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Measurement of the three-Dimensional Kinematics of the Human Lumbar and Cervical Spine using the 3Space Isotrak System

by

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SUMMARY

This thesis investigated the suitability of the 3SPACE Isotrak for monitoring motion in the human lumbar and cervical spine. The system was shown to be reliable and to give good reproducibility of results in most instances. It allowed quick and easy measurements to be obtained in the clinical setting, and was used to assess whether therapeutic treatments for patients were having their desired effect.

Data-bases of the range and coupling of movements in the 'Normal' lumbar and cervical spine were compiled. The results for the lumbar region showed the range of motion to be in excess of that expected using radiographic techniques particularly for axial rotation. A change in lumbar and cervical range of movement related to age and sex was observed. Large variations in mobility were seen within groups. Some of the reasons why variations may have occurred in the lumbar spine were investigated including investigations on the effect of the time of day when monitored and misplacement of the sensor.

In the lumbar spine coupling between the movements of lateral bend and axial rotation was observed and lateral bending was also shown to be coupled with flexion. In the cervical spine, extension was seen to accompany the primary movement of axial rotation and lateral bending was accompanied by axial rotation. Flexion and extension did not have any significant degree of coupling. All primary movements were shown to decrease with age.

A number of patient groups were studied with the most comprehensive study being conducted on those with ankylosing spondylitis (A.S.). Changes in the range of primary movements, and disruption to coupled movement patterns were observed in patients compared with the 'Normal' groups.

The effect of the 'Back' school for low back pain patients and a self help group for A.S. patients were assessed. Results for both groups showed no overall effect on mobility in the long term when comparing patients with control groups.

Acknowledgements

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SECTION 1: THE LUMBAR SPINE

CHAPTER 1

1.1 LITERATURE REVIEW

Measurement of spinal motion is a routine part of the clinical examination of patients suspected of having spinal disorders such as disc prolapse, ankylosing spondylitis, spondylolysthesis etc. which may produce limitation of movement in one or more planes (Pearcy and Shepherd, 1985; Tibrewal *et al*, 1985).

In 1827 measurements of motion in the cadaveric human spine were conducted by Weber. These were possibly the first tests conducted on the human cadaveric spine. In his tests Weber monitored the motion of three cadavers and concluded that the cervical spine was the most mobile region of the spine whilst the dorsal and lumbar regions had rotation and inclination distributed so that the lumbar vertebrae could only be flexed anteriorly, posteriorly and laterally but not at all in the longitudinal axis of the vertebral column.

One early method used for measuring spinal motion was that described by Blumenthal (1912). In his studies Blumenthal attached pieces of adhesive plaster onto individual spinous processes. Threads ran through the plaster and were marked at equal distances by a bead. The threads were held taut by means of suspended lead weights. The beads indicated the contours of the spine and were used to observe flexion and extension.

The first recorded use of roentgen rays for studying spinal motion was by Hans Virchow (1919). Dittmar (1929) described the use of roentgen rays in the investigation of the mechanics of motion of the spine, and his study is claimed to be the first earnest effort to use roentgen rays in the measurement of spinal motion. In his studies Dittmar demonstrated that movements occurred about several variously situated transitory axis, and that shearing occurred in flexion.

Other methods of monitoring motion include visual examination, modified Schober method (Macrae and Wright, 1969), measurement using flexicurves (Burton, 1986) and biplanar radiographic techniques (Pearcy and Whittle, 1982). These measurement systems, with the exception of the radiographic techniques, have the advantage of being quick, easy to apply and of requiring relatively simple instrumentation. Their disadvantage however is that they are only able to give a one or two-dimensional picture of a subjects movements and only give values at the extremes of motion without supplying a detailed picture of a patients ***pattern*** of movement.

The 3Space Isotrak system has previously been shown by Pearcy and Hindle (1989), Johnson and Anderson (1990), Buchalter *et al* (1989a) and Elnagger *et al* (1991) to be a valuable tool in monitoring a subjects movement by not only giving values at the maximal ranges of motion, but by also giving a three-dimensional picture of the way in which a subject moves in order to reach that maximum position. The main advantage of using this system is that it is able to monitor motion in three-dimensions.

The method by which the Isotrak operates has been described in detail by An *et al* (1988). The Isotrak system consists of a source module and a sensor both of which contain three sets of orthogonal coils. The source transmits a low-frequency magnetic field which is detected by the sensor. The position and orientation of the sensor relative to the source are determined by obtaining information on the changes in magnetic field between the two at various time intervals. The whole system is controlled by means of a systems electronic unit and a small portable computer (Figure 1.1).

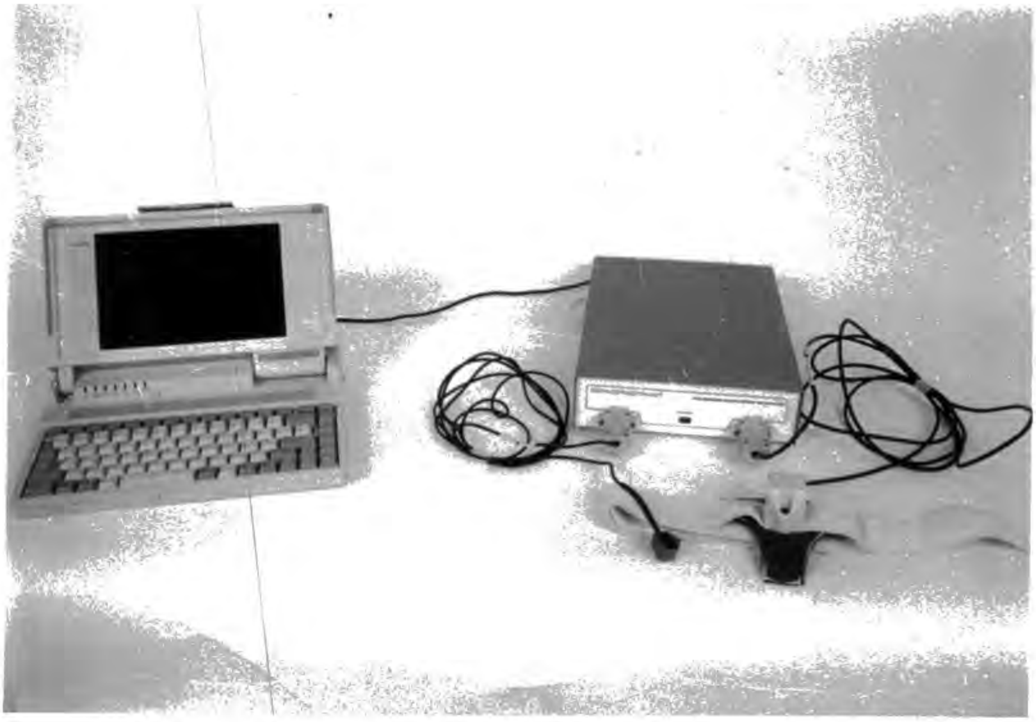


Figure 1.1 - The 3 SPACE Isotrak system

Work carried out by Burton *et al* (1989) has looked at how lumbar sagittal mobility is related to back pain by using a flexicurve technique. Seven hundred and fourty-two adults and 216 schoolchildren were tested, 485 had no history of low back pain , 214 had reported a current source transmits a low-frequency magnetic field which is detected by the sensor. The position and orientation of the sensor relative to the source are determined by obtaining information on the changes in magnetic field between the two at various time intervals. The whole system is controlled by means of a systems electronic unit and a small portable computer (Figure 1.1).

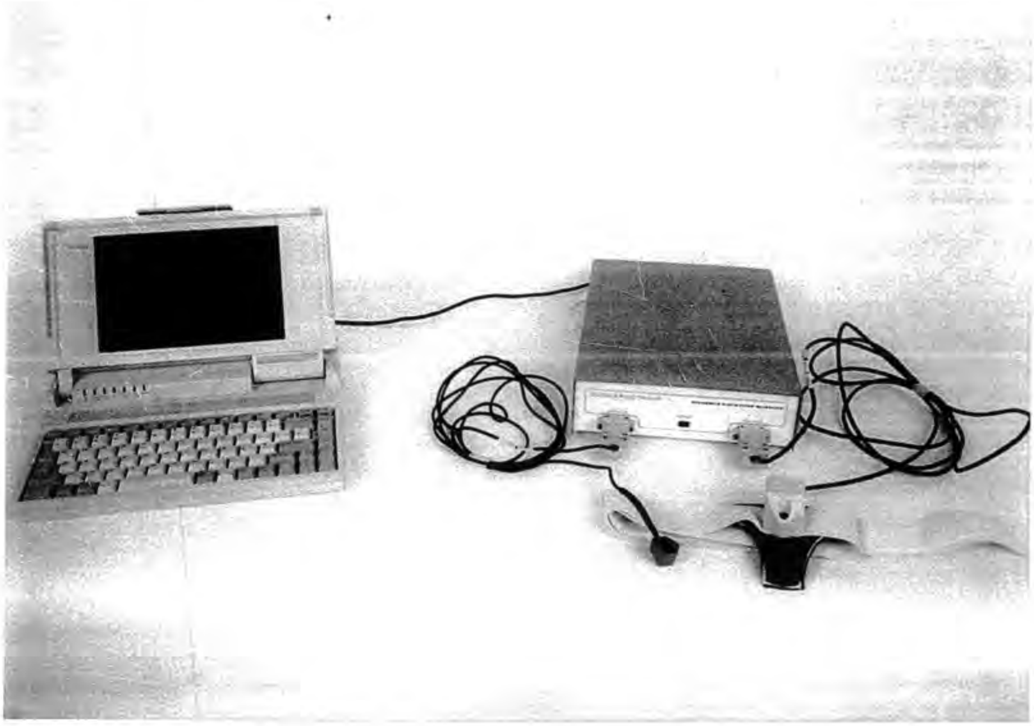


Figure 1.1 - The 3 SPACE Isotrak system

Work carried out by Burton *et al* (1989) has looked at how lumbar sagittal mobility is related to back pain by using a flexicurve technique. Seven hundred and fourty-two adults and 216 schoolchildren were tested, 485 had no history of low back pain , 214 had reported a current episode of pain and 259 had experienced low back pain. Burtons study found that the range of sagittal mobility in subjects with low back pain (LBP) was dependent on, amongst other variables, the sex and age of the sufferer. They also found that the presence or absence of a history of low back pain may affect movement. Therefore when building a data base of the so called "normal" range of movement in the lumbar spine a number of considerations have to be taken into account with allowances for sex, age and previous episodes of low back pain having to be made.

Evidence from work in this area is somewhat inconsistent with work carried out by Anderson and Sweetman (1975) on 432 male subjects being unable to relate lumbar sagittal mobility to a past history of back trouble. Mayer *et al* (1984) did however find a limitation of lumbar flexion in males with chronic low back pain and Wickstrom *et al* (1978) found limitation of lumbar flexion in males with a history of sciatica.

Another important factor which ideally should be taken into account when trying to compile a "normal" data group is the lifestyle of the person being tested. Occupation and leisure activities might be expected to have some effect on movement patterns and ranges of motion. In a study on how lumbar mobility was influenced by leisure sports activity Burton and Tilotson (1991) came to the conclusion that rather than having the effect of increasing spinal flexibility, increased exposure to adult sports actually produced a reduction in mobility. This they attributed, in part, to the infiltration of fibrous tissue into elastic periarticular structures or possibly due to a loss of disc height in response to microtraumata. People participating in regular sporting activities might therefore be expected to show a difference in range of movement compared with non-sporting people.

The advantage of measuring spinal motion in three-dimensions is obvious since the spine is a complex three-dimensional structure which can be seen to exhibit complex patterns of movement.

Even when performing the relatively simple movements of lateral bend and axial rotation, coupling of movement can be visually observed. For the movement of flexion and extension in the 'Normal' spine, the displacement of the facet joints is symmetrical with the range being dictated, to some extent, by the geometry and stiffness of the disc (Markolf, 1978). In lateral bending however an asymmetrical displacement of the facets occurs, which, combined with the asymmetric tension within the transverse ligaments, results in a rotational movement about the longitudinal axis ie. coupling of lateral bend and axial rotation occurs.

We might expect to see deviations from the 'Normal' pattern of movement when monitoring subjects with various spinal pathologies such as facet joint arthropathy, people having undergone various forms of spinal surgery etc., as the function of the intervertebral joint may well be compromised or impaired in some way (Tibrewal *et al*, 1985).

The main aims of this section of the study were therefore to use the Isotrak system to monitor movement in the normal and pathological lumbar spine to try to assess:

1. Whether changes in motion, both in the primary and coupled movement planes, that were related to age and sex could be detected.

2. Whether lumbar primary and coupled movement range of motion was dependent on external factors such as time of day when monitored, load bearing etc.

3. How accurately the Isotrak could measure intervertebral movement.

4. Whether easily identifiable changes in movement occurred between 'Normal' subjects and subjects with spinal pathology eg. Ankylosing spondylitis, lumbar disc prolapse, spondylolisis etc.

1.2 MEASUREMENT METHODS

Measurements obtained in this section of the study were obtained in essentially the same manner as those obtained by Hindle in his study on the range of movement of the lumbar spine (Hindle, 1989). The source and sensor were placed over the sacrum and L1 spinous process respectively, with every effort being made to place the sensor 'centrally' over the L1 spinous process. The L1 spinous process was identified using the method of Burton (Burton, 1987) who identified the L4 spinous process to be at the bisection of the line joining the highest points of the iliac crest. Having identified L4, L1 was found by palpation. In order to make identification easier the subjects were asked to bend forward slightly so that the spinous processes became more prominent and easily identifiable. The sensor was initially held over the skin overlying the L1 spinous process using double sided tape, this was later changed to Britfix sticky pads as they were found to give a more secure fixation of the sensor onto the skin. In Hindles work a velcro band was used to secure the source and sensor securely, in this study a wide band of elastic was used as a substitute as it enabled a firmer fixation of the sensor and source to be obtained (Figure 1.2).

Figure 1.2 - Attachment of the sensor and source over the L1 spinous process and the sacrum respectively

source to be obtained (Figure 1.2).

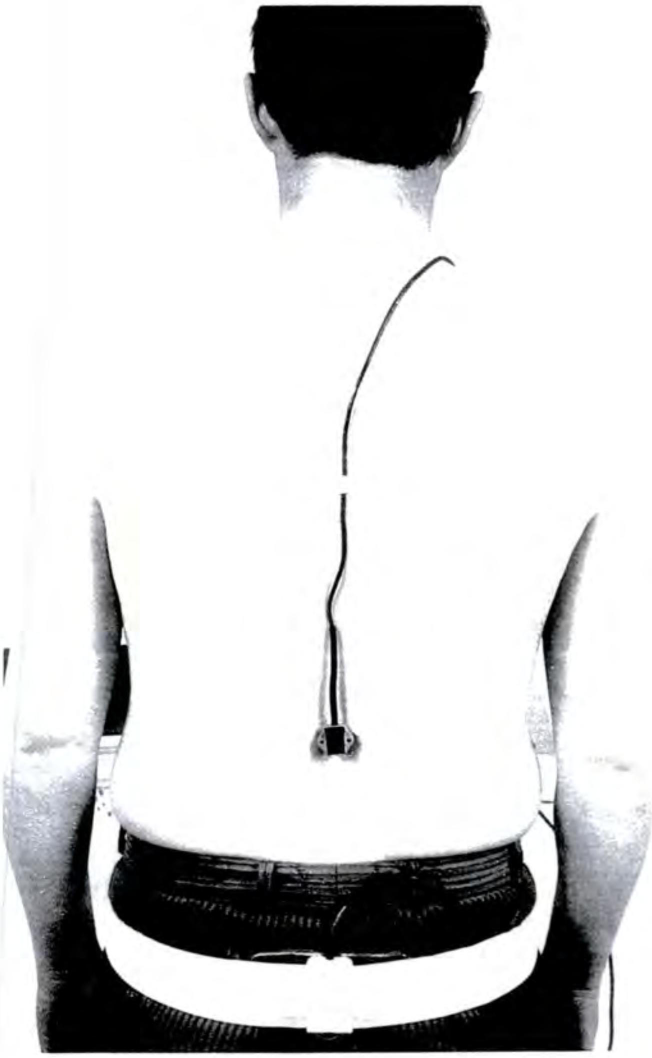


Figure 1.2 - Attachment of the sensor and source over the L1 spinous process and the sacrum respectively

CHAPTER 2

'NORMAL' RANGE OF MOTION AND COUPLING OF MOVEMENTS OBSERVED IN THE LUMBAR SPINE

2.1 INTRODUCTION

Work previously carried out by Hindle (1989) included measurement of the range and pattern of movement in groups of 'normal' subjects using the same method as that used in this study. In his study 10 subjects were tested in each age/sex catagory. Hindle came to the conclusion that lumbar spinal mobility was dependent on both age and sex. The aim of this chapter was to increase the numbers tested in each age/sex group in order to substantiate or contradict his findings.

2.2 METHOD

Measurements were obtained using the method given in chapter 1. The concensus of opinion implies that previous episodes of LBP should be taken into account when determining whether or not a subject should be included in a 'Normal' data group (Burton *et al*, 1989), and that ideally such a person should be excluded. However 80% of people will suffer from some mild form of back pain during their lifetime, most of whose symptoms resolve quickly without treatment, and which appears not to affect their movement in the long term. No study appears to have been conducted to confirm whether or not the movement pattern of such a person alters after a bout of trouble and whether or not this might have a cumulative effect.

To build-up a database of subjects who had never suffered from any back pain would be ideal but very hard to compile. Volunteers taking part in this study were asked to confirm that to the best of their knowledge they had no diseases known to affect the spine, that they had never undergone any treatment for spinal problems; either physiotherapy or surgery, that they had been free from any form of back pain for the previous six months and that at the time of the test they were not suffering from an abnormally stiff back eg. due to gardening, vigorous exercise etc. In this way any patients who had suffered from any significant episodes of previous LBP were excluded from the study. Due to the relatively large numbers of subjects tested and the hazards involved, X-rays were not obtained for any of them.

Since we wanted to look at the "normal" range of motion in people without spinal problems, any person who participated in sport at a professional level was excluded (Burton and Tilotson, 1991) but those who participated in sporting activities on a regular basis were included. No record was kept of the subjects sporting activities. None of the volunteers were currently involved in heavy manual work with the majority of the subjects being either students, technicians, secretaries, lecturers, physiotherapists or retired. Most of the retired people tested were ex- schoolteachers or lecturers.

In order to assess how results obtained from this study compared with the results obtained by Hindle a further minimum number of 10 subjects per age/sex group were tested so that the size of each group was increased to a minimum of 20. (see Table 2.1 for group details). Before analysis of the combined groups could be carried out, data obtained by Hindle (RH) and data obtained from this study (PR) were compared to assess whether the results were compatible, or if they differed significantly from one another.

TABLE 2.1

DETAILS OF 'NORMAL' GROUPS STUDIED

AGE GROUP	MALES			FEMALES		
	NO.	MEAN AGE	SD	NO.	MEAN AGE	SD
20 - 29 RH	4	25.5	2.6	10	24.6	2.5
PR	31	22.6	2.3	16	23.8	3.3
30 - 39 RH	10	35.5	2.5	10	33.9	3.5
PR	17	33.5	3.0	15	34.7	3.7
40 - 49 RH	10	42.9	2.9	10	43.4	2.0
PR	19	44.1	2.8	16	45.1	2.7
50 - 59 RH	8	55.9	3.0	10	53.1	2.2
PR	13	53.8	2.7	11	54.3	2.5
60 - 69 RH	0	----	---	0	----	---
PR	23	63.8	2.4	20	63.2	2.5

2.2.1 ANALYSIS OF DATA

Data were analysed using the student t-test, paired t-test, regression analysis, analysis of variance and chi-squared statistics where appropriate. Statistical significance was taken to be at $P < 0.05$.

2.3 RESULTS

The results obtained for the mean maximum primary motions and coupled motions observed were treated separately for clarity. Typical movement patterns obtained for subjects have been given in figures 2.1 - 2.3.

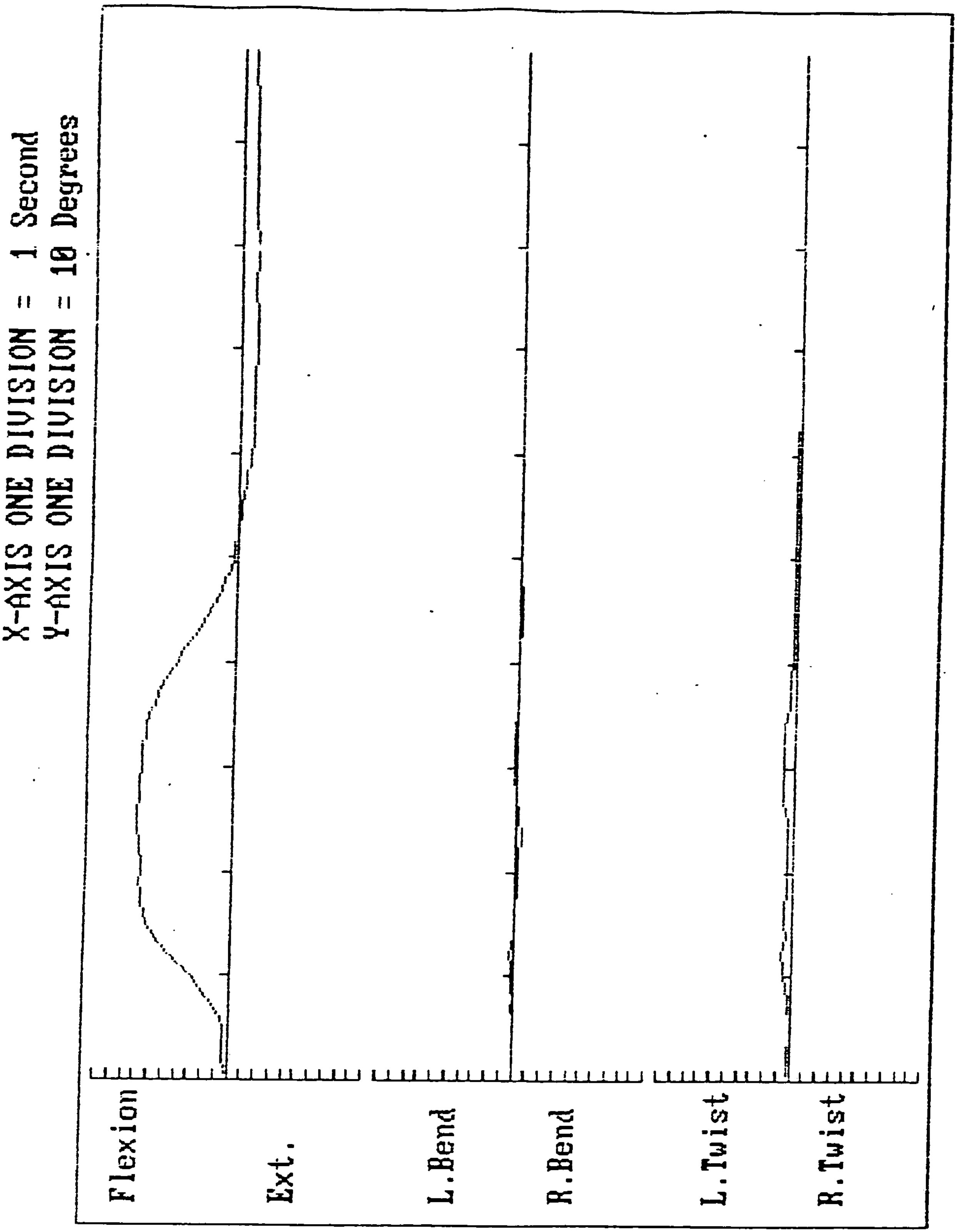


Figure 2.1 - Subject performing the primary movement of flexion and extension

(Coupled movement patterns of lateral bend and axial rotation are also shown).

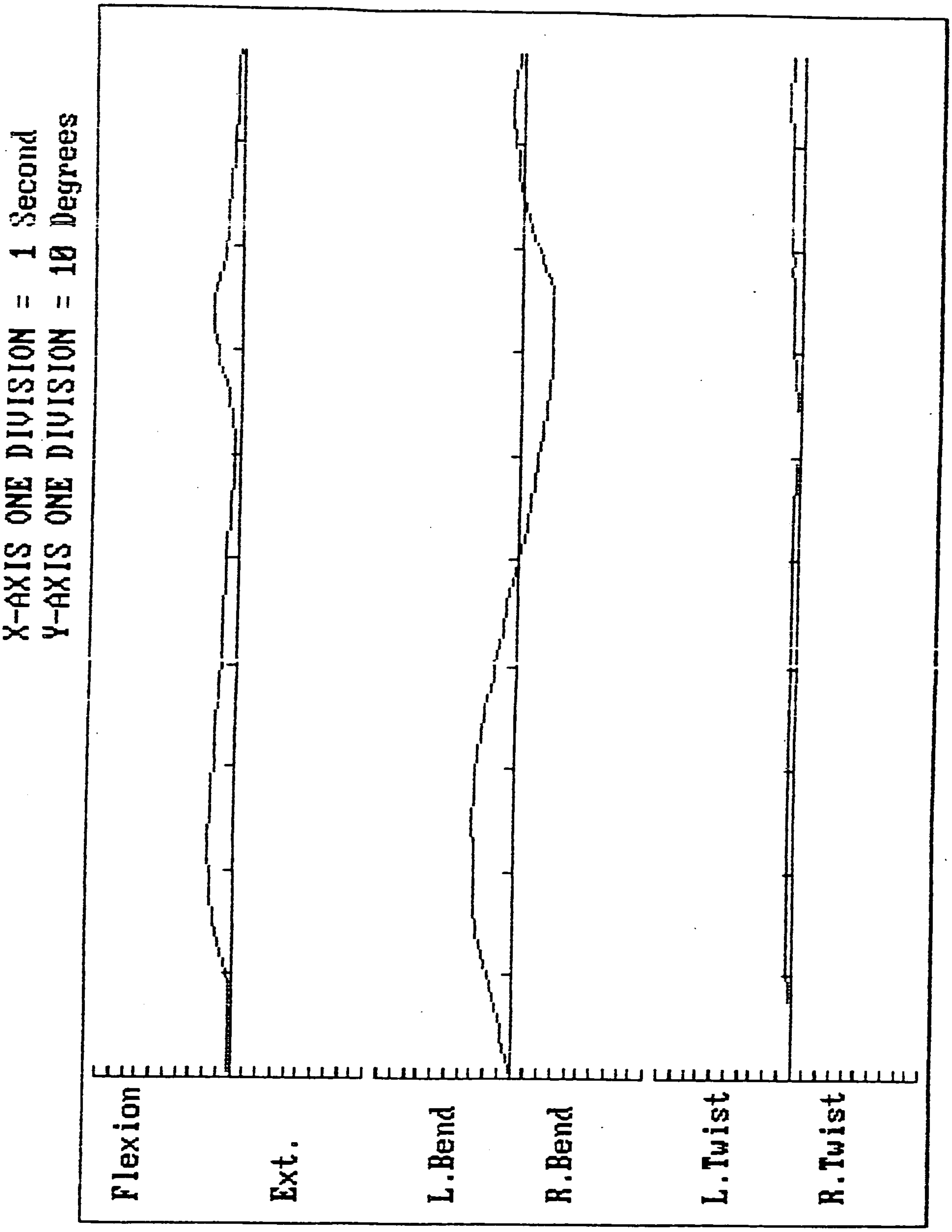


Figure 2.2 - Subject performing the primary movement of lateral bending

(Coupled movement patterns of flexion/extension and axial rotation are also shown).

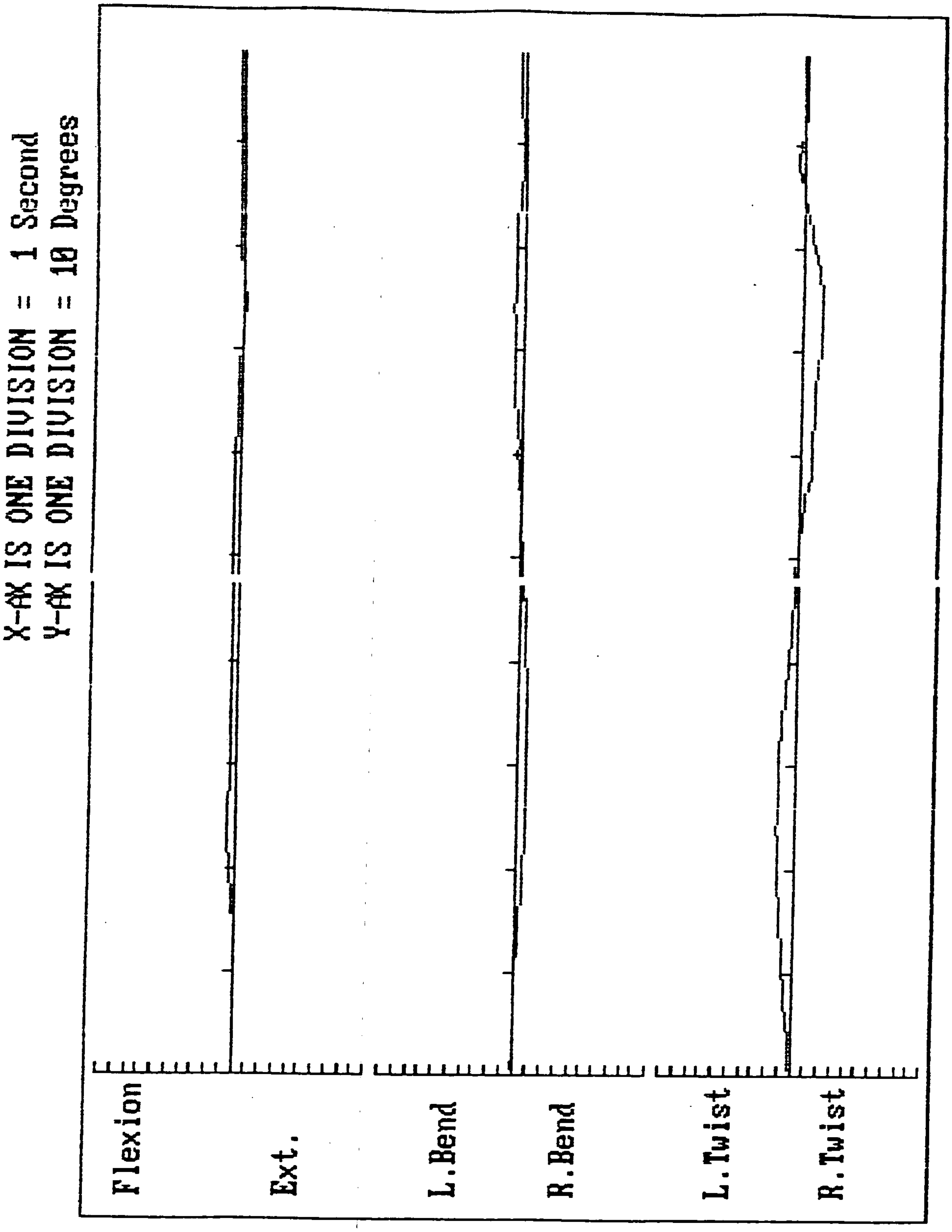


Figure 2.3 - Subject performing the primary movement of axial rotation

(Coupled movement patterns of flexion/extension and lateral bend are also shown).

2.3.1 Primary Motion

2.3.1.1 Relationship between results obtained from this study and RH's study

Results of the mean maximum obtained ranges of movement for RH (Hindle) and for PR (Russell) are shown in Table 2.2 which indicates any significant differences obtained between the two.

As can be seen the majority of the data groups obtained by Hindle and Russell did not give significantly different results. The exceptions to this were in i) the male 20 - 29 age group where the range of extension for PR was significantly higher than that for RH. ii) male 50 - 59, female 20 - 29 and female 30 - 39 age groups where range of axial rotation for PR was significantly greater than that for RH. iii) female 20 - 29 age group where the range of flexion for PR was significantly higher than that for RH.

In the male 20 - 29 age group only 4 sets of results obtained from RH's extension data were included, two sets of results having to be discarded due to abnormally high readings and four sets of results unable to be used as they had accidentally been erased. It is possible therefore that the four sets of readings used were not truly representative, and indeed when comparing PR's results with the value given by RH in his PhD thesis of 26.01 degrees the two are not significantly different.

There is no obvious reason why the significantly different results in the female age groups should have occurred, however a possible explanation is that either RH or PR consistently misplaced the sensor so that it was in a position higher or lower than the position of L1. In order to ascertain whether or not this was the case the files containing information about the relative position of the sensor to the source were analysed and the relative distances between source and sensor for RH and PR calculated (See Table 2.3).

TABLE 2.2

RANGE OF MOTION IN "NORMALS"
(results for PR and RH)

SEX /TESTER	AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
MALE					
RH	20 - 29	71 ± 13	* 20 ± 3	55 ± 7	29 ± 7
PR		76 ± 9	27 ± 8	55 ± 10	32 ± 8
RH	30 - 39	69 ± 10	22 ± 5	47 ± 8	26 ± 8
PR		75 ± 12	23 ± 6	52 ± 8	29 ± 9
RH	40 - 49	73 ± 9	19 ± 7	44 ± 9	27 ± 9
PR		74 ± 9	20 ± 8	43 ± 9	26 ± 8
RH	50 - 59	68 ± 12	21 ± 7	32 ± 13	* 23 ± 8
PR		65 ± 13	12 ± 6	42 ± 12	31 ± 9
RH	60 - 69	-------	------	-------	-------
PR		63 ± 11	15 ± 5	35 ± 8	30 ± 8
FEMALE					
RH	20 - 29	* 56 ± 11	29 ± 7	58 ± 22	* 27 ± 7
PR		67 ± 9	28 ± 8	57 ± 12	36 ± 8
RH	30 - 39	68 ± 10	21 ± 7	51 ± 8	* 23 ± 8
PR		74 ± 12	26 ± 9	60 ± 12	33 ± 7
RH	40 - 49	61 ± 12	19 ± 7	53 ± 11	33 ± 8
PR		63 ± 13	20 ± 7	50 ± 11	32 ± 11
RH	50 - 59	70 ± 8	18 ± 6	47 ± 10	28 ± 9
PR		65 ± 10	22 ± 9	41 ± 10	35 ± 12
RH	60 - 69	-------	------	-------	-------
PR		58 ± 9	20 ± 6	44 ± 9	36 ± 12

N.B. * :- Indicates a significant difference between results obtained by RH and results from this study

TABLE 2.3

DIFFERENCES IN SOURCE TO SENSOR DISTANCE FOR RH AND PR

SEX	Age Group	Tested by	Source to Sensor distance cm (mean ± sd)
MALE	20 - 29	RH	11.7 ± 1.8 *
		PR	16.8 ± 2.5
		PR+RH	16.0 ± 2.5
	30 - 39	RH	15.5 ± 3.1 *
		PR	18.7 ± 2.1
		PR+RH	17.5 ± 2.9
	40 - 49	RH	13.4 ± 5.0 *
		PR	18.8 ± 2.9
		PR+RH	17.0 ± 4.5
	50 - 59	RH	14.8 ± 2.4 *
		PR	19.0 ± 1.9
		PR+RH	17.5 ± 2.9
	60 +	RH	----------
		PR	17.9 ± 2.4
		PR+RH	" " "
FEMALE	20 - 29	RH	13.6 ± 2.0
		PR	15.1 ± 2.6 **
		PR+RH	14.7 ± 2.5
	30 - 39	RH	14.0 ± 2.8
		PR	16.2 ± 2.4 **
		PR+RH	15.3 ± 2.8 **
	40 - 49	RH	14.8 ± 1.9
		PR	15.4 ± 1.6 **
		PR+RH	15.2 ± 1.7
	50 - 59	RH	15.4 ± 3.2
		PR	14.5 ± 2.4 **
		PR+RH	14.9 ± 2.7 **
	60	RH	----------
		PR	15.6 ± 3.2 **
		PR+RH	" " " **

N.B. * Denotes significant differences between PR and RH's data.
** Denotes significant difference between male and female sensor-source distances.

2.3.1.2 Combined results from RH's study and this study

Since the majority of results obtained in each age/sex catagory for RH and PR were not significantly different it was considered reasonable to combine the two data sets in order to look for common and distinct trends (Table 2.4). In order to obtain a clearer picture of what was happening these results are presented in graphical format (figs 2.4 & 2.5). Figures 2.4 and 2.5 show the mean values (± sd) for each age and sex group tested.

TABLE 2.4

RANGE OF MOTION DETERMINED BY AGE GROUP

SEX	AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
MALE	20 - 29	75 ± 10	25 ± 8	55 ± 9	32 ± 8
	30 - 39	74 ± 9	23 ± 6	50 ± 8	28 ± 9
	40 - 49	74 ± 9	20 ± 8	44 ± 8	26 ± 8
	50 - 59	65 ± 12	16 ± 7	39 ± 13	28 ± 9
	60 - 69	63 ± 11	15 ± 5	35 ± 8	30 ± 8
FEMALE	20 - 29	63 ± 11	28 ± 7	57 ± 11	33 ± 9
	30 - 39	71 ± 11	24 ± 8	55 ± 10	29 ± 9
	40 - 49	62 ± 12	20 ± 7	51 ± 11	33 ± 10
	50 - 59	67 ± 9	20 ± 8	44 ± 10	32 ± 11
	60 - 69	58 ± 9	20 ± 6	44 ± 9	36 ± 12

FIGURE 2.4

CHANGE IN RANGE OF MOTION IN 'NORMAL' MALE SUBJECTS: EFFECT OF AGE

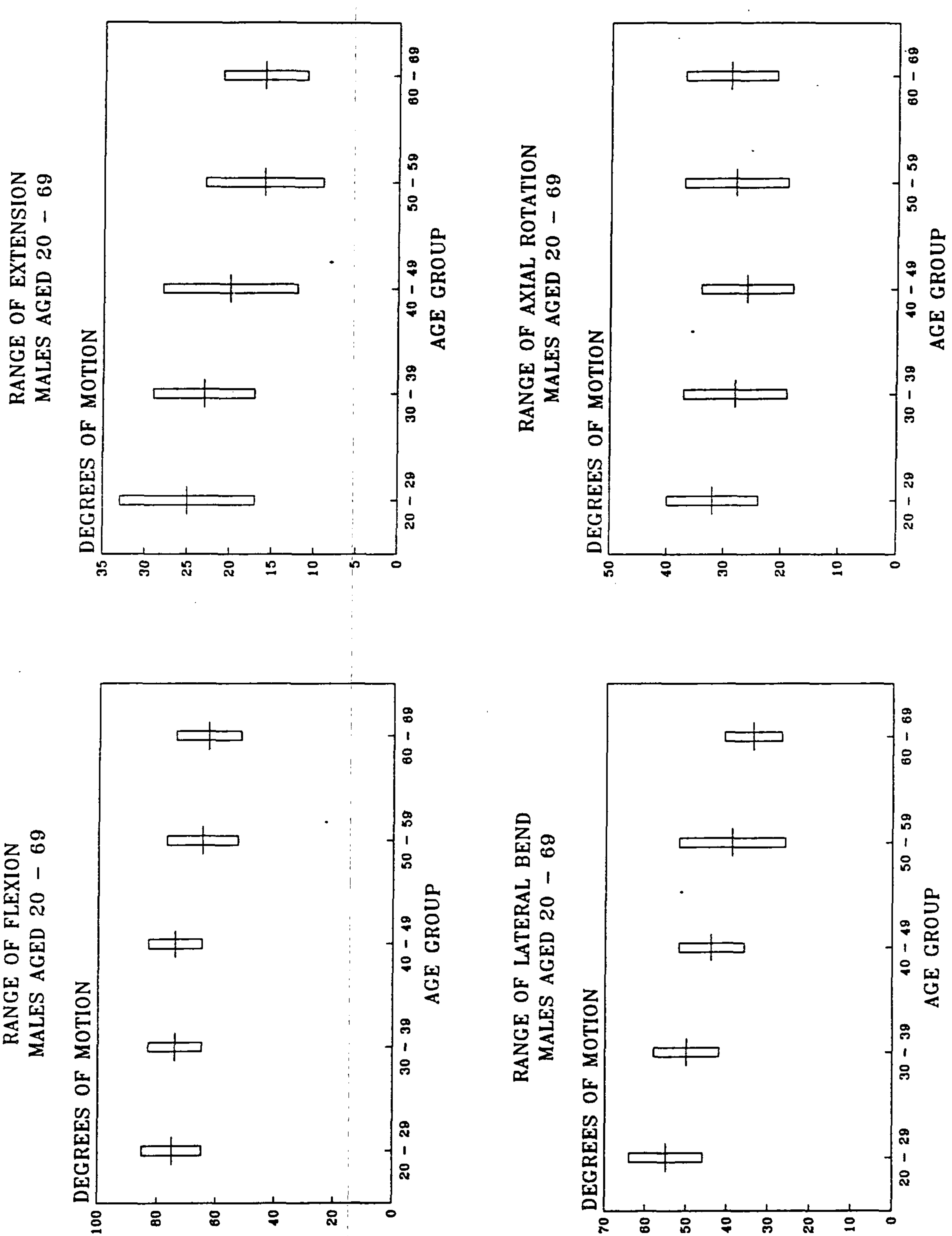
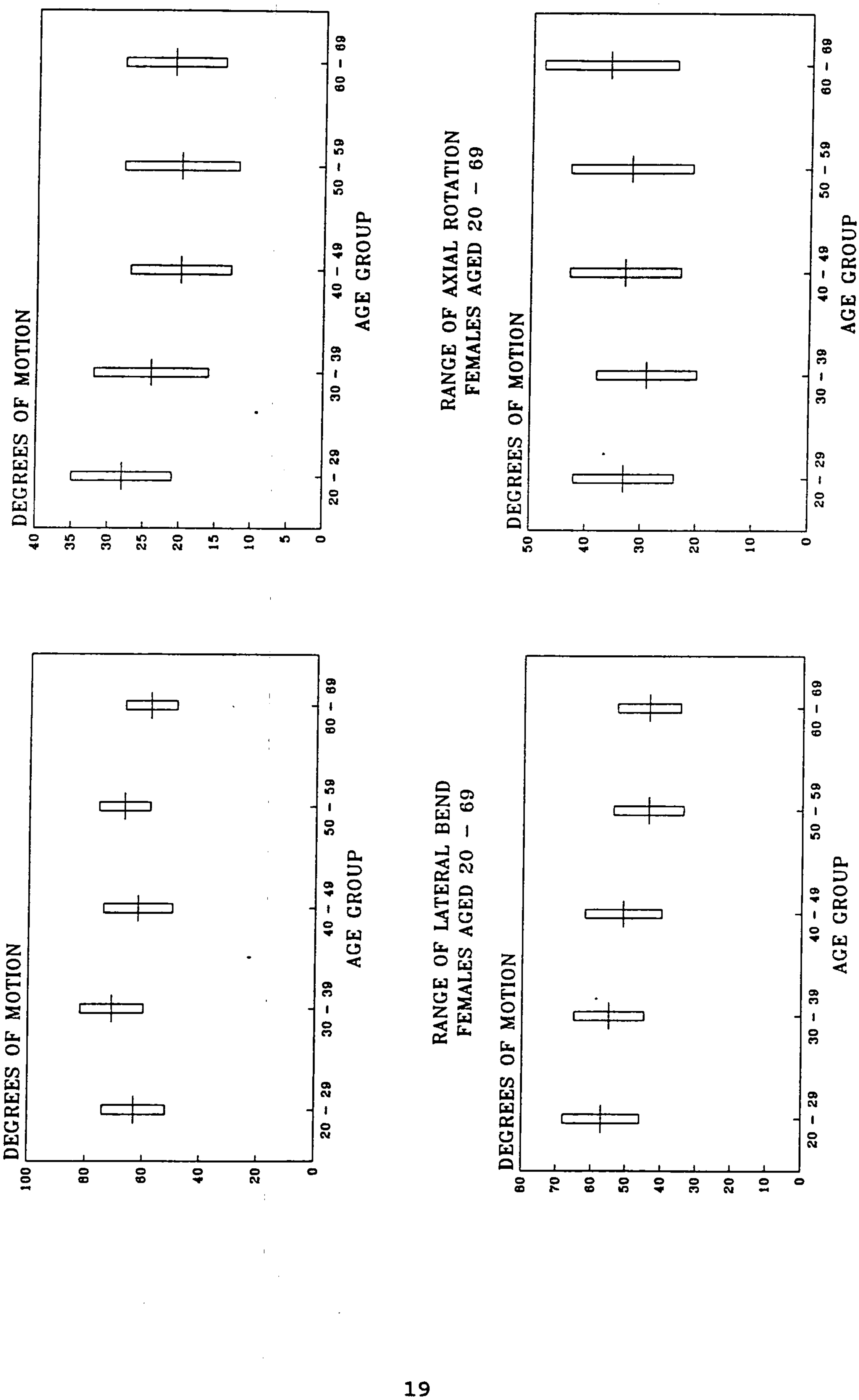


FIGURE 2.5

CHANGE IN RANGE OF MOTION IN 'NORMAL' FEMALE SUBJECTS: EFFECT OF AGE



2.3.1.3 Effect of age and sex on range of primary motion

To assess whether the trends seen in figures 2.4 and 2.5 were significant, t-test statistics were used to compare each age and sex group. Table 2.5 shows significant movement changes for males and females related to age.

TABLE 2.5

SUMMARY OF SIGNIFICANT DIFFERENCES BETWEEN AGE GROUPS

SEX	AGE GROUPS	MOVEMENT	DIFFERENCE
MALE	20 - 49 & 50 - 69	FLEXION	Y > O
	20 - 39 & 50 - 69	EXTENSION	Y > O
	20 - 39 & 40 - 69 40 - 49 & 60 - 69	LAT. BEND "	Y > O Y > O
	20 - 29 & 40 - 49	AXIAL ROT.	Y > O
FEMALE	20 - 29 & 30 - 39 30 - 39 & 40 - 49 30 - 39 & 60 - 69 50 - 59 & 60 - 69	FLEXION " " "	O > Y Y > O Y > O Y > O
	20 - 39 & 40 - 49 20 - 29 & 50 - 69 30 - 39 & 60 - 69	EXTENSION " "	Y > O Y > O Y > O
	20 - 39 & 50 - 69	LAT. BEND	Y > 0
	30 - 39 & 60 - 69	AXIAL ROT.	O > Y

N.B. Y Denotes younger age group, O Denotes older age group

In order to determine whether there were significant differences between males and females of the same age group t-tests statistics were applied to the data and Table 2.6 was constructed.

TABLE 2.6

SIGNIFICANT DIFFERENCES BETWEEN SEXES

AGE GROUP	PRIMARY MOVEMENT	DIFFERENCE
20 - 29	FLEXION	M > F
30 - 39	LAT. BEND	F > M
40 - 49	FLEXION	M > F
	LAT. BEND	F > M
	AXIAL ROT.	F > M
60 - 69	EXTENSION	F > M
	LAT. BEND	F > M
	AXIAL ROT.	F > M

Since there were differences between age groups as well as sexes it was not considered appropriate to combine all male and all female data.

2.3.2 Coupled motion: Effect of age and sex

Tables 2.7 and 2.8 show the significant differences in magnitude between coupled movements determined by age for male and female subject groups.

TABLE 2.7

EFFECT OF AGE ON COUPLED MOTION IN MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	DIFFERENCE	SIG. MOVEMENT
20 - 29 & 30 - 39	R.BEND	Y > O O > Y	R. TWIST FLEXION
	L.BEND	Y > O	R. TWIST
20 - 29 & 40 - 49	FLEXION	Y > O	R. BEND
	L.BEND	Y > O	R. TWIST
20 - 29 & 50 - 59	R.BEND	Y > O	R. TWIST
20 - 29 & 60 - 69	L. TWIST	Y > O	R. BEND
30 - 39 & 40 - 49	FLEXION	Y > O	L. BEND
	R. TWIST	Y > O	FLEXION
30 - 39 & 60 - 69	L.BEND	O > Y	R. TWIST
	L. TWIST	Y > O	R. BEND

N.B. Y denotes younger age group, O denotes older age group.

TABLE 2.8

EFFECT OF AGE ON COUPLED MOTION IN FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	DIFFERENCE	SIG. MOVEMENT
20 - 29 & 30 - 39	R. BEND	O > Y	FLEXION
	L. BEND	O > Y	FLEXION
	R. TWIST	Y > O	L. BEND
	L. TWIST	Y > O	R. BEND
20 - 29 & 40 - 49	R. BEND	O > Y	FLEXION
	L. BEND	O > Y	FLEXION
	L. TWIST	Y > O	R. BEND
20 - 29 & 50 - 59	R. BEND	O > Y	FLEXION
	L. BEND	O > Y	FLEXION
	R. TWIST	Y > O	EXTENSION
	L. TWIST	Y > O	R. BEND
20 - 29 & 60 - 69	EXTENSION	Y > O	R. BEND
	L.TWIST	Y > O	R. BEND
30 - 39 & 60 - 69	EXTENSION	Y > O	R. BEND
	FLEXION	Y > O	L. BEND
40 - 49 & 50 - 59	FLEXION	Y > O	R. TWIST
40 - 49 & 60 - 69	R. BEND	Y > O	FLEXION
	L. BEND	Y > O	FLEXION
	L. TWIST	Y > O	FLEXION
50 - 59 & 60 - 69	R. BEND	Y > O	FLEXION
	L. BEND	Y > O	FLEXION
	L. TWIST	Y > O	FLEXION

N.B. Y denotes younger age group, O denotes older age group.

Table 2.9 shows the significant differences in magnitude of coupled motion between males and females of the same age group.

TABLE 2.9

DIFFERENCES IN MAGNITUDE OF COUPLED MOTION BETWEEN MALES AND FEMALES

AGE GROUP	PRIMARY MOVEMENT	DIFFERENCE	SIG. MOVEMENT
20 - 29	R. TWIST	F > M	EXTENSION
30 - 39	R. BEND L. BEND	F > M F > M	L. TWIST R. TWIST
40 - 49	FLEXION	M > F F > M	R. BEND L. BEND
	R. BEND L. BEND	F > M F > M F > M	FLEXION FLEXION R.TWIST
	R. TWIST	F > M	EXTENSION
50 - 59	R. BEND	F > M	L. TWIST
60 - 69	R. TWIST L. TWIST	F > M M > F	EXTENSION FLEXION

In order to confirm whether there was a significant degree of coupling between movements Chi-squared tests were carried out on male and female data sets. The results of these tests are set out in Table 2.10 together with the percentages of each group showing coupling. Where a positive recording has been given this implies that the coupled movement was either flexion, left lateral bend or left twist, negative implies that the coupled movement was either extension, right lateral bend or right twist and zero was recorded where a reading of ± 1 or 0 was obtained.

TABLE 2.10

CHI-SQUARED ANALYSIS ON COUPLING OF MOVEMENTS IN MALE AND FEMALE GROUPS TESTED

COUPLED MOVEMENTS	SEX	SIGNIFICANCE	+ VE %	- VE %	ZERO %
Bend on Ext.	M F	NS NS	35.3 31.9	37.6 50.9	27.1 17.2
Twist on Ext	M F	$P < 0.001$ NS	21.8 32.8	**50.4** 36.2	27.1 29.3
Bend on Flexion	M F	NS NS	36.1 32.8	42.1 45.7	21.8 21.6
Twist on Flexion	M F	NS NS	40.6 43.0	38.3 40.5	21.1 16.4
Flexion on R. Bend	M F	$P < 0.001$ $P < 0.001$	**83.6** **78.2**	12.9 17.3	3.4 4.5
Flexion on L. Bend	M F	$P < 0.001$ $P < 0.001$	**75.9** **79.3**	14.3 12.1	9.8 8.6
Twist on R. Bend	M F	$P < 0.001$ $P < 0.001$	**62.4** 70.7	21.1 10.3	16.5 19.0
Twist on L. Bend	M F	$P < 0.001$ $P < 0.001$	20.3 8.6	**60.9** **76.7**	18.8 14.7
Flexion on R Twist	M F	NS $P < 0.001$	39.1 18.1	39.8 **64.7**	21.1 17.2
Flexion on L Twist	M F	$0.05>P>0.02$ $P < 0.001$	**47.4** **54.3**	27.1 24.1	25.6 21.6
Bend on R. Twist	M F	$P < 0.001$ $0.01>P>0.001$	**64.7** **57.8**	30.1 27.6	20.3 14.7
Bend on L. Twist	M F	$P < 0.001$ $P < 0.001$	8.3 12.9	**75.9** **80.2**	15.8 7.8

The results show a strong coupling of 'opposite' axial rotation on lateral bend and vice-versa (ie. when performing the primary movement of ***right*** lateral bend this movement was accompanied by axial rotation to the ***left*** etc.). They also show a strong coupling of flexion on lateral bend (even though subjects were told to make this movement as pure a lateral movement as possible). In general male and female results were seen to be consistent. Exceptions to this were the male group who showed a strong coupling of right twist on extension and the female group who showed strong coupling of flexion on right twist. No obvious reason for this inconsistency was apparent.

2.3.2.1 Relationship between primary and coupled motion

In order to see how the magnitude of the primary movement was related to the magnitude of the secondary "coupled" movement Pearson correlation coefficients were calculated (Table 2.11). N.B. Only movements where either the male or female correlation coefficient was greater than ± 0.5 have been listed.

One entire movement was considered to consist of either flexion + extension, left + right bend or left + right twist. Therefore, in Table 2.11 where the primary movement is listed as being extension this is actually only half of the entire movement performed.

(NB. Where both movements being considered are primary ie. flexion and extension, left and right bend etc. and the correlation coefficient is positive this implies that an ***increase*** in one movement causes an ***increase*** in the other, a negative correlation implies an ***increase*** in one movement is countered by a ***decrease*** in the other.

Where the coupled movements are both secondary (ie. arising from the primary movement) and the correlation is positive this implies that both movements are in the same relative direction ie. An increased ***left*** twist is coupled with an increased ***left*** bend. Alternatively if the correlation coefficient is negative it implies that an increased ***left*** twist is coupled by an increased *right* bend.

