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ORIGINAL ARTICLE

Movement coordination of the lumbar spine and hip during a picking up activity in low back pain subjects

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Abstract The effect of low back pain, with or without nerve root signs, on the joint coordination and kinematics of the lumbar spine and hips during everyday activities, such as picking up an object from the floor, are largely unknown. An experimental study was designed to compare lumbar spine and hip joint kinematics and coordination in subjects with and without sub-acute low back pain, while picking up an object in a sitting position. A three-dimensional real-time electromagnetic tracking device was used to measure movements of the lumbar spine and hips. Sixty participants with subacute low back pain, with or without straight leg raise signs, and twenty healthy asymptomatic participants were recruited. The ranges of motions of lumbar spine and hips were determined. Movement coordination between the two regions was examined by cross-correlation. Results showed that mobility was significantly reduced in subjects with back pain, who compensated for limited motion through various strategies. The contribution of the lumbar spine relative to that of the hip was, however, found to be similar in all groups. The lumbar spine–hip joint coordination was substantially altered in subjects with back pain, in particular, those with a positive straight leg raise sign. We conclude that changes in the lumbar and hip kinematics were related to back pain and limitation in straight leg raise. Lumbar–hip coordination was mainly affected by the presence of positive straight leg raise sign when picking up an object in a sitting position.

Keywords Kinematics · Spine · Low back pain · Hip · Activities of daily living · Joint coordination

Introduction

Low back pain (LBP) is a major health and socioeconomic problem, and is a leading cause of disability [14]. Acute LBP that lasts up to 3 months is the commonest presentation [11] and is frequently associated with reduced mobility of both the lumbar spine and hips [7, 12, 13], with consequential functional impairment [5]. The LBP victims who go on to develop chronic symptoms also show deficits in reaction time, coordination, and postural control [22].

The LBP patients with radiating leg pain are generally more disabled than patients with LBP alone [14] and exhibit marked limitations of the hip and lumbar spine during physiological movements [26]. Wong and Lee also revealed that the LBP would also affect the coordination of these movements [35]. There is still a lack of understanding of the theoretical mechanisms underlying these kinematic changes. However, it is believed that this may be due, at least in part, to the altered mechanical properties of the passive tissues and muscles of the spine [21, 34], and/or an attempt to minimize the loads on spinal tissues [7]. Another theoretical hypothesis is that back pain may be associated with abnormal tension in the sciatic nerve or its composing nerve roots [15, 16, 33]. Although there is

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increasing recognition of the importance of radiating leg pain, there is very little recorded about the impact of root symptoms on the performance of functional activities.

Spinal and hip movements are closely coordinated in many functional and daily activities, but only a few studies have investigated this relationship under anatomical, monoplanar conditions [13, 20, 25, 35]. Even fewer studies have examined this relationship in symptomatic populations performing functional tasks [30, 31]. Most kinematic studies of the lumbar spine and hips in functional activities have been limited to walking and sit-to-stand activities in asymptomatic subjects [4, 6, 17]. Picking up an object from the floor in a seated position is a common, but potentially difficult, functional activity. However, there has been no previous investigation of this task with respect to the kinematic characteristics of the lumbar spine and hip, nor has the manner in which these regions are coordinated been explored in symptomatic and asymptomatic subjects.

The purpose of this study was to investigate the effects of non-specific sub-acute LBP and nerve root symptoms manifesting as limitation in straight leg raise (SLR) on the kinematics of the lumbar spine and the hip joints while picking up an object in a sitting position. We hypothesized that angular displacement and velocity of the lumbar spine and hips would be reduced in patients with LBP and limited SLR. Further, we hypothesized that the coordination of the hip and lumbar spine would be affected by the presence of LBP and limited SLR.

