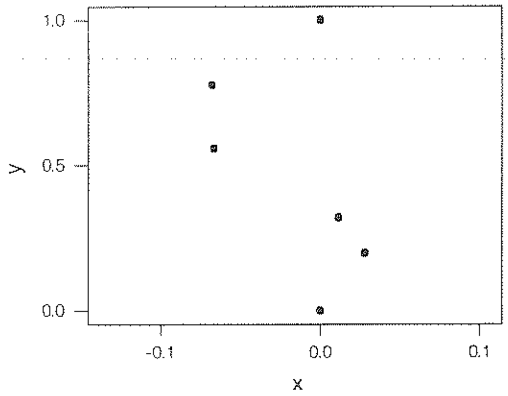

Fig 5 Score = 0.05

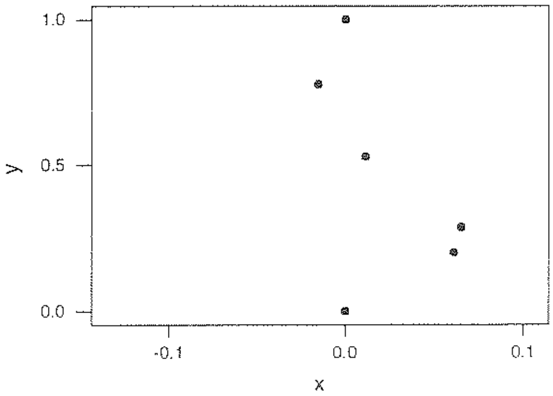

Fig 6. Score = 1.97

The 3 scores clearly predict the spinal shapes that have emerged. The scores are a clear indicator of any kyphotic/lordotic tendency.

As a point of interest , there was no difference in the curvatures of the bicycle riders and non-riders. When comparing the scores of the 2 groups the results indicated no significant difference (t=0.55 df=30 p>0.05). This confirmed Ashcroft's findings.

6. The Bootstrap.

It would be remiss not to attempt to ascertain the population coefficients of the factor scores. (recall the coefficients have been scaled to give zero mean and standard deviation of unity). The only reasonable way is via the Bootstrap.

1000 samples of size 40 were taken with repalcement and PCA with rotation applied to each. The results were:

Table 2. Bootstrap Estimates

Variable	Actual Coeff.	Bootstrap mean estimate	95% interval
T4-X	0.226	0.230	0.15,0.31
T4-Y	-0.038	-0.036	-0.12,-.02
T8-X	0.249	0.251	0.22,0.30
T8-Y	-0.027	-0.024	-0.03,.03
T12-X	0.243	0.237	0.20,0.30
T12-Y	0.059	0.059	0.02,0.12
L3-X	0.270	0.269	0.21,0.34
L3-Y	0.203	0.198	0.14,0.28

The Bootstrap results add credibility to the results obtained above.

7. Other Data Sets

A similar data set became available when a study by McKenzie (1994) compared 15 swimmers to 15 non-swimmers as to possible differences in back curvature. The same procedure was applied to this set of data and the factor coefficients were very similar. In fact they are contained in the 95% confidence intervals , obtained by bootstrapping, for the bicycle riders/non-riders . When the coefficients from this second set of data were applied to the standardised data from the first set, the correlation was 0.98.

It appears that that the index is a valid one and is seen to reflect small changes in posture.

8. Comparison to the COBB Angle.

Further evidence was gained when the index was applied to x-rays and compared with the COBB angle . 15 x-rays were available and the index had a 89% correlation with the COBB angle.

9. Conclusions and Recmmendations

The index has many desirable features. It is easily obtainable. It follows the modern trend of using digitised photographs . It is reliable and establishes normal values. It appears to have a Normal Distribution , although this is not surprising, since the index (score) is obtained by the result of a sum. It is non-invasive, and this is the big weakness of the COBB angle approach. Finally it is objective.

It is conceivable therefore as a result of the two data sets mentioned that a set of "universal" coefficients exist which will uniquely calculate this index. At present the data available is too small to claim this but it appears likely. It therefore seems an ideal opportunity to get a very large set of data from a population of people with "normal spines" . The coefficients can then be fine tuned to establish normal values. The technique appears to be an important addition in the search for quantification of posture.

This technique would also be useful when applied to other posture defects especially scoliotic defects.

10. References

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