TABLE 2.11

RELATIONSHIP BETWEEN PRIMARY AND COUPLED MOVEMENT

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENTS	CORRELATION MALE	CORRELATION FEMALE
20 - 29	EXTENSION	BEND/TWIST	-0.323	**-0.846**
30 - 39			-0.397	**-0.901**
40 - 49			**-0.681**	**-0.861**
50 - 59			**-0.823**	**-0.896**
50 - 59		FLEXION	**0.518**	-0.450
50 - 59	FLEXION	EXT/BEND	**0.504**	-0.318
60 - 69			**0.521**	0.077
20 - 29	R. BEND	R & L BEND	0.417	**0.810**
30 - 39			**0.571**	0.423
40 - 49			**0.590**	0.309
50 - 59			**0.627**	0.277
60 - 69			0.345	**0.565**
40 - 49		FLEX/TWIST	**0.506**	0.308
20 - 29	R. TWIST	BEND/TWIST	0.309	**0.597**
		R & L TWIST	0.186	**0.542**
50 - 59		BEND/TWIST	0.449	**0.717**
60 - 69		R & L TWIST	**0.711**	**0.598**
30 - 39	L. TWIST	FLEX/BEND	**0.517**	**-0.553**
40 - 49		BEND/TWIST	**-0.666**	-0.490

In order to understand Table 2.11 it is useful to consider a couple of examples. In extension the 30 - 39 year old females show that the amount of lateral bend and axial rotation accompanying this primary movement are highly correlated r_{xy} = -0.901. In the male 50 - 59 age group both 'halves' of the flexion/extension movement are correlated r_{xy} = 0.518 ie. the maximum range of flexion is dependent to some extent on the range of extension.

The results from the chi-squared analysis and regression analysis indicate that although there is a strong coupling of opposite lateral bend on axial rotation and vice-versa, and that there is a strong coupling of flexion on lateral bend the magnitude of the coupled movement is not strongly related to the magnitude of the primary movement.

2.4 DISCUSSION

The concensus of opinion implies that previous episodes of LBP should be taken into account when determining whether or not a subject should be included in a 'Normal' data group (Burton *et al,* 1989), and that ideally such a person should be excluded. However eighty percent of people will suffer from some mild form of back pain during their lifetime and most of their symptoms resolve quickly without treatment. Movement seems not to be affected in the long term.

A change in range of movement related to age and sex has been observed by many. Moll and Wright (1971) using a skin distraction method observed males to have a greater range of movement in both flexion and extension but females were observed to have a greater range of lateral flexion than their male counterparts. However a study by Burton and Tilotson (1991), which used a flexicurve technique to give angular measures of maximal sagittal mobility, observed males to have greater mobility in flexion only.

In a study by Sturrock *et al* (1973) total range of spinal mobility in flexion and extension was monitored in both normals and patients with ankylosing spondylitis using the Dunham spondylometer. The results showed, in the normal population, a decrease in mobility in all parameters of sagittal spinal mobility with increasing age. It also showed that the range of extension in females was greater than males in the 25 - 34 age group (mean difference = 9.9^{0}) whilst the range of flexion in males remained greater than that for females up to the fourth decade. In the 65+ age group females had slightly more movement in both directions compared to their male counterparts.

In comparison, results from this study showed male flexion to be greater than that for females in the 20 - 29 and 40 - 49 age groups, whilst extension was only observed to be significantly greater for females in the 60 - 69 age group.

Possible explanations for differences in results obtained for maximum range of movement by PR and RH are that either the groups tested by RH and PR were significantly different in height, weight or other factors that would affect spinal motion, or that the groups tested by PR put more effort into performing the movements.

Since RH did not keep a record of the height and weight of many of the subjects he tested, these variables could not be taken into account when comparing PR and RH subject groups.

One notable factor is that whilst RH did not show significantly different sensor-source distances between corresponding male and female groups the results obtained by PR showed the distance between sensor and source for the female groups tested to be significantly smaller than that of their male counterparts. The difference between males and females might initially be thought to be due to a difference in height between the sexes. In Grays anatomy it states that the female vertebral column length is an average of 10cm less than that in the male (vertebral column length in the male = 70cm, average lumbar column length = 18cm, sacrum and coccyx length = 12 cm). This would mean that the 20 - 29 male age group tested by RH were either below average height or that RH consistently placed the sensor at a level lower than the L1 vertebra (RH sensor - source distance = 11.7 ± 1.8cm).

When analysing the differences in overall height between males and females tested by PR in corresponding age groups no significant differences were found, and so the difference is not likely to be primarily due to height difference. When analysing sensor-source distances related to overall height the two were not highly correlated. It is possible that the difference in sensor-source distances between males and females could be partly due to the fact that the females tested may have had a greater lumbar lordosis than the males.

The question as to whether females do have significantly different degrees of lumbar lordosis is not fully resolved. Grays Anatomy states that the lumbar curve is more pronounced in the female than in the male, but in a study by Torgerson and Dorrer (1976), no significant variation in the mean lordotic angle between men and women was found. Stagnara *et al* (1982), on physical examination found an increased lordosis in women but this was attributed to a greater curve of their buttocks.

In a study by Fernard and Fox (1985), 973 subjects were monitored and categorised according to age. In the 17 - 29 age group males were found to have a mean lordotic angle of 27.24^{o} as opposed to 34.02^{o} in the female group. Males and females in the 30 - 39 group did not have significantly different lordotic angles although in the older 40 + age groups females had an average increased lordosis of 5^{o} compared with the male subjects.

If, as suggested by Fernard and Fox's study and Grays Anatomy, women do exhibit a greater lordosis than men, this would, at least in part, explain why the sensor to source distance in males was greater than that in the females and may help in explaining some of the differences obtained in the range of movements obtained in the two sexes. It would not explain why RH's sensor-source distance for males and females was not significantly different (which is more in agreement with Torgerson and Dorrer's findings).

This study has shown that males in the younger, ie. 20 - 49, age groups have a greater range of flexion than their female counterparts although there were no significant differences observed between the older groups. This finding is in agreement with the results of a study by Burton and Tilotson (1991) and also with Batti'e *et al* (1987) who observed sagittal mobility to decrease with age for both males and females although flexion was seen to fall less rapidly for females.

This study has also shown that lumbar lateral mobility decreases with age for both males and females, which is in agreement with the findings of Troup *et al* (1968). Lateral bending has been shown to be generally greater in females than in males, which is in agreement with the findings of Moll *et al* (1972).

In Hindle's study (1989), he observed that there was a slight increase in flexion with age in the female groups tested, the correlation between age and change in flexion however was poor and although Hindle explains this finding in terms of an increased lumbar lordosis with age he gives no evidence to support this. A recent study by Carr *et al* (1991), using the ISIS scanning technique to analyse back shape changes in 271 children aged 10 - 16 and in 72 adults aged 21 - 56, showed no difference in the degree of lumbar lordosis in the older female child ie. 14 - 16 years and female adult groups monitored. This study therefore implies that there is no overall change in adult lumbar lordosis with age. Individual lordotic angles could however change due to postural changes, weight gain or loss, and as clinical findings have shown, perpetual wearing of high heels (Opila *et al*, 1988) can result in hyperlordosis possibly due to changes in muscle tone due to altered pelvic inclination.

The results from this study showed a slight decrease in female flexion with age although once again the correlation between age and flexion was poor.

Large variations within groups were observed so that a more mobile person in their sixties could have as great a range of movement as a person in their twenties. This large spread in range of movement in the normal lumbar spine has led researchers to question the usefulness of lumbar bending films in ascertaining the extent of "normality" (Hayes *et al*, 1989; Penning *et al*, 1984).

The large variations in range of motion within age groups have been noted previously (Moll *et al*, 1972). Possible reasons why they may have occurred using this method of measurement include :-

(a) Weight - People who were heavier could be expected to have greater skin movement which would affect the readings obtained by causing the sensor to move a greater distance relative to the underlying vertebra.

When correlating weight and range of movement however no statistical significance was seen.

(b) Height - Batti'e *et al* (1987) have previously shown range of movement to be not only affected by age and sex, but also by height, weight and the ratio of standing to sitting height. Burton however could find no correlation between sagittal mobility and trunk length.

(c) Time of day at which readings were obtained - It is possible that range of motion may depend on the time of day when measurements were obtained with subjects being stiffer or more flexible in the morning than at night. This study did not take account of the time of day when subjects were monitored (all subjects were monitored between 9.00am and 8.00pm) and consequently some of the variation in movement could be due to time of day when tested.

(d) Although subjects were asked to confirm that to the best of their knowledge they had no diseases known to affect the spine it is possible that some of those tested were not radiologically "normal". Indeed conditions such as spondylolysis and spondylolisthesis do not necessarily produce symptoms (Libson *et al*, 1982; Magora and Schwartz, 1980) and most people develop non-symptomatic degenerative changes as they get older. Since X-rays were not obtained for any of those subjects tested this could be a large source of error in this study.

(e) Although the sensor was assumed to lie over the L1 spinous process, and whilst every effort was made to ensure that this was actually the case, there is the possibility of the sensor being misplaced by one vertebral level which could significantly alter the readings obtained.

The results obtained for the maximum ranges of motion using this system are considerably higher than the actual range of motion obtainable in the lumbar spine. The primary reason for this is due to skin movement causing the sensor to move relative to the underlying vertebra. Although readings are high, this system enables the observation of how spinal kinematics alter with age and sex (assuming that the errors induced by skin movement were approximately of the same order of magnitude for each group studied).

When looking at the movement of the spine in three-dimensions it is interesting to note that in general the younger age groups have a greater degree of coupling than the older groups. This is most likely to be due to the younger subjects putting more effort into performing movements and exceeding the natural limit of motion in the plane in which they were asked to move.

Of particular interest is the fact that lateral bend has been shown to be coupled with axial rotation and vice-versa, and that there is also a strong coupling of flexion on lateral bend.

As previously mentioned if the facet joints are symmetrical, which they should be in the normal spine, movements of flexion and extension, within the physiological range, should be unaccompanied by any lateral or rotational movement which was indeed shown by this study.

This section of the study has shown that the Isotrak system of measurement shows coupled movement patterns to exist that would be expected in the normal spine.

CHAPTER 3

VARIATION IN LUMBAR SPINE MOBILITY MEASURED OVER A 24 HOUR PERIOD

3.1 INTRODUCTION

As the study in Chapter 2 has shown there are a number of phenomena which should be taken into account when compiling a data base of the normal range of motion in the lumbar spine. One of these factors is the possible effect that might occur due to the time of day when measured.

Circadian variation of a number of physiological phenomena has been observed with great interest by researchers over the years and circadian variation in stature has been reported by many. In a study in which eight male volunteers were monitored over a 24 hour period Reilly *et al* (1984) found 71% of total height gain occurred during the initial 3.75 hours recumbent, and 80% of the total height loss occurred after 3 hours upright. Height loss continued throughout the 16.5 hours spent upright. Similar findings have been reported by others (Kramer and Gritz, 1980; Bishop, 1852).

In a study conducted by Depuky (1935) in which 1217 subjects, aged 5 - 90 years, were monitored, it was noted that the greatest diurnal change was observed in those aged between 10 - 20 years and least in those over 50. It was seen that height change was closely correlated to the ratio of disc height to vertebral body height which was interpreted as implying that diurnal height changes were related to fluctuation of water content in the intervertebral discs.

The reason for stature loss is attributed primarily to the decrease in height of the intervertebral disc due to fluid loss and also to creep deformation of the annulus fibrosus (Koeller *et al*, 1984). Koller *et al* (1981) stated that fluid is expelled from the intervertebral disc whenever the compressive load exceeds the interstitial osmotic pressure. When changing from a supine to standing position Nachemson and Elfstrom (1970) have shown that pressure on the third lumbar disc can increase approximately three fold.

When supine the discs are only lightly loaded and swell due to the decrease in pressure exerted on them. On rising, the fluid content of the disc will be at its highest and during the day, when the loading on the disc is higher, expulsion of fluid will occur. This will be greatest during the first few hours after rising (Adams and Hutton, 1983).

Adams *et al* (1987) measured the range of flexion of 21 volunteers in the early morning and in the afternoon. They found the range of movement increased by 5^{0} during the day and in conjunction with tests carried out on cadaveric spines loaded to simulate the activities of a normal day, concluded that creep loading reduced the spines resistance to bending and increased the range of lumbar flexion. They also concluded that the back muscles did not fully compensate for the increased fluid content of the disc by restricting the range of flexion movement and hence did not fully protect the disc and ligaments from increased stress.

There does therefore, appear to be a correlation between stature change and change in the range of spinal movement in flexion at least.

The aim of this study was to measure the lumbar spinal movements in flexion, extension, lateral bend and axial rotation in groups of "normal" volunteers, to determine whether or not any variation due to stature loss could be detected.

3.2 MATERIALS AND METHODS

Some of the raw data for this study were obtained from a project conducted by a final year student in the Engineering department (Weld, 1990). Two studies were undertaken. The first examined the movements of a group of normal volunteers immediately before they retired to bed for the night and again immediately on rising in the morning. This study was conducted in order to establish whether a change in mobility could be detected. Following this a second study examined the movements of another group of volunteers at two hourly intervals throughout a twenty four hour period. This was conducted in order to characterise the pattern and time at which changes occurred during this period.

The volunteers tested had never experienced back problems requiring medical attention (Mean age of volunteers = 20 sd = ± 1). All were students at Durham University.

Measurements were made using the Polhemus Navigation Sciences 3SPACE Isotrak system using the method described in Chapter 1.

Volunteers who were tested every 2 hours over the 24 hour period remained recumbent between assessments obtained during the night and went about their normal activities of daily living between readings obtained during the day. A record was kept of any activities which possibly might have affected subsequent readings.

3.3 ANALYSIS OF DATA

Significance was calculated using the paired 't' test at the 95% level.

Flexion and extension were treated as separate movements whilst for bending and twisting the movements to the left and right were summed to give one value as previous studies by Hindle *et al* (1990) and results from Chapter 2 in this study have shown there to be no significant difference between movements to the left and right.

3.4 RESULTS

3.4.1 Pre- and Post-sleep study

Male and female subjects were initially treated as two separate groups in order to determine common or distinct trends between them. Four males and six females were tested. The mean maximum measurements obtained from movements for males and females are summarised in Table 3.1. Due to the relatively small numbers in each group it was not considered relevant to perform detailed statistical analysis separately on the groups.

Combining the results for males and females and applying paired t-test statistics showed flexion pre-sleep to be significantly greater than post-sleep ($P < 0.04$) with an average difference of 9.4 degrees between the two ($SD = 12.5$). Extension pre-sleep was also found to be significantly greater than that post-sleep ($P < 0.02$) with an average difference of 6.2 degrees between the two readings ($SD = 7.0$). The average difference between pre- and post-sleep values for lateral bend was 8.6 degrees ($SD = 6$) with pre-sleep results again being significantly higher than post-sleep results (P < 0.004).

TABLE 3.1

AVERAGE MAXIMUM MOVEMENT OBTAINED FOR MALES AND FEMALES TESTED PRE - / POST - SLEEP

	PRE-SLEEP		POST-SLEEP	
MALE	MEAN (°)	SD (°)	MEAN (°)	SD (°)
FLEXION	69.8	10.0	55.2	6.0
EXTENSION	31.2	11.0	22.1	4.4
LATERAL BEND	51.7	11.6	41.8	5.9
AXIAL ROTATION	23.9	3.1	21.8	10.9
FEMALE				
FLEXION	67.2	12.5	61.3	10.4
EXTENSION	30.6	9.9	26.4	7.6
LATERAL BEND	51.9	10.8	44.4	7.7
AXIAL ROTATION	34.2	10.1	33.6	17.9
MALE + FEMALE				
FLEXION*	68.3	11.1	58.9	9.1
EXTENSION*	30.8	9.8	24.7	6.6
LATERAL BEND*	51.8	10.5	43.2	6.7
AXIAL ROTATION	29.7	9.2	28.4	15.6

* Significant difference between pre- and post-sleep values.

N.B. Statistical analysis was applied only to the Male + Female group as individual groups did not consist of sufficient numbers to make detailed statistical analysis valid.

When applying paired t-test statistics to the results for axial rotation the pre-sleep and post-sleep values were not seen to alter significantly, mean difference = 1.3 degrees (SD = 12.8).

A decrease in flexion was observed in eight out of the 10 subjects tested with two subjects showing slight increases in movement. Nine subjects had decreases in extension and lateral bend and only five showed decreases in axial rotation.

3.4.2 Variation over 24 hour period

Six male and four female subjects were tested in this group, (Mean age = 20 ± 1). Individual measurements were compared by the time of day at which they were taken and not relative to the time after waking as readings were not always obtained immediately after the subjects left their beds. Data were analysed in this manner because as Adams *et al* (1987) have previously shown, measurements not taken immediately after waking tend to affect the results unless compensation is made. Subjects did not all start the tests at the same time of day. Some started in the morning and others in the afternoon. This was for organisational reasons and was not considered likely to affect the results.

Measurement number one was taken to be that recorded between 08:00 - 09:30 and subsequent readings were taken at 2-hourly intervals.

Flexion and extension movements were again treated separately. Lateral bend and axial rotation were however treated as the sum of left and right movements.

It is known that variation in the range in movement of people with "normal" backs is large (Adams *et al*, 1988). In order to normalise the data and to allow for easy comparisons between subjects, the results were plotted as the mean maximum deviation from the result obtained at 04.00 - 05.30. The reason for comparing measurements relative to this time was that all subjects had by this time been lying supine for a minimum of 4 hours and the effect due to swelling of the intervertebral discs could be assumed to be comparable between subjects.

Figure 3.1 shows the mean change in movement for all subjects relative to the value obtained between 04:00 - 05:30. Table 3.2 shows the mean maximum ranges of movement obtained at each time interval during the test period for males and females. The results obtained between 08:00 - 09:30 on day 2 have not been shown on figure 3.1 as only 4 males were tested at this time out of the 10 subjects.

Although values in Table 3.2 for readings obtained between 08:00 - 09:30 on day 1 and 08:00 - 09:30 on day 2 might be expected to be highly correlated as the results were obtained at the same time of day, the fact that they are not might be explained by the fact that on day 1 all 6 males were tested between 08:00 - 09:30, 5 of whom had been up for periods of between 10 minutes to 1 hour prior to testing, and on day 2 only 4 were tested, 3 of whom had been supine immediately prior to testing.

Between individual subjects there was a wide variation in the range of movement obtained at any one time, this can be seen from the magnitude of the standard deviations in Table 3.2.

MEAN MAXIMUM CHANGE IN MOVEMENT RELATIVE TO MOVEMENT AT 04:00 - 05:30

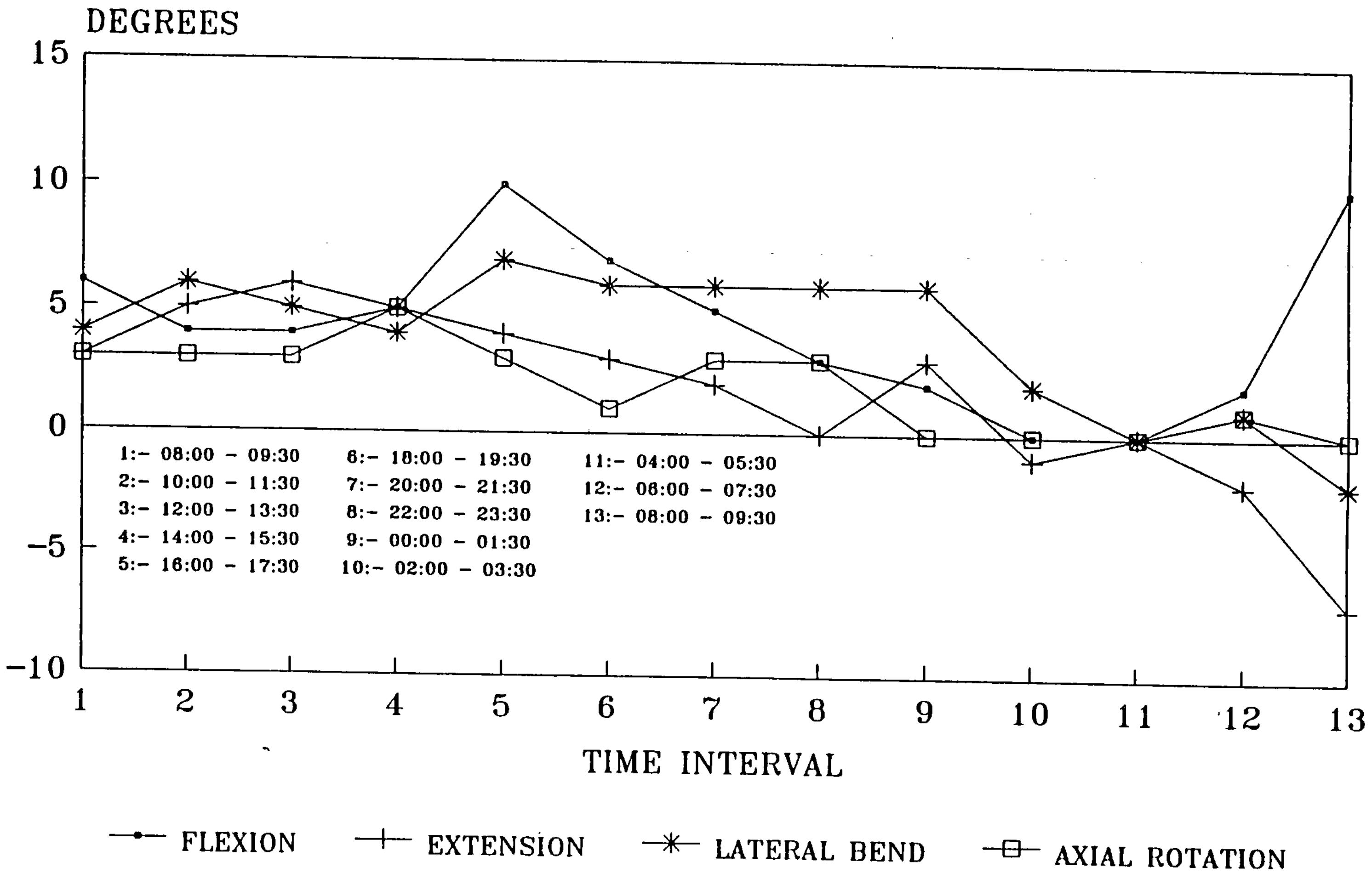


Figure 3.1

TABLE 3.2

AVERAGE MAXIMUM MOVEMENT MEASURED AT TWO HOURLY TIME INTERVALS OVER A 24 HOUR PERIOD

	TIME INTERVAL	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
MALE					
	08.00 - 09.30	67 ± 11	27 ± 20	48 ± 8	26 ± 6
	10.00 - 11.30	63 ± 11	26 ± 6	47 ± 9	23 ± 7
	12.00 - 13.30	63 ± 9	25 ± 11	46 ± 7	23 ± 5
	14.00 - 15.30	67 ± 9	26 ± 8	46 ± 8	26 ± 8
	16.00 - 17.30	73 ± 12	23 ± 8	47 ± 9	25 ± 8
	18.00 - 19.30	72 ± 20	22 ± 9	47 ± 10	21 ± 8
	20.00 - 21.30	69 ± 12	24 ± 9	47 ± 7	23 ± 6
	22.00 - 23.30	66 ± 12	19 ± 9	47 ± 9	27 ± 9
	00.00 - 01.30	63 ± 16	21 ± 6	46 ± 11	22 ± 8
	02.00 - 03.30	59 ± 11	18 ± 8	42 ± 10	22 ± 6
	04.00 - 05.30	61 ± 10	22 ± 10	43 ± 9	23 ± 6
	06.00 - 07.30	60 ± 11	17 ± 6	40 ± 11	23 ± 6
	08.00 - 09.30	65 ± 15	12 ± 11	40 ± 12	21 ± 8
FEMALE					
	08.00 - 09.30	51 ± 8	14 ± 20	42 ± 8	20 ± 9
	10.00 - 11.30	53 ± 7	22 ± 6	50 ± 9	24 ± 6
	12.00 - 13.30	52 ± 10	24 ± 11	48 ± 7	25 ± 12
	14.00 - 15.30	49 ± 14	21 ± 8	47 ± 8	25 ± 15
	16.00 - 17.30	52 ± 14	23 ± 8	50 ± 9	21 ± 8
	18.00 - 19.30	49 ± 10	23 ± 9	49 ± 10	23 ± 8
	20.00 - 21.30	47 ± 12	16 ± 9	49 ± 7	25 ± 6
	22.00 - 23.30	47 ± 6	19 ± 9	48 ± 9	20 ± 8
	00.00 - 01.30	48 ± 3	24 ± 6	51 ± 11	20 ± 10
	02.00 - 03.30	50 ± 5	19 ± 7	46 ± 10	20 ± 13
	04.00 - 05.30	45 ± 12	15 ± 10	41 ± 9	18 ± 10
	06.00 - 07.30	51 ± 11	18 ± 6	46 ± 11	21 ± 13
	08.00 - 09.30		No readings obtained		
MALE + FEMALE					
	08.00 - 09.30	61 ± 8*	22 ± 17	46 ± 8	24 ± 7
	10.00 - 11.30	59 ± 7	24 ± 11	48 ± 8	24 ± 6
	12.00 - 13.30	59 ± 10	25 ± 11	47 ± 9	24 ± 5
	14.00 - 15.30	60 ± 14*	24 ± 8	46 ± 11	26 ± 7*
	16.00 - 17.30	65 ± 14*	23 ± 8	49 ± 8*	23 ± 6
	18.00 - 19.30	62 ± 10*	22 ± 9	48 ± 9*	22 ± 7
	20.00 - 21.30	60 ± 12*	21 ± 9	48 ± 6*	24 ± 5
	22.00 - 23.30	58 ± 6	19 ± 6	48 ± 8*	24 ± 8*
	00.00 - 01.30	57 ± 3	22 ± 9	48 ± 11*	21 ± 6
	02.00 - 03.30	55 ± 5	18 ± 8	44 ± 11	21 ± 5
	04.00 - 05.30	55 ± 12	19 ± 9	42 ± 9	21 ± 6
	06.00 - 07.30	57 ± 11	17 ± 5	43 ± 12	22 ± 5
	08.00 - 09.30	65 ± 15	12 ± 11	40 ± 12	21 ± 8

* Significant difference from reading obtained between 04.00 and 05.30.

N.B. All measurements in degrees. Statistical analysis only applied to the Male + Female group as individual groups were too small for detailed statistical methods to be valid.

3.5 DISCUSSION

Hindle (1989) previously examined the day-to-day variation of the ability of an individual to perform a given movement. In his study two subjects were asked to perform the movements of flexion and extension, lateral bend and axial rotation (both to the left and right sides). Each test took place at the same time of day in order to eliminate diurnal effects. The results of these tests showed a standard deviation about the mean for flexion and extension to be approximately 5 degrees (range 2.4 - 7.8), the values for lateral bend and axial rotation were 1.6 degrees (range 1.2 - 1.9) and 2.4 degrees (range 2.1 - 2.8) respectively. Obviously this margin of error had to be allowed in all repeat tests on individuals when determining whether or not changes were significant.

The results obtained from pre-/post-sleep data showed a significant overall decrease in flexion, extension, and lateral bend post-sleep but did not indicate any significant changes in axial rotation (Table 3.2).

The reason that all subjects did not show similar reductions in movement is not known as all subjects had comparable periods of sleep and were all of a similar age group. In order to determine why this should have occurred and why the standard deviation between results for flexion was comparatively large compared with the results obtained by Adams *et al* (1987), further and more rigourously controlled tests would need to be conducted ensuring that subjects activities were more tightly controlled and of a similar nature. They would also require subjects to be tested immediately after waking and require subjects to remain supine for similar periods.

The fact that no overall change in axial rotation was observed may be due, in part, to the fact that the total range of movement in this plane is small and therefore any changes observed would be small. Any changes may therefore have been obscured by errors introduced by skin or soft tissue movement or by errors introduced by the observer when replacing the sensor on the skin.

As previously stated maximal values obtained using the Isotrak system give higher values than those expected from radiographic techniques. Repeated tests on an individual should however incorporate errors due to soft tissue and skin movement as a standard error and relative changes between movements should give "true" readings.

Results obtained from the 24 hour study showed the movements of flexion, lateral bend and axial rotation to be significantly greater in the afternoon than those measured between the hours of 02:00 - 07:30.

The fact that the range of flexion was at a minimum in the early hours of the morning is likely to have been due mainly to the fact that whilst lying supine the unloaded disc would have become swollen due to the imbibition of water. In this state the disc becomes less easy to compress causing movement to require more effort (Adams *et al,* 1987).

When the disc is in this state it is likely to subject the spinal ligaments and itself to greater stresses. Any movement designed to stretch the ligaments such as flexion, extension, lateral bend and axial rotation would be likely to create additional stress causing movements to require more effort and increase the risk of injury to the lumbar spine.

In tests conducted on cadaveric motion segments Adams *et al* (1988) have shown that creep loading reduces a discs resistance to backward bending by about 40% which it is suggested is balanced by increased resistance from the apophysial joints and spinous processes so that the resistance to backward bending of the motion segment and the range of movement remain unaltered by creep loading. This appears to be the case from this study which showed no overall change in the range of extension measured over the 24 hour period.

The range in lateral bend was also minimal during the early hours of the morning, with the stresses on the ligaments and the discs being maximal at this time. The range was again greatest during the afternoon. The reason for a decrease in lateral bend occurring slightly later during the day is difficult to determine as the activities of subjects were not tightly controlled. However this may be due to the fact that subjects tended to be more active in the morning than the afternoon. The first 2 - 3 hours in the morning when activity was greatest might therefore be expected to correlate with the greatest fluid loss from the disc which would cause the apophysial joints to come into closer contact and increase their loading. The joints would have a higher bending stiffness and strongly resist lateral bending movements. During the afternoon when the activities of the subjects were more sedentary with the majority either sitting in comfortable chairs or lying down for short periods of time, the intake of fluid to the disc would cause the apophysial joints not to be so highly compressed enabling lateral bending movements to be carried out more easily.

3.6 CONCLUSION

Pre-/post sleep results showed reductions in the range of maximal movements after sleep for all movements other than axial rotation.

The general pattern over the 24 hour period indicated that there was a change in maximal movement obtained which depended on the time of day when tested. The range of movement reached a peak during the afternoon and the subject was generally less mobile in the early hours of the morning.

In order to separate the effects of loading and circadian factors it was obvious that further work was required in which the activities of all subjects taking part were more closely controlled. This work provides the basis of Chapter 5.

CHAPTER 4

ASSESSMENT OF WHY RANGE OF MOVEMENT MEASURED USING THE ISOTRAK IS HIGHER THAN WOULD NORMALLY BE EXPECTED

4.1 INTRODUCTION

One major criticism of the use of the Isotrak system in measuring lumbar spine movement is that values obtained for maximum ranges of movement are generally much higher than those obtained using radiographic techniques.

The Isotrak itself records movement changes accurately to within 1 degree and therefore any errors introduced must be due to skin and soft tissue movement relative to the underlying vertebra and not the Isotrak system itself. Errors may have been introduced in the previous studies recorded in Chapters 2 and 3 by allowing subjects to wear loose fitting trousers or skirts and placing the source over the top of this clothing. The reason for conducting tests in this way was that some subjects were reluctant to be tested in their underwear. Also, areas where subjects were tested were not always suitable for them to be tested in this manner.

The source and clothing had previously been assumed to move with the underlying sacrum, due to the fact that clothing was loose and the source fitted tightly to the subject. It may be possible however that some movement of source and clothing relative to the skin took place and that this in turn introduced errors in the results obtained.

In order to investigate where the main sources of error occurred, and the extent of the errors, two short studies were conducted. The first involved testing a group of 22 "normal" subjects (11 males, 11 females) with the sensor positioned over the T12, L1, L2 and L3 vertebral levels respectively. This was conducted in order to determine how the intersegmental range of movement compared with values previously obtained by other researchers, using recognised techniques, and, to give a measure of the amount of variation which may have been introduced in the studies conducted in Chapters 2 and 3, caused by possible sensor misplacement.

If intersegmental values were found to differ significantly from values obtained by other researchers the extent of the error introduced by skin movement could be deduced, if no significant differences were seen to occur the errors would have to be attributed to some other source.

The second test conducted involved monitoring 3 subjects, who were tested whilst wearing different types of clothing. This was done in order to try to ascertain the effect of different types of clothing on the maximum readings of flexion, extension, lateral bend and axial rotation values obtained. Subjects were tested in their underwear, in loose fitting trousers or skirt and in tighter clothing eg. jeans.

4.2 METHOD

4.2.1 Intersegmental motion

During the tests the source remained in the same position with only the sensor position being altered. The method used was essentially that described in Chapter 1 with subjects being asked to repeat the movements of flexion, extension, lateral bend and axial rotation twice before moving the sensor to the next spinous process. Subject details have been given in Table 4.1. All subjects tested were fairly slim and their individual spinous processes easily identifiable.

TABLE 4.1

SUBJECT DETAILS

DETAILS	MALE	FEMALE
AGE (yrs)(MEAN ± S.D.)	39.9 ± 10.0	33.6 ± 10.9
HEIGHT (m)(" " ")	1.77 ± 0.05	1.63 ± 0.09
MASS (kg)(" " ")	75.3 ± 9.7	58.1 ± 9.8

Subjects were first tested with the sensor positioned over T12 after which it was moved to each successive vertebra until all movements had been performed at L3. Subjects were then retested with the sensor at T12 in order to determine any errors due to fatigue. Since subjects had already limbered up before beginning tests an effect due to warming up was considered to be negligible.

4.2.2 Effect of clothing on readings obtained

Readings were obtained with the sensor positioned over L1 and the source positioned so it lay over the sacrum for each test. Between tests the sensor was left in position and the source was positioned over the different types of clothing, trying to ensure that the sensor - source distance remained constant. Three female subjects, mean age 26 ± 1 years, height 1.68 ± 0.05 m, weight 65.1 ± 9.5 kg were tested.

4.3 RESULTS

4.3.1 Intersegmental motion

Results of the differences between levels (ie. intersegmental motion) are shown in Table 4.2.

TABLE 4.2

INTERSEGMENTAL VALUES

MOVEMENT	LEVEL	MALE MEAN ± S.D.	FEMALE MEAN ± S.D.
FLEX/EXT	T12/L1	11.7 ± 7.0	10.8 ± 5.9
	L1/2	10.6 ± 6.7	13.3 ± 8.5
	L2/3	14.2 ± 8.1	17.2 ± 11.7
LAT. BEND	T12/L1	8.4 ± 3.3	7.5 ± 3.6
	L1/2	10.5 ± 4.1	11.5 ± 6.0
	L2/3	7.4 ± 4.1	10.4 ± 6.9
AXIAL ROT	T12/L1	7.6 ± 3.5	7.9 ± 2.9
	L1/2	6.9 ± 4.3	5.6 ± 4.4
	L2/3	7.6 ± 5.4	5.6 ± 6.2

4.3.2 Effect of clothing

The effect of clothing was analysed by using paired t-test statistics with significance being at $P < 0.05$. Results were obtained for both primary and coupled movements. No significant differences were seen between tests for any of the coupled movements. Results for the primary movements have been given in Table 4.3:

TABLE 4.3

Effect of clothing on primary movements

MOVEMENT	TYPE OF CLOTHING		
	UNDERWEAR	LOOSE CLOTHING	TIGHT CLOTHING
EXTENSION FLEXION EXT + FLEX	41.0 ± 7.0 92.0 ± 7.9 132.3 ± 11.0	39.7 ± 5.5 83.7 ± 9.5 123.0 ± 13.2	36.3 ± 5.9 87.3 ± 9.3 123.7 ± 7.8
R. LAT BEND L. LAT BEND L + R BEND	39.3 ± 2.9+ 39.3 ± 4.0 78.7 ± 6.0+	38.7 ± 5.5 35.0 ± 4.0 74.7 ± 9.7	34.3 ± 3.1 35.3 ± 7.6 69.7 ± 8.3
R. ROTATION L. ROTATION L + R ROT.	29.6 ± 5.5 32.3 ± 3.2* 62.0 ± 2.0*	25.7 ± 2.3 27.3 ± 2.1 53.3 ± 1.5	25.7 ± 2.1 26.7 ± 1.2 52.3 ± 1.5+

N.B. *: Significant difference between underwear and loose clothing results; +: Significant difference between underwear and tight clothing results.

4.4 DISCUSSION

A number of studies have involved monitoring lumbar intersegmental spine motion. Amongst the more recent ones are those of Dvorak *et al* (1991), Pearcy (1985) and Yamamoto *et al* (1989). In Dvorak *et al*'s (1991) study mobility of the lumbar spine in flexion-extension and lateral bend was assessed radiographically using CAM and GCM measurement techniques. Subjects monitored had no previous episodes of LBP and were radiologically normal. Results from Dvoraks study yielded flexion-extension and lateral bending values higher than those previously obtained by other researchers (Pearcy, 1985; Yamamoto *et al*, 1989) and the primary reason for this was attributed to the fact that previous studies had used active and not passive motion as used in their study.

Pearcys study involved using stereo radiography to monitor 11 subjects in flexion and extension and 10 subjects in lateral bending, whilst Yamamoto *et al* conducted an *in vitro* study on ten cadaveric lumbar spines using stereophotogrammetry to monitor the relative motion of markers fixed at each vertebral level.

A comparison of the results obtained from the present study, using the Isotrak system and the results obtained from a number of other studies are summarised in Table 4.4:

TABLE 4.4

A COMPARISON OF THE RANGE OF INTERSEGMENTAL MOVEMENT MEASURED IN THE SAGITTAL AND LATERAL PLANES USING DIFFERENT METHODS

Flexion - Extension	Level	Mean	std	min	max
Dvorak *et al*, 1991	L1 - 2	11.9	2.27	8.6	17.9
Pearcy, 1985		13	5	6	20
Yamamoto, 1989		10.1			
This study		12.0	7.7	2.3	25.6
Dvorak *et al*, 1991	L2 - 3	14.5	2.29	9.5	19.1
Pearcy, 1985		14	2	10	16
Yamamoto, 1989		10.8			
This study		14.9	8.6	3.5	29.1
Lateral Bend	Level	Mean	std	min	max
Dvorak *et al*, 1991	L1 - 2	10.4	2.71	4.4	16.9
Pearcy, 1985		10	2	7	15
Yamamoto, 1989		4.9			
This study		10.0	4.2	2.5	16.2
Dvorak *et al*, 1991	L2 - 3	12.4	3.38	3.2	21.2
Pearcy, 1985		11	4	7	18
Yamamoto, 1989		7.0			
This study		9.1	6.0	2.5	24.1

The studies given in Table 4.4 used quite different methods for measuring intersegmental motion. Even so, the mean values obtained from all the studies were not in fact very different. The present study would have incorporated errors due to skin and soft tissue movement relative to the underlying vertebrae but even so the average values obtained for the intersegmental ranges of motion at the L1 - 2 and L2 - 3 levels were not significantly different from those obtained by the other methods given.

Values obtained for axial rotation, were not given in Table 4.4 as they were the most unreliable of the readings obtained. Comparing them with values of between 1 - 2.6° given by other researchers confirms the observation of the sensor moving with the skin relative to the underlying vertebra by a relatively large distance.

As previously mentioned all volunteers were fairly slim, and their spinous processes easily identifiable. However, the ranges of motion obtained and hence standard deviations were in general much greater than in previous studies, with the most consistent results being obtained for lateral bending. Since volunteers were 'hand picked' it is likely that the errors introduced in a 'normal' population would be much greater than those obtained from this study as the variation in weight would be greater and the ability to find the spinous process and place the sensor centrally over it, would be much harder.

This section of the study has shown the type of errors that could be obtained by misplacing the sensor at a level higher or lower than that of L1. In subjects whose spinous processes are not easily identifiable this error may be increased or decreased depending on the amount the sensor has been misplaced by.

In a study by Hindle (1989), in which the Isotrak system was used, he identified the L1 spinous process and marked distances 1 and 2 cm above and below it. By measuring two subjects he found that the amount of variation was between 1.52 and 18.51^{o} for the movement of flexion + extension when the sensor was misplaced by 2cm and 3.46 - 12.9^{o} when it was misplaced by 1 cm. The movement of lateral bending gave ranges of 7.21 - 10.61^{o} for misplacement by 2 cm and 1.37 - 2.49^{o} for misplacement by 1 cm.

Values obtained from Hindles study, and this study must be allowed for when looking at any population study in which range of motion using this measurement system is used. The large spread in range of motion obtained for the 'normal' range of motion study conducted in Chapter 2 may, as previously stated, be due partly to misplacement of the sensor in individual cases.

The second study conducted in which the effect of clothing was looked at showed that there were only small differences in range of movement depending on whether subjects wore loose fitting clothing or were tested in their underwear. The only movement where a significant change was observed was that of axial rotation, which, due to the relatively large errors introduced by skin and soft tissue movement makes it of questionable value for measurement purposes anyway.

A difference in range of movement was observed when subjects wore tight clothing compared with underwear. The most likely reason for this being that the tight clothing hindered the subjects attempts to move laterally as far as they would otherwise have been able to move. From this study it would appear that a subject may be tested in either their underwear or loose clothing without any significant difference to the overall readings being obtained, as long as the source is placed securely in position.

The readings obtained from both the studies gave values for total lumbar spinal movement larger than would be expected from other techniques where skin and soft tissue involvement was not a problem, and the results from the first study would imply that these errors occur mainly in the sacral area.

CHAPTER 5

MEASUREMENT OF RANGE AND COUPLED MOVEMENT MEASURED OVER A 12 HOUR PERIOD IN 'NORMAL' SUBJECTS

5.1 INTRODUCTION

The results from Chapter 3 imply that we might expect to observe a change in the range of motion in subjects, depending on the time of day when measured. Whether or not the change observed was mainly due to the effects of loading on the spine or due to a circadian effect or a combination of the two could not be assessed from that Chapter. This was due primarily to the fact that subjects movements were not restricted during the day and there were therefore too many variables to take into consideration.

The aim of this study was to restrict subjects activities in order to determine whether the change in motion range observed was due primarily to loading or to other influences.

5.2 METHOD

Seven subjects were monitored in this study none of whom suffered from any lumbar spine problems. Subjects were monitored every two hours over a 12 hour time period. The first readings were taken between 07:00 - 07:30. Between tests subjects remained supine, except when they ate or drank, when they were allowed to sit in a semi-upright position for a short period of time (max. period of 15 minutes). Before each test subjects were required to have been supine for a minimum period of 1 hour, and were therefore not allowed to eat or drink anything in this period. Four subjects were monitored approximately half an hour after the final test when they had been standing rather than lying down.

Subjects were monitored using the method given in Chapter 1. To ensure accurate repositioning of both the source and the sensor their skin was marked with indelible ink at these positions. Four males and 3 females were monitored. Age range was 19 - 27 (mean: 23.1 ± 2.8).

5.3 ANALYSIS OF DATA

Significance was calculated by using paired 't' test statistics.

5.4 RESULTS

Due to the small size of the group tested male and female subject results were combined and not looked at separately. The mean maximum results obtained at each two hourly interval have been given in Table 5.1.

TABLE 5.1

AVERAGE MAXIMUM MOVEMENT MEASURED AT TWO HOURLY TIME INTERVALS OVER A 12 HOUR PERIOD

TIME INTERVAL	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROT.
07:00 - 07:30	55 ± 4	18 ± 10	42 ± 6	23 ± 11
09:00 - 09:30	59 ± 10	24 ± 13	41 ± 7	23 ± 10
11:00 - 11:30	54 ± 11	19 ± 8	41 ± 14	23 ± 10
13:00 - 13:30	49 ± 7	19 ± 6	39 ± 9	30 ± 11
15:00 - 15:30	57 ± 13	20 ± 8	39 ± 7	24 ± 10
17:00 - 17:30	53 ± 7	21 ± 6	37 ± 8	24 ± 9
19:00 - 19:30	54 ± 12	17 ± 8	35 ± 7*	25 ± 9
** 21:00 - 21:30	62 ± 4	19 ± 2	39 ± 5*	27 ± 10

N.B. All measurements are mean ± s.d. (degrees)
* Significant difference from reading obtained between 07:00 and 07:30.
** Only 4 out of 7 subjects monitored

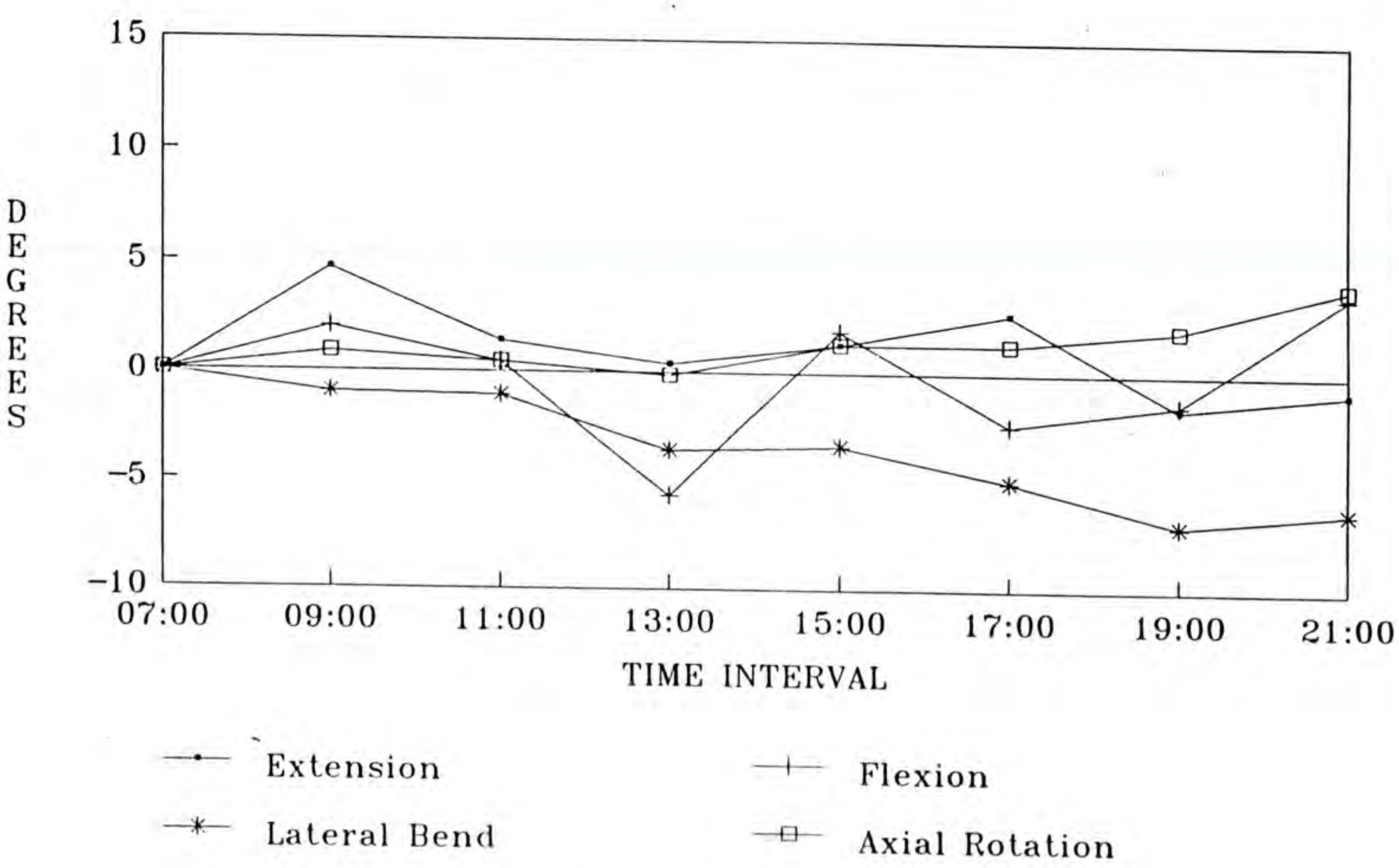

Mean change in movement measurements relative to values obtained at 07:00

FIGURE 5.1

In order to see more clearly how movements varied throughout the day, results were compared with the first set of readings obtained, ie. those recorded at 07:00. Figure 5.1 shows how movement changed throughout the day. Even though fluctuations in movement can be seen to occur throughout the day, the results from Table 5.1 show that the only significant change in movement was for that of lateral bend recorded at 19:00 and 21:00.

In order to show how readings varied throughout the day for individual subjects, the results of the mean maximum movement measured at each time interval, have been shown in figures 5.2 - 5.8. These figures show that there was considerable variation between subjects, even when they did not eat or drink between readings.