Materials and methods

Subjects

Eighty volunteers were recruited, routinely screened by a physiotherapist for inclusion and exclusion criteria and were divided into five groups (Table 1). Group 1 consisted of 20 healthy subjects with no history of back pain or pain related to the back which had required medical attention or treatment in the previous 6 months. Groups 2 and 3 each consisted of 15 subjects with low back pain (LBP) on the left and right side, respectively, presenting with a negative straight leg raise (SLR) test. Groups 4 and 5 each comprised of 15 subjects with LBP presenting with a positive SLR test on the left and right leg, respectively. The inclusion criteria for symptomatic Groups 2 to 5 were the presence of sub-acute back pain or buttock pain related to the back (duration between 7 days and 12 weeks) with back pain as the primary complaint, the pain being of sufficient intensity to require medical attention or treatment, but not warranting complete bed rest or hospitalization.

Study participants were excluded if they had any known neurological or orthopedic disorders or previous surgery; sensory, neurological or autonomic deficits; fractures, bony abnormalities or rheumatic disease. All participants had normal mobility of the hips. A standardized passive SLR test was performed [29, 33] and the maximum angle between the straight leg and the longitudinal axis of the trunk was measured using a universal goniometer. The SLR sign was considered to be positive if the lift angle was 65° or less with unilateral symptoms reproduced in the tested leg. This SLR angle was less than the 95% confidence interval of asymptomatic values [32].

The subjects were asked to rate their severity of pain using a visual analogue scale (VAS) of 0–10, and their functional ability were evaluated by Roland-Morris disability questionnaire (RMQ). Each subject gave their informed written consent and the study was approved by the University of Sydney Human Ethics Committee and the Hong Kong Polytechnic University, reference number 02/02/16.

Instrumentation

Movements of the lumbar spine and hips were measured by the 3SPACE Fastrak (Polhemus, Colchester,

Table 1 The mean (standard deviation, SD) demographic data of the five groups of subjects

	Group 1: able-bodied	Group 2: left LBP	Group 3: right LBP	Group 4: left SLR	Group 5: right SLR
N	20	15 (14 first episodes)	15 (14 first episodes)	15 (15 first episodes)	15 (14 first episodes)
Mean age	41.7 ± 8.2	41.1 ± 10.0	40.7 ± 10.0	39.0 ± 10.0	38.7 ± 9.8
Mean height/cm	169.6 ± 5.6	172.2 ± 4.9	171.2 ± 5.9	173.1 ± 5.2	172.6 ± 5.8
Mean weight/kg	71.1 ± 10.5	68.4 ± 5.0	69.8 ± 4.3	70.7 ± 4.8	70.2 ± 4.4
Mean onset of pain/weeks		7.3 ± 2.5	7.2 ± 2.8	7.1 ± 2.7	7.3 ± 2.9
Mean VAS		5.8 ± 1.7	6.0 ± 2.1	6.0 ± 2.0	5.9 ± 2.1
Mean RMQ		10.5 ± 4.6	10.6 ± 4.7	11.7 ± 4.5	11.6 ± 4.6
Mean angle of SLR		81.5 ± 2.3	81.7 ± 2.5	44.2 ± 8.9	44.1 ± 8.6

VAS Visual analogue scale, *RMQ* Roland-Morris questionnaire score, *SLR* Straight leg raise

VT 05446, USA). This consists of a source that generates a low-frequency magnetic field that is detected by sensors. Four sensors were used to measure the movements of the lumbar spine and hips [20, 35]. One was placed over the L1 spinous process and the second was placed over the sacrum. The locations of the spinous processes were determined as described by Burton [3]. Two other sensors were used to measure the movements of the hips by placing them over the lateral aspect of the left and right thighs. Each sensor was attached to a small, moldable plastic plate by double-sided adhesive tape. A Velcro band was threaded through the plate and tightly wrapped around the subject's trunk or leg to minimize movement between the sensor and the underlying skin. The cables were attached to the skin on the side of the trunk so that they did not move the sensor erroneously during the movement. Initial testing showed that this arrangement provided the most secure sensor attachments [20, 35]. Data collected by the Fastrak system was sampled at a frequency of 30 Hz per sensor and acquired by a personal computer via the serial port at 115.2 kBaud.