Figure 5.2
SUBJECT No. 1

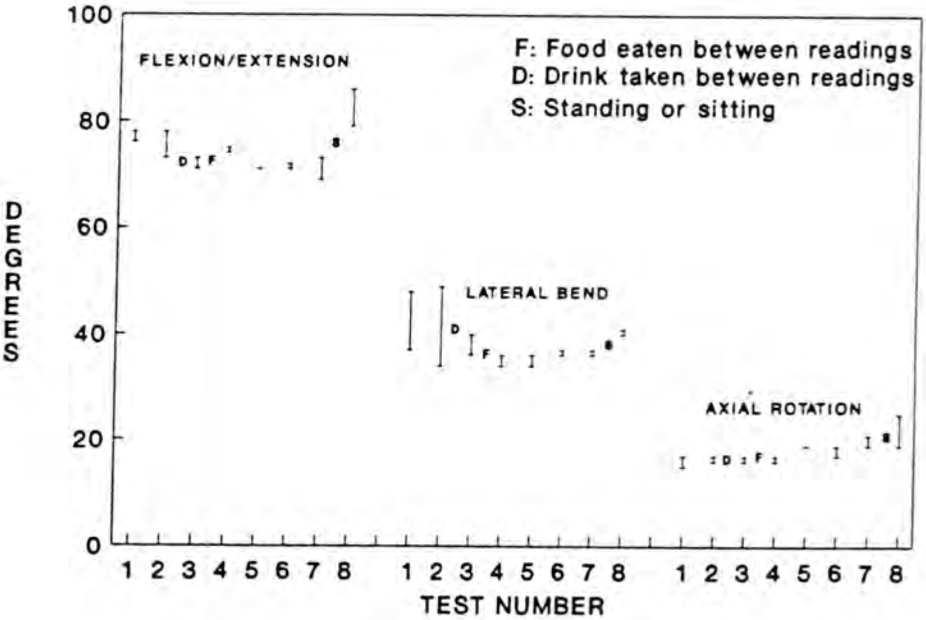


Figure 5.3
SUBJECT No. 2

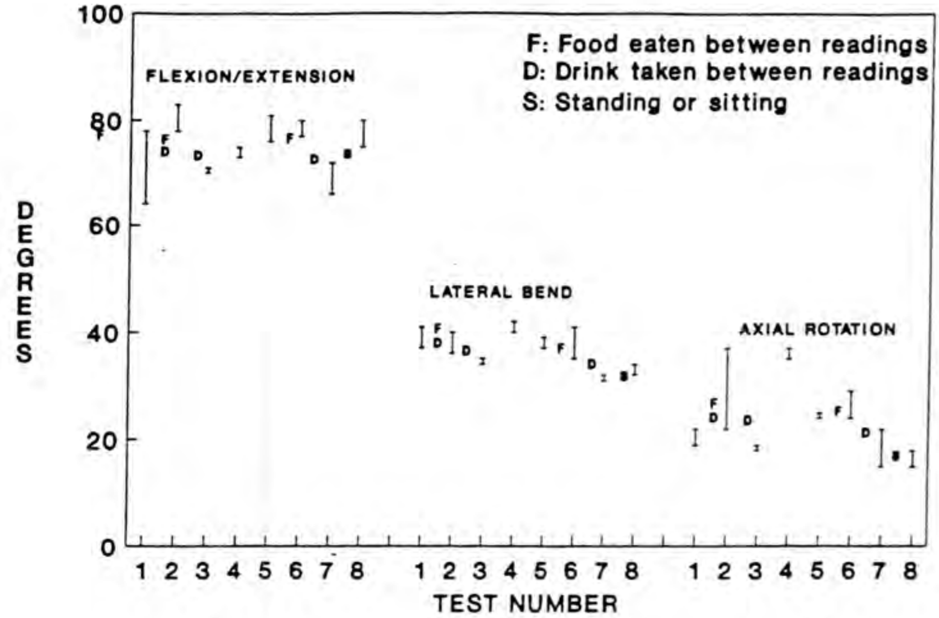


Figure 5.4
SUBJECT No. 3

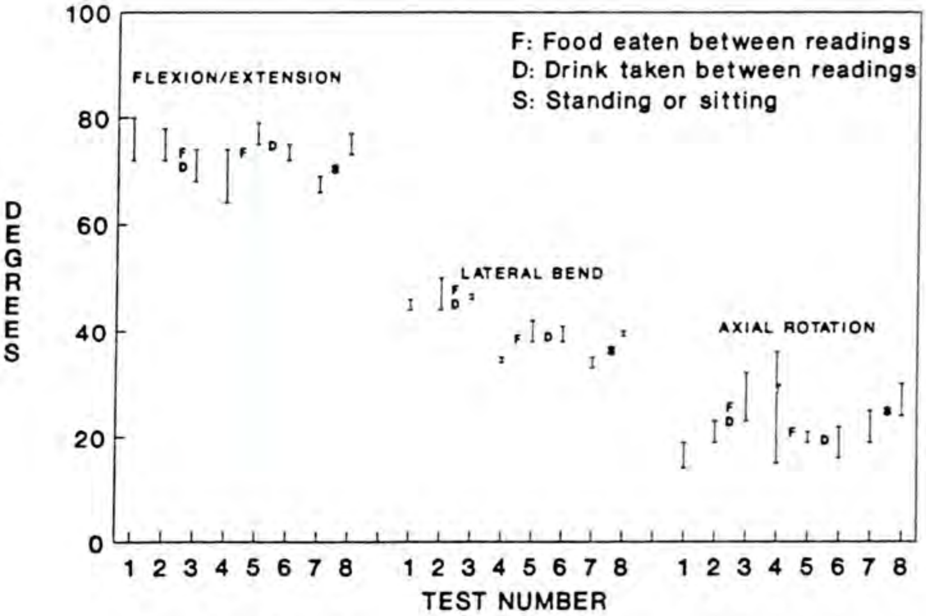


Figure 5.5
SUBJECT No. 4

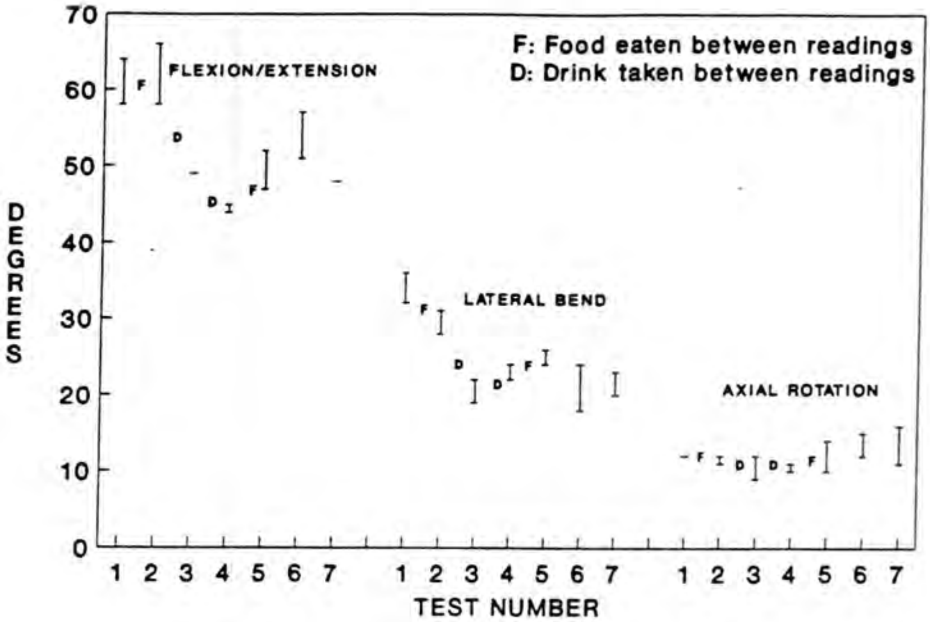


Figure 5.6
SUBJECT No. 5

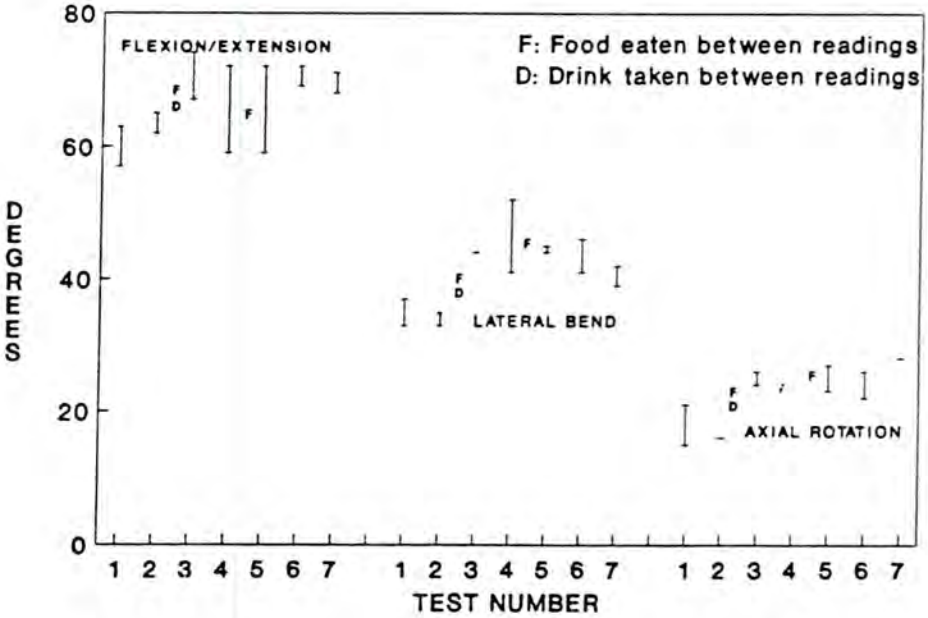


Figure 5.7
SUBJECT No. 6

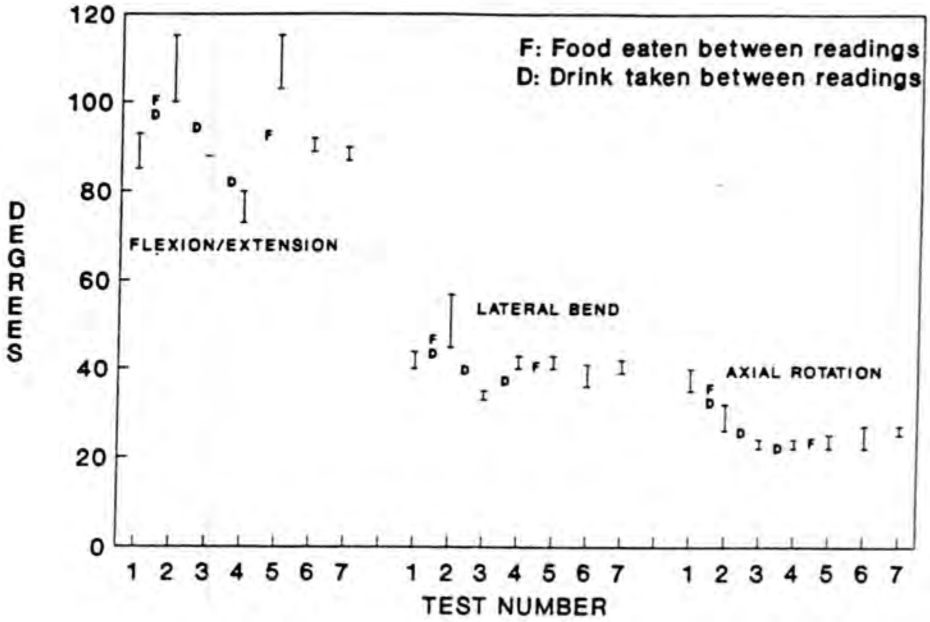
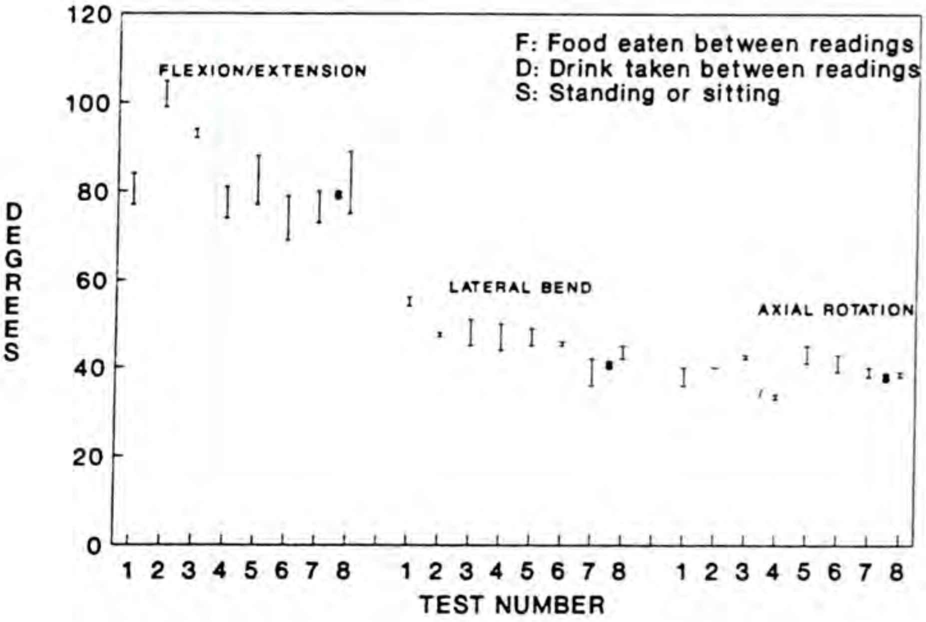


Figure 5.8
SUBJECT No. 7



The general trends that emerge from figures 5.2 - 5.8 imply that drinking causes a reduction in movement, whilst eating **and** drinking often have the opposite effect. In order to assess whether the 'trends' observed were significant changes in movement, the results were split into 5 groups.

Subjects who ate any food between two successive tests fell into Group 1; those who drank any fluid, into Group 2 (fluid being tea, coffee or water); those who ate **and** drank between two tests into Group 3; the 4 subjects who were monitored after getting up at the end of the days testing fell into Group 4; and those who did nothing but lie down between tests, into Group 5.

Since results for the majority of patients fell into each group on more than one occasion, results for each subject were averaged, and this average value used for analysis purposes. The effect of activities conducted more than 2 hours before readings were obtained were assumed not to have any significant effect on the readings.

The average changes in movement obtained between successive time intervals (eg. results before and after eating or drinking) have been shown in figure 5.9 and given in Table 5.2. The base level for significance was taken as zero for all groups studied.

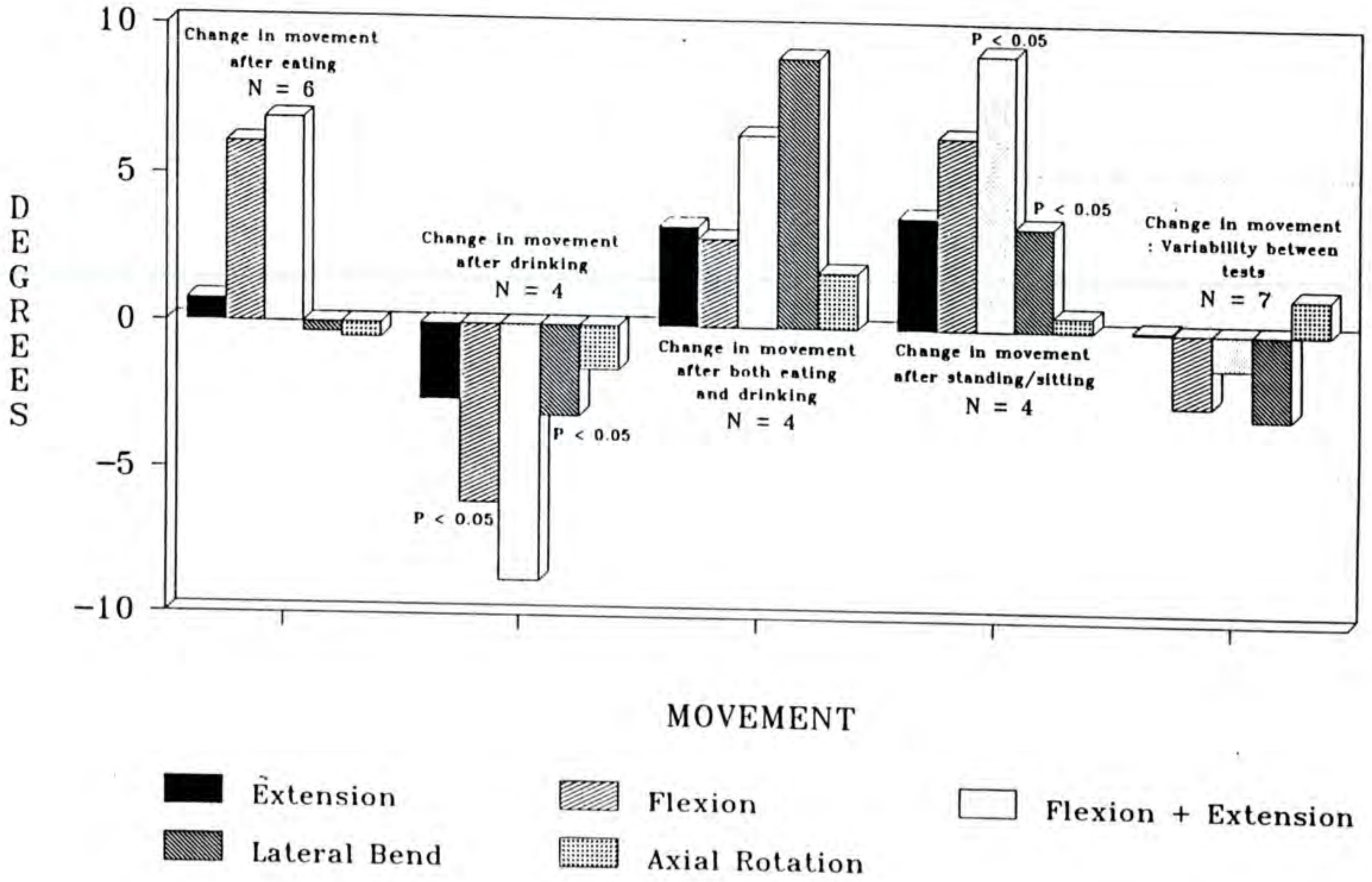

10
5
0
-5
-10
DEGREES
Change in movement after eating
N = 6
Change in movement after drinking
N = 4
P < 0.05
P < 0.05
Change in movement after both eating and drinking
N = 4
P < 0.05
P < 0.05
Change in movement after standing/sitting
N = 4
Change in movement : Variability between tests
N = 7
MOVEMENT
Extension
Lateral Bend
Flexion
Axial Rotation
Flexion + Extension

FIGURE 5.9

TABLE 5.2

EFFECT OF ACTIVITY ON MOVEMENT RANGE
Mean (± standard deviation)

	PRIMARY MOVEMENT: Mean (s.d)				
GROUP	EXT.	FLEX.	FLEX + EXT	LATERAL BEND	AXIAL ROTATION
GROUP 1	0.8 (5.9)	6.1 (9.4)	6.9 (13.3)	-0.3 (3.4)	-0.5 (4.8)
GROUP 2	-2.6 (4.5)	-6.1 (1.1)	-8.8 (9.2)	-3.1 (1.4)	-3.1 (1.4)
GROUP 3	3.4 (8.9)	3.0 (9.3)	6.5 (17.1)	9.1 (11.8)	1.9 (8.2)
GROUP 4	3.8 (4.1)	5.3 (5.7)	9.3 (1.3)	3.5 (1.7)	0.5 (1.3)
GROUP 5	0.1 (2.2)	-2.5 (5.3)	-2.9 (3.7)	1.2 (1.1)	-1.2 (3.1)

The only significant changes in movement were, an increase of 9.3 ± 1.30^{o} for the combined movement of flexion + extension and an increase of 3.5 ± 1.7^{o} for lateral bending when subjects were tested after getting up at the end of the day, and decreases of 6.1 ± 2.3^{o} and 3.1 ± 1.4^{o} for flexion and lateral bend respectively after drinking.

5.5 DISCUSSION

The results from Group 4 have shown that an increase of approximately 9.3 ± 1.3^{o} of combined flexion and extension and 3.5 ± 1.7^{o} lateral bending might be expected for a subject moving from a supine position, for a prolonged period of time, into a standing/sitting position. Although values for flexion (5.3 ± 5.7^{o}) did not reach statistical significance they were of the same order of magnitude as the value obtained by Adams *et al* (1987) of 5.0 ± 1.9^{o}. Comparing the results for lateral bending with those of 8.6 ± 6.5^{o} from Chapter 4 shows a smaller increase and less variability between subjects in this study.

It was initially thought that subjects who did nothing but remain supine between tests would have no change in movement range as the discs were not loaded to any extent. Although the majority of results did show there to be very little change in movement between tests the results for Subject 7 (Figure 5.8) who neither ate nor drank during the day showed considerable variation in readings obtained. Subject 7 did however find it increasingly painful to remain supine and therefore moved about more, even though she had had no back problems in the past. This may therefore have affected the results.

The results from Group 5 have shown that lateral bending and extension gave the most consistent results throughout the day, and that flexion gave the most variable results, although none of the readings were found to be statistically significant. This could possibly have been due to the fact that most subjects altered their position throughout the day, due to boredom, and becoming uncomfortable remaining in the same position for a prolonged period of time. The positions most commonly adopted were lying on the front or back, or in the fetal position which caused flexion of the spine. Although detailed notes of the positions kept by subjects were not recorded, it is obvious that the movement most likely to have been affected was that of flexion since the spine was moved into and out of flexion on a number of occasions, never went into extension and rarely into lateral bending.

All activities eg. eating, drinking etc. appeared to have some effect on the readings obtained, although it was not a consistent increase or decrease in movement in the majority of cases. The exceptions to this were for the movements of flexion and lateral bending which both decreased after drinking. The reasons why this phenomenon was observed are unclear as movement changes were insignificant after eating between tests and both eating and drinking between tests. The fact that the combined flexion + extension movement did not alter significantly after drinking might imply that the subjects posture had altered slightly due to fluid intake. If this were the case however, we might also expect a change due to eating and drinking which was not observed. Again no plausible reason why lateral bending decreased after drinking could be found. It is possible that psychologically subjects felt more 'bloated' after drinking and therefore were more careful when performing each movement, and did not stretch to the extremes of motion. Again, if this were the case the same effect might have been expected to have been seen in the group who ate and drank between tests.

Groups 1 and 3 ie. the eating, and eating and drinking groups, were not as closely controlled as Group 2, with some consuming slightly more or less than others. In Group 2 all subjects had approximately the same amount of fluid intake ie. one cup of tea, coffee or water between any test. Due to the variability in consumption for Groups 1 and 3, and the small number of subjects monitored it is likely that any effect could have been obscured.

Comparing the results obtained in this study with those given in Table 3.2 over the time interval 06:00/06:30 - 18:00/18:30, it can be seen that there is less variability in the results obtained from this study. The average standard deviation on results obtained from this study was 5.6, 8.6, 7.9 and 7.4 for the movements of extension, flexion, lateral bend and axial rotation compared with standard deviations of 15.3, 11.8, 14.9 and 8.1 from Chapter 3.

CHAPTER 6

CHARACTERISTIC MOVEMENTS IN ANKYLOSING SPONDYLITIS

6.1 INTRODUCTION

Ankylosing Spondylitis (A.S) has been described as a common chronic, often benign, inflammatory disease of the axial skeleton. It almost **always** involves the sacroiliac joints and may have the following complications; peripheral arthropathy, anterior uveitis, anaemia, prostatitis, aortitis and amyloidosis. It is estimated to occur in approximately 1% of the population in a mild form (Calin and Fries, 1975).

The disease generally first occurs in people aged between fifteen and twenty-four with 10% developing their first symptoms before puberty (Julkunen, 1962). Early signs include tenderness over the entheses, limitation of movement in all directions, tenderness on pelvic compression or when subjected to backward pressure on the anterior superior iliac spine in the prone position.

Another sign which may occur is weight loss (Calabro *et al*, 1986).

6.1.1 Diagnostic Criteria

Ankylosing Spondylitis is commonly diagnosed by either one of two sets of criteria, namely, the Rome or the New York criteria. For the purpose of this study A.S. patients who satisfied the New York criteria were monitored as this is the more detailed of the two, and the one most commonly used when assessing patients.

According to the New York criteria for a patient to be diagnosed as having A.S. there must be the following:

1. Limitation of lumbar spine movement in three planes (anterior flexion, lateral flexion and extension).

2. History of pain or presence of pain at the dorsolumbar junction or in the lumbar spine.

3. Limitation of chest expansion to 1 inch (2.5cm) or less, measured at the level of the 4th intercostal space.

DEFINITE A.S. is present if:

1. Grade 3-4 bilateral sacroilitis is associated with one of the above.

2. Grade 3-4 unilateral or grade 2 bilateral sacroilitis is associated with criterion 1 or with both criteria 2 and 3.

PROBABLE A.S. if Grade 3-4 bilateral sacroilitis exists without any clinical criteria.

6.1.2 Aims

The main aim of this chapter was to look at the range and pattern of movement in the lumbar spine of A.S. patients and then to compare the results with those obtained in chapter 2 for the 'normal' data group.

6.2 MATERIALS AND METHODS

The study conducted in this chapter used the same method for obtaining results as that detailed in Chapter 1.

6.3 RANGE AND PATTERN OF MOVEMENT OBSERVED IN A.S. PATIENTS

One hundred and thirty-one A.S. patients were monitored, patient details are given in Table 6.1. Only 27% of the total number of patients seen were female.

TABLE 6.1

DETAILS OF ANKYLOSING SPONDYLITIS PATIENT GROUPS MONITORED

SEX/AGE GROUP	AGE MEAN ± SD	NO. TESTED	HEIGHT MEAN ± SD	WEIGHT MEAN ± SD
MALE				
16 - 29	25.8 ± 1.9	14	1.78 ± 0.08	70.8 ± 11.7
30 - 39	35.5 ± 3.0	32	1.76 ± 0.07	69.6 ± 7.9
40 - 49	44.1 ± 2.8	24	1.71 ± 0.09	70.6 ± 11.3
50 - 59	54.3 ± 2.8	16	1.71 ± 0.10	75.2 ± 10.4
60 +	65.4 ± 3.6	9	1.71 ± 0.05	75.1 ± 7.8
FEMALE				
16 - 29	20.7 ± 5.0	3	1.62 ± 0.09	47.9 ± 4.5
30 - 39	34.9 ± 3.1	13	1.64 ± 0.08	62.4 ± 7.5
40 - 49	44.8 ± 3.6	13	1.60 ± 0.08	54.1 ± 5.9
50 - 59	52.2 ± 2.2	7	1.56 ± 0.06	57.1 ± 3.2
60 +	----------	--	----------	----------

All patients had uncomplicated ankylosing spondylitis ie. did not have psoriasis, ulcerative colitis, Crohn's disease, Reiter's disease etc.

Disease duration was a difficult parameter to estimate as patients often had the symptoms of the disease years before they were diagnosed by their local GP or consultant. Details of disease duration *and* time since 'official diagnosis' were known for only 97 of those patients tested. Details for these patients have been given in Table 6.2.

TABLE 6.2

DETAILS FOR PATIENTS FOR WHOM BOTH DISEASE DIAGNOSIS AND TIME SINCE INITIAL SYMPTOMS WERE OBSERVED WERE KNOWN

MALE					
DETAILS	16 - 29	30 - 39	40 - 49	50 - 59	60 - 69
NO. IN GROUP	12	23	17	13	6
NO. OF YEARS SINCE ONSET	5.8 ± 3.1	13.7 ± 7.2	21.1 ± 6.5	21.9 ± 12.6	29.5 ± 11.3
NO. OF YEARS SINCE DIAG.	2.9 ± 2.6	7.3 ± 5.2	12.0 ± 8.0	10.0 ± 11.5	15.1 ± 13.3
HEIGHT (m)	1.78 ± 0.09	1.75 ± 0.07	1.70 ± 0.09	1.70 ± 0.11	1.68 ± 0.06
MASS (kg)	71.2 ± 12.5	68.2 ± 8.8	68.9 ± 8.7	75.8 ± 11.4	74.5 ± 9.2
FEMALE					
NO. IN GROUP	2	10	10	4	-------
NO. OF YEARS SINCE ONSET	5.0	10.9 ± 5.0	13.8 ± 9.1	31.7 ± 5.7	-------
NO. OF YEARS SINCE DIAG.	1.5	5.4 ± 3.1	6.4 ± 4.8	9.3 ± 4.9	-------
HEIGHT (m)	1.57 ± 0.00	1.63 ± 0.09	1.61 ± 0.08	1.58 ± 0.06	-------
MASS (kg)	45.6 ± 2.9	62.0 ± 7.8	55.4 ± 5.2	56.8 ± 3.5	-------

N.B. Values given in the above Table are the mean ± S.D.

Table 6.3 was constructed in order to show the distribution of ages at which patients first showed symptoms of the disease. As can be seen initial symptoms seem to occur most commonly in the first two decades listed.

TABLE 6.3

DISTRIBUTION OF AGES AT WHICH FIRST DISEASE SYMPTOMS WERE NOTED

AGE AT ONSET	NO. OF PATIENTS	SEX		% TOTAL CASES/DECADE	
		M	F	M	F
10 - 19	30	23	7	32.4	26.9
20 - 29	39	28	11	39.4	42.3
30 - 39	20	14	6	19.7	23.1
40 - 49	7	5	2	7.0	8.0
50 +	1	1	--	1.4	----
TOTAL	97	71	26		

6.3.1 Statistical Analysis

Statistical analysis was used to compare the maximum range of motion in patients of different ages and of different gender, and was used to assess how coupled movements; and consequently movement patterns differed. When comparing patient groups the non-parametric two sample Wilcoxon rank sum test (also called the Mann-Whitney test) was used as the data appeared to be positively skewed.

When comparing the patient groups with 'Normals' the 'TWOSAMPLE' command in the Minitab statistical package was used. This was recommended as being the most appropriate method by which to compare the populations as they had different shapes and different standard deviations. The 'TWOSAMPLE' command enabled a two (independent) sample t-test and confidence interval to be calculated for the groups.

6.4 RESULTS

6.4.1 Age and Sex effects for Ankylosing Spondylitis patients

Patient groups were initially split into male and female categories, and separate age groups. Since numbers in the 50 - 59 and 60 + age groups were relatively small these groups were combined to form a 50 + age group. Table 6.4 gives the results of the median values obtained and the 95% confidence interval limits for each group.

TABLE 6.4

CHANGE IN MEDIAN RANGE OF PRIMARY MOVEMENT RELATED TO AGE FOR ANKYLOSING SPONDYLITIS PATIENTS

AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
MALE				
20 - 29	60 (21,66)	17 (3,26)	37 (19,52)	22 (12,28)
30 - 39	48 (35,60)	10 (5,15)	28 (18,40)	27 (25,31)
40 - 49	34 (30,42)	5 (3,6)	15 (10,26)	23 (17,27)
50 +	39 (29,45)	6 (2,7)	18 (10,26)	20 (17,23)
FEMALE				
20 - 29	61 (38,90)	20 (1,23)	59 (8,63)	45 (20,33)
30 - 39	49 (45,65)	12 (4,22)	34 (15,49)	30 (20,33)
40 - 49	44 (33,56)	6 (4,9)	22 (11,34)	21 (18,26)
50 +	41 (20,60)	6 (3,15)	23 (13,29)	22 (14,29)

Mann-Whitney tests were carried out to determine whether or not there were any significant differences between both primary and secondary movements performed in each patient age and sex group (Table 6.5).

TABLE 6.5

SUMMARY OF SIGNIFICANT DIFFERENCES BETWEEN A.S. PATIENT GROUPS USING MANN-WHITNEY STATISTICS

SEX	PRIMARY MOVEMENT	AGE GROUPS	SIGNIFICANT MOVEMENT	SIGN. DIFF.
FEMALE	FLEXION	30 - 39 & 50 - 59	R. AXIAL ROT	Y > O
	L. LAT. BEND	20 - 29 & 40 - 49		Y > O
	AXIAL ROT.	20 - 29 & 40 - 50+	AXIAL ROT	Y > O
	L. AXIAL ROT	20 - 29 & 30 - 39	FLEXION	Y > O
		20 - 29 & 50 +		Y > O
MALE	EXTENSION	20 - 39 & 40 - 50+	EXTENSION	Y > O
	FLEXION	30 - 39 & 40 - 49	FLEXION	Y > O
	LAT. BEND	20 - 39 & 40 - 50+	LAT. BEND	Y > O
	R. AXIAL ROT	20 - 29 & 50 +	EXTENSION	Y > O
	L. AXIAL ROT	20 - 29 & 30 - 49		Y > O
	AXIAL ROT	30 - 39 & 50 +	AXIAL ROT	Y > O
MALE & FEMALE	L. AXIAL ROT	20 - 29	FLEXION	M > F

N.B. Y :- Younger of the age groups O :- Older of the age groups M :- Male F :- Female

Due to the fact that the only significant difference between male and female age groups was for left axial rotation in the 20 - 29 age group it was considered appropriate to combine male and female age groups in order to increase numbers in each category and determine significant changes related to age. These results for primary movements are given in Table 6.6.

TABLE 6.6

SIGNIFICANT DIFFERENCE IN MEDIAN RANGE OF MOTION DETERMINED BY AGE - A.S. PATIENT GROUP

COMBINED MALE and FEMALE ANKYLOSING SPONDYLITIS GROUPS				
AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
20 - 29	61 (38,66) *+	18 (3,25) *+	38 (19,55) *+	24 (18,33)
30 - 39	49 (44,59) =\	10 (6,14) =\	28 (20,40) =\	27 (25,31) *+
40 - 49	38 (31,45) *=	6 (4,7) *=	16 (11,26) *=	21 (19,26) *
50 +	41 (31,45) +\	6 (3,7) +\	19 (12,25) +\	21 (17,23) +

N.B. *, +, =,\ denote significant differences between age groups ($P < 0.05$) eg. The 20 - 29 age group and the 40 - 49 age group have significantly different values for flexion, extension and lateral bend denoted by * against both sets of figures. The 20 - 29 age group also has significantly different values from the 50 + age group, this time denoted by + against each set of figures. Values given are median (95% confidence interval limit).

As can be seen from the above Table the main statistical differences were between those subjects in the younger two age groups and the older two age groups. This applied for the movements of flexion, extension and lateral bend. Axial rotation was only seen to be significantly different between the 30 - 39 age group and the older two age groups.

To see whether there was a significant correlation between all primary movements performed, correlation coefficients were calculated:

MOVEMENT	CORRELATION	SIGN.	REGRESSION EQUATION
Ext. & Flexion	0.710	$P < 0.001$	Ext = -4.0 + 0.3xFlex
Ext. & Lat. Bend	0.759	$P < 0.001$	Ext = 0.2 + 0.4xLatBend
Ext. & Axial Rot.	0.454	$P < 0.001$	Ext = 0.6 + 0.4xRot
Flex. & Lat. Bend	0.833	$P < 0.001$	Flex = 20.3 + 0.9xLatBend
Flex. & Rot.	0.502	$P < 0.001$	Flex = 21.0 + 0.9xRot
Lat. Bend & Rot.	0.496	$P < 0.001$	LatBend = 5.3 + 0.8xRot

The lowest correlation between movements was between axial rotation and any of the other movements performed, and the highest was between flexion and lateral bend.

6.4.2 Coupled motion in A.S. groups

In order to determine whether or not coupled movements accompanying the primary movements were significant s-tests were conducted on the patient data (this was again conducted on combined male + female groups). These tested the hypothesis that the median was not equal to zero. These results are given in Table 6.7, significance was again taken to be where $P < 0.05$.

Tests were also conducted to assess whether the magnitude of the primary movement conducted was correlated with the magnitude of the

TABLE 6.7

SIGNIFICANT COUPLED MOVEMENTS ACCOMPANYING PRIMARY MOVEMENTS FOR A.S. PATIENT GROUPS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	MEDIAN COUPLED MOTION (95% C.I.)
20 - 29	FLEXION	L. AXIAL ROTATION	3.0 (2.0, 6.0)
	R. LAT BEND	FLEXION	8.0 (1.1, 13.0)
	L. LAT BEND		6.0 (1.1, 9.9)
	R. AXIAL ROT	L. LATERAL BEND	3.0 (0.0, 8.9)
	L. AXIAL ROT	R. LATERAL BEND	3.0 (1.0, 8.9)
30 - 39	FLEXION	L. AXIAL ROTATION	2.0 (0.0, 3.0)
	R. LAT BEND	FLEXION	5.0 (2.0, 8.5)
	L. LAT BEND		5.0 (2.5, 7.0)
		R. AXIAL ROTATION	1.0 (0.0, 3.0)
	R. AXIAL ROT	EXTENSION	2.0 (0.0, 3.0)
		L. LATERAL BEND	2.0 (1.0, 5.0)
	L. AXIAL ROT	FLEXION	2.0 (0.0, 3.0)
		R. LATERAL BEND	5.0 (3.0, 8.0)
40 - 49	R. LAT BEND	FLEXION	4.0 (1.1, 8.0)
	L. LAT BEND		4.0 (2.0, 6.0)
		R. AXIAL ROTATION	2.0 (1.0, 2.0)
	R. AXIAL ROT	L. LATERAL BEND	3.0 (1.0, 6.0)
	L. AXIAL ROT	R. LATERAL BEND	3.0 (2.0, 4.9)
50 +	R. LAT BEND	FLEXION	4.0 (2.0, 6.0)
	L. LAT BEND		3.5 (3.0, 7.0)
	R. AXIAL ROT	L. LATERAL BEND	2.0 (1.0, 4.0)
	L. AXIAL ROT	R. LATERAL BEND	3.0 (2.0, 6.0)

secondary movement performed. These tests showed only a weak correlation between movements with the highest correlation being between left rotation and coupled lateral bend (corr = -0.352). Even so, the correlation between the following movements reached statistical significance:

PRIMARY & COUPLED MOVEMENTS	CORRELATION	SIGNIFICANCE
Ext & coupled bend	0.305	$P < 0.001$
R. Lat Bend & coupled flexion	0.300	$P < 0.001$
R. Lat Bend & coupled rot.	0.239	$P < 0.01$
L. Lat Bend & coupled rot.	0.351	$P < 0.001$
R. Axial rot. & Lat. Bend	0.221	$P < 0.05$
L. Axial rot. & Lat. Bend	0.352	$P < 0.001$

6.4.3 Comparison between A.S. and 'Normal' Subject groups

In this section of the study the one hundred and thirty-one A.S. patients studied, were compared with the two hundred and fifty-three 'Normal' subjects monitored in Chapter 2.

The results for the median maximum ranges of movement in all three planes for both 'Normal' and A.S. patients are given in Table 6.8. N.B. Although the results obtained for the 'Normal' group were parametric (Chapter 2) it was considered more appropriate to display these results as median and 95% confidence interval limits as it made visual comparison between groups easier. Also median and mean values for the 'normal' groups tested would not be significantly different as the data showed an approximately normal distribution pattern. These results are shown graphically in Figures 6.1 - 6.3.

Statistical tests were carried out to determine whether or not there were

TABLE 6.8

CHANGE IN MEDIAN RANGE OF PRIMARY MOVEMENTS RELATED TO AGE FOR 'NORMALS' AND A.S. PATIENTS

GROUP TESTED	AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
MALE					
A.S.	20 - 29	60 (21,66)	17 (3,26)	37 (19,52)	22 (12,28)
'NORMAL'		73 (69,80)	28 (20,31)	53 (49,64)	27 (25,36)
A.S.	30 - 39	48 (35,60)	10 (5,15)	28 (18,40)	27 (25,31)
'NORMAL'		72 (66,79)	24 (18,29)	51 (46,59)	31 (27,35)
A.S.	40 - 49	34 (30,42)	5 (3,6)	15 (10,26)	23 (17,27)
'NORMAL'		74 (70,77)	21 (13,25)	47 (36,52)	23 (20,29)
A.S.	50 +	39 (29,45)	6 (2,7)	18 (10,26)	20 (17,23)
'NORMAL'		59 (53,68)	14 (11,16)	31 (28,37)	26 (20,33)
FEMALE					
A.S.	20 - 29	61 (38,90)	20 (1,23)	59 (8,63)	45 (20,33)
'NORMAL'		63 (58,69)	28 (22,32)	59 (55,66)	31 (28,39)
A.S.	30 - 39	49 (45,65)	12 (4,22)	34 (15,49)	30 (20,33)
'NORMAL'		73 (63,80)	22 (18,28)	57 (50,66)	29 (24,35)
A.S.	40 - 49	44 (33,56)	6 (4,9)	22 (11,34)	21 (18,26)
'NORMAL'		59 (55,66)	20 (17,22)	52 (49,58)	33 (32,43)
A.S.	50 +	41 (20,60)	6 (3,15)	23 (13,29)	22 (14,29)
'NORMAL'		63 (58,67)	20 (16,22)	42 (40,45)	31 (27,37)

N.B. Values given in the above Table are median values (95% confidence interval limit).

significant differences between patient groups and 'Normal' groups studied (Twosample tests). Once again male and female patient data were combined, 'Normal' data groups were left separated as male and female groups. Results are given for the primary movements conducted as well as the accompanying secondary motions. Table 6.9 shows these results.

Figure 6.1

CHANGE IN MEDIAN RANGE OF LUMBAR FLEXION AND EXTENSION FOR A.S. PATIENTS AND 'NORMAL' SUBJECTS RELATED TO AGE

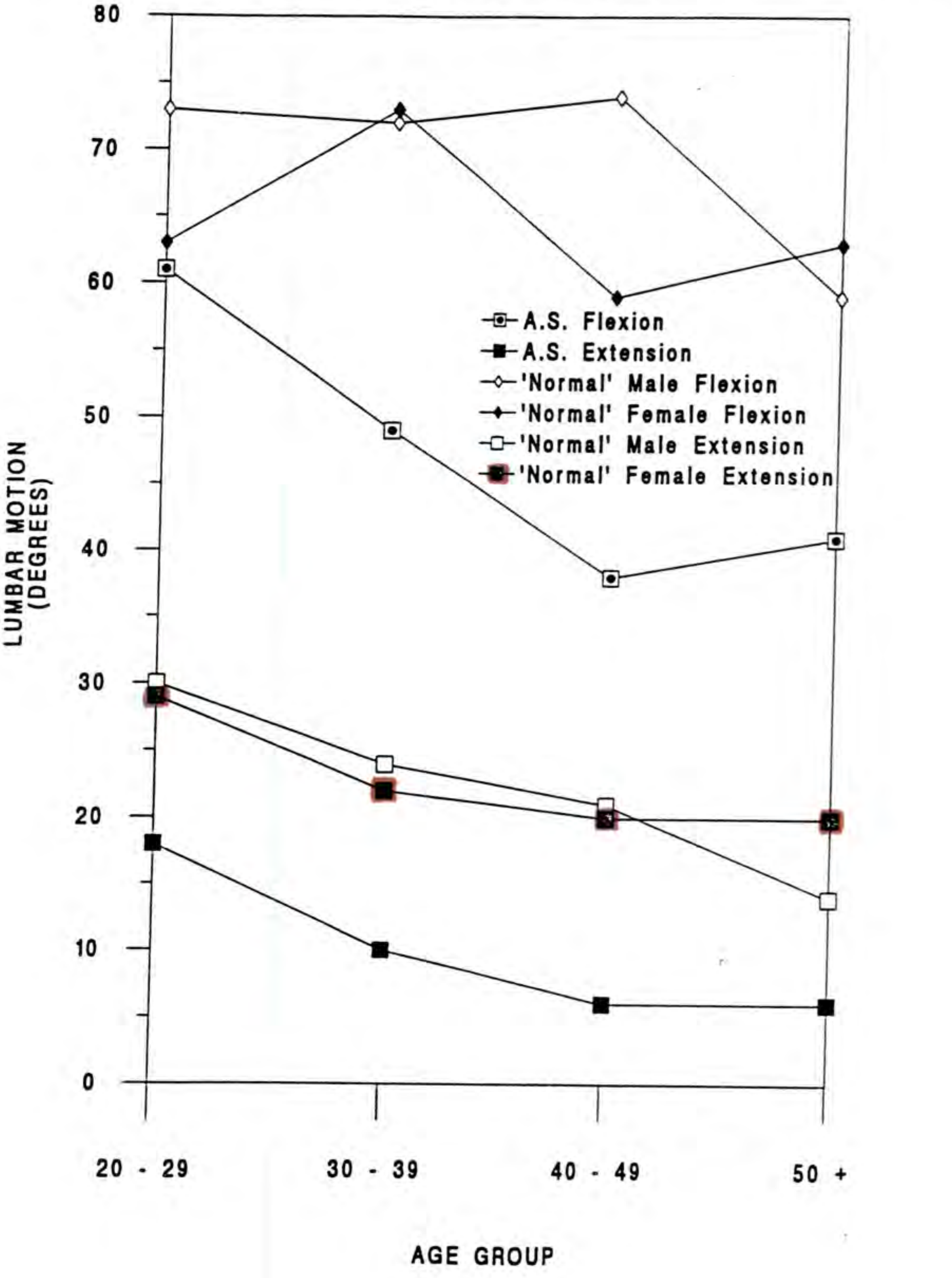


Figure 6.2

CHANGE IN MEDIAN RANGE OF LUMBAR LATERAL MOTION FOR A.S. PATIENTS AND 'NORMAL' SUBJECTS RELATED TO AGE

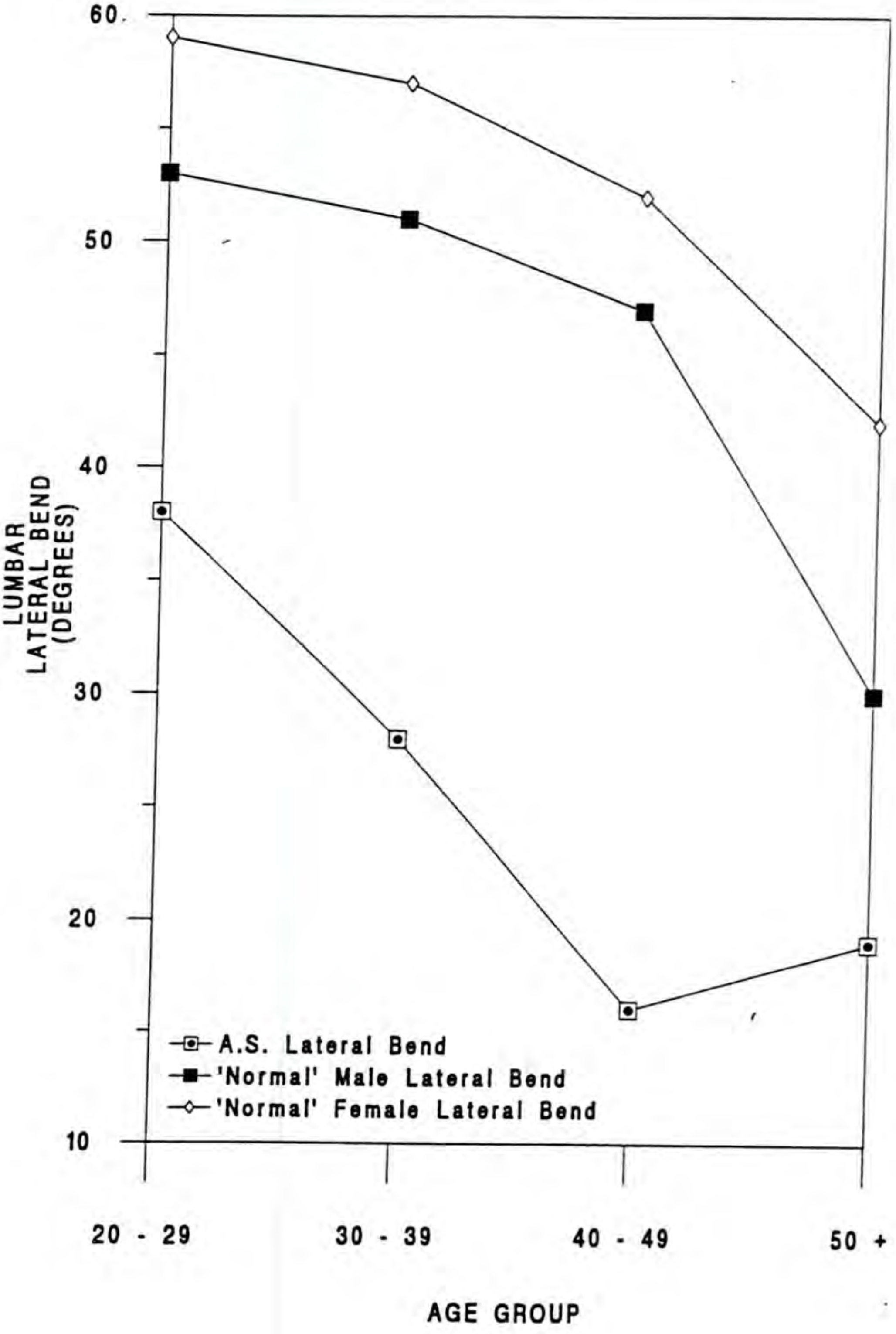


Figure 6.3

CHANGE IN MEDIAN RANGE OF LUMBAR AXIAL ROTATION FOR A.S. PATIENTS AND 'NORMAL' SUBJECTS RELATED TO AGE

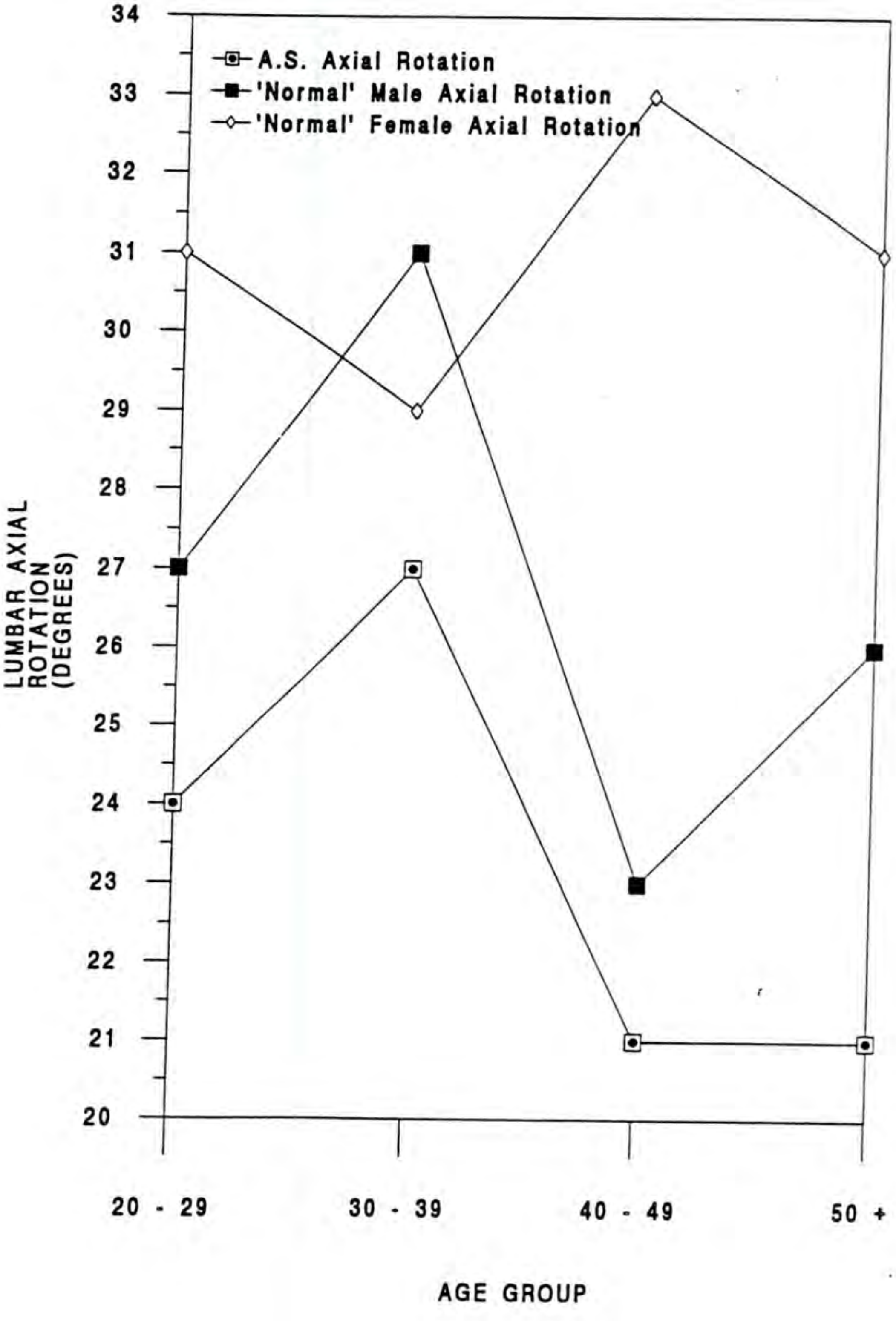


TABLE 6.9

SUMMARY OF SIGNIFICANT DIFFERENCES OBTAINED FOR 'NORMAL' SUBJECTS vs A.S. PATIENTS USING TWO-SAMPLE T-TEST STATISTICS

X rmals')	PRIMARY MOVEMENT	AGE GROUP	SIGNIFICANT MOVEMENT	SIGN. DIFF.
FEMALE	EXTENSION	20 - 50 +	EXTENSION	N > A.S.
		20 - 29	LAT. BEND	N > A.S.
	FLEXION	30 - 50 +	FLEXION	N > A.S.
		40 - 49	LAT. BEND	A.S.> N
	R. LAT BEND	20 - 49	FLEX	N > A.S.
		30 - 39	L. AXIAL ROT	N > A.S.
		50 +		N > A.S.
	L. LAT BEND	20 - 29	FLEXION	N > A.S.
		40 - 49		N > A.S.
		30 - 50 +	R. AXIAL ROT	N > A.S.
	LAT. BEND	20 - 49	LAT BEND	N > A.S.
	L. AXIAL ROT	40 - 49	FLEXION	N > A.S.
	R. AXIAL ROT	50 +	EXTENSION	N > A.S.
			L. LAT BEND	N > A.S.
ALE	EXTENSION	20 - 50 +	EXTENSION	N > A.S.
	FLEXION		FLEXION	N > A.S.
		20 - 29	R. LAT BEND	N > A.S.
	R. LAT BEND	40 - 49	FLEXION	N > A.S.
	LAT. BEND	20 - 39	LAT. BEND	N > A.S.
	R. AXIAL ROT	30 - 39	R. LAT BEND	N > A.S.
	AXIAL ROT	50 +	AXIAL ROT	N > A.S.

Figure 6.4 was constructed to show how movement in A.S. patients changed with age after allowing for the effect of 'Normal' aging. For example, in the 20 - 29 age group patients obtained 98% of the flexion that would be expected in a 'normal' female subject of the same age group, but had only 84% of the 'normal' male range of flexion. A.S. male and female groups were once again combined but were compared with both the male and female control group. Since axial rotation was not observed to change significantly with age it was not included in this figure.

6.4.4 Usefulness of monitoring Lumbar spine motion

In order to try and determine how useful measuring lumbar spinal motion was in terms of clinical assessment of a patient with ankylosing spondylitis, the percentage of patients in each age group whose range of movement fell below the 'Normal' band range ie. Mean - 2sd, was calculated, Table 6.10.

Figure 6.4

PERCENTAGE OF 'NORMAL' MOTION RETAINED BY A.S. PATIENTS: Determined by age

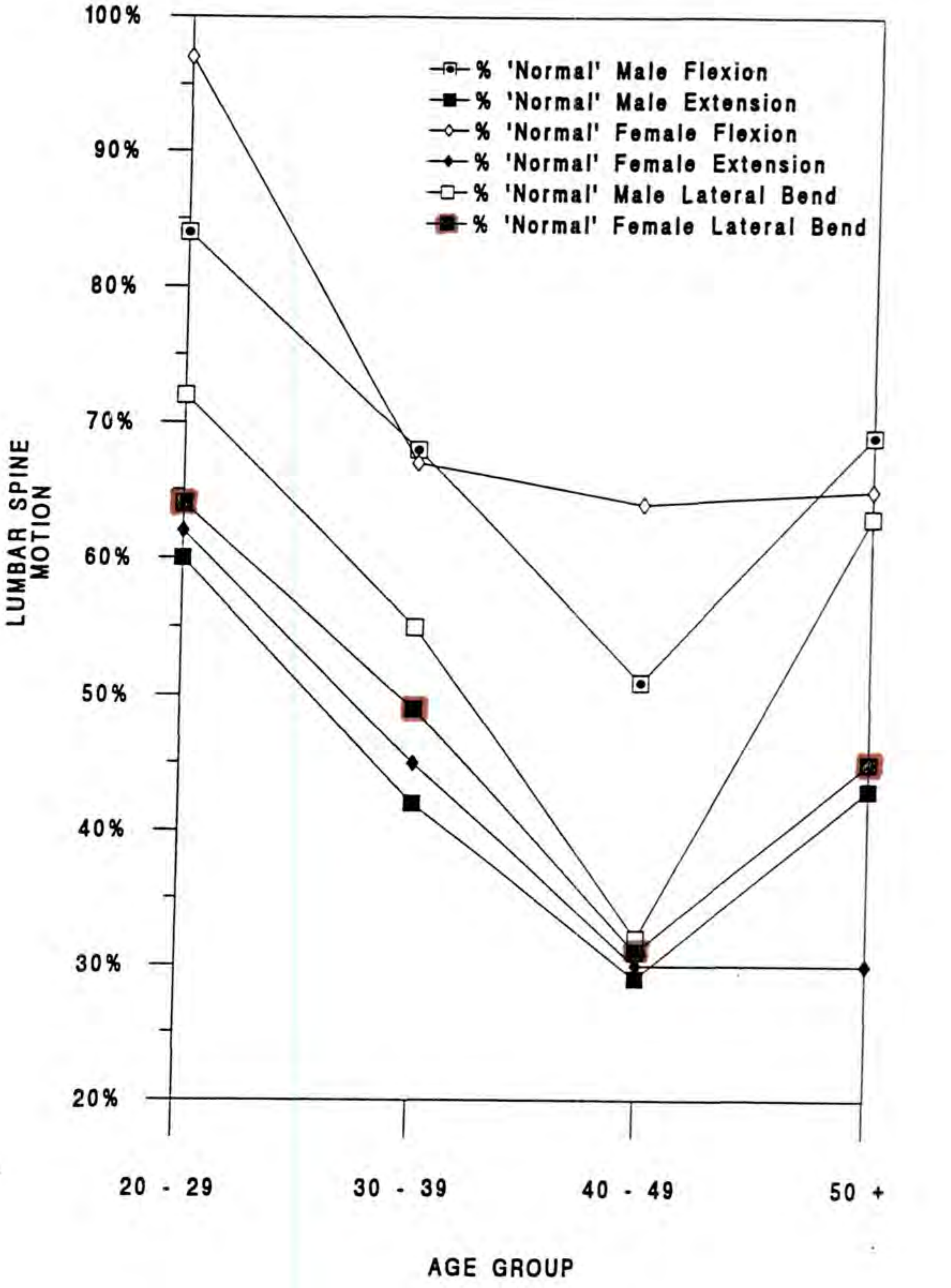


TABLE 6.10

Percentage of patients whose range of movement fell below the 'Normal' band range

AGE GROUP	SEX	EXT.	FLEXION	LAT. BEND	ROTATION
20 - 29	M	29%	43%	50%	29%
	F	33%	33%	33%	0%
	M & F	**29%**	**41%**	**47%**	**24%**
30 - 39	M	59%	56%	59%	6%
	F	46%	54%	54%	15%
	M & F	**56%**	**56%**	**58%**	**9%**
40 - 49	M	50%	79%	71%	13%
	F	50%	29%	71%	7%
	M & F	**50%**	**61%**	**71%**	**10%**
50 +	M	52%	56%	56%	12%
	F	67%	83%	83%	0%
	M + F	**55%**	**61%**	**61%**	**10%**
ALL AGES	M	47%	60%	60%	9%
	F	47%	47%	64%	19%
	M & F	**47%**	**57%**	**61%**	**16%**

The above Table shows that of all the movements axial rotation is the worst clinical indicator and that lateral bend and flexion are the best. Even so, in all groups, and the younger age groups especially, all movements gave a high percentage of false negative results ie. patients who fell within the 'Normal' band range.