The lumbar spine movements were derived from the relative displacement of the L1 and sacral sensors, and the hip movements from that between the thigh and sacral sensors. The method of computation was based on the mathematical techniques described by earlier authors [19, 27] and joint angles were derived from the direction cosine matrices of the sensors. The reliability and validity of this arrangement has previously been reported [19], the error terms from this study suggests accuracy to less than 1° for movement amplitude. The flexion/extension axis of the spine and hip was orientated to the pelvis and defined by a line joining the two anterior superior iliac spines. Conventionally, flexion, right lateral bending, and right axial rotation of the lumbar spine and flexion, external rotation and abduction of hip were considered to be positive. Movements in the opposite directions were represented by negative values.

Procedure

Each participant was seated on a stool with neither armrest nor backrest. The stool provided support from the ischial tuberosities to the middle of the thighs. Its height was adjusted for each subject to 110% of the distance from the apex of the fibular head to the floor. Subjects started in an erect seated posture looking directly forward, with the lumbar spine in neutral and the hips flexed and their arms hanging freely.

Participants were required to bend forward to pick up two light objects (mass = 0.5 kg, size = 3 cm × 3 cm × 3 cm), located 30 cm lateral and 30 cm anterior to the heel on either side of the body. They were requested to perform the reaching activities at their own preferred, comfortable speed while remaining seated. The right hand was used to pick up the objects on both sides, and thus the two reaching activities (ipsilateral and contralateral) represented two different sets of movements. To ensure the activity was as natural as possible, there was no attempt to correct any deviations during the test. All movements were first demonstrated to participants, and each subject performed the action three times for each side. The order of testing was randomized.

Data analysis

Kinematic analysis

Movements of the lumbar spine and hips, including maximum displacement and velocity were determined. The coefficient of multiple correlation (CMC) [18] was calculated to determine the repeatability of the three sets of angle–time curves. The root mean square error of the angle data was also calculated. The mean and standard deviation of the maximum range in each plane of movement and the ratio of the total movement of the lumbar spine to that of the moving hip were determined for each subject. The consistency of data for each variable over the three trials within each subject was determined using intra-class correlations, ICC (2, 1).

Coordination

Cross-correlation analysis, a standard method of establishing the extent of association between two sets of time series data, was applied to the three movement cycles of the lumbar spine and hips [20]. The peak correlation coefficient indicates the strength of correlation of the movements, and the phase relationship determines the time lag or lead for peak cross-correlation. In the present analysis, lumbar movement was used as the reference and a positive phase relationship implies that the lumbar spine moved earlier than the hip in the movement cycle.

Statistical analysis

Multivariate analysis of variance (MANOVA) was used to examine any differences in joint ranges and velocities, lumbar/hip motion ratios, mean peak cross-correlation coefficients, and the phase relationships (dependent variables) among the five groups [independent variable]. Post hoc least significant difference (LSD) test was used and the alpha level was set at 0.05.

Results

The subjects displayed no significant differences in demographics among the groups ($P > 0.05$; Table 1) nor were there any significant differences in the value of VAS and RMQ among the symptomatic subjects (Groups 2 through 5; $P > 0.05$; Table 1). Subjects with positive SLR symptoms displayed a clearly significant difference in the range of hip flexion to onset of symptoms from the non-SLR subjects ($P < 0.05$; Table 1). The mean CMC for the movement-time curves was found to be 0.94 ± 0.03 and the mean root square error was 2.1 ± 0.9. This demonstrated that the movement pattern among the three trials were very similar in shape. The mean ICC for peak range of motion of the spine and hips movements was 0.96 ± 0.02, suggesting that there were no significant differences across the three trials and that the data obtained were highly repeatable, enabling us to draw conclusions from the results.