6.4.5 Relationship between disease duration, time since diagnosis, time between diagnosis and first symptoms and lumbar mobility

In order to determine whether disease duration, time since diagnosis and the length of time between the two were significant factors when determining maximum ranges of movement regression analysis and correlation coefficients were calculated for the 97 patients for whom disease duration and onset were known. Only a weak negative correlation was observed between disease duration, time since diagnosis and mobility although for the movements of flexion, extension and lateral bend this did reach statistical significance.

The length of time a patient waited before diagnosis after they had first experienced symptoms of the disease was not a significant factor when determining mobility.

MOVEMENT	CORRELATION	SIGNIFICANCE
DURATION		
EXTENSION	-0.363	$P < 0.001$
FLEXION	-0.204	$P < 0.05$
LATERAL BEND	-0.292	$P < 0.005$
AXIAL ROTATION	-0.127	N.S.
DIAGNOSIS		
EXTENSION	-0.308	$P < 0.002$
FLEXION	-0.224	$P < 0.05$
LATERAL BEND	-0.282	$P < 0.005$
AXIAL ROTATION	-0.006	N.S.
DURATION - DIAGNOSIS		
EXTENSION	-0.159	N.S.
FLEXION	-0.038	N.S.
LATERAL BEND	-0.093	N.S.
AXIAL ROTATION	-0.159	N.S.

6.5 DISCUSSION

Moll and Wright (1973) have shown that there can be a large amount of overlap in the range of movement of patients with ankylosing spondylitis and of subjects who are not known to suffer from any form of spinal problem. The results of this study combined with results obtained in Chapter 2 of this thesis confirm this, and show that range of movement can vary enormously from patient to patient.

Moll and Wright also found that there were close relationships between chest expansion and both planes of movement (anterior flexion and extension and lateral flexion) and suggested that for epidemiological studies of ankylosing spondylitis, measurement of only one of the parameters should be sufficient. In this study, axial rotation was also measured and found to be of little clinical use, with 84% of patients exhibiting 'Normal' range of motion. Lateral bend and flexion appeared to give the most useful results, in agreement with Moll and Wright's findings (Moll and Wright 1973), although, in the younger age groups 44 - 59% of patients fell within the 'Normal' flexion range and 42 - 53% fell within the 'Normal' range of lateral bend. When combining all patient groups an overall total of 43% fell within the normal flexion band range, and 39% within the normal lateral bend band range. These results are approximately the same as those of Moll and Wright who gave figures of 38% for flexion and 40% for lateral bend. Such a high percentage of patients falling within the 'Normal' range gives rise to the question of how useful it is to assess a patient in terms of measuring his/her maximum lumbar motion. The 'New York criteria' has in its list of categories that there must be limitation of lumbar spine movement in three-planes (anterior flexion, extension and lateral flexion). This study has shown that a patient will not necessarily have limitation of movement compared with 'Normal' as the normal range and ankylosing spondylitis ranges of movement are so large.

As stated previously in Chapter 2 the normal group in this study may have had some undetected low back problems as they were not able to be radiologically screened. The number of 'false negative' results obtained, however, is favourable with the findings of Moll and Wright (1973) who compared 106 A.S. patients with 237 'Normal' subjects (Moll and Wright 1971, 1972) who had been clinically and radiologically screened and who therefore would have been as 'Normal' a subject group as was possible.

In this study, duration of disease was seen to have a weak correlation with loss of motion. This finding was in contrast with that of Russell and Jackson (1986) who found that loss of motion did not correlate significantly with sacroiliac involvement or with duration of disease, but that it was inversely correlated to apophyseal destruction. Results from Moll and Wright's study (1973), however, showed there was a statistically significant relationship between duration of disease and spinal mobility although their results gave much higher figures than those from this study (lateral flexion corr (r) : -0.51, anterior flexion r: -0.40, extension r: -0.34). The discrepancy between results obtained from Moll and Wright's study and this one could be due either to differences in patients recollection of when symptoms first occurred or to the method by which range of movement was monitored. Unfortunately since the majority of patients had not had recent X-rays taken, and for ethical reasons new ones could not be taken for research purposes, it was impossible to gauge the extent of apophyseal destruction and so compare it with range of movement.

In this study extension and lateral bend for both male and female patients was seen to have become limited more quickly than that of flexion in the youngest age group (Figure 6.4). The rate at which movement limitation occurred after the age of 20 - 29 was, however at a similar rate for flexion, extension and lateral bend. In the 50 + age group percentage loss of motion appeared to be reduced slightly, due to the fact that the rate at which motion was lost in the 'Normal' male and female subject groups increased.

Flexion, extension and lateral bend were all highly correlated which confirms the visual observation that a patient with ankylosing spondylitis has reduction of movement in all three planes. This result also confirms the results of Moll and Wright (1973).

The reason why extension is often observed to become limited more quickly than flexion (Russell and Jackson, 1986; Hart *et al*, 1974; Gran *et al*, 1984) is attributed to destructive apophyseal lesions which could reflect bony invasion by an aggressive pannus (Wilkinson and Bywaters 1958). In extension, facet joint loading is increased, which may cause impingement on the hyperplastic tissue, and therefore cause pain. In flexion the loading on the inflamed synovial joints is reduced and consequently pain relief may well occur. For the movement of lateral bend, facet joint loading would also be increased, and by the same reasoning it follows that we might expect this movement to be reduced more quickly than that of flexion.

In a study by Gran *et al* (1984) radiological spondylitic changes in the lumbar spine were observed more frequently in males than in females. They also found that there was a significant correlation between the degree of sacroiliac arthritis and restriction of lumbar mobility and that it was greater in men than women. This study found no statistical difference in restriction of mobility in either males or females. This could however be due to the small female sample size.

Sixty one percent of patients in this study first noticed disease symptoms between the ages of 20 - 40. This compares with a figure of 70 % of patients in a study conducted by Wilkinson *et al* (1958). A number of studies including work by Calin *et al* (1988), and Will *et al* (1992) suggest that the age of onset of ankylosing spondylitis is increasing. However an editorial, in which the results obtained by Calin were reviewed Fries *et al* (1989), concluded that the findings were entirely due to right and left censoring of the data, and that there was in fact no evidence to support the fact that the age at onset was changing. Differences in age at onset found from this study and that of Wilkinson *et al* (1958) could however be due to some extent to changes in the referral pattern of patients.

One positive finding was that there was no correlation between the length of time a patient waited after having experienced the first symptoms of the disease and the time since they were actually diagnosed (and therefore the time they first started to receive treatment), and loss in spinal mobility. This would imply that patients were able to treat themselves as well before receiving medical treatment, as after. This however is perhaps not surprising as the primary treatment for patients is exercise and the majority of patients seem to find, without being told, that exercise helps relieve both pain and stiffness.

CHAPTER 7

THE EFFECT OF EXERCISE THERAPY ON A.S. PATIENTS IN THE SHORT AND MEDIUM TERM

7.1 INTRODUCTION

The last chapter has shown the Isotrak system to be useful when monitoring movement in patients with ankylosing spondylitis. Since exercise is advised as the main form of treatment for such patients it was considered useful to monitor any effect exercise might have on a group of patients.

Vigorous physical therapy has been recommended as a treatment for ankylosing spondylitis since the mid 1950's (Lenoch *et al*, 1956) and it is now considered an essential part of treatment (Simon and Blotman, 1981; Hyde, 1980).

Physical therapy is highly recommended to patients with many hospitals offering exercise programmes designed to meet individual patients needs. The National Ankylosing Spondylitis Society produces literature and video cassettes on exercise and its purpose in the treatment of ankylosing spondylitis.

The aims of physical therapy are three-fold. The long term goal for the patient is to try to maintain a good posture with the primary aim being to avoid stiffening in a flexed position. The maintenance of good posture is helped by exercises designed to 'build up muscle groups that oppose the direction of potential deformity and thus strengthen extensor rather than flexor muscle groups' (Calabro *et al*, 1986). Improvement of spinal flexibility in both the short and long term is also of importance.

In a study by Kraag *et al* (1990) fifty-three A.S. patients were monitored, 26 of whom received physiotherapy and disease education over a four month period, and 27 of whom acted as controls and received no treatment. The results showed that patients receiving treatment obtained a greater improvement in fingertip-to-floor distance and in function than the controls and therefore concluded that physiotherapy with disease education was effective in the treatment of patients with A.S.

Work conducted at the Royal National Hospital for Rheumatic Diseases in Bath suggests that participation of patients in three week intensive physiotherapy sessions can help to increase chest expansion, fingertip-to-floor distance, height and occiput to wall distance over the three week period and that the increases in movement can be maintained over a five year period (Roberts *et al*, 1989).

Despite this however, the number of patients able to attend intensive three week sessions is limited and it was not possible to locate any references to studies undertaken to try to assess whether patients attending sessions for only one to two hours per week could receive any benefit in terms of increasing or simply maintaining their range of spinal motion.

Measurements of spinal motion made using the fingertips-to-floor method are prone to misinterpretation if patients are not monitored carefully. It is possible for a patient with a fused lumbar spine to bend a considerable distance forward purely by the fact that they have good hip movement and it is therefore possible that measurements obtained pre- and post-therapy in which increased spinal motion is observed using this method have infact only recorded an increase in hip movement.

The long term beneficial effect for the patient is obviously also of importance as well as an assessment of whether a specified exercise regime is better than any other. However since this section of the study was conducted over a relatively short time interval, and the activities of each group did not alter significantly from one week to the next, these two parameters were unable to be evaluated. The aim was therefore to study the range of movement in the lumbar spine and to try to assess whether physiotherapy could have the effect of increasing or simply maintaining range of movement both in the short term (ie. immediately after exercise) and over a period of up to two years.

This study assessed the effect of exercise on 3 groups of patients. One set attended a vigorous exercise session once per week, another attended a more moderate exercise session once per week and a final group did not participate in any formal exercise sessions at all.

7.2 MATERIALS AND METHODS

In this section three studies were undertaken:

7.2.1 The Short-term effect of exercise

The short-term effects of exercise were determined by monitoring two groups of volunteers with ankylosing spondylitis. Details for all groups studied are given in Table 7.1.

In the previous Chapter it was seen that measuring axial rotation appeared to be of little value, and for this reason it was not measured in this chapter. Flexion, extension and lateral bend measurements given in Table 7.1 are the median measurements obtained when testing patients prior to exercise.

As well as having lumbar spine involvement some patients from all groups suffered from peripheral joint involvement (mainly hip and ankle) as well as problems in the cervical spine.

Patients from Groups A and B were patients who regularly attended exercise sessions at their local hospitals. A high percentage of the group who attended sessions at hospital A (including those who were not regular attendants and who consequently were not used for the purposes of this study), had quite limited ranges of movement. Consequently the activities of Group A were taken at a slower, more gentle pace than those of Group B and for this reason they have been referred to as the moderate exercise group.

Patients from both groups A and B attended an exercise session once per week for an average of one and a half hours. Group A began the session with approximately 15 minutes of warm up exercises after which various bending and stretching exercises were performed. Floor exercises followed after which patients were given the option of using the hydrotherapy pool or of continuing with their own exercises using equipment from the department.

TABLE 7.1

PATIENT DETAILS

DETAILS	EXERCISING GROUPS		NON-EXERCISING GROUP
	GROUP A	GROUP B	
NO. TESTED FEMALE	6	7	5
MALE	11	19	9
MEAN AGE (SD, SE)	43.6 (10.7,3.1)	37.8 (9.1,2.3)	52.4 (11.1,3.4)
MEDIAN AGE	39.5	35.5	52.0
AGE RANGE	33 - 68	22 - 55	35 - 72
TIME SINCE DIAGNOSED	11 ± 10 yrs	10 ± 8 yrs*	11 ± 11 yrs **
TIME SINCE SYMPTOM ONSET	22 ± 12 yrs	13 ± 8 yrs+	25 ± 11 yrs ++
HEIGHT (m) MEAN (SD,SE)	1.69 (0.1,0.0)	1.67 (0.1,0.0)	1.67 (0.1,0.0)
MASS (Kg) MEAN (SD,SE)	66.4 (9.8,2.5)	65.1 (9.3,2.0)	69.8 (12.4,3.7)
FLEXION (°) (range)	42 (13 - 71)	48 (12 - 76)	42 (21 - 66)
EXT. (°) (range)	6 (3 - 29)	8 (1 - 33)	9 (2 - 32)
LAT.BEND (°) (range)	24 (4 - 65)	32 (4 - 65)	23 (3 - 56)

N.B.

* :- Details known for only 22 of the patients
\+ :- Details known for only 17 of the patients
** :- Details known for only 12 of the patients
\+ + :- Details known for only 6 of the patients

The activities of Group B followed the format of those of Group A although exercises were performed more vigorously with the warm up session taking the form of a "high powered" aerobics session. The final part of the session took the form of either floor exercises concentrating on stretching muscles and ligaments, or circuit training.

The non-exercising group consisted of patients who, due to work commitments or difficulty in getting to sessions did not participate in any regular exercise activities either at home or elsewhere.

Patients attending exercise sessions were tested with the Isotrak before and immediately after each exercise session by attaching the system by the method described in Chapter 1. They were asked to perform the movements of maximum voluntary flexion, extension and lateral bend. Although patients were asked to make each movement as pure as possible the tendency was for those with only a small range of movement to try and flex, bend or twist until they felt they had achieved a larger range. This was discouraged as much as possible since although it should not have had any effect on the values obtained for the maximum range of movement in the primary plane it would show up on the readings obtained in the secondary planes of motion.

Once patients had completed all the movements the sensor and source were removed and the position of the sensor on the skin was marked with indelible ink. This was carried out in order that its position could be accurately relocated when testing the patient after completion of their exercises.

7.2.2 The effect of exercise measured over a period of 2 - 6 months

In this study the effect of exercise over a longer time interval of 2 to 6 months was monitored. This was carried out on the same volunteers although numbers in the exercise groups were less than those tested originally (10 in Group A, 19 in group B) as during this time some patients stopped attending sessions and others due to the fact that they did not attend regularly were excluded. Reasons for irregular attendance included work commitments and transportation difficulties.

To try to determine whether a change in movement was an actual long term increase or decrease, and not due simply to a weekly fluctuation in movement, 11 patients (3 females and 8 males) from both groups A and B were monitored each week for 4 - 5 weeks and the average fluctuation in values obtained for maximum flexion, extension and lateral bend. Initial ranges of motion for patients varied from severely restricted to 'normal'. As well as being a measure of the fluctuation in movement the values obtained would also incorporate any effect due to sensor displacement. The likelihood of sensor misplacement however was considered to be minimal as patients from all groups were quite thin and the spinous processes relatively easy to identify.

7.2.3 Movement measured over a one - two year time interval

In order to assess how patients movement varied over a period of up to two years and in order to assess whether or not there were any seasonal variations patients were monitored at regular intervals over a 1 - 2 year time period.

Sixteen patients were monitored. Eight of whom attended the vigorous exercise group, and eight who were unable to participate in any formal exercise sessions.

The non-exercising group were monitored every month over a period of 1 year whilst those who attended regular exercise sessions were monitored at regular intervals over a slightly longer time period.

Although on an individual basis subjects were able to have repeat measurements obtained at the same time of day, it was not possible to obtain readings at the same time on a group basis. It was also not possible to monitor all patients on the same day due to time constraints, and the fact that some patients were only able to attend on certain days.

7.3 ANALYSIS OF DATA

As stated previously the results obtained from the Isotrak system for the mean maximum range of motion are higher than might be expected from radiography since errors are introduced by skin movement which causes the sensor to move relative to the underlying vertebrae. In the three studies conducted however this error should be consistent each time a subject was re-tested and therefore 'true' changes in motion should be observed.

Traces were produced for each of the patients showing their pattern of movement. Typical traces are shown in figures 7.1 and 7.2. Due to the fact that patients sometimes had difficulty in achieving the whole movement in exactly 10 seconds the data were normalised so that maximum values were obtained at 2.5 seconds and 7.5 seconds with

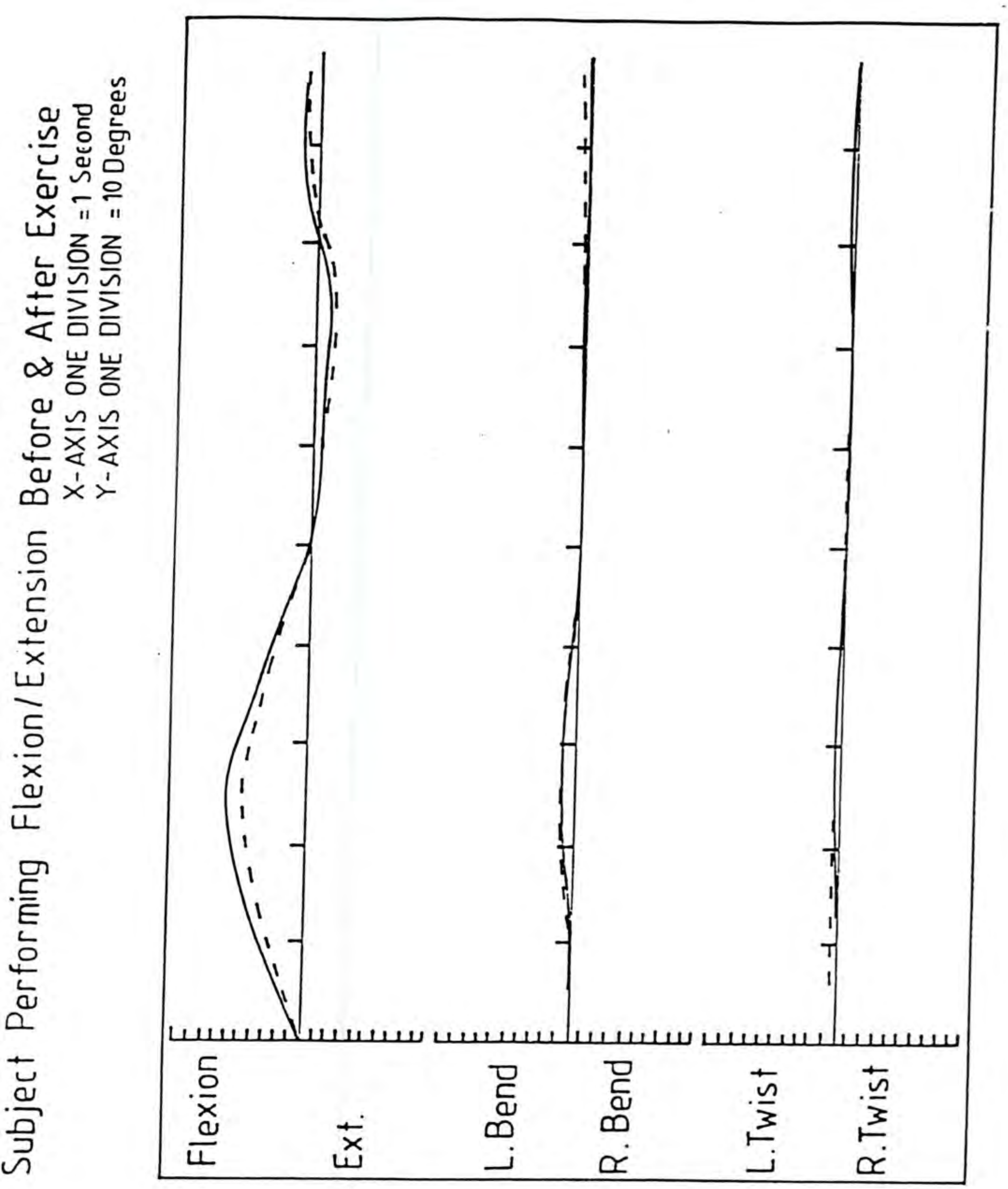


Figure 7.1

- - - - - - - - : Before exercise, ———————— : After exercise

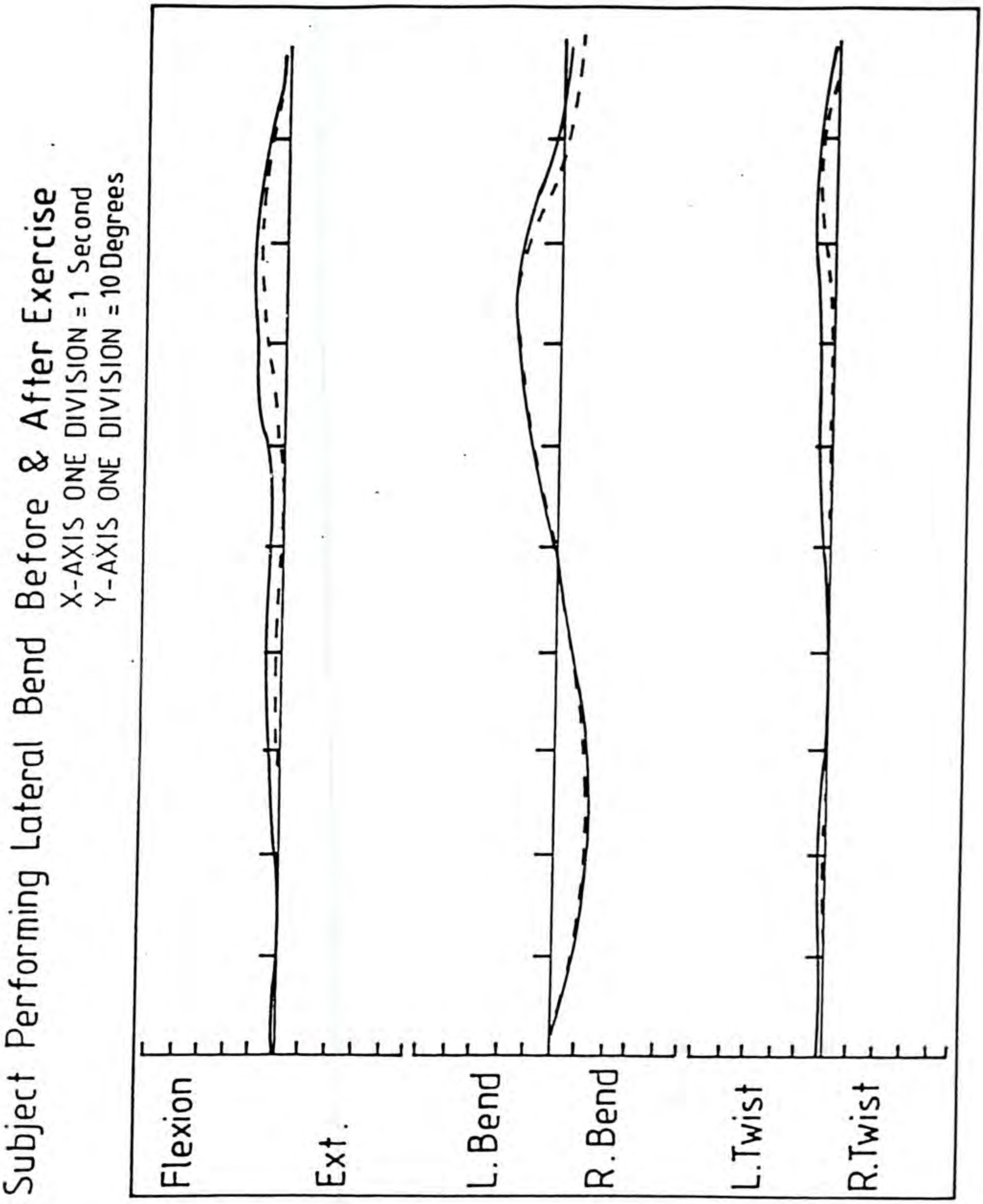


Figure 7.2

- - - - - - - - : Before exercise, ——— : After exercise the patient going through the neutral ie. upright stance position at 5 seconds this ensured that traces for different patients could be easily superimposed and analysed.

Data were analysed using Wilcoxon test statistics as the data were non-parametric.

Flexion and extension were again treated as separate movements whilst for bending, the movements to the left and right were summed to give one value as no significant differences between movements to the left and right were observed.

7.4 RESULTS

Applying the Wilcoxon rank sum test to all groups showed there were no significant differences between either groups A and B or the non-exercising group, for both the study on the short term-effect of exercise, and the study on the effect of exercise measured over a 2 - 6 month time period.

For the study in which the effect over a 1 - 2 year time interval was looked at, the only significant difference between groups at presentation was for the median age (Exercising: median 35.5 (range 22 - 48), Non-exercising: median 51.1 (range 40 - 63). Although range of lateral bending for the non-exercising group was less than that of the exercising group (median: 21^{o} compared with 32^{o}) this did not reach statistical significance.

7.4.1 Effect of natural weekly fluctuation on range of movement

The results obtained for the 11 subjects tested over the 4-5 week period showed an average mean fluctuation of ± 6 degrees (range 2 - 11^{o}) for flexion, ± 1 degree (range 0 - 3^{o}) for extension and ± 3 degrees (range 1 - 5^{o}) for lateral bend. Mean fluctuation did not appear to be dependent on the mobility of the patient (ie. a person with severely restricted motion showed as great a fluctuation in movement as someone with 'normal' range of movement).

7.4.2 Pre- and Post- single exercise session

Patients from both groups were tested at the same time of day in order to eliminate diurnal effects. Changes in the mean maximum range of movement obtained before and after exercise for the movements of flexion, extension and lateral bend are shown in figures 7.3 - 7.5. The results showed there to be a large amount of variability between patients and whilst some patients did exhibit quite large increases in movement, shown as positive on the y-axis, others appeared to have experienced a reduction in movement, shown as negative on the y-axis. Others showed no change at all.

The majority of patients were re-tested before and immediately after exercise on more than one occasion in order that the overall effect of the exercise sessions could be calculated. For these patients the average change in movement was recorded.

When applying Wilcoxon test statistics to the results no significant differences were found for any of the movements performed in the

DIFFERENCE BETWEEN READINGS OBTAINED
BEFORE AND AFTER AN EXERCISE SESSION

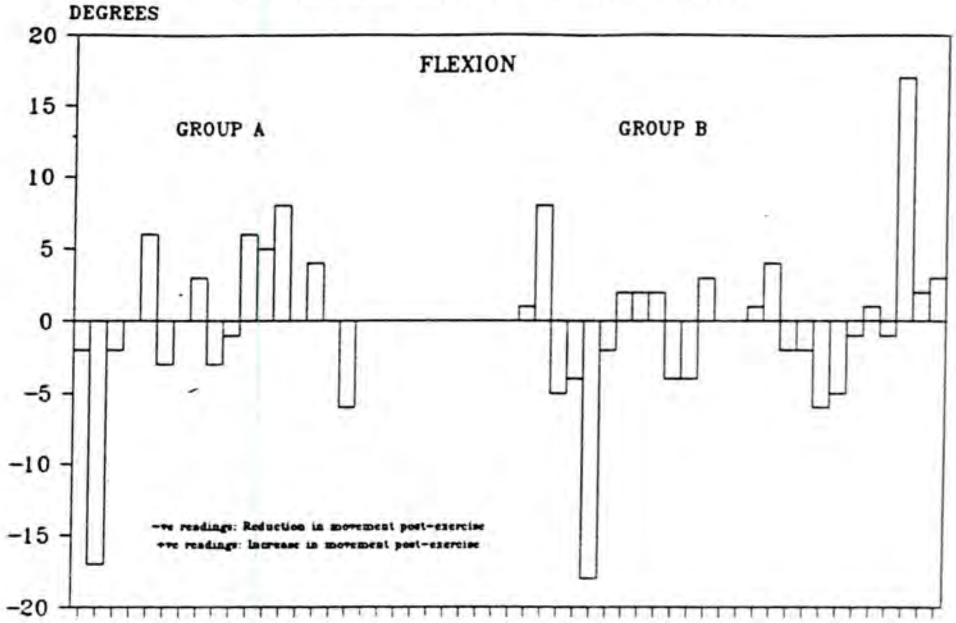


Figure 7.3

DIFFERENCE BETWEEN READINGS OBTAINED
BEFORE AND AFTER AN EXERCISE SESSION

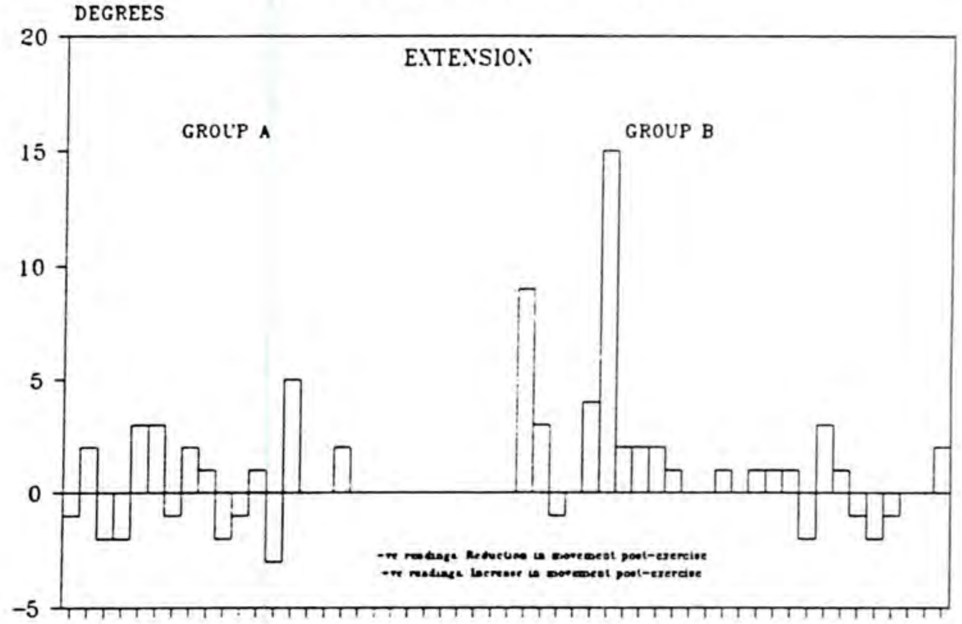


FIGURE 7.4

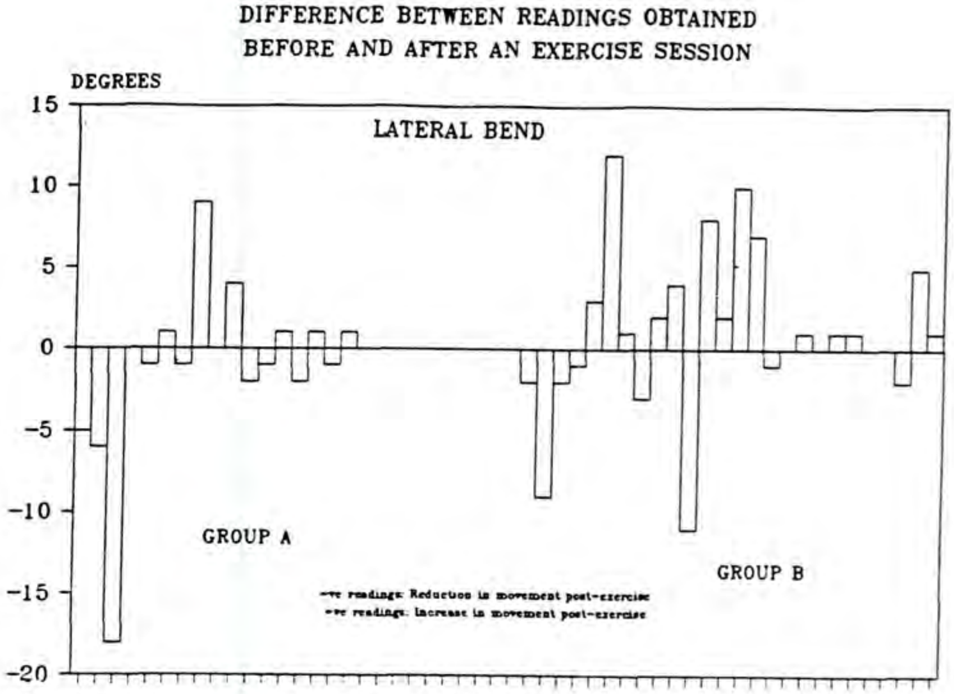


FIGURE 7.5

moderate exercise group. For the vigorous group no significant changes were observed for flexion or lateral bend. When looking at the change in extension before and immediately after exercise however, a small but statistically significant increase in movement after exercise was observed (median increase = 1 degree).

7.4.3 Two - six month follow-up

Results for all groups tested are shown in figures 7.6 and 7.7 which show the median changes (and 95% confidence interval limits) after an elapsed period of 2 - 3 months and 5 - 6 months). Once again a lot of variability in the overall change in range of motion over time between patients was observed. When applying Wilcoxon statistics no significant reduction in any of the movements for any of the groups was observed

CHANGE IN RANGE OF MOVEMENT AFTER 2 - 3 MONTHS

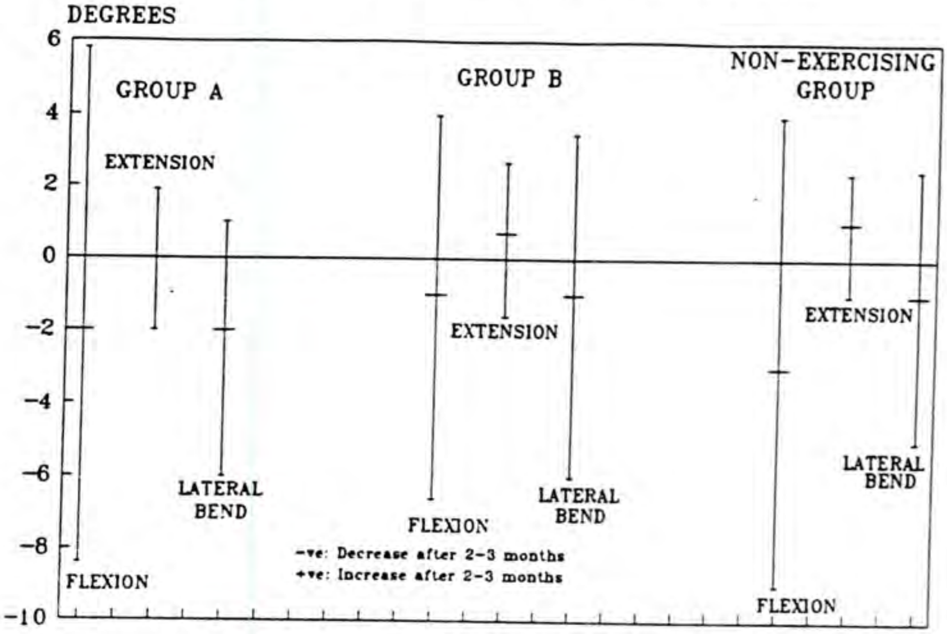


FIGURE 7.6

CHANGE IN RANGE OF MOVEMENT AFTER 5 - 6 MONTHS

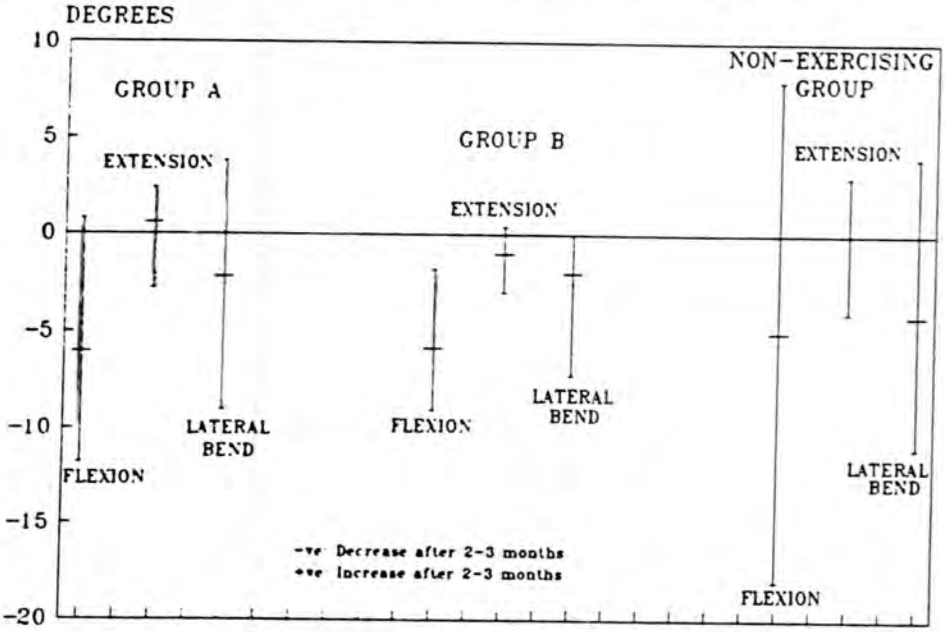


FIGURE 7.7

over a 2 - 3 month time interval.

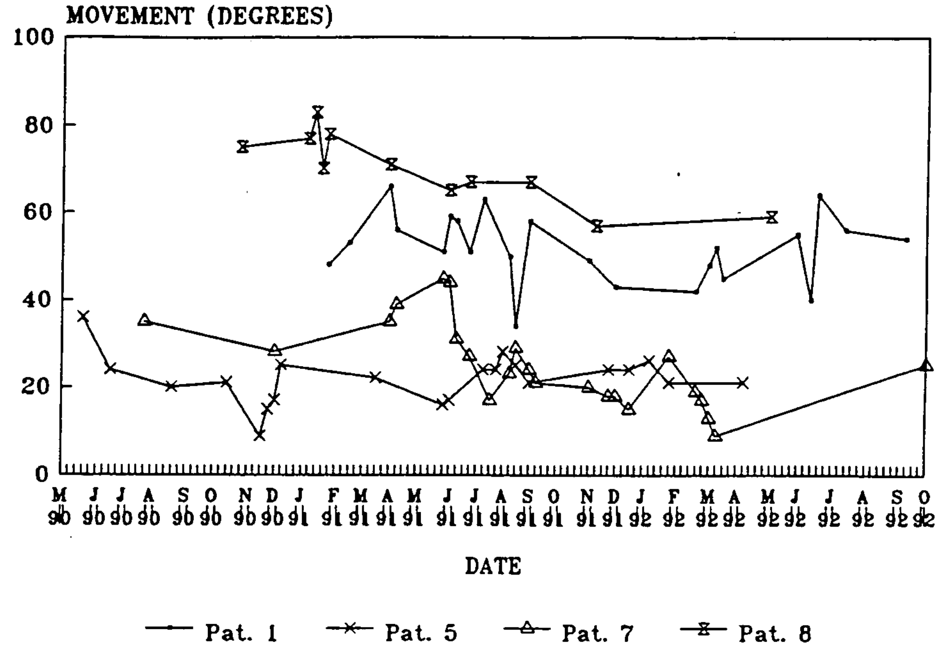
Over a 5 - 6 month period a significant decrease in flexion and lateral bend for patients in the vigorous exercise group was observed (median decrease = -5.5 degrees flexion, -2 degrees lateral bend). No significant changes were observed in any of the other groups.

When combining groups, a significant overall loss of movement for flexion and lateral bend was observed (median = -5.5 degrees flexion, -3 degrees lateral bend). And the general trend appeared to be for flexion and lateral bend to decrease more rapidly over this time interval than extension.

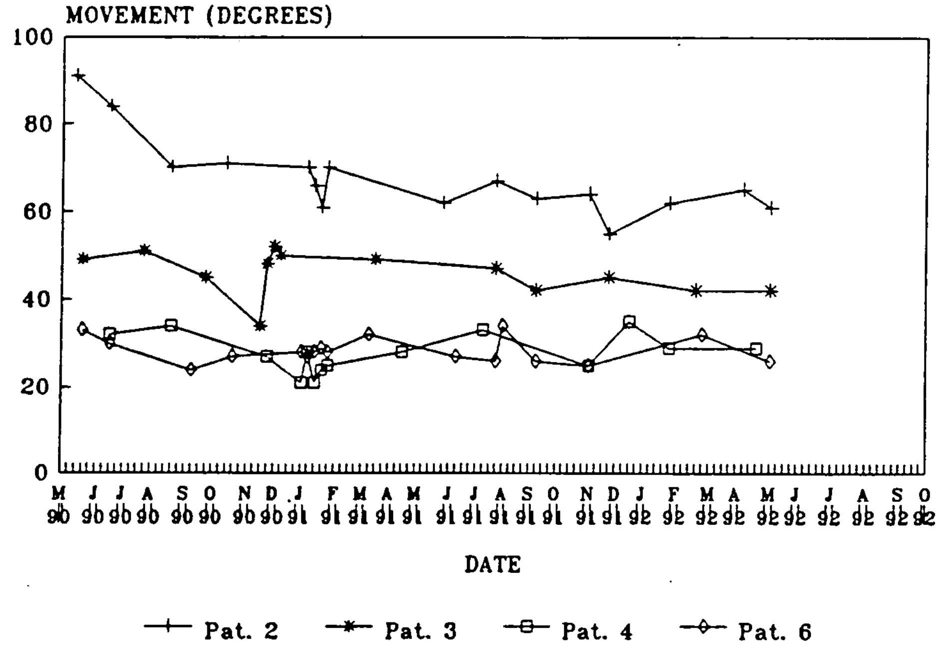
7.4.4 One - two year follow-up

In order to try and determine whether there were any common trends observed between patients over a 1 - 2 year time period figures 7.8 - 7.13 were constructed. These figures show the mean maximum readings obtained for individual patients, and the variation between individuals can be seen to be considerable. N.B. The reason for splitting the patient groups into groups of four was in order to be able to see trends more clearly.

The patients appeared to show unique changes in movement range, with no apparent overall reduction in movement at any particular time of year. Since it was not possible to obtain readings for all patients on the same day, or even the same week, it was considered inappropriate to combine all patient data. Instead regression analysis was conducted on individual patients results in order to see whether there were any general trends



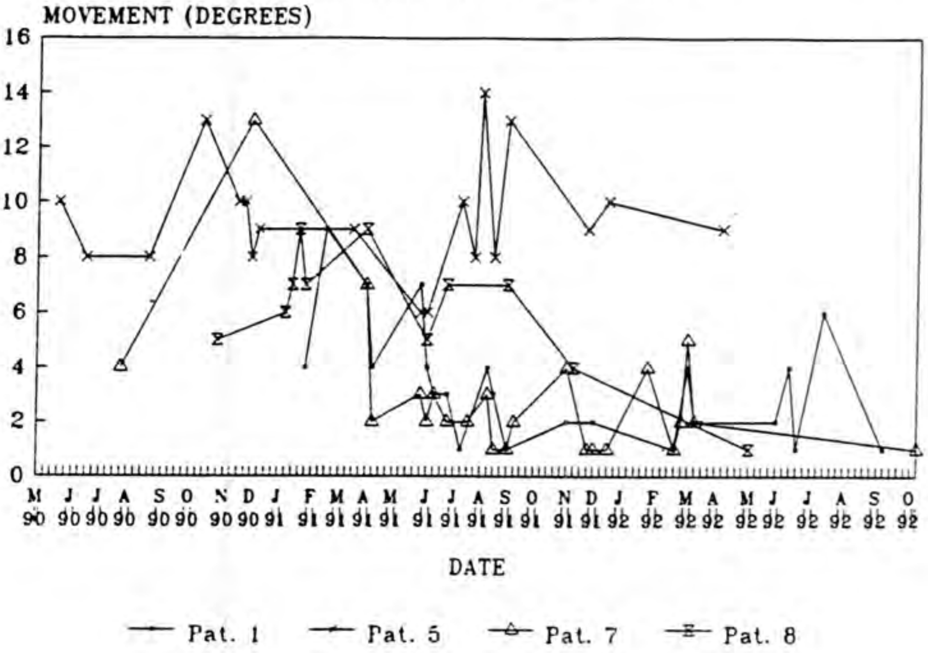
CHANGE IN RANGE OF FLEXION MEASURED OVER A 1 – 2 YEAR TIME INTERVAL: EXERCISING PATIENTS



CHANGE IN RANGE OF FLEXION MEASURED OVER A 1 – 2 YEAR TIME INTERVAL: EXERCISING PATIENTS

FIGURE 7.8

CHANGE IN RANGE OF EXTENSION MEASURED OVER A 1 - 2 YEAR TIME INTERVAL: EXERCISING PATIENTS



CHANGE IN RANGE OF EXTENSION MEASURED OVER A 1 - 2 YEAR TIME INTERVAL: EXERCISING PATIENTS

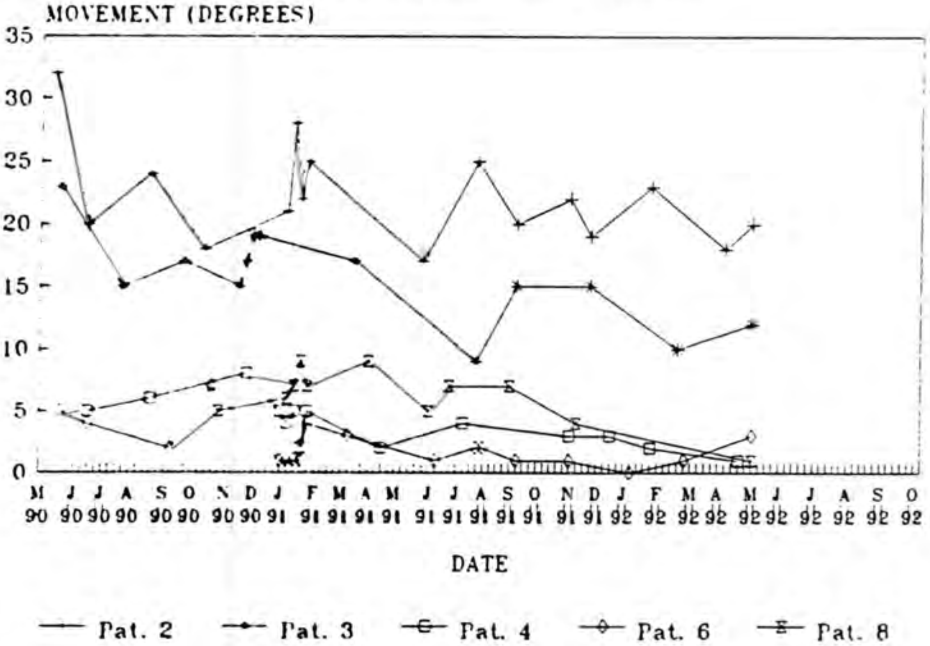
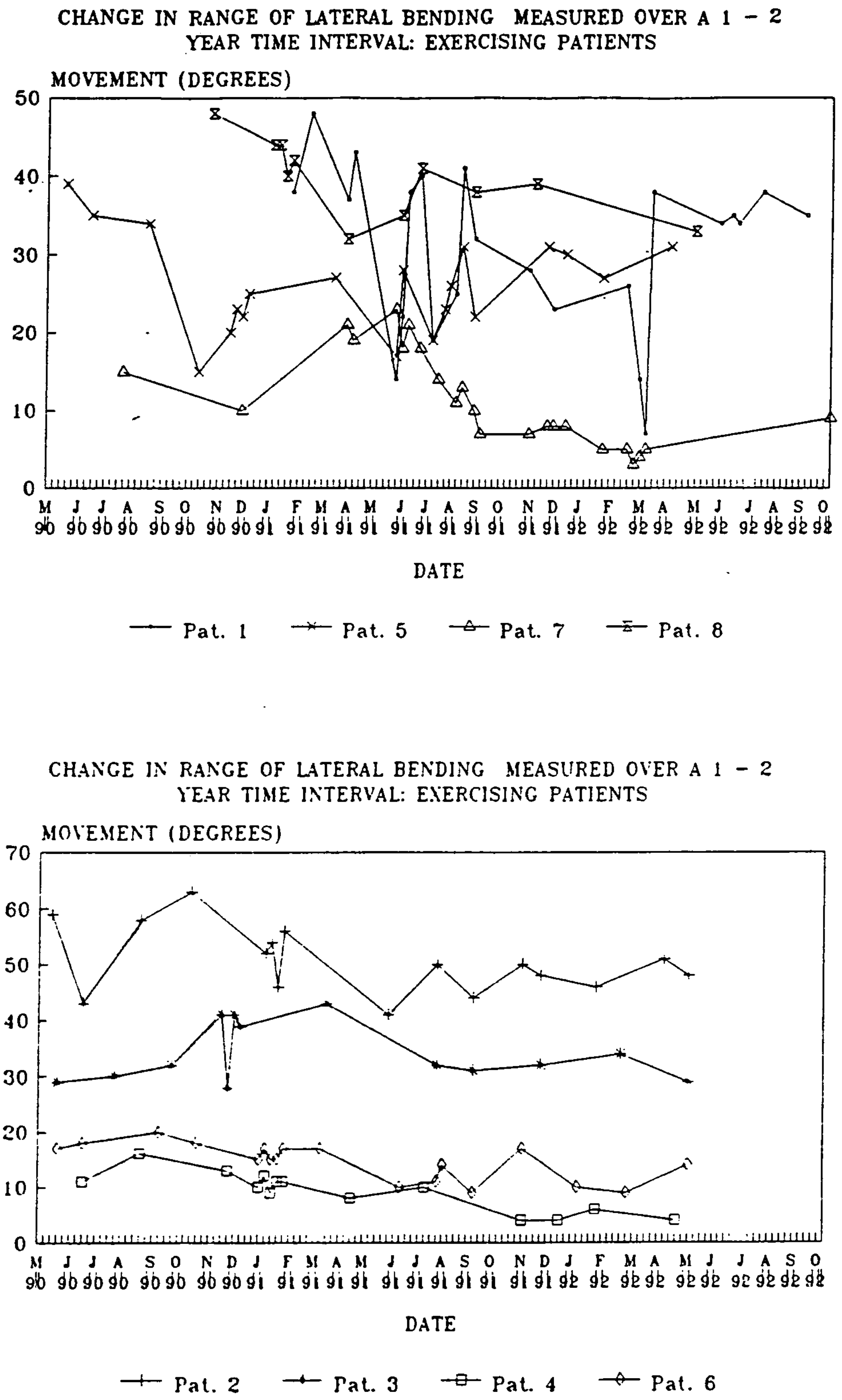


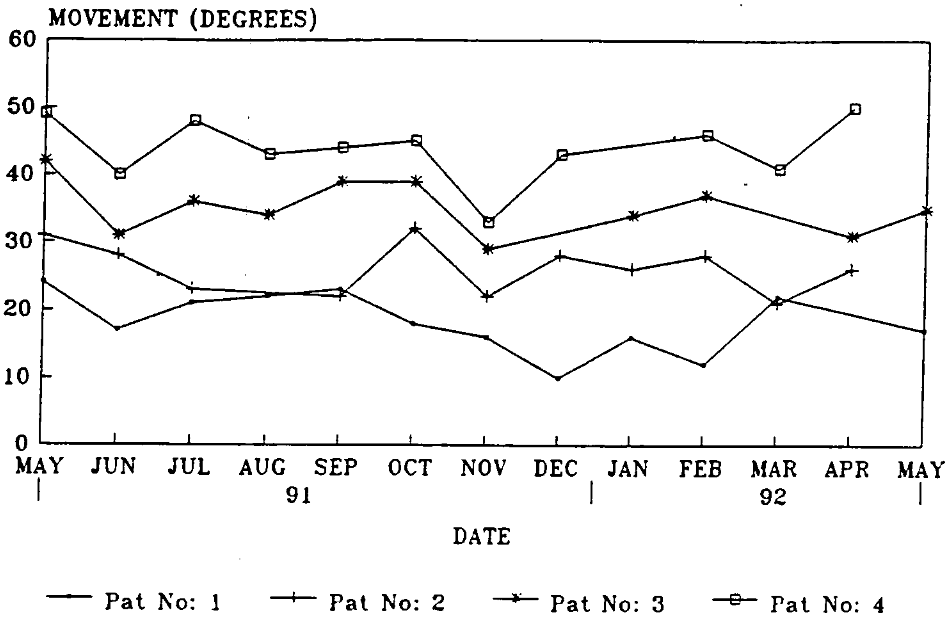
FIGURE 7.9



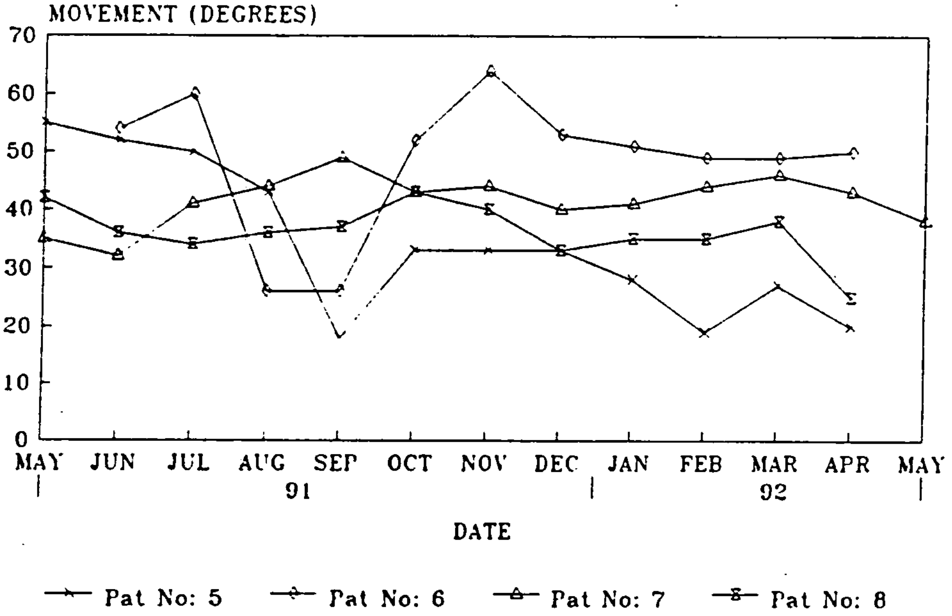
CHANGE IN RANGE OF LATERAL BENDING MEASURED OVER A 1 – 2 YEAR TIME INTERVAL: EXERCISING PATIENTS

CHANGE IN RANGE OF LATERAL BENDING MEASURED OVER A 1 – 2 YEAR TIME INTERVAL: EXERCISING PATIENTS

FIGURE 7.10



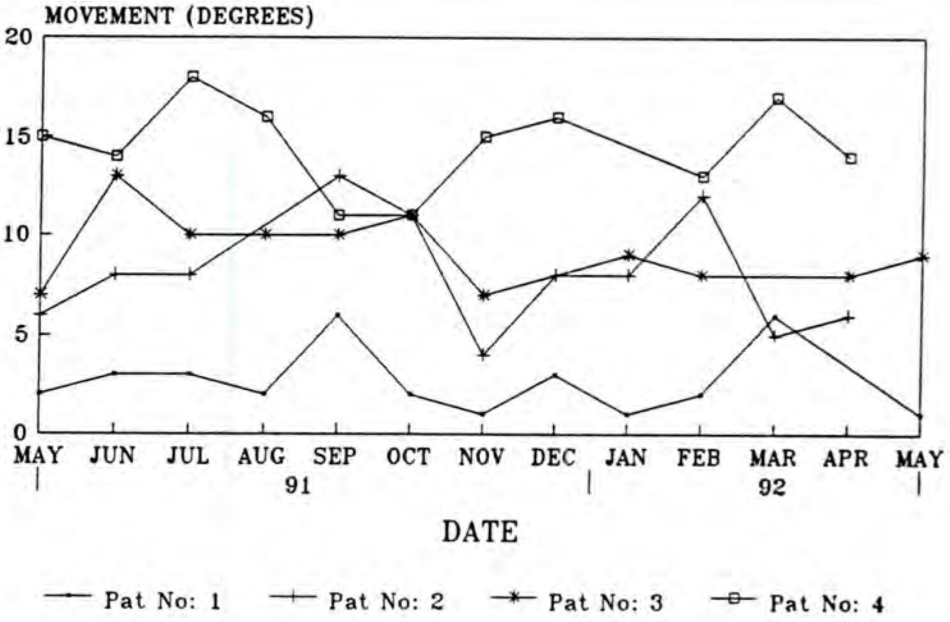
CHANGE IN RANGE OF FLEXION MEASURED OVER A 1 YEAR TIME INTERVAL: NON-EXERCISING PATIENTS



CHANGE IN RANGE OF FLEXION MEASURED OVER A 1 YEAR TIME INTERVAL: NON-EXERCISING PATIENTS

FIGURE 7.11

CHANGE IN RANGE OF EXTENSION MEASURED OVER A 1 YEAR TIME INTERVAL: NON-EXERCISING PATIENTS



CHANGE IN RANGE OF EXTENSION MEASURED OVER A 1 YEAR TIME INTERVAL: NON-EXERCISING PATIENTS

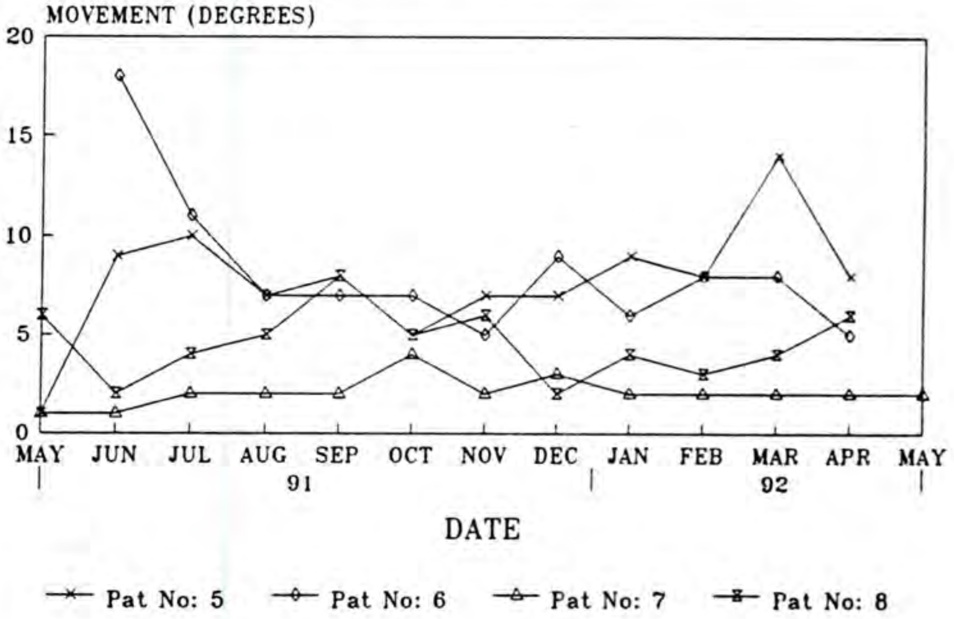
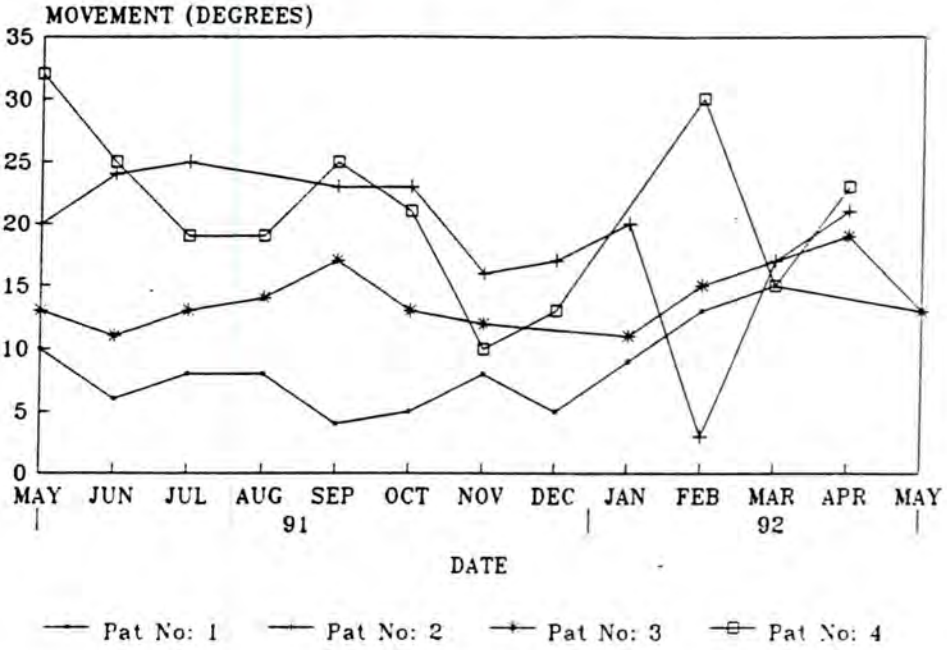


FIGURE 7.12

CHANGE IN RANGE OF LATERAL BENDING MEASURED OVER A 1 YEAR TIME INTERVAL: NON-EXERCISING PATIENTS



CHANGE IN RANGE OF LATERAL BENDING MEASURED OVER A 1 YEAR TIME INTERVAL: NON-EXERCISING PATIENTS

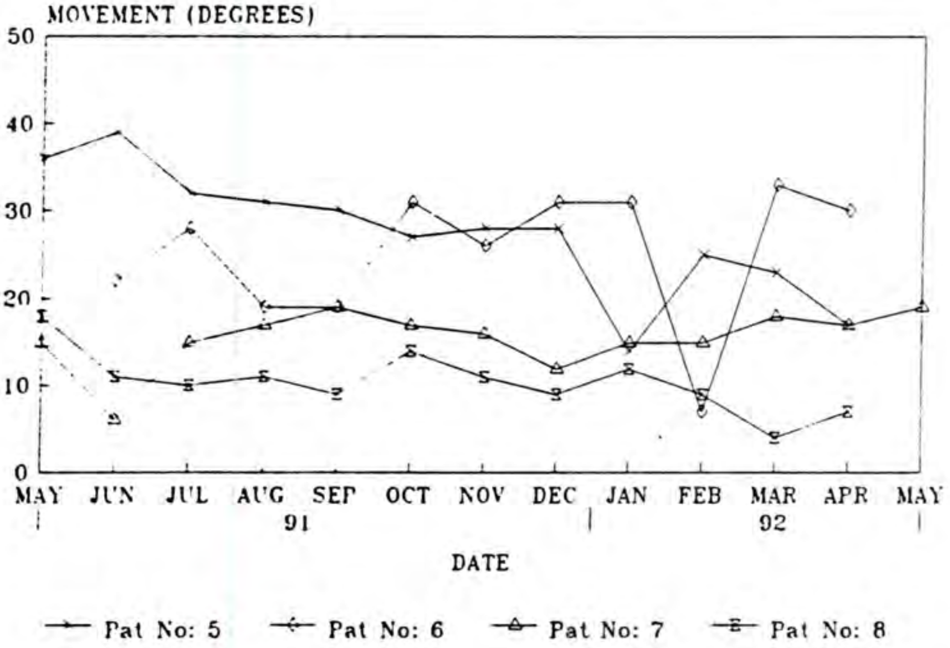


FIGURE 7.13

over the time period. The results of patients who showed significant changes in movement are given in Table 7.2.

TABLE 7.2

Significant changes in range of movement observed over a one - two year time period

Movement	Subject (Ex./ Non-ex.)	Regression Equation (Measurements in degrees)
Flexion	2 (Exercise)	Flex = 78.6 - 0.290 x Week
	7 (Exercise)	Flex = 42.4 - 0.248 x Week
	5 (Non-exercise)	Flex = 53.7 - 0.750 x Week
	8 (Exercise)	Flex = 85.9 - 0.290 x Week
Extension	1 (Exercise)	Ext = 6.47 - 0.04 x Week
	3 (Exercise)	Ext = 19.8 - 0.09 x Week
	3 (Non-exercise)	Ext = 11.2 - 0.08 x Week
	4 (Exercise)	Ext = 6.33 - 0.09 x Week
	6 (Exercise)	Ext = 3.79 - 0.03 x Week
	6 (Non-exercise)	Ext = 13.0 - 0.17 x Week
	7 (Exercise)	Ext = 6.65 - 0.05 x Week
	8 (Exercise)	Ext = 9.69 - 0.07 x Week
Lateral Bend	1 (Non-exercise)	Lat. Bend = 5.08 + 0.544 x Week
	4 (Exercise)	Lat. Bend = 14.9 - 0.110 x Week
	5 (Non-exercise)	Lat. Bend = 38.7 - 0.430 x Week
	6 (Exercise)	Lat. Bend = 18.8 - 0.081 x Week
	7 (Exercise)	Lat. Bend = 23.0 - 0.160 x Week
	7 (Non-exercise)	Lat. Bend = 14.7 - 0.165 x Week
	8 (Exercise)	Lat. Bend = 47.4 - 0.140 x Week
	8 (Non-exercise)	Lat. Bend = 19.4 - 0.201 x Week

7.5 DISCUSSION

The results obtained when comparing data immediately pre- and post-exercise showed a significant overall increase post-exercise for extension for patients in Group B (the more vigorous of the two exercise groups). No overall changes were observed for the moderate exercise group (Group A) or for the non-exercising group for any movement.

Although the increase in the range of maximum extension immediately post-exercise for Group B was statistically significant its magnitude makes it unlikely to be of any clinical importance.

The results suggest that vigorous exercise can have the 'immediate' post-exercise effect of improving the range of movement for a person with ankylosing spondylitis and that this improvement is primarily observed in extension.

Group B (including those not participating in this study) were of a younger age group than those in Group A (again including those not participating in this study), and this made it easier for more vigorous exercises to be carried out. It is also possible that because of this those members with less movement than their counterparts were given more incentive to try and " keep up" with the other members of the group and consequently tried harder than they might otherwise have done.

The general trend was for range of movement to decrease slowly over a period of up to two years. The presence or absence of exercise did not appear to affect the rate at which loss of range of movement occurred.

The importance of exercise is stressed to patients with A.S. and consequently it was difficult to find a non-exercising control group to monitor. Some of the non-exercising patients studied, although not able to attend regular exercise sessions did exercise eg. swimming, on a non-regular basis. All those monitored in this group helped with housework, regularly walked short distances, and helped with all the usual household activities such as shopping, vacuuming etc. All these activities although not strictly classified as formal exercise are in themselves forms of exercise and in doing them patients would in fact be stretching, bending and lifting. It is possible therefore that the true effect of exercise as regards maintenance of range of lumbar movement was obscured.

Also, although initial ranges of movement in all 3 groups were not significantly different the non-exercising group was of a generally older age group than the two exercising groups, and it is possible therefore that the disease was more established and that deterioration over such a short time interval might not expect to be seen.

In order to determine the full long term effect of exercise on patients other parameters such as the effect on chest expansion, hip movement etc. would need to be looked at in conjunction with measurements of lumbar spinal motion changes over a number of years.

This study was limited in that it was only conducted over a relatively short period of time with a relatively small number of patients. It does show however that the progression of A.S. is generally slow. Against that the loss was not dependent on the initial age of the subject which implies steady loss which appears to be one of the conclusions drawn in Chapter 6 (Figure 6.4).

The results from the last part of this study appear to confirm the findings of a recent study by Goodacre *et al* (1991) in which variation of disease activity was measured in 22 patients over a one year time period. In Goodacres study it was observed that the profiles of disease activity were 'virtually unique' for each patient, with individual patients having periods of exacerbation and remission. It was also found that there was no significant difference in the number of patients experiencing active disease at any particular time of the year.

It was not possible within the confines of this study to obtain measurements of other parameters such as increase in disease activity, and so the fluctuations in range of movement were unable to be correlated with any such changes. No obvious change in range of motion was observed in patients depending on the time of year when tested although the period over which subjects were tested was quite mild both in the summer and winter months, and so any change due to increasing or decreasing temperature would be hard to detect.

This study emphasises the importance of regularly monitoring patients, as readings obtained annually, as is common in many clinics, will not be able to take account of fluctuations in movement and will be liable therefore, to give misleading results unless they are firstly interpreted against a knowledge of the normal 'random' fluctuation in movement.

It appears that patients with ankylosing spondylitis make a small but steady loss of movement despite regular weekly exercise sessions. This contrasts with the gains showed in in-patient studies (Wordsworth *et al*, 1984) and also the previous data from the armed forces (Winn Parry, 1980). This raises two questions. Is it possible within the constraints of civilian life, to generate sufficient vigour and regularity of exercise to enable maintenance of movement?. Alternatively, should our everyday practice include intermittent periods of intensive treatment, possibly as an in-patient, in order to gain movement.

CHAPTER 8

CHANGE IN RANGE OF MOVEMENT MEASURED OVER A 12 HOUR PERIOD - A.S. PATIENTS

8.1 INTRODUCTION

One characteristic of ankylosing spondylitis is early morning stiffness. 'Recurrent back pain is often nocturnal, and of varying intensity ... as is early morning stiffness that is characteristically relieved by activity' (Calabro *et al*, 1986).

As stated by Rhind *et al* (1987) the term stiffness appears to mean different things to different people. In Rhind's study, 100 patients with rheumatoid arthritis were monitored in order to investigate amongst other things a) the patients' definition of stiffness with and without the aid of descriptive words and b) their ability to report the severity of their symptom verbally and with the aid of rating scales. The results showed that patients most frequently chose the descriptor 'limited movement' followed by 'painful'. Although they were able to assess the severity of stiffness their definition of the word was ambiguous. The conclusions were that patients who claimed to be stiff were equally likely to be referring to pain, limited movement or a combination of the two. In this study patients with ankylosing spondylitis were monitored, none of whom were currently experiencing a flare up in disease activity. When asking patients to fill in stiffness rating forms in this study, stiffness was defined as being limitation of movement, with patients who complained of stiffness being those who were unable to move as far as they would normally be able to move. As previously stated the patients perception of stiffness may also have included an element due to pain.

As seen in Chapter 5, the maximum range of movement in 'Normal' subjects varied over a 12 hour period even though subjects remained recumbent between tests. The aim of this chapter was to try to assess whether range of movement altered significantly over a 12 hour period for a small group of A.S. patients, by monitoring them immediately after rising and prior to going to bed. Ideally it would have been useful to have monitored patients over a 24 hour period since, as previously stated, back pain is often nocturnal, and we might therefore expect to see the greatest variations in movement during the night. However due to lack of facilities it was not possible to monitor patients over a 24 hour period. We might still expect to observe variations in mobility shortly after a patient arose in the morning however, since this is the time when a large number of patients complain of feeling the most stiff.

8.2 MATERIALS AND METHOD

In this study three patients volunteered to be monitored once per hour over a 12 hour period. As well as having their range of motion monitored patients were asked to complete three visual analogue pain and stiffness rating forms each hour. The forms were used to record information relating to each of the movements of flexion, extension and lateral bend. Each form consisted of a small section in which the patient was asked to record any activities he had participated in during the time since the last test, and two horizontal visual analogue scales, one of which was used to record the patients perceived stiffness, and the other which was used to monitor the degree of pain felt at the time of conducting the test. A reading of zero stiffness ('Complete range of movement') was recorded if a patient felt that they had been able physically to move as far as they could compared with the maximum distance they could normally move.

Maximum stiffness was recorded if they were unable to move at all. The scales used were 10 cm in length with 1 cm intervals marked off. The 'pain' scale was marked at either extreme as either 'No pain' (rating:- 0) or 'Severe pain' (rating:- 10), and the 'stiffness' scale as either 'No movement' (rating:- 0) or 'Complete range of movement' (rating;- 10). Complete range of movement was the maximum range of movement the patient felt they could achieve, even if this would be perceived as being restricted compared with 'Normal'.

When monitoring lateral bend, left and right movements were marked on the same scale. This was to make it easier for the patient when determining which side felt more restricted or painful.

8.3 RESULTS

Details for the three patients tested are given in Table 8.1.

TABLE 8.1

PATIENT DETAILS

DETAILS	PATIENT NO.		
	1	2	3
SEX	M	M	M
AGE	55	31	49
DIS. DURATION (Yr)	24	6	26
HEIGHT (m)	1.75	1.78	1.73
MASS (kg)	79.1	79.5	79.5

Figures 8.1 - 8.3 show how patients movements varied over the 12 hour

FIGURE 8.1

LUMBAR FLEXION MEASURED OVER A TWELVE HOUR PERIOD

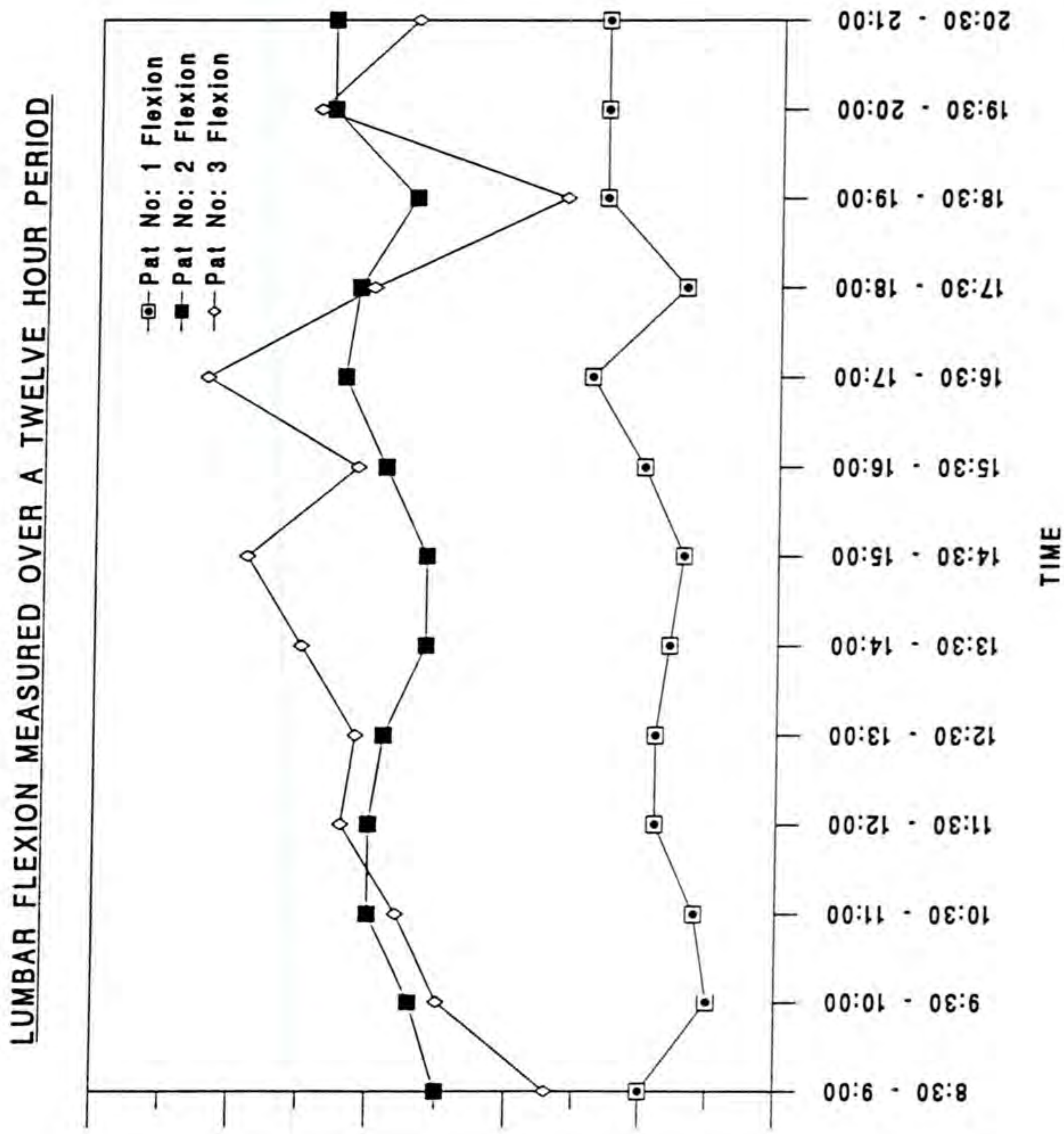


FIGURE 8.2

LUMBAR EXTENSION MEASURED OVER A TWELVE HOUR PERIOD

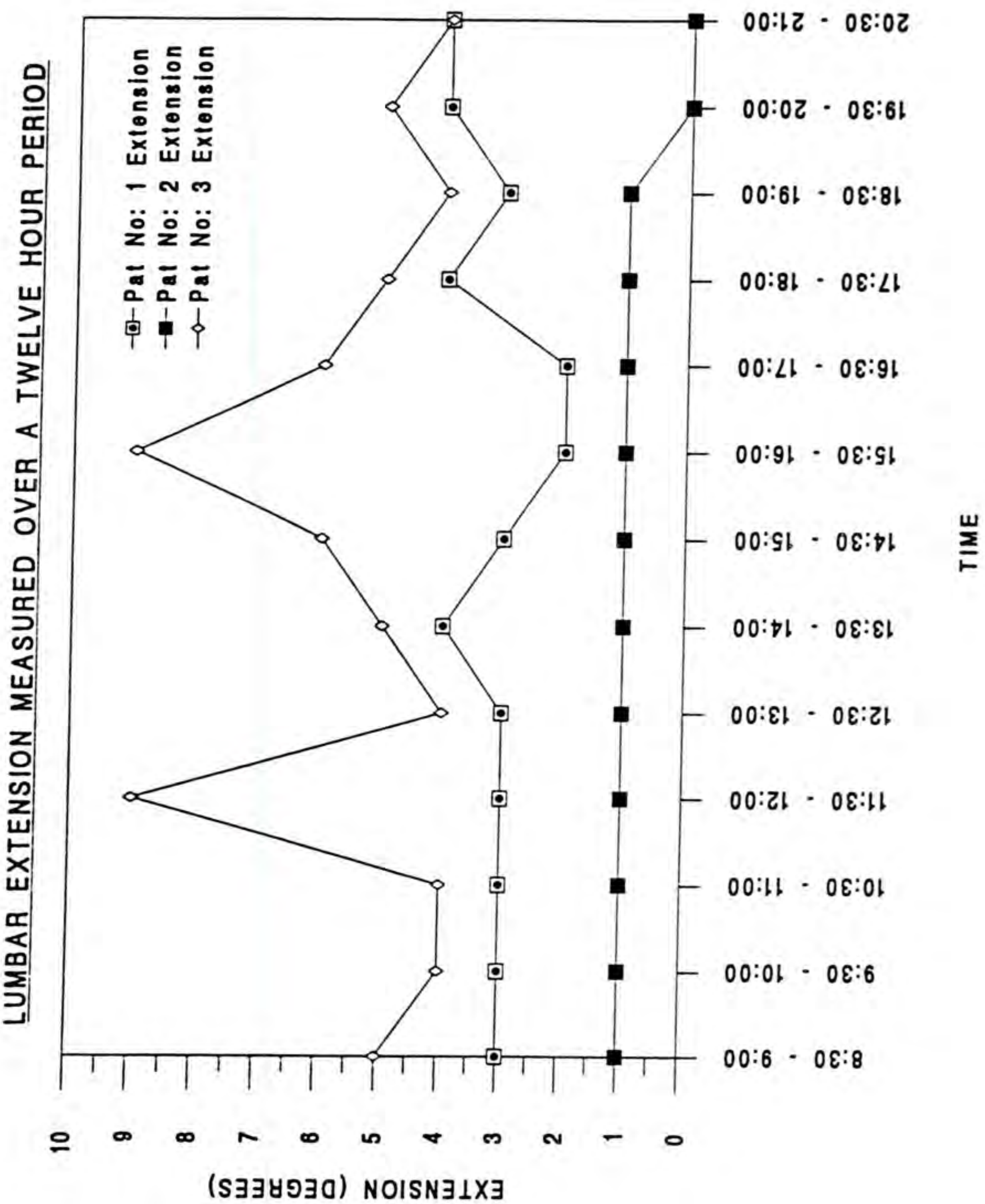
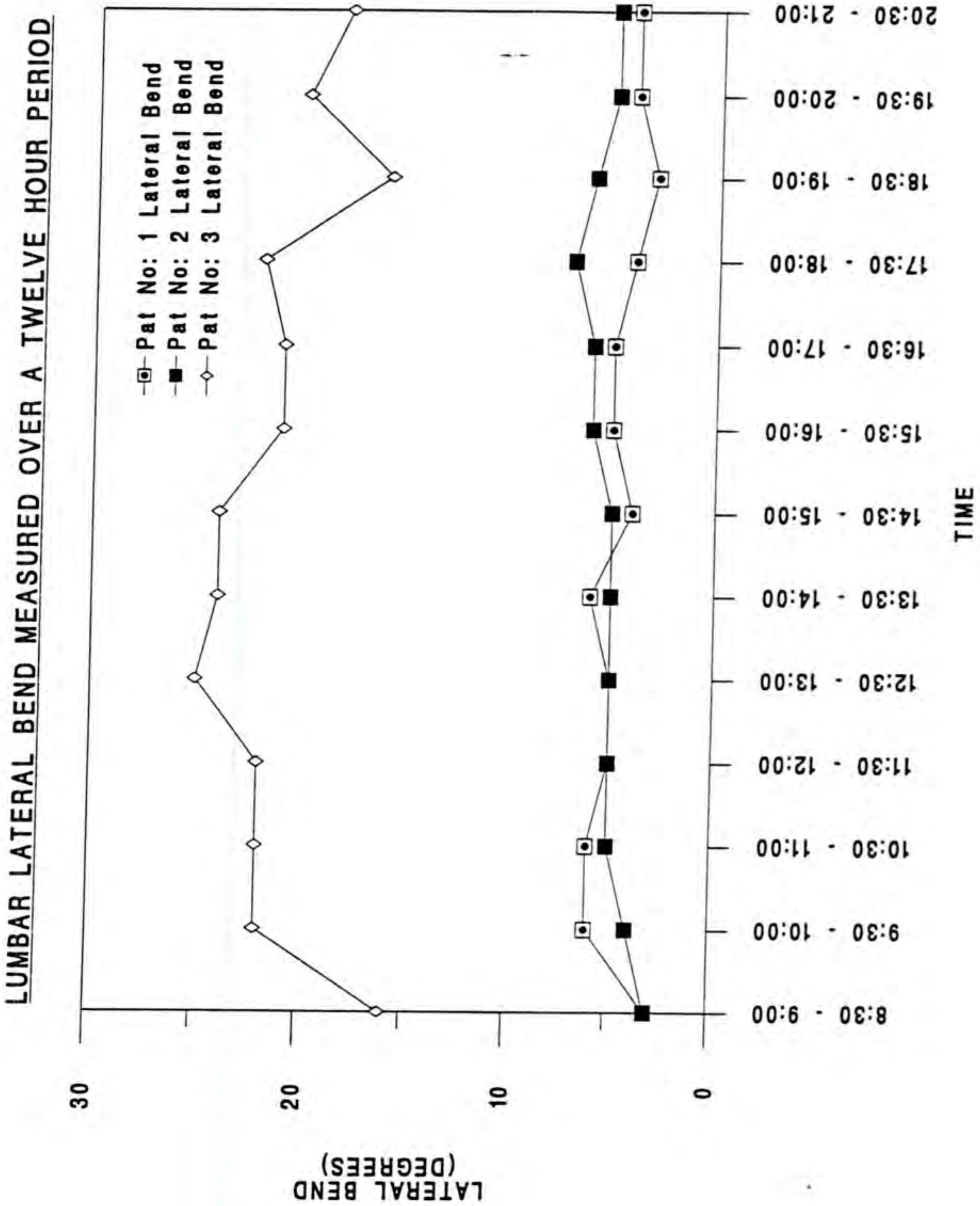


FIGURE 8.3

LUMBAR LATERAL BEND MEASURED OVER A TWELVE HOUR PERIOD



period.

Due to the fact that patients often rated pain and stiffness for left and right lateral bend differently, movements to the left and right were initially treated separately, although for the purpose of clarity, movements to the left and right were combined in figure 8.3. When applying student t-test statistics to the data, a greater overall lateral bend to the right-hand side was observed throughout the day than towards the left (mean: $1.18^{o} \pm 1.96^{o}$).

In order to determine whether primary and secondary movements and pain and stiffness rating scores were correlated, Pearson correlation statistics were used. Combining results for the three subjects gave the following results:

CORRELATED MOVEMENTS/PAIN/STIFFNESS	CORRELATION	SIGNIFICANCE
Flexion & Pain	-0.746	$P < 0.001$
R. Lateral Bend & Pain	-0.693	$P < 0.001$
L. Lateral Bend & Pain	-0.687	$P < 0.001$
R. lateral Bend & Stiffness	-0.410	$P < 0.02$
L. Lateral Bend & Stiffness	-0.474	$P < 0.01$
Coupled twist on L. Bend & Stiffness	0.724	$P < 0.001$
Coupled Flexion on R. Bend & Stiffness	0.378	$P < 0.05$
Coupled Twist on R. Bend & Pain	0.444	$P < 0.01$
Coupled Twist on L. Bend & Pain	0.350	$P < 0.05$

N.B. Only significant results have been listed ($P < 0.05$) A negative correlation coefficient implies increased pain/stiffness produced decreased range of motion. Positive correlation implies increased pain/stiffness produced increased range of motion.

To determine if the patients were able to predict whether lateral motion was more limited to one side than another, pain and stiffness rating scores were compared with which side showed greater limitation in movement. These results showed that patients perceived difference in stiffness rating for lateral bend to the left and right was reasonably correlated with the actual difference in movement (correlation = 0.569 $P < 0.001$) but that there was no correlation between pain and difference in movement.

Due to the small number of patients tested it was considered invalid to conduct detailed statistical analysis on data obtained over the twelve hour period. The results did indicate however that all three patients exhibited individual changes in movement throughout the day even though their activities did not vary, with all patients sitting either reading or watching television for the majority of the day.

8.4 CONCLUSIONS

All patients complained of stiffness during the early hours of the morning, before the tests commenced, and stated that they had got up for a short time during the night to alleviate the stiffness. This study did not show any obvious overall change in the maximum range of lumbar spine motion measured over the 12 hour period and it may be that the greatest observed changes in mobility would have been observed earlier in the morning. All patients seen did state that pain was not the restricting factor when they performed each exercise, and that they moved in all directions as far as they felt able with restriction being due to mechanical factors alone. One interesting observation was that when patients performed the movement of flexion finger-to-floor distance decreased as the day progressed, even though no change in range of lumbar movement was observed. This would appear to indicate the loosening of the hamstring muscles. N.B. Finger-to-floor distance was observed visually with no detailed measurements being obtained.

Due to the fact that all three patients seen had fairly restricted movement (particularly in extension and lateral bend) large fluctuations in movement would not have been expected to be seen, however the study did indicate that there were changes in the range of movement which were dependent on the time of day when the patient was seen. It appears however that changes in range of movement cannot be easily predicted since individual patients showed different patterns of change. All patients seen took medicinal treatment ie. analgesics when they felt they needed them, but over the study time period and 24 hours prior to its commencement no treatment was taken.

As part of a study conducted by Taylor *et al* (1991) pain and stiffness measurements were obtained using a 10cm horizontal visual analogue scale and lumbar spinal motion was monitored using the finger-to-floor method. A lack of correlation between spinal flexion and pain and stiffness ratings was observed and this was attributed to the fact that spinal flexion is a measure of disease severity or deformity rather than disease activity. This finding is in direct contrast to the results of this study in which the movements of flexion and left and right bend were seen to correlate with patients perceived pain. However in this study finger-to-floor distance was seen to alter throughout the day and did not correspond to changes in spinal flexion eg. Patient 2 was able to touch the floor with his fingers for the first time at 1.00 pm which does not correspond with the results given in figure 8.1 which suggests that he should have been able to touch the floor from 10.30 am if spinal flexion were the only factor involved. This suggests that it is likely that the study conducted by Taylor *et al* was in fact measuring an increase in hip mobility as well as change in lumbar spinal flexion.

Fluctuations in movement over the day could not be attributed to any specific activity, for instance Patient No. 3 did not change his activities between 16:30 and 19:30 and yet a wide variation in range of lumbar flexion was observed over this time interval.

This study was limited in that only a small number of patients volunteered to take part, and those who did were not necessarily representative of the A.S. population as a whole. It did show, however, that movement patterns for the patients studied were unique and again shows the importance of monitoring patients at a set time to eliminate any diurnal effects.

CHAPTER 9

THE EFFECT OF ATTENDING BACK SCHOOL ON PATIENTS WITH LOW BACK DISORDERS

9.1 INTRODUCTION

Approximately 60% of patients who are referred for physiotherapy suffer from low back pain (LBP) (Newton and Waddell, 1991). A person presenting with LBP may be offered a wide variety of different types of treatment including flexion or extension exercises, traction, massage, manipulation, short-wave diathermy or in some cases the wearing of a corset.

A number of studies have been conducted into the value of exercise treatment when treating LBP both in assessing rate of recovery (Davies *et al*, 1979), increasing spinal mobility and muscle strength (Martin *et al*, 1986) and making subjective measurement scores of pain and functional capacity (Lankhorst *et al*, 1983).

When considering exercise treatment there is conflict as to which type of exercises are preferable. Flexion exercises are thought to work by opening the intervertebral foramen and facet joints, thereby causing reduction of nerve compression (Jackson and Brown, 1983). They are also used to strengthen the abdominal muscles and to stretch the hip flexors and back extensors.

Extension exercises are thought to work by ensuring that the correct lumbar curve is maintained, thereby allowing the spine to withstand greater pressures, and by unloading the disc. Subjectively it is often the case that a patient finds that they experience a reduction in back pain if they move from a position in which their spine is in flexion to one of extension. Extension exercises are used to improve mobility of the spine, strengthen the back extensor muscles and where there is a bulge caused by the intervertebral disc to reduce it by shifting the nuclear material anteriorly.

The value of exercise in the treatment of LBP has been looked at in some detail. There are however conflicting opinions as to whether flexion or extension exercises are preferable. Kendall and Jenkins (1968) conducted a double blind study in which patients were assessed before and after treatment. Three different treatment regimes were used the first being designed to increase the range of movement in non-weight bearing positions, to strengthen supporting muscle groups, to correct posture deficiencies and to teach correct lifting techniques (Group A). The second treatment was designed to correct abnormal forward pelvic tilting and to strengthen abdominal and trunk muscles (Group B), and the third group (Group C) were taught exercises designed to strengthen back extensor muscles, to correct posture deficiencies and again shown correct lifting techniques. The results from the study showed that there was an improvement in symptoms and signs in all groups of patients, although Group A showed a significantly greater improvement. The results from the study led Kendall and Jenkins to believe that the role of extension exercises as a treatment for LBP should be questioned and that more interest should be taken in the role of isometric flexion exercises. The view that flexion exercises are preferable to extension exercises was also held by Lidstrom and Zachrisson (1970) who observed that they gave better clinical results than extension exercises.

The McKenzie technique is based on using extension exercises designed to restore lordosis, increase muscle strength and to cause an anterior shift of nuclear material in the disc. A study by Davies (1979) has shown this type of exercise to yield better clinical results in terms of pain reduction and increasing spinal mobility than those of flexion exercises. Extension exercises are not generally prescribed in acute disc prolapse, in patients who have pathologies such as spondylolisthesis, in patients who have significant scarring or who have been operated on in the past for lumbar problems.

In a recent study by Elnagger *et al* (1991) the effects of spinal flexion and extension exercises were looked at using the Isotrak system. Fifty-six patients who presented with chronic mechanical LBP were monitored. The findings from the study showed that both the group who participated in flexion exercises, and those who did the extension exercises had significantly less LBP after treatment and that sagittal mobility increased after exercises. Coronal and transverse mobility was not seen to alter. Elnaggers study did however choose a relatively high probability value of $P < 0.1$ and no reasons were given as to why the more usual value of $P < 0.05$ was not used.

9.1.1 The Back School at the Royal Victoria Infirmary (R.V.I) Newcastle

The Back school run at the R.V.I has three main objectives. Patients who attend are given sheets with the main objectives given as follows (and also given in more detail in Appendix I):

1. EDUCATION OF THE PATIENT: This is done by explaining the causes of back and leg pain, the aggravating factors and relieving factors, the need for good posture, showing how symptoms can be relieved by self-care and trying to prevent the recurrence of symptoms.

2. TEACHING THE PATIENT: Patients are taught the basic principles of back care with reference to posture, resting positions, seating, working, lifting and corsets. They are also given basic exercises for the treatment and prevention of symptoms in the acute and chronic stages, and taught the resting positions in acute attacks.

3. ANSWERING PATIENTS QUESTIONS: Questions that are covered might include questions about general types of back problems, how patients can apply what they have learnt to their individual lifestyles etc.

The aim of this study was to assess over a nine month period whether exercises taught at the Back School helped patients in terms of increasing spinal mobility.

9.2 METHOD

Twenty-six patients attended Part I of the Back school, and 17 of these returned one week later for Part II. Reasons for non attendance of Part II included inability to get time off work (4 patients) and difficulty in getting to the session (2 patients). Reasons for non attendance for the remaining 3 patients were not known.

For the purpose of this study the 17 patients who attended both Parts I and Parts II of the Back school were monitored. Recent X-rays were not available for any of the patients seen and for ethical reasons it was not possible to obtain any. Patients were referred to the Back School by local GPs or consultants and were described as having low back pain or lumbar disc prolapse. Only those with LBP of duration greater than 6 months were asked if they would participate in this study. This was in order to minimise the likelihood of spontaneous recovery. Of the 17 patients who attended Parts I and II eleven returned after a nine month period to be re-monitored. Two were unable to be seen as they experienced disc prolapse in the time interval and were awaiting surgery. Four of the patients were unable to be contacted.

Of these eleven patients 6 had continued with the exercises taught over the nine month period and 5 stopped exercising after less than four months due to the fact that they were 'too busy' or 'didn't feel the exercises helped'. None of those who stopped exercising over this period said that it was primarily because exercising made them feel worse. All the patients were monitored using the method detailed in Chapter 1 after attending Parts 1 and 2 of the Back School.

In any study it is useful, if not essential, to have a control group when trying to assess the effect of a particular form of treatment. Unfortunately in this study it was not possible to get hold of a comparable group of patients who were not attending the Back school. Those who were contacted were unable to participate due to the fact that they either worked full time and were unable to get time off, or were undergoing different types of treatment which could have affected the results. For these reasons it was decided after the nine month period to treat the patients who had 'dropped out' of the exercise programme as the control group for those who continued with the exercises.

Details of all patients are given in Table 9.1.

TABLE 9.1

PATIENT DETAILS

PATIENT No.	SEX/ AGE	HEIGHT	WEIGHT	DURATION OF SYMPTOMS	CAUSE	CONTINUED EXERCISES AFTER BS?
1	M52	5'8"	11.5st	30 years	lifting	no
2	M64	5'8"	13st	unknown	unknown	no
3	F39	5'3"	8st	10 months	lifting	no
4	F55	5'6"	7.5st	10 months	lifting	yes
5	F29	5'8"	11st3	1.5 years	lift/twist	awaiting surg.
6	M29	5'8"	13st	24 years	sneezing	awaiting surg.
7	F34	5'2"	10st4	2 years	lifting	no
8	M34	5'7"	13st	3 years	lift/twist	no
9	M60	5'8"	13.5st	6 months	fall	yes
10	F49	5'5"	9st	unknown	unknown	for 4 mth
11	F50	5'6"	10st4	unknown	unknown	yes
12	M54	5'5"	10st	unknown	unknown	yes
13	M59	5'8"	13st	6 months	lifting	yes
14	M60	6'2"	12st	unknown	unknown	yes
15	F55	5'4"	8st8	2 years	lifting	yes
16	M40	5'9"	12st4	unknown	unknown	no
17	M45	5'7"	10st4	2 years	lift/twist	no

Due to the fact that a number of patients experienced more difficulty in bending laterally to one side than the other lateral bend to the left and right sides were treated separately.

9.2.1 Analysis of data

Since data appeared to be non-parametric they were analysed using Mann-Whitney or Wilcoxon statistical tests.

9.3 RESULTS

The results of the median maximum range of movement for flexion, extension, lateral bending and axial rotation together with the coupled movements obtained for patients tested after Parts I and II of the Back School are given in Table 9.2.

TABLE 9.2

MOVEMENT	PART I	PART II
	Median(95% confidence interval)	
Extension	13.8(8.0,20.0)	14.0(7.0,21.0)
Coupled bend on Ext	-0.3(-0.5,8.0)	2.8(-1.5,8.0)
Coupled rot. on Ext	0.8(-2.8,2.0)	-1.5(-5.0,1.0)
Flexion	51.7(40.5,61.5)	55.3(44.5,66.0)
Coupled bend on Flex	-2.1(-3.5,1.3)	4.0(1.5,6.5)
Coupled rot. on Flex	0.8(-3.8,3.8)	-1.5(-4.5,2.0)
Flexion + Extension	65.3(54.3,77.8)	68.3(54.0,84.0)
Right Lateral Bend	13.3(10.0,17.5)	14.5(9.5,18.0)
Coupled F/E on R Bend	7.5(2.0,13.5)	7.2(1.5,12.0)
Coupled rot. on R Bend	2.0(3.0,15.0)	1.3(-1.0,4.0)
Left Lateral Bend	14.5(10.5,18.0)	13.0(8.5,16.5)
Coupled F/E on L Bend	7.0(3.0,15.0)	6.5(1.0,15.0)
Coupled rot. on L Bend	-4.3(-7.0,-1.0)	-1.5(-4.5,0.5)
Left + Right Bend	27.3(20.5,34.5)	27.0(18.5,34.5)
Right axial rotation	12.0(9.5,15.0)	13.0(9.5,16.5)
Coupled F/E on r rot.	-0.5(-4.0,1.0)	-1.0(-3.0,1.5)
Coupled Bend on r rot.	3.3(0.5,7.0)	6.5(3.5,10.0)
Left axial rotation	13.0(10.0,16.0)	13.0(10.0,16.0)
Coupled F/E on l rot.	1.5(-1.0,4.0)	2.5(0.5,5.0)
Coupled Bend on l rot.	-6.0(-9.5,-2.5)	-8.5(-11.5,-5.0)
Left + Right rotation	24.3(20.5,30.0)	26.2(20.0,33.5)

The primary reason for monitoring patients after both Part I and Part II of the Back school was in order to attempt to assess any errors that might have incurred. These could be due to fluctuation in activity of symptoms or might be due to misplacement of the sensor. The effect of anything taught in Part I of the Back school was assumed to be minimal in terms of affecting range of movement. This was because Part I concentrated on teaching correct posture and anatomy rather than concentrating on any exercises that might seriously affect movement range.

Since no significant change in range of movement was observed between

Part I and Part II of the Back school the results obtained from these two sessions were averaged before comparing with the results obtained nine months after completion of Part II.

The results obtained for the 11 patients monitored after 9 months are given in Table 9.3.

TABLE 9.3

MEDIAN RANGE OF MOVEMENT OBTAINED AFTER COMPLETING PARTS I AND II OF THE BACK SCHOOL AND NINE MONTHS AFTER COMPLETION

MOVEMENT	**AVERAGE PARTS I & II**	**AFTER 9 MONTHS**
	Median(95% confidence interval limit)	
Extension	13.8(8.0,20.0)	14.0(7.0,21.0)
Coupled bend on Ext	-0.3(-2.0,1.0)	2.8(-1.5,8.0)
Coupled rot. on Ext	0.8(-2.8,2.0)	-1.5(-5.0,1.0)
Flexion	51.7(41.0,61.5)	55.3(44.5,66.0)
Coupled bend on Flex*	-2.1(-3.5(1.3)	4.0(1.5,6.5)
Coupled rot. on Flex	0.8)-3.8,3.8)	-1.5,4.5,2.0)
Flexion + Extension	65.3(54.3,77.8)	68.3(54.0,84.0)
Right Lateral Bend*	13.1(7.2,17.5)	4.5(2.5,8.5)
Coupled F/E on R Bend	3.9(0.0,10.8)	1.3(-1.5,5.0)
Coupled rot on R Bend	1.9(-1.0,4.5)	3.5(0.5,5.5)
Left Lateral Bend*	11.6(7.0,15.8)	4.0(3.5,6.0)
Coupled F/E on L Bend	2.7(-0.8,15.5)	3.8(-3.0,4.0)
Coupled rot on L Bend	-3.0(-6.3,1.3)	-3.3(-8.0,-2.0)
Left + Right Bend*	24.4(14.5,33.3)	8.5(6.5,14.5)
Right axial rotation	13.8(9.5,17.8)	9.3(6.5,13.0)
Coupled F/E on r rot	-1.8(-6.0,1.0)	1.0(-3.0,4.0)
Coupled Bend on r rot*	5.9(2.5,9.8)	12.0(8.0,16.0)
Left axial rotation	12.9(9.8,35.5)	10.5(7.0,17.0)
Coupled F/E on l rot	1.5(-1.3,4.3)	1.0(-1.0,7.0)
Coupled Bend on l rot	-8.5(-12.5,-4.0)	-13.0(-16.5,-9.5)
Left + Right rotation	25.6(18.0,35.5)	20.0(16.0,28.5)

N.B. * Denotes significant differences between readings obtained before and after the nine month time interval.

Results for the primary movements obtained for each of the eleven patients seen are given below in Tables 9.4 - 9.6

TABLE 9.4

RANGE OF FLEXION AND EXTENSION BEFORE (AND AFTER) NINE MONTH TIME INTERVAL

PAT.	EXTENSION	FLEXION	FLEX + EXT	CONTINUED EXERCISES?
1	15.5(15.0)	50.5(44.0)	66.0(61.0)	NO
2	3.0(4.0)	26.0(34.0)	27.5(36.0)	YES
3	31.0(24.0)	53.5(56.0)	84.5(80.0)	NO
4	8.0(5.0)	52.0(64.0)	60.0(68.0)	YES
5	7.5(10.0)	55.0(78.0)	64.0(88.0)	NO
6	15.0(24.0)	76.0(56.0)	91.0(80.0)	YES
7	7.0(21.0)	57.0(66.0)	74.0(86.0)	YES
8	20.5(12.0)	44.5(63.0)	65.0(76.0)	YES
9	24.5(27.0)	43.5(68.0)	63.5(95.0)	YES
10	13.5(2.0)	68.0(38.0)	81.5(40.0)	NO
11	10.0(7.0)	35.0(33.0)	45.0(40.0)	NO

TABLE 9.5

RANGE OF LATERAL BEND BEFORE (AND AFTER) NINE MONTH TIME INTERVAL

PAT.	R. BEND	L. BEND	R + L BEND	CONTINUED EXERCISES?
1	6.0(6.0)	7.0(3.0)	13.0(9.0)	NO
2	20.0(3.0)	2.0(4.0)	4.5(7.0)	YES
3	21.0(4.0)	28.0(5.0)	48.5(10.0)	NO
4	14.0(16.0)	12.0(10.0)	26.0(26.0)	YES
5	21.0(7.0)	15.5(4.0)	36.5(11.0)	NO
6	21.0(5.0)	17.0(4.0)	38.0(10.0)	YES
7	13.0(3.0)	3.0(3.0)	16.0(6.0)	YES
8	15.0(3.0)	12.5(4.0)	28.5(7.0)	YES
9	12.5(7.0)	14.0(5.0)	26.5(12.0)	YES
10	12.5(1.0)	14.5(5.0)	21.5(6.0)	NO
11	1.0(1.0)	3.0(2.0)	4.0(3.0)	NO

TABLE 9.6

RANGE OF AXIAL ROTATION BEFORE (AND AFTER) NINE MONTH TIME INTERVAL

PAT.	R ROT	L ROT	R + L ROT	CONTINUED EXERCISES?
1	10.0(11.0)	9.5(14.0)	19.5(24.0)	NO
2	6.0(5.0)	11.0(9.0)	16.5(16.0)	YES
3	17.5(11.0)	14.5(10.0)	31.5(22.0)	NO
4	18.0(8.0)	15.5(9.0)	34.0(16.0)	YES
5	18.0(15.0)	13.5(17.0)	31.0(32.0)	NO
6	22.0(11.0)	33.0(10.0)	55.5(22.0)	YES
7	6.0(6.0)	8.0(4.0)	14.0(10.0)	YES
8	17.5(8.0)	20.0(17.0)	37.0(24.0)	YES
9	14.5(19.0)	15.5(26.0)	29.5(45.0)	YES
10	9.0(7.0)	10.0(4.0)	20.0(12.0)	NO
11	10.0(6.0)	6.0(10.0)	15.0(16.0)	NO

9.4 DISCUSSION

The inherent problems of trying to assess the effectiveness of different treatments when monitoring motion in low back pain patients are many. It is well known that LBP may spontaneously resolve either for short or long periods of time, and that the severity of LBP does not necessarily follow any well defined pattern in terms of gradually getting better, worse etc. This makes it difficult when monitoring a small group of patients as in this study, since a number of patients may well spontaneously recover, and this may give a false idea of the effect that treatment is having on them.

Another problem of monitoring motion in low back pain patients by using the method in this study is that patients are asked to perform the movement in a given time interval of 10 seconds (although this time may be extended or reduced slightly if needed). Patients may be weary when asked to perform a movement to the full range of their ability because they have experienced pain when performing that movement in the past. This means that often they do not move as far as they are physically able to, but the distance moved is governed to some extent by their tolerance of pain, and their past experience.

The value of assessing low back mobility in patients with low back pain without also obtaining information on whether the severity of the pain has increased or decreased is questionable. Of the 11 patients who were assessed 9 months after attending the Back school 6 had continued with their exercises, 5 had not. Of the 6 who had continued exercising, 5 had an increased range of total sagittal plane movement after 9 months, 4 had a decrease in lateral movement and 4 a decrease in axial rotation. This compared with the results obtained for those who had not continued with the exercises taught of a decrease in sagittal movement in 4 patients, a decrease in lateral bending in all 5 patients and a slight increase in axial rotation in 3 of the patients seen. The only significant difference between the group that did and the group that did not continue with their exercises was for sagittal movement.

Of all the 11 patients seen only 1 patient said they felt any better than when they attended the Back school 9 months previously. One other patient felt his/her back pain had decreased but that the pain in his/her legs was about the same. One patient although admitting to feeling slightly better, took analgesics constantly.

Patients who attended the Back school stated, in many cases, that they had undergone other remedies over the years, and many felt that their doctor had sent them for treatment at the Back school as a 'last resort'. Results obtained from a study on patients with chronic LBP attending the

Swedish Back school showed no positive effect of the Back school after one year, compared with the results of a control group who received only detuned pulsating shortwave treatment (Lankhorst *et al*, 1983). The conclusion reached was that the Back school was of little use in chronic LBP and that efforts should therefore be 'directed towards the prevention of chronicity of LBP'. Over a one year period spinal mobility showed a slight decrease whereas there was no change in pain.

The results from this study have shown that patients did not generally feel any better 9 months after attending the Back school and the 'drop out' rate, in terms of continuing with the exercises taught, was quite high (5 out of 11 patients). Patients who were monitored had often had the symptoms for many years with some not able to remember how long they had had back problems. From the results obtained from Lankhorst *et als* study we might not therefore expect any improvement.

On questioning, all patients stated that if their back pain felt worse they would start trying the exercises taught again but would often stop as soon as they felt better. One of the aims of the Back school was to teach patients how to relieve their pain and this appears to have been successful. The problem remains however that patients did not see the exercises as a preventative measure, and because they often felt that they were only being sent for treatment because their doctor could not do anything else for them their compliance was poor.

CHAPTER 10

THE RANGE AND PATTERN OF MOVEMENT IN THE PATHOLOGICAL LUMBAR SPINE

10.1 INTRODUCTION

The importance of monitoring motion in more than one plane is evident when considering the problem of differentiating between pathologies such as lumbar disc prolapse and ankylosing spondylitis. As pointed out by Moll and Wright (1971) when referring to Bailey (1960) 'An important practical application of the measurement of back movement in 3 planes (anterior flexion, lateral flexion and extension) concerns the frequent difficulty in differentiating ankylosing spondylitis from disorders of the lumbar disc. It has been reported that limitation of mobility in spondylitis usually affects all planes of spinal movement in contrast with the pattern in acute lumbar disc lesions in which lateral flexion is often spared'. The concern expressed by Lawrence (1970) was that if flexion was the only motion monitored when setting the criteria for limitation of movement in ankylosing spondylitis, that a number of patients with disc disorders might also be included in this group.

The results from Chapter 6 have shown that there are significant differences in primary and coupled movements in patients with ankylosing spondylitis compared with 'normal' subjects. The work reported in this chapter was to monitor a number of patients with mechanical low back problems in order to compare their movements with both the 'normal' subject group in Chapter 2 and the ankylosing spondylitis group in Chapter 6. If significant differences were observed between patient groups it would show that the Isotrak could be a useful tool in helping to distinguish between different patients with different pathologies.

The patient groups chosen to be included in this study included those with confirmed lumbar disc prolapse, spondylosis, spondylolysis and spondylolisthesis. Patients who participated in this study attended either the outpatient clinic at Sunderland District General Hospital or the outpatient clinic at North Tees General Hospital. Only those who had been given a definite diagnosis by their Consultant were included. Patients who had previously undergone any surgical intervention for their back problem, or whose back problem caused them considerable pain if asked to perform all of the movements of flexion, extension, lateral bend or axial rotation were excluded.

10.2 METHOD

One hundred and eighty-seven patients participated in this study. Details of those patients tested are given below.