Movement patterns

In the asymptomatic group, picking up the object from the ipsilateral (right) side was accomplished by flexion and right lateral bending of the lumbar spine, flexion, abduction and external rotation of the right hip, and flexion and internal rotation of the left hip. Picking up the object on the contralateral (left) side involved flexion and lateral bending of the lumbar spine, but there was also significant left axial rotation. Both hips flexed as in ispilateral reaching, but the rotations of both hips were reversed in directions. There was significant abduction of the left hip but negligible adduction of the right hip (Fig. 1).

Symptomatic subjects, in particular those with positive right SLR (Group 5), exhibited significant limitations compared to asymptomatic subjects with respect to flexion of the lumbar spine (11 to 16°—ipsilateral; 16 to 21°—contralateral) and both hips (13 to 25°—ipsilateral; 22 to 33°—contralateral) ($P < 0.05$, Tables 2, 3). When reaching to the ipsilateral side, ranges of lumbar right axial rotation (3°) and left hip adduction (6 to 18° were significantly greater in all low back pain subjects ($P < 0.05$, Table 2). While picking up from contralateral side, right hip adduction (10°) in symptomatic subjects (Groups 2 to 5) was significantly greater than asymptomatic subjects. Subjects with a positive right SLR (Group 5) exhibited significant movement limitations in the range of lumbar left axial rotation (6°) but showed an increase in left hip abduction (13°) ($P < 0.05$, Table 3), suggesting a compensatory adjustment. As with the asymptomatic subjects, the movements differed between tasks.

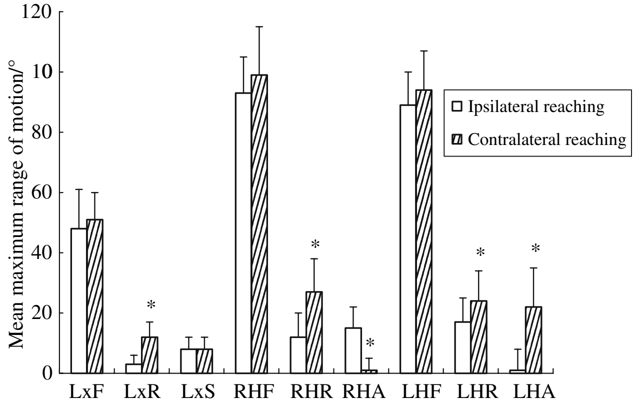

Fig. 1 Maximum angular displacements of asymptomatic group during ipsilateral and contralateral reaching manoeuvres. *$P > 0.05$, significant differences in the angular displacement between ipsilateral and contralateral reaching manoeuvres

Velocity

Generally speaking, it took longer for low back pain subjects to pick up an object from both right and left sides in a sitting position ($P < 0.05$, Tables 2, 3). The velocities of the lumbar spine and hip movements were significantly reduced in Groups 2 to 5 ($P < 0.05$, Tables 2, 3). The velocities of left spine rotation and right hip internal rotation were further decreased during contralateral picking up ($P < 0.05$, Table 3).

Movement ratios

Movement ratio expresses the relative contribution of the lumbar spine and hip to the total movement pattern and is expressed as the quotient of lumbar and hip range. There were no significant differences in the mean ratios between lumbar spine and hip movements in the sagittal plane among the five groups. The lumbar spine/right hip (Lx/RH) and lumbar spine/left hip (Lx/LH) ratios were about 0.5, suggesting that the total contribution of the lumbar spine was about half of that of the hips in the sagittal plane ($P > 0.05$, Tables 2, 3).