TABLE 10.1

PATIENT DIAGNOSIS

DIAGNOSIS	MALE	FEMALE
A.S.	95	36
DISC PROLAPSE	19	19
SPONDYLOSIS	2	3
SPONDYLOLYSIS	3	1
SPONDYLOLISTHESIS	5	4

A further 19 patients were tested who had degenerative changes. Since their diagnosis was either complicated due to the fact that they were suffering from more than one specific pathology, or was unconfirmed, their results were not included in this study.

Before direct comparison between groups could be undertaken it was first necessary to make 'within group' comparisons for the disc prolapse group. This was because there were a number of variables within the group to consider.

10.2.1 ANALYSIS OF DATA

Data were analysed using Mann-Whitney tests, two-sample t-tests and Pearson correlation coefficients where appropriate. Significance was taken to be at $P < 0.05$ unless otherwise stated.

10.3 RESULTS

10.3.1 Disc Prolapse group

Of the thirty-eight patients seen in this group 1 was affected at the L3/4 level, 15 at the L5/S1 level and 14 at the L4/5 level. Two patients were affected at both the L4/5 and L5/S1 levels and 6 were later diagnosed as having disc degeneration rather than prolapse. Patient details have been given in Table 10.2.

TABLE 10.2

DISC PROLAPSE PATIENT DETAILS

DETAILS	MALE	FEMALE
TOTAL NUMBER TESTED	19	19
AGE (Mean ± s.d.)	37.6 ± 10.2	40.3 ± 10.7
AGE RANGE	26 - 54	22 - 63
LEVEL AFFECTED: L3/4 AGE	 1 49	 -
L4/5 AGE (Mean ± s.d.)	7 34 ± 9	7 44 ± 13
L5/S1 AGE (Mean ± s.d.)	7 37 ± 9	8 37 ± 10
L4/5 AND L5/S1 AGE	1 44	1 55
DISC DEGENERATION AGE (Mean ± s.d.)	4 40 ± 15	2 39 ± 4

10.3.1.1 Dependence of range of movement on level affected

Mann-Whitney statistical tests were used to compare the group of patients affected at the L4/5 level with the group affected at the L5/S1 level and the group with disc degeneration. The results showed that there were no significant differences in range of movement (either primary or coupled movement) for the group who were affected at the L4/5 level or at the L5/S1 level and they were therefore combined for all subsequent analysis. Numbers in the other two disc prolapse groups were too small for detailed statistical analysis to be valid but results for patients in both groups fell within the 95% confidence interval limit of the results for the L4/5 and L5/S1 groups. The only significant difference seen between groups was for the range of flexion which was significantly greater in the disc degeneration group (median 57.5, 95% C.I. 39.0 - 66.5) compared with the group affected at the L4/5 level only (median 37.5, 95% C.I. 26.0 - 46.0).

10.3.1.2 Side of prolapse and its effect on movement

Of the 30 patients who were affected at only one level, 7 had a right hand side prolapse (RHS), 6 had a left hand side (LHS) prolapse and the side of prolapse was not known for the other 17. When comparing each of the movements in the RHS prolapse and LHS prolapse groups no significant differences were observed in either the primary or coupled movements. No significant differences were observed between left and right lateral bend or left and right axial rotation for either of the groups.

10.3.1.3 Effect of gender

When analysing differences between male and female subject groups the only significant difference observed was for left axial rotation where the maximum range for the male group (median 9.5, 95% C.I. 7.5 - 11.5) exceeded that of the female group (median 6.0, 95% C.I. 5.0 - 7.5). When combining left and right axial rotation however no significant difference was observed between groups.

10.3.1.4 Effect of age

No significant changes were observed in either primary or coupled movement ranges for patients in the 20 - 29, 30 - 39, 40 - 49 or 50 + age groups.

From the results obtained from this section of the study it was decided that it would be appropriate to combine the results of all patients, both male and female, who had only one level affected. This group of 30 patients was used in all subsequent analysis.

10.3.2 Spondylosis, Spondylolysis and Spondylolisthesis

The results obtained from these three groups were analysed using two-sample t-tests as the results showed a symmetrical distribution pattern. There were no significant age differences between any of the groups. Age range was 21 - 66 for the spondylosis group, 35 - 54 for the spondylolysis group and 15 - 50 for the spondylolisthesis group.

A significant difference in the magnitude of the coupled movement of rotation on extension was observed between the spondylosis group (mean 1.4 ± 1.5), and the spondylolysis (mean -2.3 ± 2.1) and spondylolisthesis (mean -0.6 ± 0.9) groups. No significant difference in the magnitude of any of the other primary or coupled movements was observed. For the purpose of this study the groups were combined when primary movement range was of importance.

10.3.3 Ankylosing Spondylitis

The results for these patients have been given in Chapter 6.

10.3.4 Comparison between the 'Normal' group and the disc prolapse group

Before the disc group was compared with any of the other patient groups it was first compared with the 'Normal' group studied in Chapter 2.

Each patient was compared with their 'Normal' control group, ie. A woman in her 20's had her range of movement compared with the normal female 20 - 29 age group range. Of the 30 patients whose movement was affected at only one level 8 (27%) had restricted extension (restriction occurring where a patients movement was more than 2 standard deviations below the mean of the 'normal' group), 22 (73%) had restricted flexion, 21 (70%) restricted lateral bending and 6 (20%) restriction of axial rotation. None of the coupled movement ranges fell outside the 95% confidence interval limit for any of the patients.

Due to the fact that 'normal' subject range was seen to vary considerably with both age and sex (Chapter 2) it was not considered appropriate to conduct any detailed statistical analysis between the two groups as numbers in the disc prolapse group were too small.

10.3.5 Comparison between the 'Normal' group and the Spondylosis, Spondylolysis and Spondylolisthesis groups

Once again detailed statistical comparison with the 'Normal' group was not possible.

Comparison of each patient with their 'normal' control group gave the results shown in Table 10.3.

TABLE 10.3

DIFFERENCE IN RANGE OF MOVEMENT BETWEEN 'NORMAL', SPONDYLOSIS, SPONDYLOLYSIS AND SPONDYLOLISTHESIS GROUPS

DIAGNOSIS	SEX/ AGE	FLEXION	EXT.	LAT. BEND	AXIAL ROT.
Spondylosis					
	F21	Normal	< 2 sd	< 2 sd	< 2 sd
	M62	< 2 sd	< 2 sd	Normal	Normal
	M45	< 2 sd	Normal	Normal	Normal
	F66	< 2 sd	< 2 sd	< 2 sd	Normal
	F41	< 2 sd	< 2 sd	< 2 sd	Normal
Spondylolysis					
	M54	< 2 sd	< 2 sd	< 2 sd	< 2 sd
	F35	Normal	Normal	< 2 sd	Normal
	M49	< 2 sd	Normal	< 2 sd	< 2 sd
	M37	Normal	Normal	Normal	Normal
Spondylolisthesis					
	M34	< 2 sd	< 2 sd	< 2 sd	< 2 sd
	F36	< 2 sd	Normal	Normal	Normal
	F34	< 2 sd	< 2 sd	< 2 sd	Normal
	F46	< 2 sd	< 2 sd	< 2 sd	Normal
	M15	Normal	Normal	Normal	< 2 sd
	M47	< 2 sd	Normal	< 2 sd	Normal
	F50	< 2 sd	Normal	Normal	< 2 sd
	M52	Normal	Normal	Normal	Normal
	M47	< 2 sd	Normal	< 2 sd	Normal

The results in Table 10.3 show that of the eighteen patients seen 13 (72%) had a restriction of flexion (compared to the 'normal' group), 6 (33%) a reduction of extension, 11 (61%) a reduction of lateral bending and 6 (33%) a reduction of axial rotation.

10.3.6 Comparison between Ankylosing spondylitis and disc prolapse groups

Since age was seen to have an effect on movement in patients with ankylosing spondylitis (A.S.) (Chapter 6, Table 6.6), but did not appear to have an effect on the disc prolapse patient group it was decided to compare the entire disc prolapse group with each A.S. patient age group. Since data for both the disc and A.S. groups were non-parametric Mann-Whitney statistical analysis was used to compare them. The results of the significant differences between the two groups have been given in Table 10.4.

TABLE 10.4

COMPARISON BETWEEN DISC AND A.S PATIENT GROUPS: SIGNIFICANT DIFFERENCES IN RANGE OF MOVEMENT

AGE GROUP	MOVEMENT	SIGNIFICANT DIFFERENCE
20 - 29	LEFT AXIAL ROTATION	A.S. > DISC
	COUPLED EXT ON R ROT	A.S. > DISC
30 - 39	AXIAL ROTATION	A.S. > DISC
	COUPLED FLEX ON L ROT	A.S. > DISC
	COUPLED ROT ON R BEND	DISC > A.S.
	COUPLED ROT ON L BEND	DISC > A.S.
40 - 49	EXTENSION	DISC > A.S.
	FLEXION + EXTENSION	DISC > A.S.
	LATERAL BEND	DISC > A.S.
	AXIAL ROTATION	A.S. > DISC
	COUPLED ROT ON R BEND	DISC > A.S.
	COUPLED ROT ON L BEND	DISC > A.S.
	COUPLED BEND ON R ROT	A.S. > DISC
50 +	EXTENSION	DISC > A.S.
	FLEXION + EXTENSION	DISC > A.S.
	LATERAL BEND	DISC > A.S.
	AXIAL ROTATION	A.S. > DISC
	COUPLED ROT ON R BEND	DISC > A.S.
	COUPLED ROT ON L BEND	DISC > A.S.
	COUPLED FLEX ON R BEND	A.S. > DISC

The magnitude of the significantly different movements have been given in Tables 10.5 and 10.6.

TABLE 10.5

MAGNITUDE OF SIGNIFICANT DIFFERENCES BETWEEN THE A.S. GROUP AND THE DISC GROUP: PRIMARY MOVEMENTS
MEDIAN (95% CONFIDENCE INTERVAL)

MOVEMENT	AGE GROUP	A.S. GROUP	DISC GROUP
EXTENSION	40 - 49	6.0 (4.0,7.0)	12.0 (10.0,13.5)
	50 +	6.0 (4.0,8.0)	
FLEX + EXT	40 - 49	43.0 (37.5,51.0)	55.5 (50.0,62.5)
	50 +	46.0 (36.5,51.5)	
LEFT BEND	40 - 49	7.0 (7.0,12.5)	14.0 (12.0,17.0)
	50 +	9.5 (6.5,11.5)	
RIGHT BEND	40 - 49	8.9 (8.0,12.0)	17.0 (13.5,19.5)
	50 +	10.5 (7.5,12.5)	
LATERAL BEND	40 - 49	16.0 (14.5,24.5)	32.5 (26.5,36.5)
	50 +	18.5 (14.0,23.5)	
LEFT ROTATION	20 - 29	12.0 (9.0,16.5)	7.0 (6.5,9.5)
	30 - 39	15 (12.5,15.5)	
	40 - 49	12.0 (9.5,13.0)	
	50 +	11.0 (9.5,12.5)	
RIGHT ROTATION	30 - 39	13.0 (11,14.5)	9.0 (8.0,11.0)
AXIAL ROTATION	30 - 39	27.0 (24.0,29.5)	17.5 (15.0,19.5)
	40 - 49	21.0 (19.0,25.0)	

TABLE 10.6

MAGNITUDE OF SIGNIFICANT DIFFERENCES BETWEEN THE A.S. GROUP AND THE DISC GROUP: COUPLED MOVEMENTS
MEDIAN (95% CONFIDENCE INTERVAL)

MOVEMENT	AGE GROUP	A.S. GROUP	DISC GROUP
F/E ON R ROT	20 - 29	-4.0 (-8.5,-1.5)	-1.0 (-2.0,0.5)
F/E ON L ROT	30 - 39	2.0 (1.0,4.0)	0.0 (-1.5,1.5)
ROT ON R BEND	30 - 39 40 - 49 50 +	1.0 (0.0,2.5) 0.0 (0.0,2.0) 0.0 (-0.5,2.0)	3.0 (2.0,4.0)
ROT ON L BEND	30 - 39 40 - 49 50 +	-1.0 (-2.5,0.0) -2.0 (-2.0,-0.5) -1.0 (-2.5,0.0)	-3.0 (-4.5,-2.0)
BEND ON R ROT	40 - 49	3.0 (2.0,5.5)	0.0 (-1.0,2.5)

10.3.7 Comparison between disc prolapse, spondylosis, spondylolysis and spondylolisthesis groups

Due to the fact that only a relatively small number of patients were seen in the spondylosis, spondylolysis and spondylolisthesis groups, and the ages of patients were fairly well spread over the decades, the results for males and females of all ages were combined and compared with the entire disc group.

The only significant difference observed between the two groups was for the movement of left lateral bend where coupled rotation in the disc group was greater than that in the combined spondylosis, spondylolysis and spondylolisthesis group.

10.3.8 Comparison between the spondylosis, spondylolysis, spondylolisthesis and A.S. groups

Due to the small numbers of patients seen in the combined spondylosis, spondylolysis and spondylolisthesis group, and the fact that movement variation between different age groups in A.S. patients is often considerable, it was not thought appropriate to conduct detailed statistical analysis between patient groups. Each patient in the spondylosis, spondylolysis or spondylolisthesis group was compared with the comparable age group in the ankylosing spondylitis group.

TABLE 10.7

DIFFERENCE IN RANGE OF MOVEMENT BETWEEN ANKYLOSING SPONDYLITIS AND SPONDYLOSIS, SPONDYLOLYSIS AND SPONDYLOLISTHESIS GROUPS

DIAGNOSIS	SEX/ AGE	FLEXION	EXT.	LAT. BEND	AXIAL ROT.
Spondylosis					
	F21	Same	Same	Same	<
	F41	>	<	Same	>
	M45	>	>	>	>
	M62	Same	<	Same	<
	F66	Same	<	Same	<
Spondylolysis					
	F35	Same	Same	Same	Same
	M37	Same	>	>	Same
	M49	Same	Same	Same	<
	M54	Same	<	<	<
Spondylolisthesis					
	M15	Same	Same	Same	Same
	M34	<	<	<	<
	F34	Same	<	<	<
	F36	Same	Same	>	<
	F46	Same	Same	Same	<
	M47	>	>	Same	<
	M47	Same	<	Same	<
	F50	>	<	>	<
	M52	>	>	>	>

N.B. In Table 10.7 < and > imply that the results for spondylosis, spondylolisis or spondylolisthesis patients were either less than or greater than the 95% confidence interval limit for the corresponding ankylosing spondylitis patient age group.

10.3.9 Comparison between ankylosing spondylitis patients, disc prolapse patients, and the combined spondylosis, spondylolysis and spondylolisthesis group of patients - Correlation coefficients

Chapter 6 showed that primary movements in A.S. were highly correlated. A comparison between the correlation coefficients for the primary movements of all groups was therefore conducted.

TABLE 10.8

CORRELATION COEFFICIENTS: PRIMARY MOVEMENTS

	PATIENT GROUP		
MOVEMENT	A.S. GROUP	DISC GROUP	SPONDY GROUP
EXTENSION & FLEXION	0.71	0.15	0.50
EXTENSION & LATERAL BEND	0.76	0.51	0.68
EXTENSION & AXIAL ROTATION	0.45	0.20	0.47
FLEXION & LATERAL BEND	0.83	0.49	0.59
FLEXION & AXIAL ROTATION	0.50	0.50	0.46
LATERAL BEND & AXIAL ROTATION	0.50	0.50	0.60

N.B. SPONDY :- Denotes the group of spondylosis, spondylolysis and spondylolisthesis patients

10.4 DISCUSSION

The results have shown that it is possible to make distinctions between some patient groups using the Isotrak system of measurement.

Although the maximum range of movement in the disc prolapse (D.P.) patients was not seen to be significantly different from those of the combined spondylosis, spondylolisis and spondylolisthesis group the correlation between the primary movements of flexion and extension and of extension and rotation were considerably lower in the D.P. group.

A comparison between D.P. patients and ankylosing spondylitis (A.S.) patients showed that a distinction could be made between patients of the same age group. The A.S. patients showed a consistently greater range of axial rotation than the D.P. patients whilst the D.P. patients had greater ranges of flexion, extension and lateral bend in the 40 - 49 and 50 + age groups. The only consistent change in coupled movement between the two groups in the age groups 30 - 50 + was for the movement of rotation on lateral bend which, in the A.S. patients was significantly smaller than that for the D.P. patients. Differences in the younger, 20 - 29, age group were less and not consistent ie. although there was a significantly higher range of coupled extension on right rotation there were no significant differences on left rotation.

When comparing the patients in the combined spondylosis, spondylolysis and spondylolisthesis group with the 'Normal' group studied in Chapter 2 the movement most commonly seen to be restricted was that of flexion followed by that of lateral bending. There was restriction of extension and axial rotation in 33% of patients. No significant differences in the magnitude of coupled movement were seen between the two groups. Results obtained from a study by Pearcy and Shepherd (1985) in which ten patients with spondylolisthesis at L5/S1 were monitored showed limitation of flexion and extension compared to a 'normal' control group. This was explained by the fact that L5 had slipped forward on the sacrum putting ligaments into tension which, coupled with muscle spasm caused the reduction in movement. Pearcy and Shepherds study also showed a lack of consistent coupling of lateral bend and axial rotation during flexion and extension which they suggested was the result of muscle action rather than mechanical coupling of the joints. This study showed no significant differences in the magnitude of coupled movements from the 'Normal' group. However, as mentioned in Chapter 2 a number of subjects in the 'Normal' group may have had undiagnosed lumbar spine problems. The wide range of values obtained in each age/sex catagory in the 'Normal' group may have also obscured some of the changes in the relatively small number of spondylosis, spondylolysis and spondylolisthesis patients seen.

In a study by Tibrewal *et al* (1985) movement was monitored, using biplanar radiography, in a group of patients with disc prolapse all of whom required surgery. The results showed that of the 15 patients measured, all were restricted to one half of the normal range of movement at each lumbar level with there being no greater degree of limitation at the level affected. In this study flexion was seen to be the movement most commonly restricted followed by restriction of lateral bending. In the study of Tibrewal *et al* no correlation between coupled movements with side of prolapse was seen, this agrees with the results of this study where no significant differences were observed between side of prolapse and the effect on primary or coupled movements.

Due to the fact that disc degeneration or prolapse often occurs in spondylolisthesis and that disc space narrowing can occur in spondylosis it is perhaps not surprising that no significant differences in movement patterns were seen between the disc group and the combined spondylosis, spondylolysis and spondylolisthesis group monitored, especially when numbers in the groups were not large.

The results from this section of the study have shown that it is possible to make distinctions between patients with different spinal pathologies. The fact that patients with disc prolapse, spondylosis, spondylolysis or spondylolisthesis were often limited by pain as well as mechanical factors may well have meant that patients braced themselves when performing movements. Since movements were performed in a given time interval this may well have given unrealistic figures for the extent of involvement as patients may have been able to move considerably further if allowed to move slowly or 'at their own pace'.

Once again this study has shown that there is considerable overlap between patients and 'Normal' subjects.

SECTION 2: THE CERVICAL SPINE

CHAPTER 11

11.1 LITERATURE REVIEW

In 1928 Wilson and Cochrane found that the widest range of movement in the human spine occurred in the cervical region with the occipito-atlantal joints allowing motion in the anteroposterior plane and rotation being effected by the atlanto-axial articulations. Lateral bending was purported to occur mainly in the mid cervical spine, with flexion and extension being the primary movements in the lower cervical spine.

Methods of assessing cervical spinal motion include, amongst others; CT scans (Penning and Wilmink, 1987; Dvorak *et al*, 1987), radiography (Mimura *et al*, 1989), goniometers (Buck *et al*, 1959; Alund and Larson, 1990), and visual examination (Youdas *et al*, 1991) each with its own intrinsic merits and demerits. Radiography has been described as being the most accurate and objective technique for measuring joint motion (Mimura *et al*, 1989), the time, expense and problems that may be incurred due to exposure to radiation however prohibit this method from being used extensively and would exclude it from being generally used in assessing the outcome of treatments for patients. In general 'Normal' subjects not requiring treatment but who were intended to be used in a 'Normal' data base would not be assessed using this method especially if a large number were required for testing for reasons already given.

The universal goniometer currently appears to be the most widely used instrument in physiotherapy departments. It enables measurements to be obtained quickly and without discomfort to the patient and has none of the inherent drawbacks of radiographic techniques. Although the goniometer is used extensively its reliability when measuring cervical spinal motion has not been looked at in any great detail. Tucci *et al* (1986) found poor reliability when measuring all motions except extension (correlation coefficient -0.08 - +0.60). In another study conducted by Youdas *et al* (1991), measurements obtained by the same therapist on more than one occasion had an intraclass correlation coefficient (ICC) greater than 0.80. However when measurements were made by different physiotherapists the ICC was less than 0.80 (range 0.54 - 0.79) which indicated poor reliability if measurements were to be made by more than one tester.

The main disadvantage of using the methods outlined above is that they cannot monitor motion in three-dimensions. Cervical spine motion is known to be a complex movement with coupling of motion in two or more planes and it is therefore important to be able to measure motion in three dimensions if we want to get an accurate picture of motion in this area.

Measuring cervical spinal motion using the Isotrak system of measurement has, as far as is known, only been described in two papers. Chao *et al* (1989) monitored thirty 'normal' subjects with the sensor placed on the subjects forehead and the source fastened to the trunk. They found that women had a larger range of motion than males and that age had a significant effect on neck movement. They also found coupling to occur between lateral bend and axial rotation. Details of the exact source positioning and exact amounts of coupling associated with each movement were not given.

Another study conducted by Trott *et al* (1991) in which thirty subjects aged 20 to 29 years were monitored also showed coupling of movements although no significant differences in range of movement for males or females was observed. In Trotts' study the sensor was again placed on the forehead of the subject and the source was this time placed over the C7 spinous process.

Movement in the cervical spine differs significantly from that in the lumbar spine due to many differences including vertebral configuration, differences in musculature, ligaments and disc height. According to Fick (1911) the fact that the cervical disc is relatively high compared to its surface explains why cervical range of motion is large compared with other areas of the spine.

In order to understand the complex motion of the cervical spine it is necessary to look at the cervical spine in two sections ie. the upper and lower portions:

11.1.1 Upper cervical spine

The upper section of the cervical spine consists of the occiput, atlas and the odontoid process of the axis. Movements allowed in this section include flexion and extension, lateral bend, axial rotation, vertebral approximation and lateral gliding (Hohl 1964). Based on the values given by White and Panjabi (1978) from a review of literature, approximately 13^{o} flexion and extension and 8^{o} of lateral bending are allowed at the atlanto-occipital joint. Axial rotation at this joint is negligible with the atlanto-axial joint allowing approximately 10^{o} flexion/extension and approximately 47^{o} of axial rotation.

C1 and C2 differ in shape from the vertebrae of C3 to C7. In place of the body of C1 (the atlas), the odontoid process projects upwards from the body of C2 (the axis) forming the pivot joint needed for rotation of the head. The posterior arch of the atlas is much larger than the other arches and allows for cord movement in this area.

The two movements observed in the cervical spine which are not observed in the lumbar spine are vertebral approximation and lateral gliding. Vertebral approximation occurs due to the fact that the joint surfaces between the atlas and axis are bi-convex and appears as an apparent increase in neck length. In the neutral position the high points of both joint surfaces are in contact whereas in maximum rotation the low points of both joint surfaces are in contact.

Lateral gliding is associated with lateral bending of the head, and occurs when there is 10 - 15 degrees of atlanto-axial rotation combined with lateral tilting of the atlas on the axis. 'With lateral gliding the odontoid process appears asymmetrically placed between the lateral masses of the atlas, the articular surfaces appear to be offset 2 - 4mm and usually the joint spaces narrowed in normal subjects' (Hohl, 1964).

At least 50% of all rotational movement of the cervical spine occurs at the atlanto-axial joint due to the fact that there is no intervertebral disc, and also because of the shape of the articular facets in this region. Limitation of rotation in this region occurs primarily due to restriction caused by the alar ligaments at the extremes of motion (Crisco *et al*, 1991). In a study by Mimura *et al* (1989) 70% of the total axial rotation in the cervical spine was found to occur between the occiput and C2, whilst each segment between C2 and C7 showed 4 - 8^{o} rotation on average.

11.1.2 Lower cervical spine

The lower cervical spine reaches into the upper portion by means of the odontoid process, and it connected to the occiput with strong occipito odontoid ligaments.

From a study conducted by Penning (1978) in which flexion and extension were monitored using the superimpositioning of two films it was shown from a posterior view that the spinous process of C2 takes a central position in the cervical region with muscles radiating in all directions.

All sections in the lower portion of the cervical spine (C2 - C7) exhibit the same type of movement due to the fact that the vertebrae and connecting muscles and ligaments are not significantly different between adjacent vertebral structures.

Whilst the muscles in the upper cervical region from C2 upwards have a specialised arrangement the muscles in the lower region are interwoven This means each muscle may activate several levels at one time causing this section of the cervical spine to operate as a single unit. The majority of lateral bending occurs between C2 and C7 and a large proportion of the rotational movement occurs in this section of the cervical spine (although 50% of rotation occurs at the atlanto-axial joint). Rotation in this area is limited by the intervertebral disc and articular facet joints.

In order to understand why the cervical spine moves as it does it is necessary to have at least a basic knowledge of the musculature and ligaments which play a significant role in allowing and limiting motion.

11.2 MUSCULATURE

Muscles and ligaments allow the following movements:

Flexion: Sternocleidomastoid (anterior fibres), longus capitis, longus colli, rectus capitis anterior, (scalenus anterior, rectus abdominis and psoas major).

Extension: Splenius capitis and cervicis, semispinalis capitis and cervicis, longissimus capitis and cervicis, trapezius, interspinalis, rectus capitis posterior major and minor, obliquus capitis superior and sternocleidomastoid (posterior fibres).

Lateral bending and axial rotation: splenius cervicis and cervicis, scalenie, sternocleidomastoid, longissimus capitis, levator scapulae, longus colli, iliocostalis cervicis, multifidi, intertransversarii, obliquus capitis inferior and superior, rectus capitis lateralis.

Axial rotation is also affected by alar ligaments, tectorial membrane capsular ligament, anterior longitudinal ligament, accessory atlanto-axial ligament and possibly the transverse ligament.

In a paper by Snijders *et al* (1991) in which a biomechanical model for the analysis of movement in the cervical spine was assessed it was stated that in lateral bending the m sternocleidomastoideus is active, and when lateral bending is greater than 16^{o} the m rectus capitus is used to prevent the head from rotating backwards.

When the head is rotated the centre of gravity stays at the ventral side of the atlanto occipital joint.(Snijders *et al*, 1991). When rotating to the left by less than 35^o the muscle force of the right m trapezius muscle is increased which is countered by an almost equal decrease in the left m trapezius muscle force. The force is in the vertical direction, and at this stage only a small force from the sternocleidomastoid muscle is required to balance the head. It is not possible to increase rotation to greater than 35^o purely by using the right and left trapezius muscles, and at this stage the right sternocleidomastoid muscle is required (for rotation to the left). The left sternocleidomastoid muscle is also needed at this stage to balance the head in the frontal plane causing joint reaction forces to quickly increase.

Limitation of movement at the atlanto-axial joint is due primarily to the alar ligaments. In a paper by Crisco *et al* (1991) a model of the role of the alar ligaments was developed which predicted that a significant percentage of rotation at the atlanto-axial joint could occur without ligamentous resistance.

In Snijders study (Snijders *et al*, 1991) the following conclusions were reached:

1. In flexion the muscle forces and joint reaction forces increase except the force between the odontoid and ligamentum transversum atlantis (which is minimum during moderate flexion)

2. Joint reaction forces at levels C_0 - C_1, C_1 - C_2 and C_7 - T_1 reach

minimum values during extension, although all at different times.

3. Axial rotation $< 35^{o}$ does not need great muscle forces but $> 35^{o}$ causes muscle forces and joint reaction forces to increase fast.

4. In lateral flexion muscle forces and joint reaction forces increase rapidly in order to balance the head.

Previous studies and knowledge of the complex manner in which the cervical spine moves make it evident that monitoring motion in three-dimensions is important and may be particularly useful when assessing patients with various cervical spinal disabilities. The aims of this section of the study were to therefore:

1. Build up a data base of the 'Normal' range and pattern of movement in the cervical spine and to assess how movement altered with age and sex.

2. To assess a group of patients with ankylosing spondylitis in order to see how movement varied depending on the extent of involvement.

11.3 METHOD

In Chao *et al* (1989) and Trott *et al's* (1991) studies, the sensor was attached to the subjects forehead with the source attached to the trunk or C7 respectively. In the studies conducted in this section, the sensor and source were initially attached using this configuration. Large errors in coupled movements were observed however when the primary movement of extension was conducted. After checking that there were no errors in the computer program which might cause this fault, and checking that the sensor was not working outside the operative hemisphere it was confirmed with another two users of the Isotrak that they were observing the same pattern with their machines. It therefore appeared that the Isotrak was not able to work as effectively with this particular orientation of sensor and source, and indeed when looking at the results obtained by Trott *et al* (1991) for the coupled movements of lateral bend on extension in which an average coupled movement of $13.2^{o} \pm 22.1^{o}$ was obtained, it appears that the same phenomenon was occurring there. Visual examination showed that 'normal' subjects did not tend to deviate laterally by more than a few degrees when extending their necks.

It was found that it was impossible to position the source over the C7 spinous process without causing the subjects extension movement to be restricted due to source size. After a number of trials using different methods to fix the source and sensor securely to the subject, a method was devised by which the source was fixed to the base of the cervical region so that it overlay T2. The sensor was attached to the back of the skull (fig. 11.1). By using this method none of the subjects tested felt that their range of movement was limited. Also because the sensor was light weight its fixation to the back of the head did not cause pulling on the neck when the subject performed any movement. Due to the size of the source it was not possible to place it any higher without causing restriction of movement in extension.

Subjects were asked to perform the movements of flexion and extension,

Figure 11.1 - Attachment of source and sensor when measuring cervical motion

left and right lateral bend and left and right axial rotation, each complete movement again taking a time period of 10 seconds.

One potential problem was that of determining a subjects neutral position. When reviewing the literature the neutral position was not

Figure 11.1 - Attachment of source and sensor when measuring cervical motion

left and right lateral bend and left and right axial rotation, each complete movement again taking a time period of 10 seconds.

One potential problem was that of determining a subjects neutral position. When reviewing the literature the neutral position was not always clearly defined with Penning (1978) stating that the lower margin of the orbita should lie in the same horizontal plane as the external auditory meatus, whilst others stated that the subject should assume a comfortable position or a 'natural position' (Dittmar, 1931; Buck *et al*, 1959), and others did not state the neutral position at all (Kottke and Mundale, 1959). In order to determine how well individual subjects could resume their neutral positions, and how reproducible results were seven subjects were monitored on one occasion and asked to perform each of the movements twice. A further five subjects were monitored on three separate occasions, one week apart, in order to assess reproducibility over a longer time interval. The results of these tests are given in Chapter 12.

When performing each movement subjects were asked to try to make them as 'pure' as possible eg. when performing the movement of left lateral bend subjects were asked to try to bend their left ear towards their left shoulder without moving their trunk and trying not to rotate at the same time. For the movement of axial rotation subjects were asked to rotate as far to the left and right sides as possible keeping their chin on a level in order to ensure that any accompanying lateral bending was kept to a minimum.

The reason for asking subjects to move in this manner was that it was found that if subjects were asked to move without any verbal encouragement to keep the movement as pure as possible, a number moved with an exaggerated coupled movement which would not have given a true indication of the coupling between lateral bend and axial rotation. Asking subjects to move in this manner also gave a clearer indication of how well subjects were able to control each movement which was important when taking readings for patients with known cervical spine problems when muscle function and vertebral function were often altered or impaired.

All movements were repeated twice in succession as this was found to give good reproducibility of results without causing fatigue in the subject (Chapter 12). Figures 11.2 - 11.4 demonstrate the type of movement patterns that were observed in the 'normal' cervical spine.

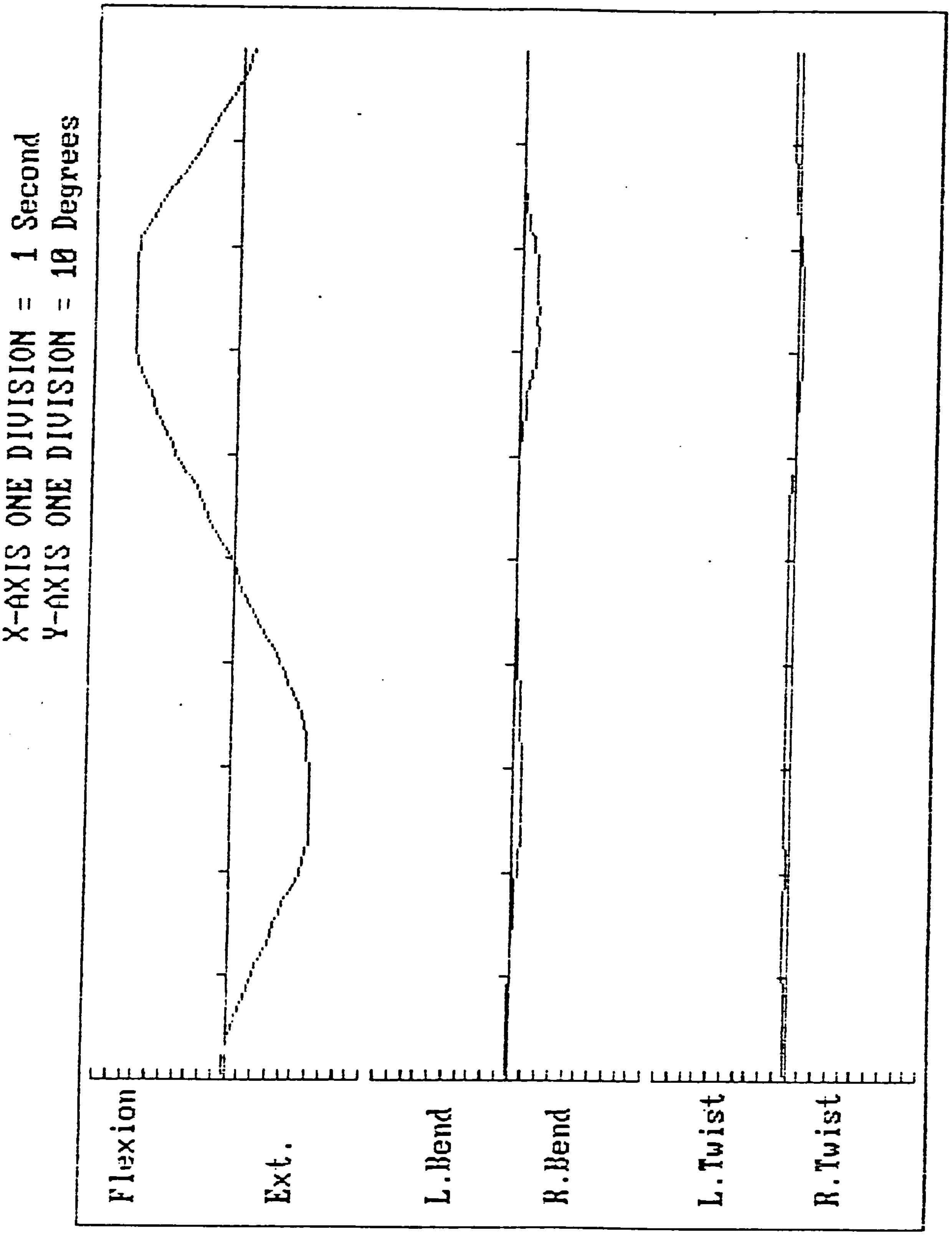


Figure 11.2- - Subject performing the primary movement of flexion and extension

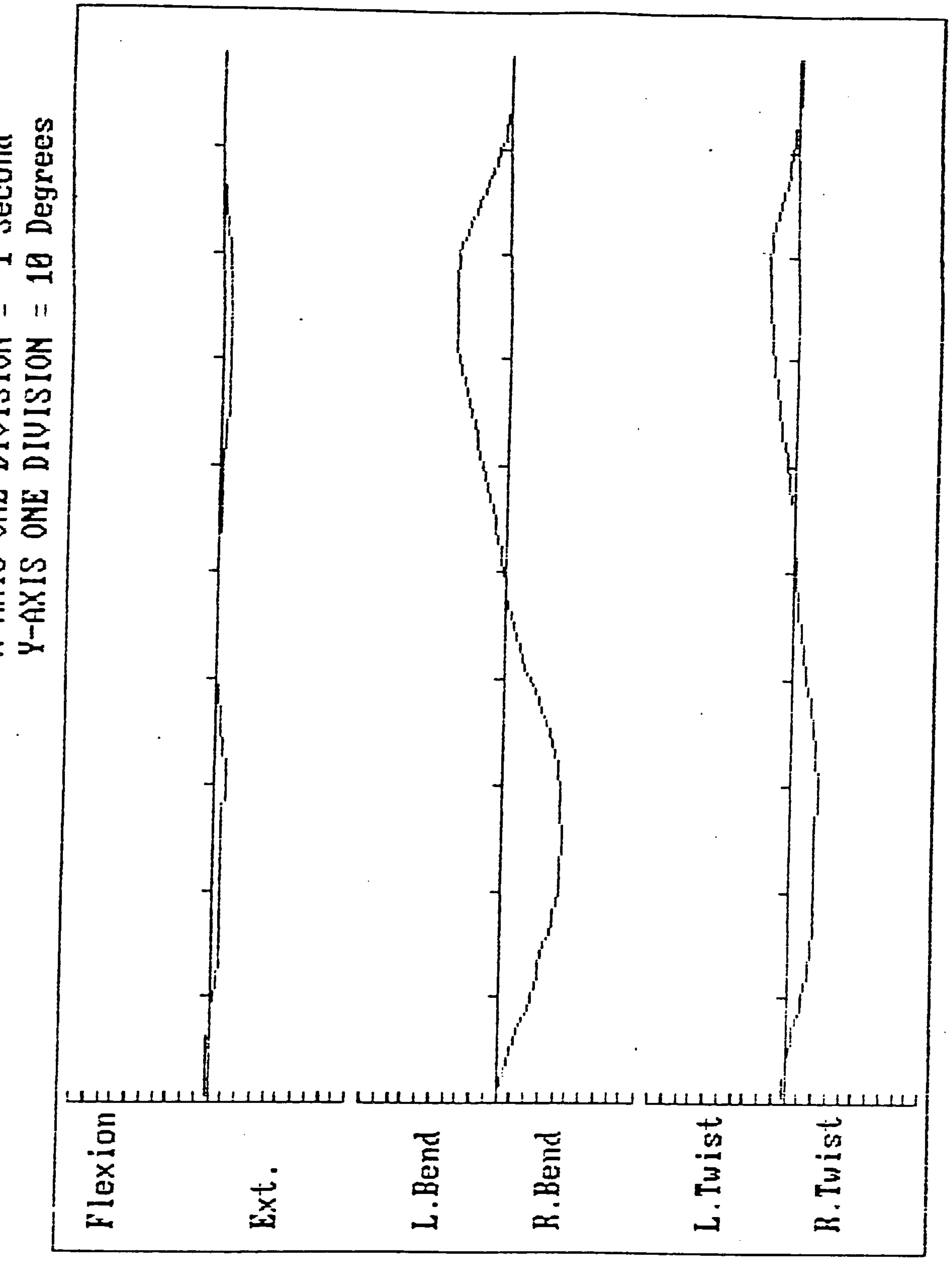


Figure 11.3- - Subject performing the primary movement of lateral bend

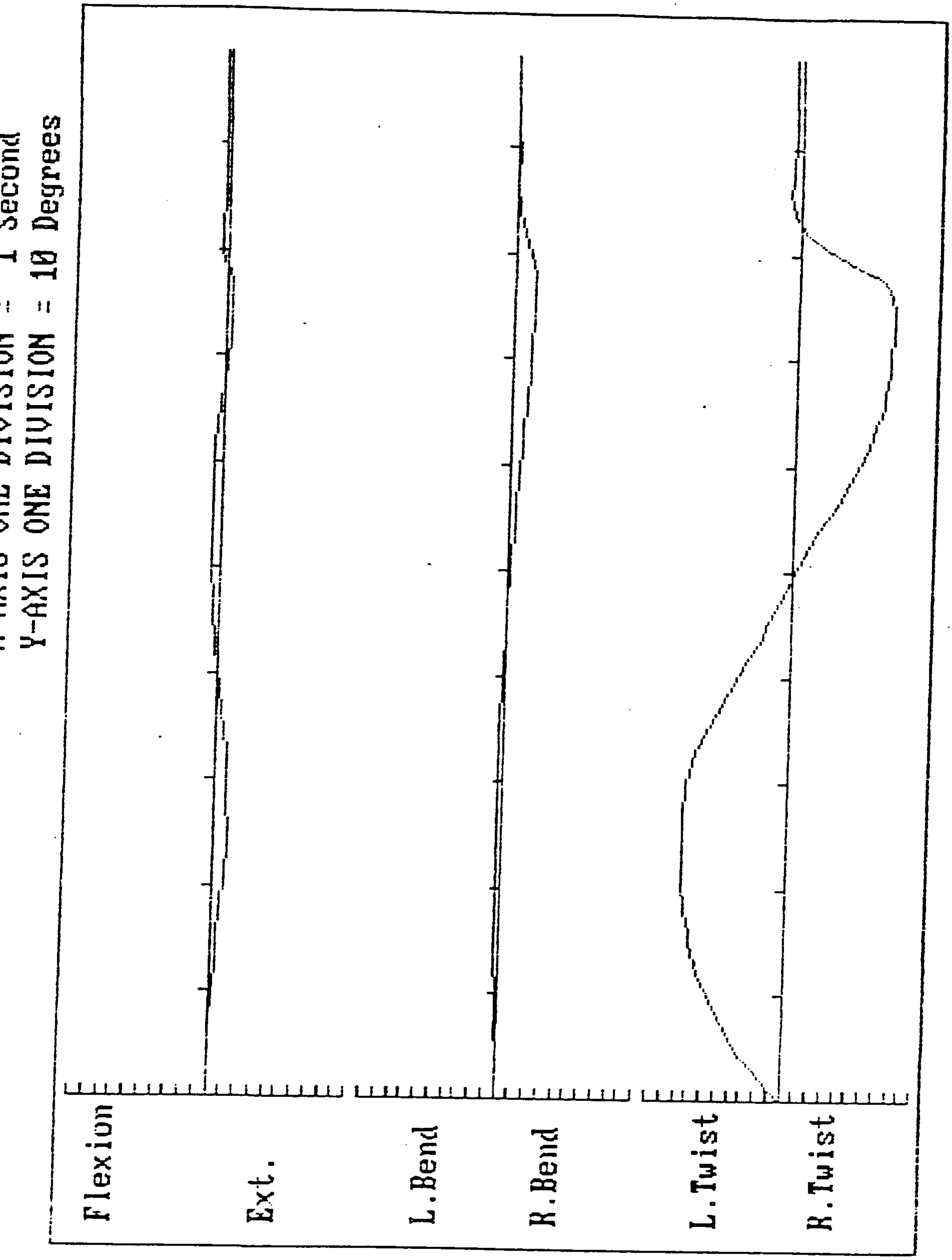


Figure 11.4-- Subject performing the primary movement of axial rotation

CHAPTER 12

NORMAL PATTERN AND RANGE OF MOVEMENT IN THE CERVICAL SPINE

12.1 INTRODUCTION

The aim of this section of the study was to build up a data base of the range and pattern of movement in the 'Normal' cervical spine and to assess how age and gender affected mobility.

12.2 METHOD

Measurements were obtained using the method given in Chapter 11. Three studies were conducted in this section. The first assessed the repeatability of the method used by monitoring a group of seven subjects on one occasion and asking them to perform the movements of flexion, extension, lateral bend and axial rotation twice in succession. This was conducted in order to determine how easily subjects were able to resume a neutral position, and to help determine the number of times a subject would need to repeat a given movement to ensure that consistent results were being obtained without causing fatigue.

Once this study had been conducted a further five subjects were monitored on three separate occasions, with a time interval of one week between tests. This study was conducted in order to assess reproducibility over a longer time interval, and would include any errors that might occur due to sensor misplacement.

Once the repeatability studies had been conducted one hundred and thirty-five subjects who did not suffer from cervical spinal problems were assessed using the method in Chapter 11. Subjects were split into groups categorised by age and sex.

Due to the fact that a large number of subjects were being tested it was not feasible to obtain X-rays to confirm normality. Subjects were therefore considered to be 'Normal' if they had never suffered from an abnormally stiff neck which required medical treatment, or which lasted for a period of more than a few days. Any patient who had suffered from lumbar or thoracic spine problems requiring medical treatment was also excluded from the study. Experience from 'back school' clinics has shown that a significant number of patients who require treatment for spinal problems in the lumbar region often present again after a number of years as they start experiencing problems including restriction of movement in the cervical region. This is thought to be due, in many cases, to altered posture, muscle tone etc. caused by the original problem.

12.3 ANALYSIS OF DATA

Data were analysed using the students t-test, paired t-test, chi-squared and regression analysis where appropriate. Significance was taken to be at $P < 0.05$ unless otherwise stated.

12.4 RESULTS

12.4.1 Reproducibility

The results for the seven subjects who were tested twice in succession have been given in Table 12.1. The results given are the standard

TABLE 12.1

REPRODUCIBILITY OF CERVICAL RESULTS MEASURED TWICE IN SUCCESSION :- ± s.d.

SUBJECT NO.	EXT/FLEX (± s.d.)	COUPLED BEND ON EXT/FLEX (± s.d.)	COUPLED ROT. ON EXT/FLEX (± s.d.)
1	4.2 / 2.1	3.5 / 0.7	1.4 / 0.7
2	4.2 / 2.1	1.4 / 0.0	3.5 / 0.7
3	1.4 / 4.2	2.1 / 1.4	0.0 / 1.4
4	2.8 / 2.8	7.8 / 1.4	0.7 / 0.7
5	0.7 / 0.7	0.0 / 3.5	1.4 / 2.1
6	4.2 / 0.7	2.8 / 0.7	0.0 / 2.1
7	0.0 / 3.5	2.1 / 4.9	0.7 / 4.9
SUBJECT NO.	L/R LAT. BEND (± s.d.)	COUPLED F/E ON L/R BEND (± s.d.)	COUPLED ROT. ON L/R BEND (± s.d.)
1	3.5 / 5.7	0.0 / 2.1	0.0 / 2.1
2	1.4 / 0.7	13.4 / 16.3	6.4 / 1.4
3	2.1 / 2.1	2.8 / 0.7	0.7 / 2.8
4	0.7 / 4.9	6.4 / 4.2	0.0 / 7.8
5	2.1 / 2.8	6.4 / 2.1	0.0 / 3.5
6	7.8 / 0.7	2.8 / 6.4	0.0 / 0.7
7	1.4 / 2.1	0.0 / 5.7	0.0 / 7.8
SUBJECT NO.	L/R AXIAL ROTATION (± s.d.)	COUPLED F/E ON L/R ROT. (± s.d.)	COUPLED BEND ON L/R ROT. (± s.d.)
1	0.7 / 1.4	0.0 / 4.2	1.4 / 4.2
2	4.2 / 4.2	9.9 / 4.2	4.2 / 9.9
3	4.2 / 7.1	2.8 / 2.8	4.2 / 4.2
4	4.2 / 0.7	0.7 / 2.8	1.4 / 0.7
5	0.7 / 0.7	3.5 / 4.9	1.4 / 1.4
6	4.2 / 2.8	1.4 / 7.1	2.8 / 5.7
7	1.4 / 6.4	7.8 / 1.4	3.5 / 4.9

deviation on the mean of the two maximum values obtained. Five of the subjects tested were female and 2 were male. Age range was 20 - 47 years. Since it is important for *coupled motion* to be as consistent as possible when monitoring motion in three-dimensions, results of the standard deviations for each of the coupled movements have also been given.

Table 12.1 shows that in general, subjects were able to reproduce movements quite accurately. Exceptions to this included the results from subject no. 2 who when performing the movement of lateral bend appeared able to achieve the maximum primary movement of left and right accurately, but moved differently on each occasion to achieve that position.

Asking subjects to repeat each movement more than twice did not result in more accurate results, but did cause fatigue in the subject. For this reason, subjects in all further studies were only asked to repeat each movement twice.

The errors incurred when repeating tests on five female subjects (age range 29 - 49) on three separate occasions have been given in Table 12.2. The standard deviations were again calculated on the mean of the results obtained on each occasion.

The results from Table 12.2 again show repeatability to be fairly good. The most easily repeated, and therefore most accurate movement performed appeared to be that of lateral bend (including coupled movements). When performing the movement of axial rotation some subjects appeared to have difficulty in repeating the movement by moving their heads in the same manner, although they achieved a good level of accuracy in the primary movement.

TABLE 12.2

REPRODUCIBILITY OF CERVICAL RESULTS MEASURED ON THREE SEPARATE OCCASIONS

SUBJECT NO.	EXT/FLEX (± s.d.)	COUPLED BEND ON EXT/FLEX (± s.d.)	COUPLED ROT. ON EXT/FLEX (± s.d.)
1	8.0 / 3.2	1.5 / 6.4	3.0 / 3.6
2	4.2 / 1.0	6.7 / 2.1	17.9 / 11.5
3	2.5 / 3.5	6.7 / 1.5	5.7 / 1.5
4	4.4 / 6.8	2.1 / 0.0	2.3 / 5.3
5	1.7 / 3.5	3.8 / 2.3	1.0 / 4.0
SUBJECT NO.	L/R LAT. BEND (± s.d.)	COUPLED F/E ON L/R BEND (± s.d.)	COUPLED ROT. ON L/R BEND (± s.d.)
1	0.6 / 3.1	5.1 / 3.8	1.7 / 3.8
2	3.2 / 4.4	2.6 / 0.0	1.2 / 0.6
3	0.7 / 4.9	4.9 / 3.5	0.0 / 1.4
4	4.9 / 3.5	2.9 / 3.1	7.2 / 2.6
5	3.0 / 2.9	7.5 / 2.5	3.1 / 1.0
SUBJECT NO.	L/R AXIAL ROTATION (± s.d.)	COUPLED F/E ON L/R ROT. (± s.d.)	COUPLED BEND ON L/R ROT. (± s.d.)
1	5.3 / 2.1	10.4 / 8.5	5.3 / 2.1
2	6.4 / 5.0	2.5 / 5.0	4.5 / 6.2
3	2.6 / 5.3	7.5 / 11.2	13.7 / 7.0
4	2.0 / 1.5	6.1 / 3.0	1.0 / 4.6
5	1.7 / 2.3	4.6 / 6.7	6.5 / 7.5

The margin of error obtained from these tests was incorporated into the results obtained in the collection of the 'Normal' data.

From the results obtained from these two studies it appeared that subjects were generally able to assume the same starting 'neutral' position on a number of occasions. The neutral position was therefore defined to be the most comfortable position for the subject, and the position which they assumed when sitting straight.

12.4.2 Effect of age and gender on cervical spine motion

Details of the one hundred and thirty-five subjects tested in this section are given in Table 12.3.

TABLE 12.3

SUBJECT DETAILS

AGE GROUP	MALES			FEMALES		
	NO.	MEAN	SD	NO.	MEAN	SD
18 - 29	14	26.5	2.3	17	24.6	2.5
30 - 39	18	35.3	2.7	15	33.9	3.5
40 - 49	16	44.5	2.9	19	43.4	2.0
50 - 66	15	55.0	4.6	21	53.1	2.2

Results of the maximum primary movements obtained for male and female groups together with the accompanying secondary movements are given in Tables 12.4 - 12.9. Significant differences between groups were calculated using t-test statistics.