Coordination of movements

In total, eighteen inter-joint coordinations between the lumbar spine and bilateral hips were analysed

Table 2 Mean (SD) of the angles and various kinematic parameters of the lumbar spine and hip when picking up from ipsilateral side

Ipsilateral (right) reaching	Group 1: able-bodied	Group 2: left LBP	Group 3: right LBP	Group 4: left SLR	Group 5: right SLR
Mean maximum range of motion					
Lumbar flexion/°	48 ± 13	36 ± 11*	32 ± 9*	37 ± 9*	32 ± 8*
Lumbar right axial rotation/°	3 ± 3	6 ± 4*	6 ± 3*	6 ± 3*	6 ± 2*
Lumbar right lateral flexion/°	8 ± 4	5 ± 4	7 ± 6	7 ± 5	7 ± 5
Right hip flexion/°	93 ± 12	79 ± 11*	80 ± 17*	77 ± 14*	68 ± 9*
Right hip external rotation/°	12 ± 8	14 ± 9	13 ± 7	14 ± 9	10 ± 7
Right hip abduction/°	15 ± 7	13 ± 8	13 ± 9	9 ± 8	13 ± 10
Left hip flexion/°	89 ± 11	73 ± 10*	75 ± 15*	73 ± 11*	63 ± 13*
Left hip internal rotation/°	17 ± 8	14 ± 8	13 ± 10	14 ± 11	14 ± 8
Left hip adduction/°	1 ± 7	7 ± 6*	7 ± 6*	13 ± 11*	19 ± 9*
Mean maximum velocity					
Lumbar flexion velocity/° s^{-1}	30 ± 11	16 ± 9*	18 ± 8*	19 ± 6*	19 ± 11*
Lumbar right axial rotation velocity/° s^{-1}	10 ± 4	8 ± 6	8 ± 7	8 ± 4	8 ± 3
Lumbar right lateral flexion velocity/° s^{-1}	10 ± 4	7 ± 4	10 ± 6	9 ± 5	8 ± 6
Right hip flexion velocity/° s^{-1}	53 ± 16	32 ± 20*	35 ± 17*	33 ± 12*	34 ± 12*
Right hip external rotation velocity/° s^{-1}	21 ± 11	15 ± 9	17 ± 5	16 ± 6	15 ± 10
Right hip Abduction velocity/° s^{-1}	9 ± 3	10 ± 5	11 ± 3	11 ± 5	11 ± 6
Left hip flexion velocity/° s^{-1}	48 ± 14	27 ± 16*	29 ± 16*	31 ± 13*	33 ± 11*
Left hip internal rotation velocity/° s^{-1}	26 ± 10	16 ± 10*	17 ± 10*	13 ± 5*	12 ± 6*
Left hip adduction velocity/° s^{-1}	13 ± 3	9 ± 6	10 ± 4	9 ± 5	10 ± 5
Time	3.1 ± 0.3	4.2 ± 1.4*	3.8 ± 0.8*	4.1 ± 0.9*	4.7 ± 1.8*
Ratio in the sagittal plane					
Lx/RH	0.53 ± 0.13	0.50 ± 0.20	0.42 ± 0.16	0.51 ± 0.29	0.45 ± 0.25
Lx/LH	0.56 ± 0.15	0.50 ± 0.20	0.43 ± 0.16	0.50 ± 0.26	0.48 ± 0.25
LH/RH	0.95 ± 0.06	1.00 ± 0.07	0.98 ± 0.07	1.01 ± 0.16	1.02 ± 0.13

No significant differences between symptomatic groups*$P < 0.05$, significant difference in symptomatic subjects when compared with asymptomatic subjects (Group 1)

using lumbar motion as the independent variable. Cross-correlation coefficients greater than 0.8 are considered to be high, suggesting close coupling of movements.

Flexion of the lumbar spine and both hips in asymptomatic subjects (Group 1) were highly correlated in both picking up activities (Table 4). The cross-correlation between lumbar and hip flexion was significantly reduced in subjects with positive right SLR sign ($P < 0.05$, Table 4).