Tables 12.4 - 12.9 give the measurements as mean values ± sd. Negative coupled values indicate left bend or rotation, positive coupled values indicate right bend or rotation. *, + and - indicate significant differences between groups ($P < 0.05$)

TABLE 12.4

PRIMARY FLEXION AND EXTENSION:- MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	FLEXION	LAT. BEND	AXIAL ROT.
18 - 29	62.6 ± 8.3 *+-	1.1 ± 9.6	3.0 ± 8.1
30 - 39	52.9 ± 10.6 -	0.8 ± 6.4	*-2.5 ± 6.9
40 - 49	52.7 ± 6.2 *	-1.8 ± 6.0	-0.3 ± 8.2
50 - 66	52.3 ± 8.8 +	-2.7 ± 5.2	* 2.7 ± 5.0
	EXTENSION	LAT. BEND	AXIAL ROT.
18 - 29	61.6 ± 10.2 *-	5.4 ± 11.9	-1.4 ± 8.9
30 - 39	54.6 ± 10.5	-0.9 ± 10.9	2.2 ± 7.7
40 - 49	53.5 ± 10.3 -	0.9 ± 10.0	-0.1 ± 8.1
50 - 66	50.7 ± 6.9 *	5.4 ± 7.6	-1.5 ± 5.2

TABLE 12.5

PRIMARY FLEXION AND EXTENSION:- FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	FLEXION	LAT. BEND	AXIAL ROT.
18 - 29	59.4 ± 8.1 *	-0.5 ± 6.4	1.8 ± 6.4
30 - 39	57.7 ± 10.0	-0.1 ± 7.3	1.3 ± 6.2
40 - 49	55.5 ± 9.6	-1.8 ± 7.6	1.7 ± 6.9
50 - 66	52.5 ± 9.5 *	2.0 ± 5.2	0.9 ± 6.0
	EXTENSION	LAT. BEND	AXIAL ROT.
18 - 29	61.1 ± 9.0	-2.7 ± 10.3	1.6 ± 8.5
30 - 39	65.1 ± 11.7 *	* 1.9 ± 9.8	0.3 ± 8.2
40 - 49	61.6 ± 13.3	+ 2.0 ± 9.5	-0.3 ± 8.0
50 - 66	56.6 ± 9.0 *	+*-5.6 ± 9.2	0.2 ± 6.4

TABLE 12.6

PRIMARY LATERAL BEND:- MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	42.1 ± 10.2 *	-5.9 ± 6.5	-8.3 ± 13.0
30 - 39	38.7 ± 5.1 $^{+}$	-6.3 ± 8.3	-11.2 ± 10.9
40 - 49	40.4 ± 9.6 $^{-}$	-7.8 ± 12.3	-7.6 ± 12.8
50 - 66	34.0 ± 6.9 $^{*+-}$	-6.5 ± 8.0	-11.1 ± 12.9
	LEFT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	45.3 ± 6.5 $^{*+-}$	-6.7 ± 8.0	8.6 ± 9.3
30 - 39	38.8 ± 5.2 *	-9.0 ± 6.3	11.8 ± 10.9
40 - 49	38.4 ± 8.5 $^{+}$	-7.5 ± 12.7	8.9 ± 11.8
50 - 66	36.8 ± 6.3 $^{-}$	-8.6 ± 10.9	10.2 ± 11.5

TABLE 12.7

PRIMARY LATERAL BEND:- FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	44.9 ± 9.1	-7.8 ± 9.1	-5.4 ± 11.9
30 - 39	45.6 ± 7.3	-7.8 ± 7.6	-9.5 ± 11.7
40 - 49	44.1 ± 9.1	-2.2 ± 13.9	-8.4 ± 6.7
50 - 66	41.5 ± 5.7	-5.0 ± 9.8	-10.8 ± 14.1
	LEFT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	43.6 ± 5.5	-5.0 ± 8.6	5.4 ± 11.8
30 - 39	42.7 ± 5.6	-4.9 ± 6.7	12.6 ± 10.0
40 - 49	42.5 ± 7.1	-4.4 ± 10.3	7.9 ± 11.1
50 - 66	40.1 ± 5.4	-0.9 ± 10.2	7.3 ± 12.4

TABLE 12.8

PRIMARY AXIAL ROTATION:- MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	75.8 ± 7.7 *+	0.4 ± 12.9	4.1 ± 12.9
30 - 39	72.3 ± 8.7	-7.3 ± 13.9	2.3 ± 17.3
40 - 49	67.4 ± 10.2 *	2.5 ± 13.0	7.4 ± 14.8
50 - 66	69.8 ± 6.0 +	0.1 ± 9.8	6.3 ± 13.4
	LEFT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	79.1 ± 9.4 *+	-5.6 ± 11.5	-8.9 ± 14.8
30 - 39	70.8 ± 9.8 *	-7.4 ± 15.0	-2.9 ± 13.2
40 - 49	71.8 ± 10.3	-1.0 ± 11.3	-8.6 ± 14.8
50 - 66	70.5 ± 9.0 +	-3.5 ± 9.8	-6.5 ± 14.7

TABLE 12.9

PRIMARY AXIAL ROTATION:- FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	68.8 ± 7.3 *	-6.5 ± 13.1	-4.8 ± 16.9
30 - 39	75.9 ± 6.5 *+	-9.5 ± 12.9	-2.3 ± 14.3
40 - 49	71.8 ± 7.6	-12.4 ± 16.5	-9.5 ± 18.1
50 - 66	67.2 ± 11.7 +	-12.8 ± 11.5	-12.3 ± 15.4
	LEFT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	71.4 ± 9.5 *	-7.9 ± 14.5	-0.5 ± 21.4
30 - 39	76.5 ± 7.4 +-	-8.1 ± 13.4	2.5 ± 17.8
40 - 49	70.4 ± 9.8 +=	-12.4 ± 12.9	7.4 ± 16.3
50 - 66	63.8 ± 8.0 *-=	-12.6 ± 11.4	9.8 ± 13.6

Since no significant differences were found to exist between left and right lateral bend and left and right axial rotation movements were combined. Table 12.10 gives the results of combined primary movements for male and female groups.

TABLE 12.10

COMBINED PRIMARY MOVEMENTS

AGE GROUP	PRIMARY MOVEMENT		
	FLEX/EXT	LAT. BEND	AXIAL ROT.
FEMALE			
18 - 29	120.4 ± 11.0 *	*88.5 ± 10.2	140.2 ± 15.4 *
30 - 39	122.7 ± 14.0 -	88.3 ± 10.5	152.4 ± 12.1 /=*
40 - 49	117.1 ± 15.5	86.6 ± 15.0	142.2 ± 14.6 =-
50 - 66	109.1 ± 11.6 *-	*81.6 ± 9.6	131.0 ± 16.8 /-
MALE			
18 - 29	124.2 ± 13.2 *-/	*87.4 ± 15.0	154.9 ± 15.5 *+
30 - 39	106.2 ± 13.5 *	+78.0 ± 9.2	144.4 ± 16.6
40 - 49	106.2 ± 13.8 -	78.8 ± 17.3	139.2 ± 17.2 *
50 - 66	101.4 ± 12.3 /	+*68.7 ± 13.0	139.1 ± 12.3 +

*, -, /, =, denote significant differences between age groups in either the male or female groups tested. For example females in the 18 - 29 age group have significantly more flexion/extension and lateral bend than females in the 50 - 66 age group.

Table 12.11 gives the significant differences between male and female age groups tested.

TABLE 12.11

SIGNIFICANT DIFFERENCES FROM T-TESTS BETWEEN MALE AND FEMALE GROUPS

PRIMARY MOVEMENT	AGE GROUP	SIGNIFICANT DIFFERENCE	SIGNIFICANT MOVEMENT
EXTENSION	30 - 39 50 - 66 50 - 66	F > M F > M M > F	EXTENSION EXTENSION COUPLED BEND
FLEXION	50 - 66	F > M	COUPLED BEND
FLEXION + EXTENSION	30 - 39 40 - 49	F > M F > M	FLEX + EXT FLEX + EXT
R. LATERAL BEND	30 - 39 50 - 66	F > M F > M	R. BEND R. BEND
L. LATERAL BEND	50 - 66	M > F	COUPLED F/E
L + R LATERAL BEND	30 - 39 50 - 66	F > M F > M	L + R BEND L + R BEND
R. AXIAL ROTATION	20 - 29 40 - 49 50 - 66	M > F M > F M > F M > F M > F	R. ROTATION COUPLED F/E COUPLED BEND COUPLED F/E COUPLED BEND
L. AXIAL ROTATION	20 - 29 40 - 49 50 - 66	M > F M > F M > F M > F F > M	L. ROTATION COUPLED F/E COUPLED BEND COUPLED F/E COUPLED BEND
L + R ROTATION	20 - 29 50 - 66	M > F M > F	L + R ROTATION L + R ROTATION

In order to assess the extent of coupling between movements chi-squared analysis was conducted (Table 12.12)

TABLE 12.12

CHI-SQUARED ANALYSIS ON COUPLING OF MOVEMENTS IN MALE AND FEMALE GROUPS TESTED

(analysis between +ve and -ve values obtained)

COUPLED MOVEMENTS	SEX	SIGNIFICANCE	+ VE %	- VE %	ZERO %
Bend on Ext.	M F	NS NS	49.2 34.7	31.7 48.6	19.1 16.7
Twist on Ext	M F	NS NS	50.8 41.7	41.3 47.2	7.9 11.1
Bend on Flexion	M F	NS NS	36.5 40.3	42.9 37.5	20.6 22.2
Twist on Flexion	M F	NS NS	42.9 47.2	41.3 33.3	15.8 19.5
Flex/Ext on R. Bend	M F	$P < 0.0005$ $P < 0.0005$	15.9 22.2	**76.2** **69.4**	7.9 8.4
Flex/Ext on L. Bend	M F	$P < 0.0005$ $P < 0.025$	14.3 30.6	**79.4** **55.6**	6.3 13.8
Twist on R. Bend	M F	$P < 0.0005$ $P < 0.0005$	17.5 16.7	**76.2** **80.6**	6.3 2.7
Twist on L. Bend	M F	$P < 0.0005$ $P < 0.0005$	**77.8** **73.6**	14.3 19.5	7.9 6.9
Flex/Ext on R Twist	M F	NS $P < 0.0005$	39.7 12.5	54.0 **77.8**	6.3 9.7
Flex/Ext on L Twist	M F	$P < 0.005$ $P < 0.0005$	25.4 16.7	**63.5** **80.6**	11.1 2.7
Bend on R. Twist	M F	NS $P < 0.0005$	50.8 20.8	30.2 **69.4**	19.0 9.8
Bend on L. Twist	M F	$P < 0.0005$ $P < 0.0005$	27.0 **63.9**	**61.9** 25.0	11.1 11.1

N.B. Significance has been taken to be at $P < 0.05$

Negative values imply extension, right lateral bend or axial rotation.

Positive values imply flexion, left lateral bend or axial rotation.

Zero: Implies a reading of ± 1 or 0 was obtained.

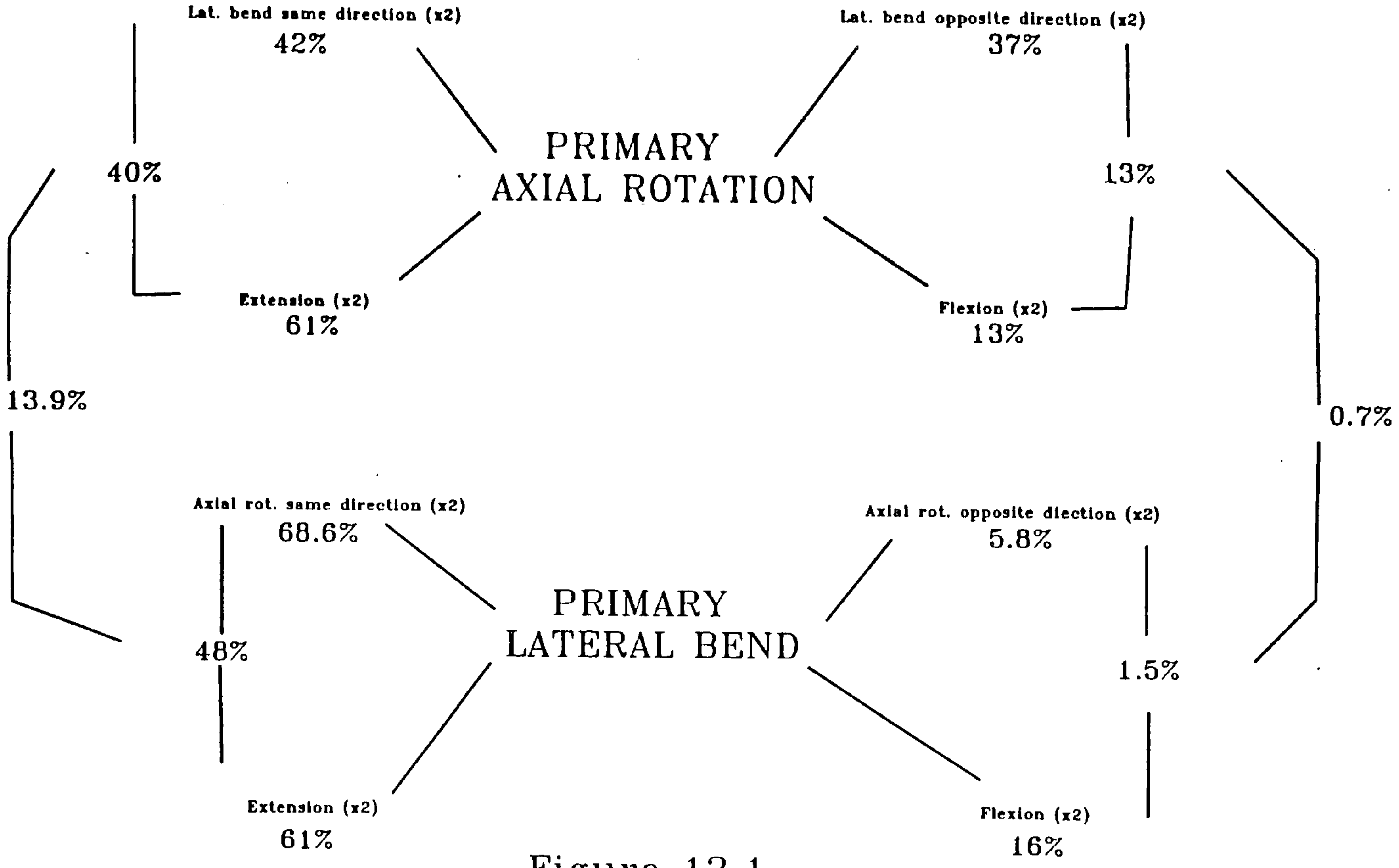
In order to determine the relative numbers of subjects who exhibited motion patterns which might be expected as the 'norm' (Mimura *et al*; 1989), figure 12.1 was constructed. This figure shows that for the primary movement of axial rotation 13% of subjects showed coupling of both flexion and lateral bend in the opposite direction to that expected, whereas 40% had coupling of both extension and lateral bend in the direction that would be expected. For the movement of lateral bend approximately 69% of subjects had coupling of axial rotation in the same relative direction, 48% had both extension and axial rotation (in the same relative direction as the primary movement) and only 1.5% had a combination of flexion and opposite axial rotation on lateral bend.

12.5 DISCUSSION

Two kinds of coupled motion are well known in the cervical spine, (Fielding, 1957; Penning, 1978; White and Panjabi, 1978), namely coupling of axial rotation in the same direction as lateral bending, and coupling of lateral bending in the same direction as axial rotation. Lysell (1969) found a coupled rotation of 28^{o} associated with 45^{o} lateral bending in cadaveric specimens, and an over all average lateral bending of 15.1^{o} when rotating to either the left or right.

In a study by Mimura *et al* (1989) twenty 'normal' men aged between 25 - 31 had the range of rotation in their cervical spine studied using biplanar roentgenograms. It was found that when the head was rotated, lateral bending occurred by coupling in the same direction as rotation at each segment below C3-C4, and in the opposite direction at each segment above C2-C3. Flexion was found to accompany rotation at each segment below C5-C6, whilst extension accompanied rotation at each

COUPLED MOVEMENTS ON LATERAL BEND AND AXIAL ROTATION



x2:.Movement the same
for both left and
right primary motion

Same direction:
Left bend accompanies
left rotation, right
bend accompanies right
rotation etc.

Opposite direction:
Left bend accompanies
right rotation, right
bend accompanies left
rotation etc.

Figure 12.1

level above C4-C5. This finding was seen to be consistent with results obtained by Hayashi *et al* (1983) in which osteophytes were seen to develop posteriorly above the C4-C5 level and anteriorly below the C5-C6 level.

In Mimuras' study axial rotation between the occiput and C2 was found to be approximately 75.2 degrees (70% of total cervical rotation), which was accompanied by $14.0^{o} \pm 5.9^{o}$ extension. Each level below this was found to have an average of between 4.2 and 7.4 degrees of rotation, accompanied by approximately 2 - 3^{o} extension (or flexion, depending on the level assessed). Alund and Larsson (1990) conducted a study in which movement of the cervical spine was monitored using electrogoniometric equipment and found rotation to the left and right to be accompanied by 5 ± 4^{o} and 3 ± 5^{o} of lateral bending respectively, whilst lateral bending to the left and right was accompanied by 22 ± 13^{o} and 26 ± 12^{o} axial rotation respectively.

According to this study, a significant degree of overall extension was seen to accompany the primary movement of axial rotation. From Mimuras' study an overall average extension of 14.6 ± 10.1 degrees might be expected to accompany the primary movement of axial rotation to the left or right. However this study showed there to be an overall coupled extension of 6.3 ± 13.6 degrees to the right and 7.9 ± 12.5 degrees to the left. In Trott *et al's* (1991) study $13.9^{o} \pm 10.6^{o}$ extension accompanied left axial rotation and $14.0^{o} \pm 7.2^{o}$ accompanied right axial rotation. Trotts results appear be more in agreement with those of Mimura *et al* (1989). Movements conducted in this study, unlike those in Trotts study were however designed to make coupled movements a minimum which could explain why smaller values were obtained.

In Mimuras study 15.1 ± 17.3 degrees of lateral bend accompanied axial rotation to either the left or the right compared with values of 8.8 ± 10.6^{0} to the left and 11.3 ± 8.6^{0} to the right from Trotts study, and 1.9 ± 16.4 to the left and 0.2 ± 16.7 to the right from this study.

Comparing the values from this study with those of Alund and Larsson and Trott *et al* for coupled movements on the primary movements of lateral bend and axial rotation gives the following results:

MOVEMENT	THIS STUDY	TROTT ET AL	ALUND & LARSSON
Ext on l. lat bend	5.8 ± 9.6	2.5 ± 6.9	----------
Ext on r. lat bend	6.0 ± 9.8	11.4 ± 9.7	----------
Rot on l. lat bend	8.9 ± 11.0	5.1 ± 9.3	26 ± 12
Rot on r. lat bend	-9.1 ± 11.6	-11.5 ± 7.9	22 ± 13
Ext on l. rot	7.9 ± 12.5	13.9 ± 10.6	----------
Ext on r. rot	6.3 ± 13.6	14.0 ± 7.2	----------
Lat bend on l. rot	-0.2 ± 16.7	8.9 ± 10.6	3 ± 5
Lat bend on r. rot	-1.9 ± 16.4	-11.3 ± 8.6	5 ± 4

N.B. Where results are negative this indicates right axial rotation or lateral bend, positive indicates left axial rotation or lateral bend.

The results from Trotts study and those from this study appear, in general, to give similar results the exceptions being for coupled lateral bend on rotation which was not significant in this study.

In general lateral bending was seen to be coupled with axial rotation to the same side ie. right lateral bending was accompanied by axial rotation to the right which is in agreement with the findings of Chao *et al* (1989), Trott *et al* (1991) and Alund and Larsson 1990). Axial rotation was not found to have any significant degree of coupling other than that of extension.

The results from figure 12.1 imply that lateral bending might be a better clinical indicator than axial rotation of abnormal cervical motion with only 5% of subjects having coupling of axial rotation in the opposite direction to that which would be expected, and 1.5% of subjects exhibiting patterns of both coupled sagittal motion and rotation in the opposite direction to that expected. It does not necessarily follow that 'normal' motion can be defined as lateral bending coupled by extension and axial rotation in the same relative direction, as only 48% of subjects exhibited this pattern, with the others having a combination of coupled extension, flexion and lateral bending movements.

Mean ratio between extension and lateral bend and axial rotation and lateral bend was 0.14 and 0.22 respectively, this corresponds to values obtained by Trott of 0.15 and 0.13. Mean ratio between extension and axial rotation and lateral bend and axial rotation from this study was 0.10 and 0.01 compared with values of 0.18 and 0.13 from Trotts study and 0.28 and 0.29 from Mimuras study. Alund and Larssons result of a ratio of 0.05 between coupled lateral bend on axial rotation does however appear more in agreement with the results of this study. Trotts study also showed that coupling of movement occurred for the primary movements of flexion and extension whereas this study has shown flexion and extension to be pure movements ie. not accompanied by any significant degree of either lateral bending or axial rotation.

In a recent study conducted by Dvorak *et al* (1992) the CA 6000 Spine motion analyser was used to monitor the cervical spines of 150 asymptomatic 'Normal' subjects. Subjects were split into male and female groups which were then sub-divided into age groups (20 - 29, 30 - 39, 40 - 49, 50 - 55, 60+). In the tests passive rather than active movements were analysed as these were seen to give a larger maximum range of motion with smaller associated standard deviations. (Obviously when analysing coupled motion patterns active rather than passive movement would need to be assessed). Dvorak found that the overall tendency was for the range of movement to decrease with age with the most dramatic change being observed between the 30 - 39 and 40 - 49 age groups. He also found women in the 30 - 39 age group to have a greater range of lateral bend than their male counterparts, and that men in the 30 - 49 age groups had a greater range of axial rotation than women in corresponding age groups. In contrast the results from this study, in which active cervical spine motion was monitored, showed women in the 30 - 49 age groups to have significantly more flexion + extension than males, females in the 30 - 39 and 50+ age groups to have a greater range of lateral bend than males, and males in the 20 - 29 and 50+ age groups to have a greater range of axial rotation than females.

This study has been shown to give results for the maximum range of movement in the primary plane of motion of approximately the same order of magnitude as a number of other studies using different methods of monitoring motion in the cervical spine, Table 12.13.

In 1961 Ferlic monitored the range of cervical movement of one hundred and ninety-nine 'normal' subjects between 15 and 74 years of age. He found that the ranges of flexion + extension, lateral bend and axial rotation decreased by approximately 17%, 23% and 15% respectively between the 15 - 24 and 55 - 64 age groups and by approximately 9%, 16% and 11% between the 25-34 and 55-64 age groups compared with reductions of approximately 11%, 15% and 10% between the 18-29 and 50-66 age groups tested in this study.

The general observation from this study is that range of motion decreases with age (figure 12.2). The rate at which loss occurs in males appears to be greater than that of females for the movement of lateral bend, although range of rotation for women appears to decrease at a faster rate than that for men. The sharpest change in range of movement appears between the 18 - 29 and 30 - 39 age groups in men although it appears to be a more gradual loss in women.

The reasons for these observations could be due in part to the occupations of those subjects studied. The majority of females studied were secretaries (95%) with the other 5% being students or post-graduates within the University. The majority of the males studied were technicians (75%) with the other 25% being either students or post-graduates. Whilst all the men in the 18 - 29 age group studied were students and those in the 30 - 39 age group were mainly technicians the majority of females in all age groups were secretaries, the change in range of movement between males in the 18 - 29 age group and other

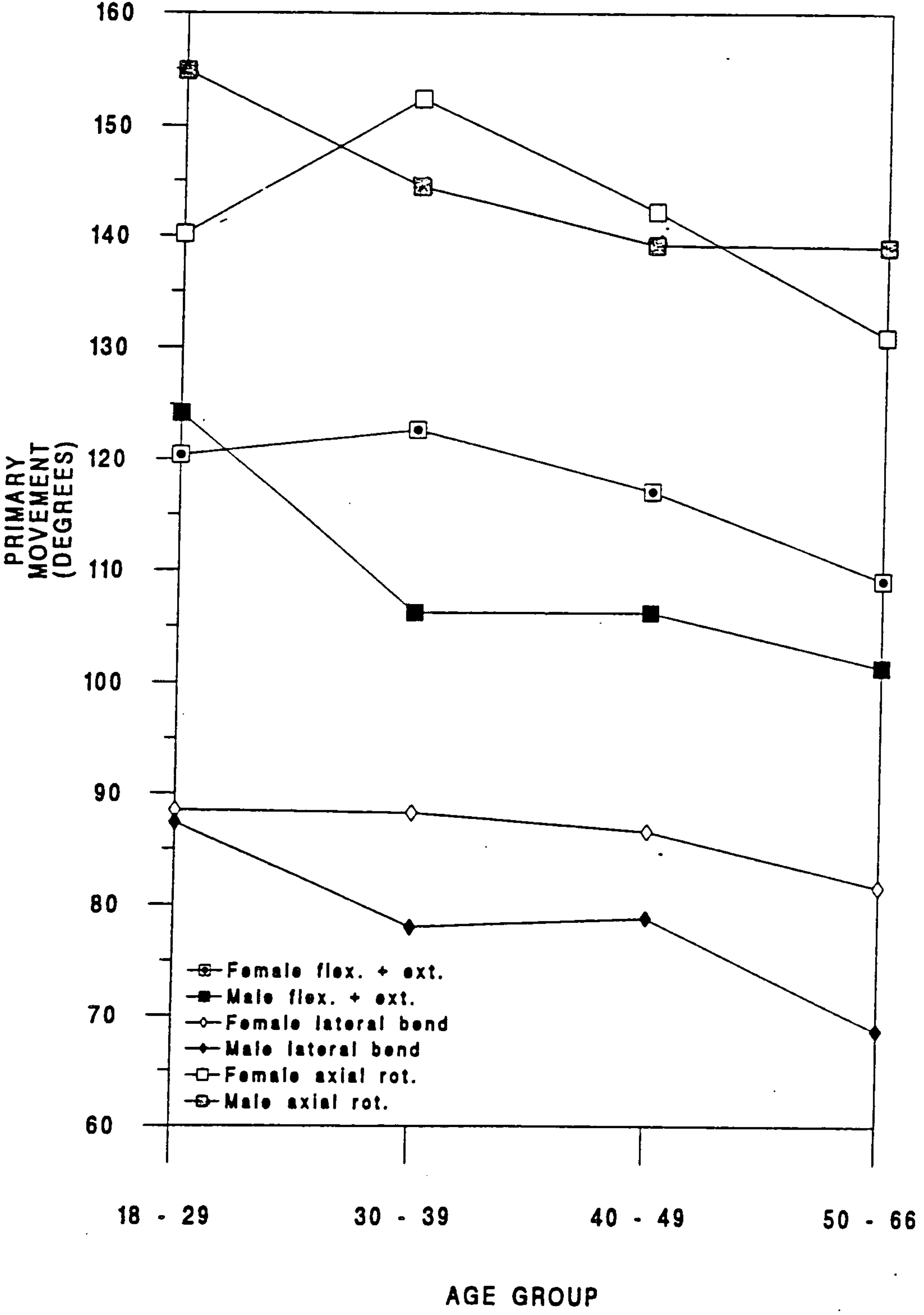
TABLE 12.13

RANGE OF CERVICAL SPINE MOTION

AUTHOR (METHOD)	AGE GRP (No.)	FLEX/EXT	LAT. BEND	AXIAL ROT.
Present study (Isotrak)	18 - 66 (135)	F 55.5 (9.5) E 58.0 (11.0)	L 41.5 (6.7) R 41.0 (8.1)	L 71.3 (9.9) R 70.9 (8.9)
Present study (Isotrak-subset)	18 - 29 (31)	F 60.8 (8.2) E 61.3 (9.4)	L 44.4 (7.9) R 43.7 (6.0)	L 74.9 (10.1) R 72.0 (8.2)
Chao *et al* (Isotrak)	Adults (20)	F 58.9 (9.7) E 65.8 (14.2)	L 47.7 (10.5) R 46.6 (7.0)	L 78.7 (9.9) R 75.1 (7.8)
Trott *et al* (Isotrak)	20 - 29 (30)	F 57.5 (7.6) E 76.1 (9.6)	L 45.5 (5.7) R 47.9 (4.8)	L 71.7 (6.0) R 78.0 (6.2)
Alund *et al* (Electro-gonio)	24 - 58 (10)	140 (18)	L 45 (6) R 46 (7)	L 74 (11) R 78 (9)
Bennett *et al* (Bubble-gonio)	18 - 24 (50F)	147.6 (12.2)	---------	151.0 (6.1)
Buck *et al* (Bubble-gonio)	18 - 23 (47M) (53F)	Male F 66 (8) E 73 (9) Female F 69 (10) E 81 (9)	--------- --------- --------- ---------	Male R 72 (5) L 74 (4) Fem. R 73 (6) L 74 (4)
Leighton *et al* (Gravity-gonio)	18 (100)	127 (15)	98 (17)	159 (22)
Dvorak *et al* (CT)	17 - 49 (9)	----------	--------	L 76.4 R 67.4
Penning *et al* (CT)	20 - 26 (26)	----------	--------	144.4 (122 - 168)
Ferlic *et al* (Protractor)	15 - 74 (199)	127 (19.5)	73 (15.6)	142 (17.1)

Figure 12.2

MEAN MAXIMUM PRIMARY RANGE OF CERVICAL MOVEMENT DETERMINED BY AGE



age groups might therefore be expected to be greater than those of the females whose occupations did not vary as much.

Schoening and Hannan (1964) conducted a study to try and determine some of the factors which affected spinal mobility and also found age to be one of the factors involved as well as finding that range of motion decreased with increased musculature, which might help to explain why the males tested who were involved in more 'active' occupations than the females generally appeared to have less movement (although this did not reach statistical significance in all groups).

Grays anatomy states that the adult females skull is a little lighter and smaller than that of a male, we might therefore expect to observe degeneration in the cervical spine of the male sooner than that in the female due to the increased loading. A study by Milne (1991) however did not find any significant association between sex and pathology, although it did show that the male and female vertebral specimens were significantly different when measuring the linear dimensions of facet width in the transverse and sagittal planes, biuncinate diameter and vertebral body depth, where male dimensions were larger than those of the women.

In Milnes study it was seen that the vertebra of C3 and C4 both had inturned superior articular facet joints which 'would function to block pure axial rotation'. The lower vertebra were seen to have 'zygopophyseal joints with interfacet orientations similar to the thoracic vertebrae'. The results seen from Milnes study help explain why Lysell (1969) found the ratio of the coupled motions of lateral bend and axial rotation in the upper cervical spine to be more constant than that in the lower cervical spine. Milne hypothesized that the interfacet angle was responsible for controlling how strictly lateral bending and axial rotation were coupled, so that in the upper cervical spine the in-turned facets would mean that pure axial rotation was not possible, and that the movement would have to be a combination of lateral bending and axial rotation whilst in the lower cervical spine the change in facet angle would mean that the coupling of axial rotation with lateral bending was not so strong.

If this is infact the case we might expect to see obvious changes in the pattern of movement of a patient with ankylosing spondylitis compared to that of a 'Normal' subject, where ankylosis in the cervical region generally starts at the base of the region and works upwards.

CHAPTER 13

RANGE OF CERVICAL MOTION IN PATIENTS WITH ANKYLOSING SPONDYLITIS

13.1 INTRODUCTION

As mentioned in Chapter 12 there have been a number of studies in which cervical spine movement has been monitored in three-dimensions. Studies in which intersegmental movement has been monitored include those of Mimura et al (1989) and Penning and Wilmink (1987). Since ankylosing spondylitis tends initially to affect the mid and lower cervical regions, measurement of cervical movement should help to determine the extent of involvement (Beetham *et al*, 1966).

In the 'normal' cervical spine the tendency is for extension and lateral bending to accompany axial rotation (lateral bending in the same direction as axial rotation). The results from Chapter 12 showed that for the primary movement of lateral bend, 48% of subjects had both coupled extension and rotation in the same direction as the primary movement, whilst only 1.5% had flexion and lateral bending in the opposite direction to that of the primary movement.

The importance of monitoring cervical mobility in patients with ankylosing spondylitis has shown from a study conducted by Daltroy *et al* (1990) in which 44 patients with spondylitis were evaluated by the Health Assessment Questionnaire - S (HAQ-S) and measures of spinal flexibility were obtained. The results of their study showed that neck rotation was the movement which correlated most strongly with the HAQ-S which they suggested implied 'an important role for this measure in clinical management and follow-up of spondylitis'.

Movements both in the primary plane of motion and the accompanying secondary (or coupled) motions in the cervical spine have been shown to vary in their magnitude depending on the area that is under observation (Mimura *et al* 1989). In patients with ankylosing spondylitis with cervical involvement we might therefore expect to see changes in both the range and coupling of movements compared with the 'normal' values obtained.

The aim of this study was to measure the range of cervical movement of a group of patients with ankylosing spondylitis, in order to try to assess how their movement range and pattern altered from the 'norm'.

13.2 METHOD

The method used was that detailed in Chapter 11. Sixty-four patients with ankylosing spondylitis were studied, and their details have been given in Table 13.1. Figures 13.1 - 13.3 show the typical movement patterns obtained for patients.

TABLE 13.1

PATIENT DETAILS

MALE				
DETAILS	20 - 29	30 - 39	40 - 49	50 +
NO. IN GROUP	8	12	10	13
MEAN AGE	26 ± 1.6	34.8 ± 3.1	43.6 ± 2.6	57.6 ± 8.1
NO. OF YEARS SINCE ONSET	5.1 ± 3.4	10.2 ± 7.2	18.1 ± 8.0	21.0 ± 10.3
NO. OF YEARS SINCE DIAG.	2.9 ± 3.1	4.7 ± 4.1	8.9 ± 2.7	10.3 ± 10.9
FEMALE				
NO. IN GROUP	1	8	7	5
MEAN AGE	26	34.5 ± 2.7	45.0 ± 3.6	54.0 ± 1.6
NO. OF YEARS SINCE ONSET	5.0	10.5 ± 6.1	13.4 ± 8.5	24.4 ± 6.7
NO. OF YEARS SINCE DIAG.	1.5	5.4 ± 3.6	4.9 ± 3.4	13.0 ± 7.9

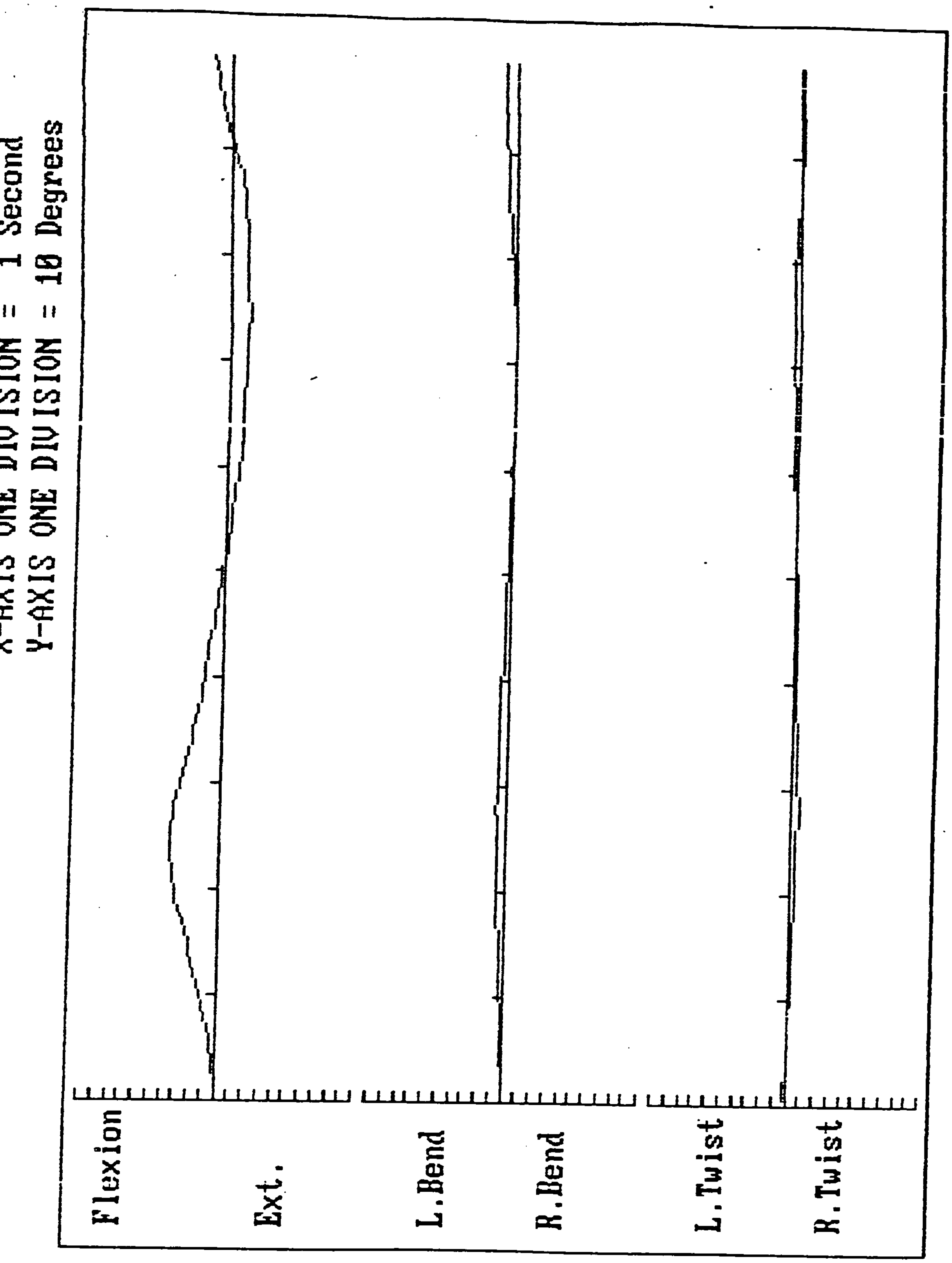


Figure 13.1- Patient performing the primary movement of flexion and extension

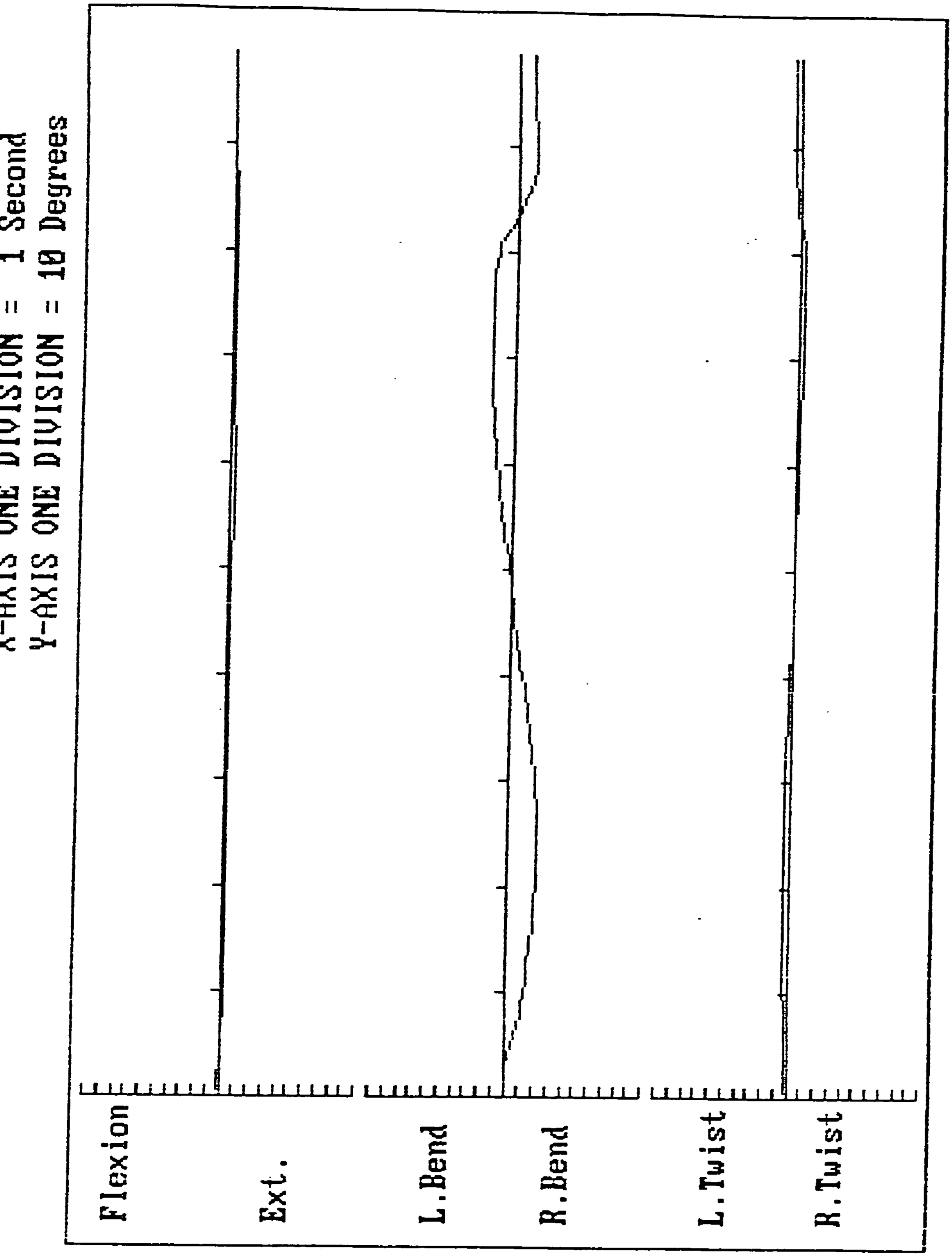


Figure 13.2- Patient performing the primary movement of lateral bending

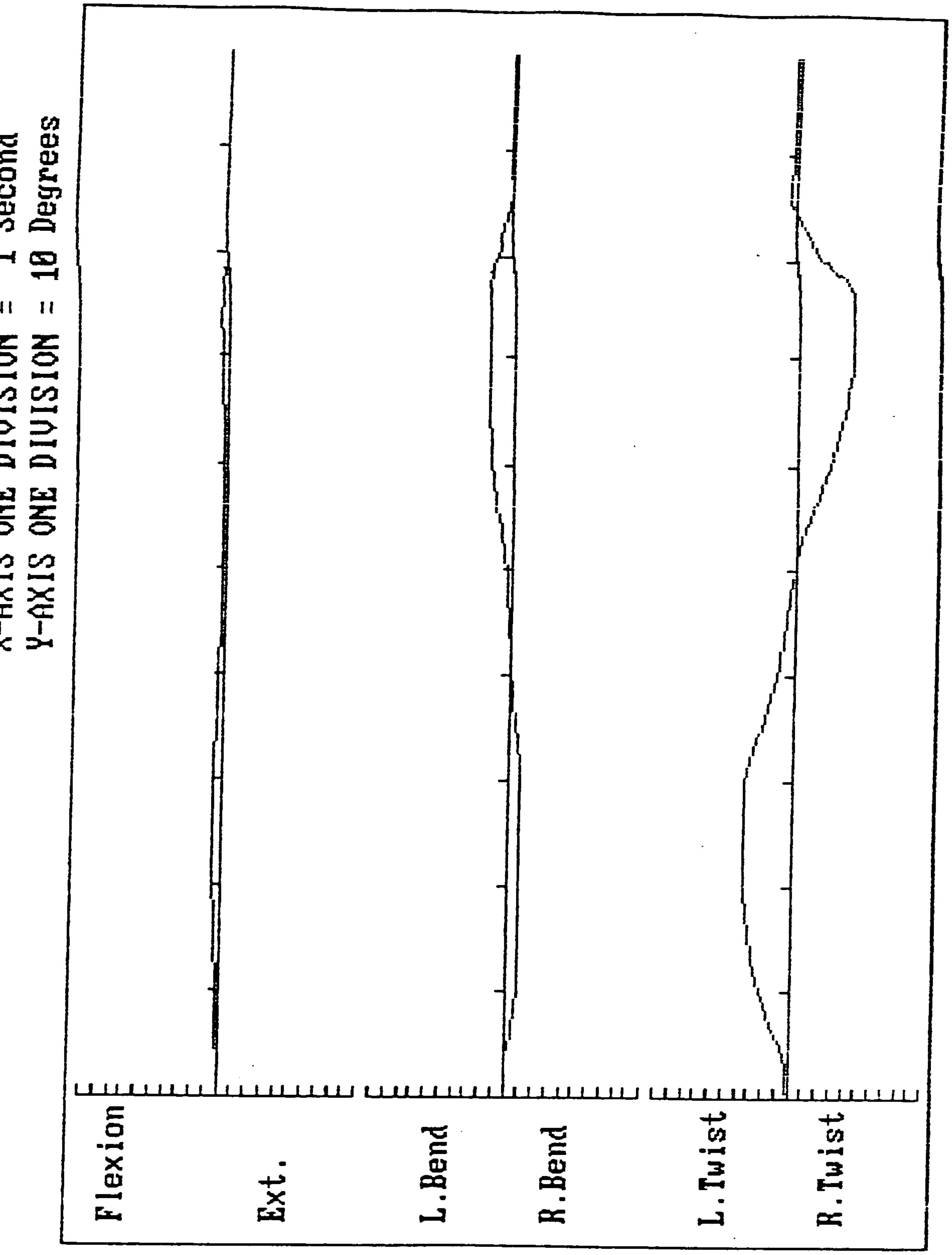


Figure 13.3- Patient performing the primary movement of axial rotation

13.3 RESULTS

13.3.1 Effect of age and gender

Results of the maximum primary, and associated coupled movements for flexion, extension, lateral bend and axial rotation for the patient groups studied have been given in Tables 13.2 - 13.7. Since results obtained were non-parametric measurements given in Tables 13.2 - 13.7 are median values (95% confidence interval limit). Negative coupled values indicate extension, right bend or rotation, + ve coupled values indicate flexion, left bend or rotation.

*, +, - and \ denote significant differences obtained from Mann-Whitney tests between age groups. For example in Table 13.2 the 30 - 39 and 40 - 49 age groups have significantly different values of flexion (+) and coupled lateral bend (*).

TABLE 13.2

PRIMARY FLEXION AND EXTENSION: MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	FLEXION	LAT. BEND	AXIAL ROT.
20 - 29	55.5 (27,83) *	3.0 (-27,12)	-1.5 (-11,5)
30 - 39	55.5 (48,69) +-	-3.0 (-13,25) *	-1.0 (-10,14)
40 - 49	43.0 (29,67) +\	2.0 (-8,6) +*	-2.5 (-9,7)
50 - 66	29.0 (1,68) *-\	0.0 (-12,3) +	-1.0 (-6,5)
	EXTENSION	LAT. BEND	AXIAL ROT.
20 - 29	60.0 (27,79) *+	-7.0(-24,10) *+	-1.5 (-7,14)
30 - 39	50.5 (28,64) -\	-3.0(-33,43) *-\	-1.0 (-18,21)
40 - 49	26.5 (17,63) *-	-2.0 (-25,9) -	2.0 (-6,16)
50 - 66	26.0 (1,59) +\	2.0 (-8,12) +\	-1.0 (-8,11)

TABLE 13.3

PRIMARY FLEXION AND EXTENSION: FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	FLEXION	LAT. BEND	AXIAL ROT.
18 - 29	69.0 (---)	-2.0 (---)	-11.0 (---)
30 - 39	55.0 (33,80)	2.0 (-30,32)	3.5 (-12,9) *
40 - 49	40.0 (12,69)	3.0 (-12,29)	-1.0 (-4,8) *
50 - 66	53.0 (22,64)	-3.0 (-12,7)	2.0 (-4,6)
	EXTENSION	LAT. BEND	AXIAL ROT.
18 - 29	81.0 (---)	-11.0 (---)	7.0 (---)
30 - 39	32.5 (22,71)	-3.0 (-13,7)	0.0 (-4,18)
40 - 49	50.0 (2,78)	10.0 (-31,24)	-6.0 (-24,9)
50 - 66	42.0 (22,56)	0.0 (-7,12)	1.0 (-23,2)

TABLE 13.4

PRIMARY LATERAL BEND: MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	41.5 (13,55) *+	-3.0 (-24,9)	-10.5 (-28,3) *+
30 - 39	30.0 (8,63) -	-4.5 (-11,8)	1.5 (-35,12)
40 - 49	23.0 (5,39) *	1.5 (-22,6)	5.5 (-30,21) *
50 - 66	9.0 (3,47) +-	-3.0 (-6,19)	-1.0 (-13,11) +
	LEFT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	46.5 (13,60) *+	-10.5 (-30,6) *+	5.0 (-6,18)
30 - 39	28.5 (3,63) -	3.0 (-8,8) *	2.0 (-8,23)
40 - 49	18.0 (7,36) *	-1.0 (-28,4)	-2.0 (-15,37)
50 - 66	9.0 (1,45) +-	-1.0 (-8,5) +	-2.0 (-8,19)

TABLE 13.5

PRIMARY LATERAL BEND: FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	44.0 (---)	10.0 (---)	20.0 (---)
30 - 39	28.5 (7,46)	5.0 (-15,22)	-4.5 (-31,10)
40 - 49	23.0 (2,61)	1.0 (-14,9)	-9.0 (-17,6)
50 - 66	32.0 (22,48)	8.0 (0,29)	-4.0 (-19,5)
	LEFT LAT. BEND	FLEX/EXT	AXIAL ROT.
18 - 29	39.0 (---)	2.0 (---)	-26.0 (---)
30 - 39	26.0 (2,51)	-1.0 (-16,12)	-0.5 (-13,29)
40 - 49	18.0 (1,37)	2.0 (-16,6)	4.0 (-7,24)
50 - 66	35.0 (11,49)	2.0 (-2,6)	11.0 (-9,22)

TABLE 13.6

PRIMARY AXIAL ROTATION: MALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	77.5 (47,95) *+	4.0 (-21,28)	0.0 (-18,26)
30 - 39	67.0 (39,89) -\	10.5 (-49,51)	1.5 (-30,32)
40 - 49	52.0 (19,75) *-	2.5 (-10,18)	4.0 (-9,24)
50 - 66	38.0 (6,77) +\	1.0 (-21,39)	9.0 (-26,20)
	LEFT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	77.0 (32,93) *	-2.0 (-17,27)	-2.5 (-24,20)
30 - 39	72.5 (31,107) +-	-1.0 (-10,33)	-14.0(-48,51)
40 - 49	59.5 (23,77) +	3.0 (-13,9)	-6.0 (-28,9)
50 - 66	37.0 (2,84) *-	0.0 (-20,23)	-11.0(-27,30)

TABLE 13.7

PRIMARY AXIAL ROTATION: FEMALE SUBJECTS

AGE GROUP	PRIMARY MOVEMENT	COUPLED MOVEMENT	
	RIGHT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	81.0 (---)	-25.0 (---)	-19.0 (---)
30 - 39	63.5 (24,85)	-2.0 (-15,20)	-7.5 (-23,12)
40 - 49	53.0 (6,90)	6.0 (-26,46)	0.0 (-18,20)
50 - 66	67.0 (57,69)	11.0 (-24,15)	-9.0 (-37,-2)
	LEFT AXIAL ROT.	FLEX/EXT	LAT. BEND
18 - 29	77.0 (---)	-11.0 (---)	-28.0 (---)
30 - 39	60.0 (30,90)	-3.0 (-19,25)	10.5(-23,20)
40 - 49	45.0 (6,85)	-5.0 (-39,39)	3.0 (-27,22)
50 - 66	61.0 (55,74)	1.0 (-9,9)	6.0 (-15,17)

Table 13.8 gives a summary of the median maximum values and the 95% confidence interval limits for each of the primary movements performed. Lateral bend and axial rotation have been given as the sum of movements to both the left and right as no significant differences were found between the two movements.

TABLE 13.8

EFFECT OF AGE AND GENDER ON PRIMARY MOVEMENTS

AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
MALE				
20 - 29	56 (38,76)	59 (43,70)	87(58,102)	155 (116,173)
30 - 39	58 (50,65)	50 (41,56)	60 (39,86)	138 (116,158)
40 - 49	44 (37,54)	31 (21,44)	44 (26,60)	102 (76,129)
50 +	29 (18,44)	26 (16,38)	31 (12,52)	82 (52,110)
FEMALE				
20 - 29	69 (-----)	81 (-----)	83 (-----)	158 (-----)
30 - 39	55 (33,70)	39 (27,59)	52 (15,79)	117 (77,156)
40 - 49	43 (25,58)	49 (25,66)	42 (14,75)	108 (49,146)
50 +	51 (22,64)	40 (22,56)	65 (42,97)	128 (112,135)

Mann-Whitney statistics were used to determine any significant differences between males and females of the same age group (Table 13.9)

TABLE 13.9

DIFFERENCES BETWEEN MALE AND FEMALE PATIENT GROUPS

PRIMARY MOVEMENT	AGE GROUP	SIGNIFICANT MOVEMENT
EXTENSION	30 - 39	COUPLED LATERAL BEND
LATERAL BEND	50 +	R. LATERAL BEND
		COUPLED FLEX. ON R. BEND
AXIAL ROTATION	50 +	R. AXIAL ROTATION
	50 +	COUPLED BEND ON R. ROT.

Since no major differences were observed between male and female groups the data were combined in order that age differences might be looked at in more detail. Results for the primary movements obtained are given in Table 13.10.

TABLE 13.10

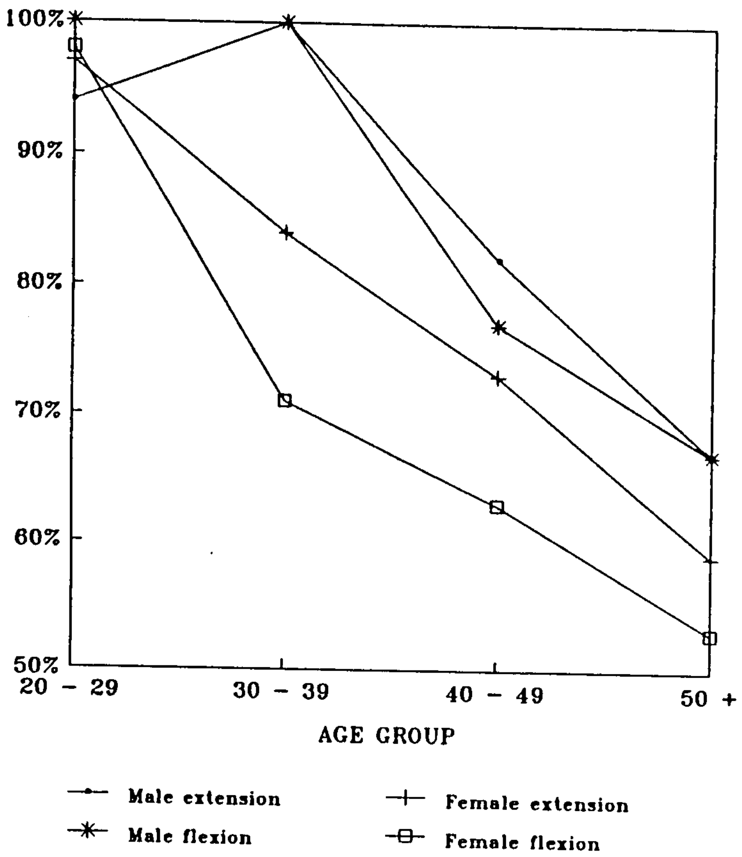
SIGNIFICANT DIFFERENCE IN MEDIAN RANGE OF MOTION DETERMINED BY AGE - A.S. PATIENT GROUP

COMBINED MALE and FEMALE ANKYLOSING SPONDYLITIS GROUPS				
AGE GROUP	FLEXION	EXTENSION	LATERAL BEND	AXIAL ROTATION
20 - 29	59 (44,76)$^{+}$	60 (44,71)$^{+*}$	87 (58,99)$^{*+/}$	156(118,172)$^{+*}$
30 - 39	57 (51,63)*	46 (39,54)$^{/}$	57 (39,75) $^{/}$	131(110,149)$^{/}$
40 - 49	43 (37,51)$^{*/}$	39 (27,50)*	42 (29,56) *	105 (82,124)*
50 +	35 (25,46)$^{+/}$	30 (21,39)$^{+/}$	39 (25,56) $^{+}$	96 (72,123)$^{+/}$

In Table 13.10 *,+,=,/ denote significant differences between age groups ($P < 0.05$). Values given are median (95% confidence interval limit).

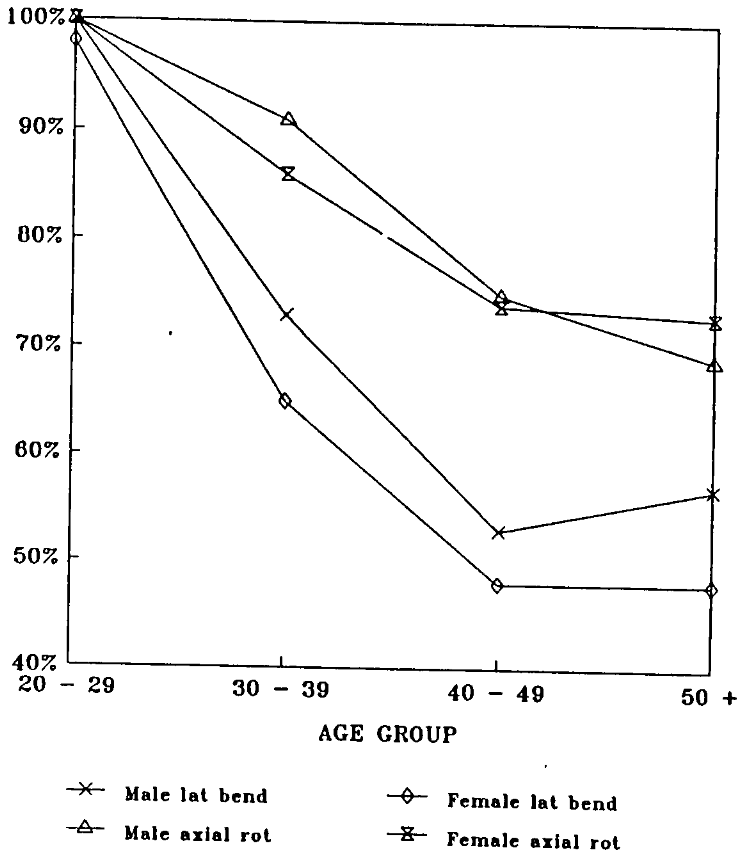
Range of motion in the 20 - 29 age group was significantly greater than that in the 50 + age group for all movements performed, and was greater for all movements other than flexion in the 40 - 49 age group.

Figures 13.4 and 13.5 show how the range of movement decreased with age after allowing for 'normal' aging.



AVERAGE 'NORMAL' PERCENTAGE RANGE OF FLEXION AND EXTENSION RETAINED BY A.S. PATIENTS

Figure 13.4



AVERAGE 'NORMAL' PERCENTAGE RANGE OF LATERAL BEND AND AXIAL ROTATION RETAINED BY A.S. PATIENTS

Figure 13.5

To see whether there was a significant correlation between all primary movements performed, correlation coefficients were calculated. (Correlation coefficients for the 'normal' subjects monitored in chapter 12 have also been given as a comparison):

MOVEMENT	CORRELATION	SIGN.	REGRESSION EQUATION
A.S. PATIENTS			
Ext. & Flexion	0.739	$P < 0.001$	Ext = 4.2 + 0.8xFlex
Ext. & Lat. Bend	0.622	$P < 0.001$	Ext = 21.4 + 0.4xLatBend
Ext. & Axial Rot.	0.815	$P < 0.001$	Ext = -0.2 + 0.4xRot
Flex. & Lat. Bend	0.552	$P < 0.001$	Flex = 30.8 + 0.3xLatBend
Flex. & Rot.	0.789	$P < 0.001$	Flex = 9.4 + 0.3xRot
Lat. Bend & Rot.	0.797	$P < 0.001$	LatBend = -14.5 + 0.6xRot
NORMAL SUBJECTS			
Ext. & Flexion	0.073	N.S.	
Ext. & Lat. Bend	0.436	$P < 0.001$	Ext = 29.4 + 0.3xLatBend
Ext. & Axial Rot.	0.330	$P < 0.001$	Ext = 26.4 + 0.2xRot
Flex. & Lat. Bend	0.307	$P < 0.001$	Flex = 37.9 + 0.2xLatBend
Flex. & Rot.	0.205	$P < 0.05$	Flex = 38.3 + 0.1xRot
Lat. Bend & Rot.	0.401	$P < 0.001$	LatBend = 34.0 + 0.4xRot

The correlation between primary movements for patients was in general much higher than that for the 'normal' subjects. The lowest correlation between movements was between flexion and lateral bend ($r = 0.552$) and the highest between that of extension and axial rotation ($r = 0.815$).

13.3.2 Coupled motion in A.S. groups

In order to determine whether the coupled movements were significant s-tests were conducted on the patient data (this was again conducted on combined male + female groups). No significant degree of coupled motion on any primary motion was observed. Since, however patients with ankylosing spondylitis do not always have cervical spine involvement and X-rays were not available for the majority of those seen it was decided to sub-divide the group into those whose range of motion, in all three-planes, fell within the normal range and those who fell outside it (mean - 2 s.d.). This was done since movement patterns might have been obscured by putting all patients into the same group.

Twenty-four patients had completely normal range of motion, compared with the 'normal' database obtained in Chapter 12, 23 had limitation in all three planes, 13 had limitation in two planes, of which one was lateral bending, and 4 had limitation in one or two planes, neither of which was lateral bending.

In order to determine whether there were significant differences between the 'Normal' A.S. group studied and the restricted groups Mann-Whitney statistical analysis was applied to all movement measurements obtained. The restricted group was initially divided into three groups: 'Rest x 3': those with restriction in all three planes, 'Rest x 2': those with restriction in two or more planes one of which was lateral bending, 'others': those who did not fall into either of the above two categories. Statistical analysis showed no difference in those movements of either groups 'Rest x 3' or 'Rest x 2' other than for the primary movement of right lateral bend. However, when left and right lateral bend were combined, no significance was seen in the movement of the two groups, although the median value for the 'Rest x 3' group (median: 16.0; confidence interval 14.5 - 31.0) was considerably less than that of the 'Rest x 2' group (median: 43.0; confidence interval 20.9 - 51.6). Due to the lack of differences between these two groups they were combined. Table 13.11 gives the statistically significant results for the coupled movements obtained.

TABLE 13.11

SIGNIFICANT DIFFERENCES BETWEEN COUPLED MOVEMENTS OF 'NORMAL' A.S. GROUP AND THOSE WITH RESTRICTION OF MOVEMENT - Mann-Whitney

MOVEMENT	'NORMAL' GROUP	RESTRICTED GROUP	SIGN.
F/E on R. rotation	-4.0 (-10.0,10.8)	6.0 (1.3,15.0)	$P < 0.01$
F/E on L. rotation	-5.0 (-9.8,17.0)	3.0 (-1.0,5.0)	$P < 0.05$
Lat. bend on R. rot	-3.0 (-11.8,5.2)	3.0 (-0.7,12.7)	$P < 0.05$
Lat. Bend on L. rot	0.0 (-9.8,17.0)	-9.0 (-16.0,0.0)	$P < 0.05$

Negative values imply coupling of extension or right lateral bend, positive values imply coupling of flexion or left lateral bend.

As the above Table shows the only significant change in the pattern of movement performed was for that of axial rotation where the restricted group showed a greater tendency towards coupled flexion on axial rotation, and a greater tendency towards opposite lateral bend on axial rotation (ie. left lateral bend coupled with right axial rotation).

13.3.3 Comparison between 'Normal' and A.S. cervical spine movement

In order to compare the results obtained from the 'Normal' subjects studied in Chapter 12 and the results obtained for the patients in this study twosample t-test statistics were used. This method of statistical analysis was used instead of the Mann-Whitney (two-sample rank test) as the data sets appeared to have different shapes, and different standard deviations. It was recommended as being the most appropriate form of statistical analysis as it assumes less about the populations ie. does not assume the populations have equal variances, and therefore gives a more conservative estimate of significance. Patients were again split into groups; those patients who exhibited 'normal' range of motion in all three planes ('Normas'), those whose motion was restricted in all three planes of motion ('Rest x 3'), those whose motion was restricted in 2 planes one of which was lateral bending ('Rest x 2') and the remaining patients who did not fit into any of the other categories ('Others'). The groups who had restriction in at least two planes one of which was lateral bending ie. 'Rest x 2', and 'Rest x 3', were also combined and analysed ('Allrest'). Tables 13.12 and 13.13 give the results of significant differences for both primary and coupled motion obtained between patient groups and the 'Normal' group studied in Chapter 12.

TABLE 13.12

ANALYSIS OF DIFFERENCES BETWEEN RANGE OF MOTION IN 'NORMAL' SUBJECTS AND A.S. PATIENTS: Primary movements

PRIMARY MOVEMENT			
GROUPS BEING COMPARED	MOVEMENT	MEAN (± s.d) 'NORMALS'	MEAN (± s.d.) A.S. GROUP
'Norm' vs 'Rest x 3'	Extension	57.8 ± 11.0	25.4 ± 16.6
	Flexion	55.2 ± 9.5	31.4 ± 14.7
	Right lat. bend	41.3 ± 8.3	14.3 ± 12.7
	Left lat. bend	40.8 ± 6.8	1.3 ± 13.2
	Right axial rot.	70.9 ± 8.9	37.3 ± 20.7
	Left axial rot.	71.3 ± 9.8	37.3 ± 19.1
'Norm' vs 'allrest'	Extension	57.8 ± 11.0	32.6 ± 18.4
	Flexion	55.2 ± 9.5	39.3 ± 18.4
	Right lat. bend	41.3 ± 8.3	16.6 ± 11.4
	Left lat. bend	40.8 ± 6.8	14.7 ± 12.4
	Right axial rot.	70.9 ± 8.9	46.0 ± 21.3
	Left axial rot.	71.3 ± 9.8	46.4 ± 21.9
'Norm' vs 'Rest x 2'	Extension	57.8 ± 11.0	45.2 ± 14.8
	Right lat. bend	41.3 ± 8.3	20.5 ± 7.7
	Left lat. bend	40.8 ± 6.8	17.3 ± 10.8
	Right axial rot.	70.9 ± 8.9	61.3 ± 11.6
'Norm' vs 'others'	Extension	57.8 ± 11.0	28.8 ± 1.5

N.B. The results from this Chapter and Chapter 12 were not subdivided into age and sex categories as numbers in groups would have been too small for valid statistical calculations to have been carried out. Since ages of the A.S. groups and Normal groups were fairly evenly spread this was not considered to affect the results to any great extent.

TABLE 13.13

ANALYSIS OF DIFFERENCES BETWEEN RANGE OF MOTION IN 'NORMAL' SUBJECTS AND A.S. PATIENTS: Coupled movements

COUPLED MOVEMENTS			
GROUPS BEING COMPARED	MOVEMENT	MEAN (± s.d) 'NORMALS'	MEAN (± s.d.) A.S. GROUP
'Norm' vs 'Normas'	Flex/ext on R.Bend	-6.0 ± 9.8	1.7 ± 12.2
'Norm' vs 'Rest x 3'	Flex/ext on R.Bend	-6.0 ± 9.8	-0.3 ± 6.5
	Flex/ext on L.Bend	-5.8 ± 9.6	-1.9 ± 8.1
	Rotation on R.Bend	-9.1 ± 11.6	-2.6 ± 10.9
	Rotation on L.Bend	8.9 ± 11.0	2.3 ± 11.7
	Flex/ext on R Rot.	-6.3 ± 13.6	7.3 ± 11.7
	Flex/ext on L Rot.	-7.9 ± 12.5	1.8 ± 9.7
	Lat Bend on R Rot.	-1.9 ± 16.4	6.6 ± 11.3
	Lat Bend on L Rot.	-0.2 ± 16.7	-7.9 ± 13.1
'Norm' vs 'allrest'	Flex/ext on R.Bend	-6.0 ± 9.8	0.8 ± 6.7
	Flex/ext on L.Bend	-5.8 ± 9.6	-1.2 ± 7.4
	Rotation on R.Bend	-9.1 ± 11.6	-3.1 ± 11.5
	Rotation on L.Bend	8.9 ± 11.0	3.3 ± 10.9
	Flex/ext on R Rot.	-6.4 ± 13.6	10.8 ± 16.6
	Flex/ext on L Rot.	-7.9 ± 12.5	3.8 ± 12.8
	Lat Bend on R Rot.	-1.9 ± 16.4	5.7 ± 12.2
	Lat Bend on L Rot.	-0.2 ± 16.7	-7.2 ± 15.1
'Norm' vs 'Rest x 2'	Flex/ext on R.Bend	-6.0 ± 9.8	2.5 ± 6.8
	Flex/ext on L.Bend	-5.8 ± 9.6	0.2 ± 6.2
	Flex/ext on R rot.	-6.3 ± 13.6	17.0 ± 22.0
	Flex/ext on L rot.	-7.9 ± 12.5	7.2 ± 16.8
'Norm' vs 'others'	Rotation on flex	1.1 ± 6.7	-2.8 ± 2.2

The results show that the number of significant changes in both primary and coupled movements increased as restriction of movement changed from 'normal' range to limitation of movement in three-planes. Figures 13.4 - 13.6 illustrate this point by showing how the percentage of patients exhibiting different types of coupled movement patterns altered depending on the extent of the involvement.

13.4 Relationship between age, disease duration and mobility

In order to determine whether age and disease duration were significant factors when determining maximum ranges of movement regression analysis was conducted and correlation coefficients calculated.

Patients seen were again split into groups; those who had 'normal' range of movement and those who had restriction of movement. Those with restriction of movement were again sub-divided into those who had restriction in all three primary planes and those whose restriction was in one or two planes one of which was lateral bend. The results of Mann-Whitney test analysis showed no significant differences in age of patients with limitation in one or two planes compared with those who had restriction in all three planes, but it did show that patients with 'normal' range of movement were of a significantly lower age group (mean age 37 ± 10) compared with patients whose movement was limited (mean age 47 ± 13)

Only a weak negative correlation was observed between disease duration, time since diagnosis and mobility although for the movements of flexion, extension and lateral bend this did reach statistical significance.

COUPLED MOVEMENTS ON LATERAL BEND AND AXIAL ROTATION

Results for 64 Ankylosing Spondylitis patients

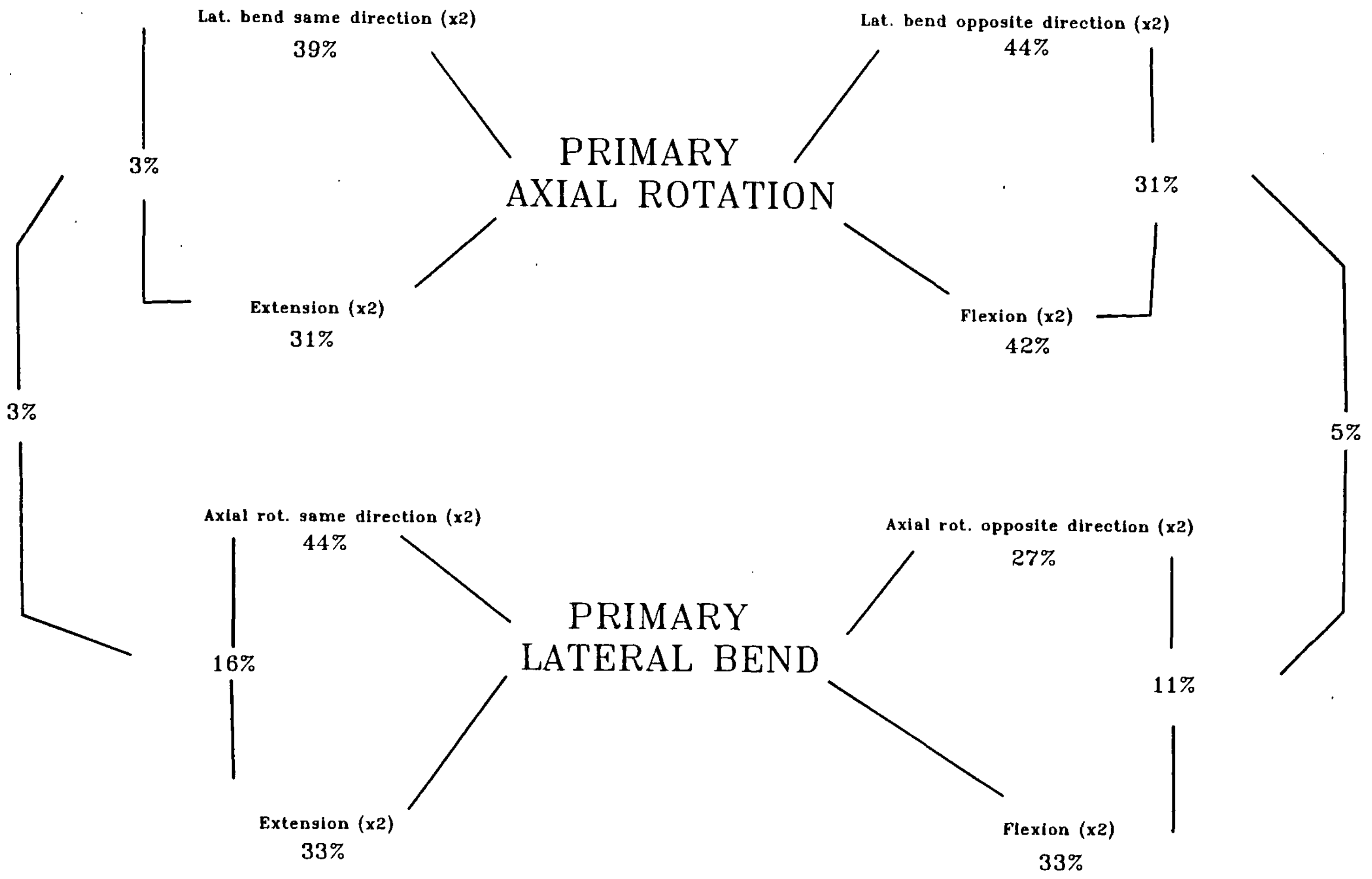


Figure 13.6

COUPLED MOVEMENTS ON LATERAL BEND AND AXIAL ROTATION

Results of 23 patients with limitation of motion in 3 planes

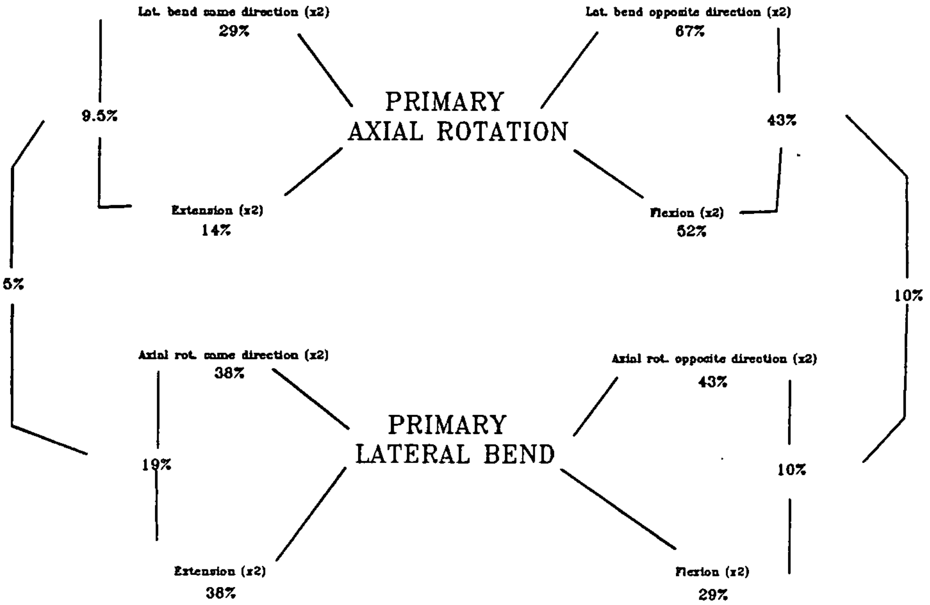


Figure 13.7

COUPLED MOVEMENTS ON LATERAL BEND AND AXIAL ROTATION

Results of 24 patients with 'Normal' primary range of motion

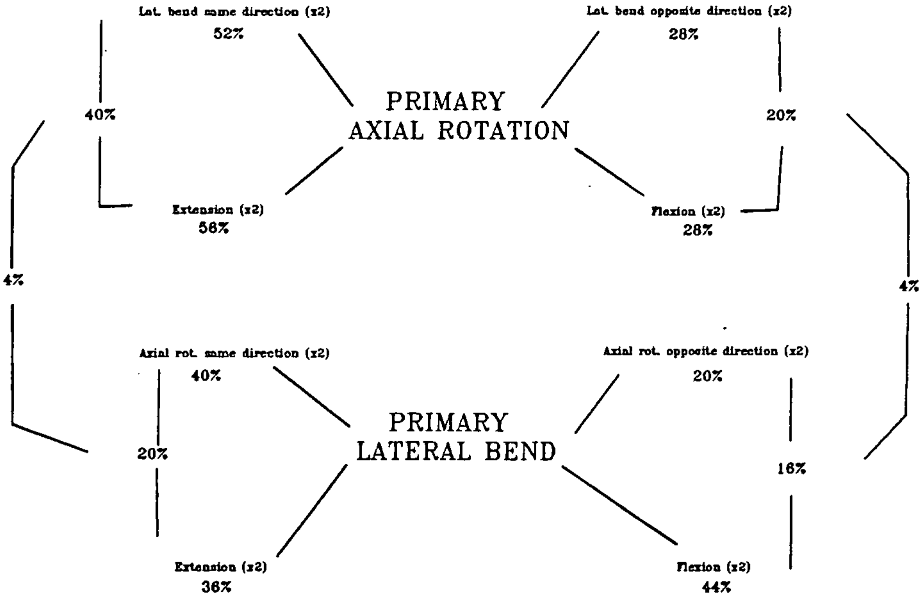


Figure 13.8

N.B. For both the above figures:

x2: Movement the same for both left and right primary motion.

Same direction: Left bend accompanies left rotation, right bend accompanies right rotation etc.

Opposite direction: Left bend accompanies right rotation, right bend accompanies left rotation etc.

The length of time a patient waited before diagnosis after they had first experienced symptoms of the disease was not a significant factor when determining mobility.

MOVEMENT	CORRELATION	SIGNIFICANCE
DURATION		
EXTENSION	-0.363	$P < 0.001$
FLEXION	-0.204	$P < 0.05$
LATERAL BEND	-0.292	$P < 0.005$
AXIAL ROTATION	-0.127	N.S.
DIAGNOSIS		
EXTENSION	-0.308	$P < 0.002$
FLEXION	-0.224	$P < 0.05$
LATERAL BEND	-0.282	$P < 0.005$
AXIAL ROTATION	-0.006	N.S.
DURATION - DIAGNOSIS		
EXTENSION	-0.159	N.S.
FLEXION	-0.038	N.S.
LATERAL BEND	-0.093	N.S.
AXIAL ROTATION	-0.159	N.S.

13.5 DISCUSSION

The results from this study have shown that the Isotrak system was able to detect differences in cervical spine motion in patients with ankylosing spondylosis compared with 'Normal' subjects.

Motion changes were not only observed in the primary plane under observation, but changes were also observed in the coupled movement patterns. Flexion and extension did not exhibit any significant degree of coupling motion, which is in agreement with the results obtained for the 'normal' subjects tested in Chapter 12. The movements where changes were observed in coupled movement patterns were those of axial rotation and lateral bending. The first change for both movements compared with the 'normal' coupled motion pattern was that flexion was seen to accompany each primary movement rather than extension which would normally be expected (Chapter 12). This is surprising since ankylosis tends to begin in the mid to lower cervical spine (O'Driscoll *et al*; 1978) , and Mimura *et al* (1989) have shown that flexion accompanies rotation at each segment below C5-C6 and extension at each level above C4-C5.

Coupled axial rotation on lateral bend and coupled lateral bend on axial rotation were only seen to alter significantly in magnitude compared with the 'normal' values expected. However, when looking at figures 13.6 - 13.8 and comparing them with figure 12.1 it can be seen that the incidence of coupled bending and rotation in a direction opposite to that which would normally be expected increased as the extent of limitation increased. This finding is again in agreement with the results of Mimura *et al* (1989) if we can assume that ankylosis began in the mid to lower cervical spine.

When looking at figures 13.6 - 13.8 it appears that the most useful movement to use for analysis purposes when monitoring patients would be that of axial rotation rather than that of lateral bending as a larger number of patients exhibited the coupling pattern of flexion on the primary movement of axial rotation compared with the normal value expected (ie. 52% of A.S. patients compared to 13% of 'Normal' subjects), and the incidence of coupled lateral bend opposite to that which would normally be expected was higher than the incidence of axial rotation opposite to that expected on lateral bending. Also only 14% of patients showed coupling of extension on axial rotation compared with

61% of 'normal' subjects and 56% of 'normal' A.S. subjects.

Even so, comparing figures 13.8 and 12.1 it can be seen that the coupled movement patterns for the patients with a 'normal' range of movement in all three-planes was altered slightly compared with the 'norm'. This is possibly due to the fact that all the patients seen in this study had ankylosis of the lumbar spine, to varying degrees. This would have caused a number of patients to lose some of their lumbar lordosis which could therefore have altered the degree of lordosis in the cervical spine. (N.B. Although not actually measured it was observed visually that most patients had a reduction of lumbar lordosis compared with that usually seen). Altering the amount of lordosis in the cervical spine would cause a change in the 'neutral' position and changes in the relative distance between vertebral structures thereby altering coupled motion patterns.

The usefulness of looking at coupled movement patterns for diagnostic purposes is questionable. Although movement patterns were seen to alter as patients movement became more restricted the extent of restriction was enough to ascertain that the patient had a problem in the cervical spine without looking at coupled movements in any detail. It may however be useful to use this method to monitor patients over a period of time in order to detect how the disease is progressing, and how courses of treatment such as physiotherapy affect movement in this area.

What was interesting from this study was that coupled movement was seen to alter as would be expected depending on the section of the spine that was being looked at. In patients with severe involvement, motion in the lower section of the cervical spine had been lost, and so what was being observed was the coupled movement in the upper cervical spine.

Since ankylosing spondylitis is a disease which causes mechanical restriction of movement, and patients who were seen in this study were not limited by pain but rather by a 'physical barrier' which stopped motion they were a useful group to monitor.

CONCLUDING REMARKS

This thesis has described the use of the 3SPACE Isotrak system in measuring lumbar and cervical spine motion in both the 'Normal' healthy spine and in patients with spinal problems.

In the first section lumbar spine movement was monitored, and it was shown that movement in the 'Normal' spine alters with age and that differences in range of movement between males and females exist. Values for maximum movements generally exceeded values expected from radiological techniques especially for the movement of axial rotation. Coupling of movements was seen to exist for lateral bending and axial rotation, with both range and coupling movement patterns being disrupted and altered in patients with spinal pathologies. The Isotrak system was seen to be quick and easy to use in the clinical setting. The most reliable lumbar movement monitored, when conducting repeat tests on subjects, was that of lateral bending, and the most inaccurate was that of axial rotation. Large intra-group variations were observed and the reasons why these may have occurred were examined using 'Normal' subjects. Possible explanations for the variations included the misplacement of the sensor, errors introduced by soft tissue and skin movement, the fact that subjects movements could vary depending on the time of day when monitored and the fact that within the 'Normal' groups a number of asymptomatic patients may have also inadvertently been monitored.

The Isotrak was shown to be a reliable method when re-monitoring patients with intra-observer errors being generally low. It was also seen to be a useful method when attempting to assess the effects of exercise therapy on patients in terms of altering movement range. When monitoring patients, considerable overlap in range of movement between patients and 'Normal' subjects was seen.

Some differences in movement between patients with different pathologies was observed although once again there was considerable overlap between groups. No differences were observed in patients whose movement was limited by both pain and mechanical factors which might suggest that the Isotrak is not particularly useful if monitoring continuous movement in patients experiencing a significant amount of pain. This may be due to 'bracing' of the spine which could obscure the true pattern of movement caused by mechanical factors.

In Section 2 the cervical spine was monitored and the Isotrak was shown to give values for maximum ranges of movement similar to those obtained by other techniques. It was easy to use in this area and due to the fact that the sensor and source were both relatively light weight, it did not cause any discomfort or restriction of movement in subjects who were monitored. Some of the patients with ankylosing spondylitis who were monitored showed significant alterations in both primary range of movement and coupled movement patterns. There was some overlap between the 'Normal' and patient groups when monitoring cervical motion although this was to be expected as not all the patients had cervical involvement.

The Isotrak would appear to be best suited, when monitoring patients as in this study, to use with patients with diseases such as ankylosing spondylitis. Such patients often experience long periods where they are painfree and this enables measurements to be obtained which relate to movement alterations due to mechanical factors alone. Patients with A.S. are also well educated about their disease and tend to move as far as they are able without fear of doing themselves any harm. Patients with low back pain on the other hand appear to be reluctant to perform certain movements as experience has taught them that it may cause more pain and they do not know what damage they are doing to their back.

Much of the work contained in Chapters 2, 3 and 7 of this thesis has been accepted for publication in the British Journal of Rheumatology. A paper entitled 'Variation in lumbar spine mobility measured over a 24-hour period' has already been published and a copy is included in Appendix 2.

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APPENDIX 1

Forms distributed to patients at the R.V.I. Back School

BACK CLASS

[illegible] sessions every month.

Session (i) one hour
Session (ii) one and a half hours.

Aims

1. EDUCATE THE PATIENT TO
   - (i) causes of back and leg pain
   - (ii) aggravating factors/relieving factors
   - ((iii) need for good posture
   - (iv) relief of symptoms by self-care
   - (v) prevention of recurrence of symptoms.
2. TEACH THE PATIENT:
   - (i) basic principles of back care with reference to posture, resting positions, seating, work, lifting and corsets
   - (ii) basic exercises for the treatment and prevention of symptoms in acute and chronic stages
   - (iii) resting positions in acute attacks.
3. ANSWER
   - (i) general questions about conditions at home, work and in leisure leading to back and leg symptoms
   - (ii) general questions on type of back problems.

CRITERIA

1. Chronic back problems - no acute inflammatory conditions
2. Postural problems
3. Resolving acute problems.

METHOD

1. Presentation of information using overheads of
   - (i) normal posture
   - (ii) anatomy of disc, vertebrae, nerves and ligaments
   - (iii) effect of flexion on disc
   - (iv) disc protrusion onto the nerve
   - (v) intradiscal pressure related to posture
2. Practical application of back care using a model to illulstrate:
   - (i) good and bad sitting positions
   - (ii) good and bad standing positions
   - (iii) lying positions inc. lying ↔ sitting
   - (iv) lifting techniques
3. Group exercise session to teach general exercises.
4. Use of information sheets.
5. Discussion of principles of back care.
6. Frequent opportunity for questions throughout the sessions.

G.H. 5/90.

BACK CLASS

Session 1 - one hour

General format

1. Introduction to back problems
    - (i) general anatomy
    - (ii) function of spine
    - (iii) normal shape
    - (iv) common terminology and meanings, e.g. sciatica
      disc narrowing
2. Common types of back problems
    - (i) disc - annular and nuclear protrusions
    - (ii) arthritis - osteoarthritis/wear and tear
      - rheumatoid arthritis/ankylosing spondylitis
    - (iii) postural
    - (iv) scar tissue - post surgery
3. Symptoms and referred pain
    - (i) centralisation and proximalisation
    - (ii) theory of referred pain
    - (iii) movement limitation related to types of problems outlined above.
4. Posture
    - (i) normal/abnormal
    - (ii) stress on ligaments leading to postural pain
    - (iii) protrusion and reduction of disc
    - (iv) pain sensitive structures affected
5. Common investigations and implications, and surgery
    - (i) x-rays
    - (ii) myelogram
    - (iii) epidural
    - (iv) discectomy
6. Types of treatment and principles related to conditions
    - (i) postural condition - re-education
      muscle strengthening
      postural awareness
    - (ii) disc problems - reduction by manipulation
      traction
      exercises
      maintenance of reduction
    - (iii) arthritis problems - pain management with hot and cold, and electrotherapy
      - exercises for range of movement
      muscle strength
      - postural awareness.
7. Discussion and round-up of main points.

G.H. 5/90.

BACK CLASS

Session 2 - one and a half hours

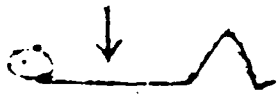
General format

1. Recap of Session One with opportunity for questions arising from the session.
2. Sitting:
    - (i) good and bad sitting posture
    - (ii) lumbar lordosis
    - (iii) types of chair - points to look for
    - (iv) angle of seat - wedge cushion
      blocks for back legs
    - (v) length of time spent sitting
    - (vi) working in sitting
    - (vii) sitting to standing and vice versa
    - (viii) driving
3. Standing:
    - (i) good and bad posture
    - (ii) maintain lordosis
    - (iii) step-standing
4. Work environment:
    - (i) height of work surfaces
    - (ii) application of sitting and standing postures
    - (iii) opportunity for individual questions
5. Lifting principles and techniques
6. Lying:
    - (i) comfortable positions and use of pillows in supine and side lying
    - (ii) sitting to lying and vice versa
7. Exercises (see sheet for specific exercises)
    - (i) principles of centralisation
    - (ii) changing exercises for acute, sub-acute and chronic stages
    - (iii) continuation even after symptoms stop.
8. Discussion.

G.H. 4/6/90

BACK SCHOOL. PART 2.

(1) Push back down into bed, hold, then relax.



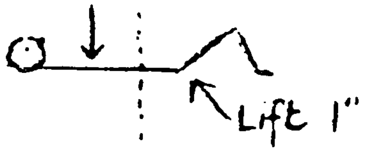
AIM

(i) Tighten abdominal wall - to use in conjunction with lifting, reaching, etc.

(ii) Promote relaxation.

(2) Abdominal bracing with pelvic tilting

Hold, then relax.



AIM

(i) Gentle mobilisation for lumbar spine/ Reduce stiffness.
(ii) Relaxation
(iii) Strengthen abdominal bracing.

(3) Pelvic tilting using a lumbar roll (or rolled up towel)

AIM

(i) Mobilisation for lumbar spine

(ii) Abdominal stabilisation.

(4) Gentle hip flexion

AIM

(i) Gentle stretch.

(ii) Hold - relax, each time bending hips closer to chest.

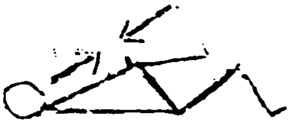
PLAN - Start with 5 repetitions of each exercise, progressing to 10 repetition

Use exercises 1, 2, 3, 4 to reduce stiffness in the spine, especially first thing in the morning.

- If any exercise causes sudden, severe pain, especially in the leg, STOP!

(5) Auto resisted exercises

AIM - To increase abdominal strength. Maximum "push" but minimal movement on the spine.



a) Push (R) knee against (R) hand/ (L) -> (L)
b) Push (R) knee against (L) hand/ (L) -> (R) Diagon. push
c) Diagonal push with (R) hand resisting inside of (L) knee and vice versa.
d) Diagonal push with (R) hand resisting outside of (L) knee and vice versa.

(6) Extension exercise x 10.

→ PLAN Exs. 5 to be done later in the day - e.g. in the bath.)

BACK CARE

Many back problems result from or are aggravated by our lifestyle, as in particular the way we sit, stand and move.

It is possible, whatever the cause of your back pain to minimise discomfort and restore a good posture by following a few simple rules.

1. **SLEEPING** - The mattress should be firm (but not rock hard!). If the mattress is soft, a board should be placed underneath it.

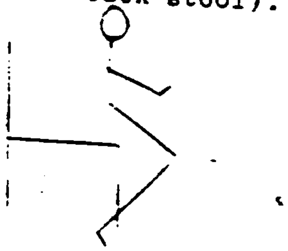
   When getting out of bed, roll onto your side, swing knees over the edge of the bed and use your arm to push up into a sitting position.

2. **SITTING**

   a) Always sit with the curve maintained in your lower back. this can be achieved even in soft chairs by placing a rolled up towel or a small cushion in the small of your back.

   b) Do not try to sit for long periods. Regular interruption of the sitting position is essential to prevent pain.

   c) If your job involves a lot of sitting e.g. at a desk try and maintain the curve at all times by either sitting with a cushion /roll in your lower back or by sitting forwards on the chair and having the knees at a lower angle than the hips (as seen with the back stool).

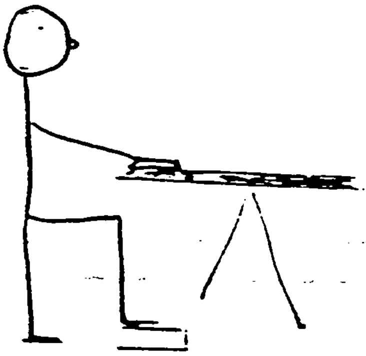


   d) When getting up from sitting move to the front of the chair, maintaining the natural curve, and then stand up. Reverse this procedure when sitting from standing.

   e) Driving - the principle is to maintain the curve in your lower back even when driving. This may be achieved by putting a small cushion roll in the bac or a wedge on the seat to raise your hips higher than the knees.

3. STANDING - Never maintain a stooped position when standing.

   The best way to stand is to adopt the posture commonly seen in a hotel pub i.e one foot on the ground and the foot on the brass rail. If there is no rail available use any raised aspect e.g. bottom of a desk, telephone directory, step stool.



LIFTING

a) **Never** bend to lift something off the ground with the knees straight - always bend your knees.

b) Throughout the lift you must attempt to retain the curve in your low back. The lift should be made by straightening the legs.

c) Stand close to the load with a firm footing and a wide base.

d) Always hold the load as close to you as possible and get a secure grip.

e) Never jerk.

f) When upright move your feet to turn to avoid twisting at the lower back.

5. WORKING IN STOOPED POSITIONS

Many activities around the home and many occupations require prolonged stooped positions.

This is the most likely cause of back pain during the day. To minimise this interrupt the stooped posture at regular intervals **before** pain starts.

This can be achieved by placing the hands in the small of the back 5 - 6 times.

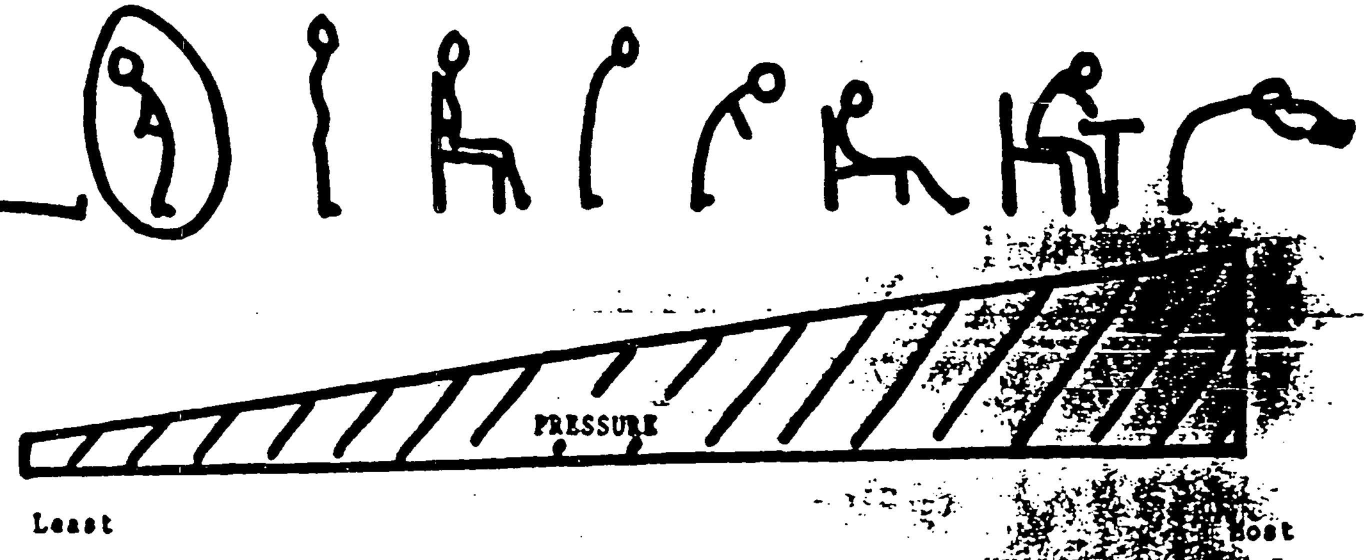
Hints for working

1. Kneel down to make the bed and clean the bath.
2. Use long handles on the hoover.
3. Rearrange kitchen to avoid reaching or stooping too often.
4. Carry many small loads rather than one heavy load.
5. Sit or use perching stool to do ironing, washing dishes etc.
6. Assess your work situation in order to incorporate the rules of standing, sitting etc.

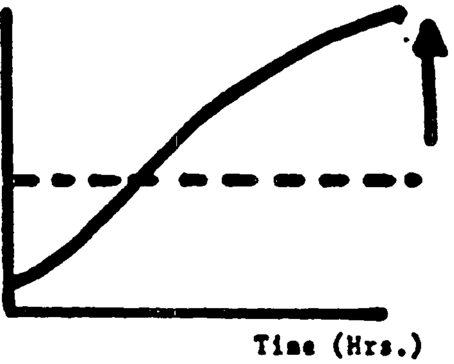
XERCISES

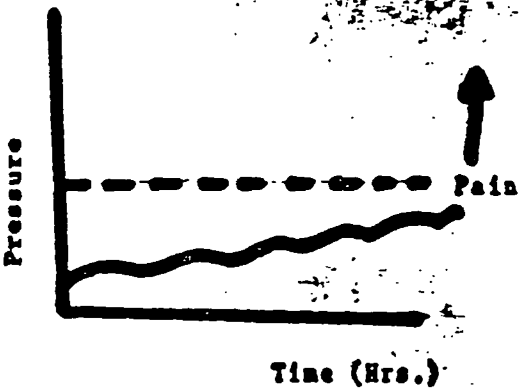
Only do the exercises as instructed by your physiotherapist.

This diagram shows how the pressure increases - the <u>GREATER THE PRESSURE, THE GREATER THE RISK TO YOUR SPINE.</u>



<u>PRESSURE IN YOUR BACK INCREASES AS THE DAY GOES ON</u>





Arching your back at hourly intervals can help dissipate

Arching your back immediately <u>before</u> and <u>after</u> lifting can reduce the <u>risk</u> of injury to the spine.

<u>CORSETS</u> Corsets may be useful in the initial stages of your back problem.

<u>OR</u>/ if your job involves a lot of lifting.

<u>BUT</u>/ IT IS BETTER TO HAVE GOOD POSTURE AND CORRECT LIFTING TECHNIQUES.

IF IT IS TOO HEAVY OR TOO AWKWARD - DON'T LIFT IT!

Always consider 1) Your body position

2) The weight of the load

3) The distance of the load from your body

4) The purpose of your lift

Body Position

Minimise intra-discal pressure

- Avoid twisting spine
- Feet astride and facing direction of lift
- reduce load distance - do not reach as this increases apparent weight of load.
- Adjust curve of spine to accommodate the lift, and brace abdominals.
- Prepare the destination - is it clear ? are there any obstacles in the way?

Hollow back Increase arch when lifting loads which are BELOW waist level

Flattened back To be used while lifting objects which are ABOVE waist level

Tighten your abdominal muscles

THINK BEFORE YOU LIFT

APPENDIX 2

Prior Publications

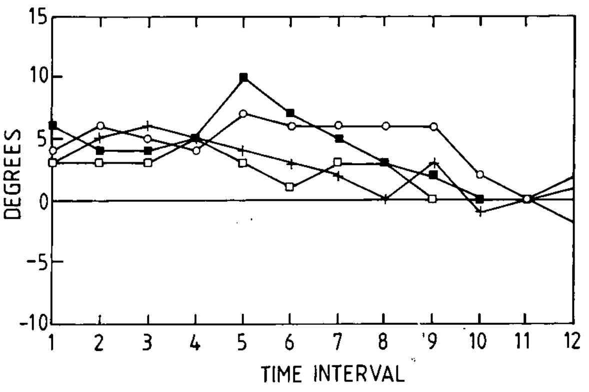


FIG. 1.—Mean change in movement relative to value at 04:00–05:30. 1, 08:00–09:30; 2, 10:00–11:30; 3, 12:00–13.30; 4, 14:00–15:30; 5, 16:00–17:30; 6, 18–00–19:30; 7, 20:00–21:30; 8, 22:00–23:30; 9, 00:00–01:30; 10, 02:00–03:30; 11, 04:00–05:30; 12, 06:00–07:30. Time interval —■— Flexion; —+— Extension; —○— Lateral bend; —□— Axial rotation.

between 08:00 and 09:30 on day one and 08:00 and 09:30 on day two might be expected to be highly correlated as the results were obtained at the same time of day, the fact that they are not can be explained by the fact that on day one all six males were tested between 08:00 and 09:30, five of whom had been up for periods of between 10 min and 1 h prior to testing, and on day two only four were tested, three of whom had been supine immediately prior to testing.

Between individual subjects there was a wide variation in the range of movement obtained at any one time; this can be seen from the magnitude of the standard deviations in Table II.

DISCUSSION

Hindle [12] previously examined the day-to-day variation of the ability of an individual to perform a given movement. In his study two subjects were asked to perform the movements of flexion and extension, lateral bend and axial rotation (both to the left and right sides). Each test took place at the same time of day in order to eliminate diurnal effects. The position of the sensor on the back was marked with indelible ink so that it could be repositioned accurately for each measurement. The results of these tests showed a standard deviation about the mean for flexion and extension to be aproximately 5 degrees (range 2.4–7.8), the values for lateral bend and axial rotation were 1.6 degrees (range 1.2–1.9) and 2.4 degrees (range 2.1–2.8) respectively. Obviously this margin of error had to be allowed in all repeat tests on individuals when determining whether or not changes were significant.

The results obtained from pre-/post-sleep data showed a significant overall decrease in flexion, extension, and lateral bend post-sleep but did not indicate any signficant changes in axial rotation (Table II).

The reason all subjects did not show similar reductions in movement is not known as all subjects had comparable periods of sleep and were all of a similar age group. In order to determine why this should have occurred and why the standard deviation between results for flexion was comparatively large compared to the results obtained by Adams *et al.* [8], further and more rigorously controlled tests would need to be conducted. These tests would ensure that subjects' activities were more tightly controlled and of a similar nature. They would also require subjects to be tested immediately after waking and require subjects to remain supine for similar periods.

The fact that no overall change in axial rotation was observed may be due in part to the fact that the total range of movement in this plane is small and therefore any changes observed would be small. Any changes may therefore have been obscured by errors introduced by skin or soft tissue movement or by errors introduced by the observer when replacing the sensor on the skin.

TABLE II
AVERAGE MAXIMUM MOVEMENT MEASURED AT 2-HOURLY TIME INTERVALS OVER A 24-H PERIOD

Time interval	Flexion	Extension	Lateral bend	Axial rotation
Males				
08:00–09:30	67 ± 11	27 ± 20	48 ± 8	26 ± 6
10:00–11:30	63 ± 11	26 ± 6	47 ± 9	23 ± 7
12:00–13:30	63 ± 9	25 ± 11	46 ± 7	23 ± 5
14:00–15:30	67 ± 9	26 ± 8	46 ± 8	26 ± 8
16:00–17:30	73 ± 12	23 ± 8	47 ± 9	25 ± 8
18:00–19:30	72 ± 20	22 ± 9	47 ± 10	21 ± 8
20:00–21:30	69 ± 12	24 ± 9	47 ± 7	23 ± 6
22:00–23:30	66 ± 12	19 ± 9	47 ± 9	27 ± 9
00:00–01:30	63 ± 16	21 ± 6	46 ± 11	22 ± 8
02:00–03:30	59 ± 11	18 ± 8	42 ± 10	22 ± 6
04:00–05:30	61 ± 10	22 ± 10	43 ± 9	23 ± 6
06:00–07:30	60 ± 11	17 ± 6	40 ± 11	23 ± 6
08:00–09:30	65 ± 15	12 ± 11	40 ± 12	21 ± 8
Females				
08:00–09:30	51 ± 8	14 ± 20	42 ± 8	20 ± 9
10:00–11:30	53 ± 7	22 ± 6	50 ± 9	24 ± 6
12:00–13:30	52 ± 10	24 ± 11	48 ± 7	25 ± 12
14:00–15:30	49 ± 14	21 ± 8	47 ± 8	25 ± 15
16:00–17:30	52 ± 14	23 ± 8	50 ± 9	21 ± 8
18:00–19:30	49 ± 10	23 ± 9	49 ± 10	23 ± 8
20:00–21:30	47 ± 12	16 ± 9	49 ± 7	25 ± 6
22:00–23:30	47 ± 6	19 ± 9	48 ± 9	20 ± 8
00:00–01:30	48 ± 3	24 ± 6	51 ± 11	20 ± 10
02:00–03:30	50 ± 5	19 ± 7	46 ± 10	20 ± 13
04:00–05:30	45 ± 12	15 ± 10	41 ± 9	18 ± 10
06:00–07:30	51 ± 11	18 ± 6	46 ± 11	21 ± 13
08:00–09:30		No readings obtained		
Males + Females				
08:00–09:30	61 ± 8*	22 ± 17	46 ± 8	24 ± 7
10:00–11:30	59 ± 7	24 ± 11	48 ± 8	24 ± 6
12:00–13:30	59 ± 10	25 ± 11	47 ± 9	24 ± 5
14:00–15:30	60 ± 14*	24 ± 8	46 ± 11	26 ± 7*
16:00–17:30	65 ± 14*	23 ± 8	49 ± 8*	23 ± 6
18:00–19:30	62 ± 10*	22 ± 9	48 ± 9*	22 ± 7
20:00–21:30	60 ± 12*	21 ± 9	48 ± 6*	24 ± 5
22:20–23:30	58 ± 6	19 ± 6	48 ± 8*	24 ± 8*
00:00–01:30	57 ± 3	22 ± 9	48 ± 11*	21 ± 6
02:00–03:30	55 ± 5	18 ± 8	44 ± 11	21 ± 5
04:00–05:30	55 ± 12	19 ± 9	42 ± 9	21 ± 6
06:00–07:30	57 ± 11	17 ± 5	43 ± 12	22 ± 5
08:00–09:30	65 ± 15	12 ± 11	40 ± 12	21 ± 8

*Significant difference from reading obtained between 04:00 and 05:30.

Note: All measurements in degrees. Statistical analysis only applied to the males + females group as individual groups were too small for detailed statistical methods to be valid.

Maximal values obtained were higher than those expected from radiographic techniques. This could again have been due to soft tissue and skin movement. Repeated tests on an individual should, however, incorporate this as a standard error and relative changes between movements should give 'true' readings.

Results obtained from the 24-h study showed the movements of flexion, lateral bend and axial rotation to be significantly greater in the afternoon than those measured between the hours of 02:00 and 07:30.

The fact that the range of flexion was at a minimum in the early hours of the morning is likely to have been due mainly to the fact that whilst lying supine the unloaded disc would have become swollen due to the imbibition of water. In this state the disc becomes less easy to compress, causing movement to require more effort [8].

When the disc is in this state it is likely to subject the spinal ligaments and itself to greater stresses. Any movement designed to stretch the ligaments such as flexion, extension, lateral bend and axial rotation would be likely to create additional stress, causing movements to require more effort and increase the risk of injury to the lumbar spine.

In tests conducted on cadaveric motion segments Adams, Dolan and Hutton have shown that creep loading reduces a discs' resistance to backward bending by about 40% [11] which it is suggested is balanced by increased resistance from the apophyseal joints and spinous processes so that the resistance to backward bending of the motion segment and the range of movement remain unaltered by creep loading. This appears to be the case from our study which showed no overall change in the range of extension measured over the 24-h period.

The range in lateral bend was also minimal during the early hours of the morning, with the stresses on the ligaments and the discs being maximal at this time. The range was again greatest during the afternoon. The reason for a decrease in lateral bend occurring slightly later during the day is difficult to determine as the activities of subjects were not tightly controlled. However, this may be due to the fact that subjects tended to be more active in the morning than the afternoon. The first 2–3 h in the morning when activity was greatest might therefore be expected to correlate with the greatest fluid loss from the disc which would cause the apophyseal joints to come in closer contact and increase their loading. The joints would have a higher bending stiffness and strongly resist lateral bending movements. During the afternoon when the activities of the subjects were more sedentary with the majority either sitting in comfortable chairs or lying down for short periods of time, the intake of fluid to the disc would cause the apophyseal joints not to be so highly compacted, enabling lateral bending movements to be carried out more easily.

CONCLUSION

Pre-/post-sleep results showed reductions in the range of maximal movements after sleep for all movements other than axial rotation.

The general pattern over the 24-h period indicated that there was a change in maximal movement obtained which depended on the time of day when tested. The range of movement reached a peak during the afternoon and the subject was generally less mobile in the early hours of the morning.

In order to separate the effects of loading and circadian factors, further work is required in which the activities of all subjects taking part should be closely controlled.

ACKNOWLEDGEMENTS

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CALIBRATION OF ISOTRAK SYSTEM

The Isotrak was calibrated in the same manner as that described by Richard Hindle in his thesis (Hindle 1989). Four wooden wedges with different angles of inclination were used, and their angles measured using the 3SPACE Isotrak and a precision optical clinometer. These were the same wedges as those used by Hindle. The angle of inclination was assessed by taking readings a total of five times for each measuring device. The results are given below.

Wedge No.	Mean clinometer Reading (x^{o})	Mean Isotrak Reading (y^{o})	Difference ($y^{o} - x^{o}$)
1	8.672	7.645	-1.027
2	18.042	16.692	-1.350
3	26.853	25.020	-1.833
4	34.573	32.163	-2.407

Linear regression analysis showed that the accuracy of the system was greater for smaller angles and varied according to the equation $y = 1.06x + 0.513$.

APPENDIX 4

Description of two other non-invasive measuring techniques

DESCRIPTION OF TWO OTHER NON-INVASIVE MEASURING TECHNIQUES

1. CODA-3 Scanner

This system is an opto electronic device. It works by sending out fan shaped beams of light, from a Xenon arc lamp, to retro reflective prisms which are attached to a subject. The light is split and sent out by three octagonal, synchronised rotating mirrors, two of which are mounted on vertical axles and the third which is mounted on a horizontal axle between the other two.

When the emitted light crosses a marker made up of four retro reflective prisms, arranged in a pyramid, a pulse of light is reflected back along the same path to photodiodes in the scanner unit. By knowing the orientation of the mirrors the position of the marker can be calculated.

The main problem with the CODA-3 scanner is that if any two marker rigs come within approximately 25mm of each other, either in the horizontal or vertical plane, the machine loses information about their postions. Another problem as shown by Hindle (1989) is that it is a fairly bulky device and data collation is quite a time consuming procedure.

2. The ISIS technique

This system (Integrated Shape Imaging System) also works by using optics. It basically consists of a projector, a camera and an imaging system.

The projector shines light onto the object from which readings are to be taken, the image of which is viewed from below by the camera. Two dimensional co-ordinates of the line are obtained as the light falls on the 3 dimensional object, and are recorded by a mini-computer. By moving the projector and camera a set of co-ordinates are obtained and a full 3 dimensional image of the object can be produced. The accuracy of the system is ± 3 mm.