Picking up on the ipsilateral side by asymptomatic subjects was characterized by high cross-correlation coefficients between lumbar flexion and left hip adduction ($R = 0.84$), lumbar flexion and right hip abduction ($R = 0.93$), and lumbar right lateral bending and hip flexion on both sides ($R = 0.84$; Table 4). Cross-correlation between lumbar flexion and right hip abduction was significantly reduced in symptomatic subjects with positive right SLR sign (Group 5; $P < 0.05$, Table 4); however, cross-correlation was significantly increased between lumbar flexion and hip rotation on both sides in these subjects ($P < 0.05$, Table 4), suggesting closer coupling of these movements in these subjects.

During picking up from the contralateral side by asymptomatic subjects, high cross-correlation coefficients were found between lumbar flexion and hip abduction/adduction on both sides, lumbar axial rotation and all axes of left hip motion, and lumbar flexion and right hip flexion and rotation (Table 4). Comparison of values for ipsilateral and contralateral picking up in asymptomatic subjects revealed a significant

Table 3 Mean (SD) of the angles and various kinematic parameters of the lumbar spine and hip when picking up from contralateral side

Contralateral (left) reaching	Group 1: able-bodied	Group 2: left LBP	Group 3: right LBP	Group 4: left SLR	Group 5: right SLR
Mean maximum range of motion					
Lumbar flexion/°	51 ± 9	35 ± 10*	34 ± 9*	34 ± 12*	30 ± 15*
Lumbar left axial rotation/°	12 ± 5	9 ± 6	9 ± 4	9 ± 3	6 ± 3*
Lumbar left lateral flexion/°	8 ± 4	9 ± 5	12 ± 9	9 ± 5	12 ± 7
Right hip flexion/°	99 ± 16	67 ± 10*	72 ± 17*	77 ± 16*	66 ± 17*
Right hip internal rotation/°	27 ± 11	13 ± 12*	12 ± 11*	12 ± 13*	13 ± 11*
Right hip adduction/°	1 ± 4	12 ± 8*	11 ± 10*	12 ± 8*	10 ± 3*
Left hip flexion/°	94 ± 13	73 ± 7*	77 ± 11*	77 ± 9*	68 ± 7*
Left hip external rotation/°	24 ± 10	14 ± 10*	14 ± 8*	14 ± 12*	14 ± 9*
Left hip abduction/°	22 ± 13	28 ± 12	29 ± 14	29 ± 16	35 ± 6*
Mean maximum velocity					
Lumbar flexion velocity/° s^{-1}	31 ± 10	17 ± 6*	18 ± 6*	17 ± 7*	23 ± 9*
Lumbar left axial rotation velocity/° s^{-1}	19 ± 7	10 ± 4*	10 ± 4*	12 ± 6*	13 ± 5*
Lumbar left lateral flexion velocity/° s^{-1}	14 ± 5	12 ± 6	14 ± 6	13 ± 5	13 ± 3
Right hip flexion velocity/° s^{-1}	48 ± 14	32 ± 17*	33 ± 17*	31 ± 14*	30 ± 15*
Right hip internal rotation velocity/° s^{-1}	–34 ± 13	–20 ± 9*	–23 ± 11*	–18 ± 6*	–21 ± 8*
Right hip adduction velocity/° s^{-1}	19 ± 8	21 ± 12	24 ± 12	18 ± 9	20 ± 6
Left hip flexion velocity/° s^{-1}	48 ± 13	33 ± 15*	35 ± 16*	33 ± 13*	35 ± 13*
Left hip external rotation velocity/° s^{-1}	34 ± 11	22 ± 11*	23 ± 6*	19 ± 7*	22 ± 10*
Left hip abduction velocity/° s^{-1}	23 ± 10	22 ± 11	22 ± 12	17 ± 6	18 ± 5
Time	3.3 ± 0.4	5.0 ± 1.8*	5.0 ± 0.9*	4.9 ± 1.3*	5.3 ± 2.2*
Ratio in the sagittal plane					
Lx/RH	0.52 ± 0.14	0.53 ± 0.25	0.45 ± 0.14	0.48 ± 0.30	0.48 ± 0.25
Lx/LH	0.55 ± 0.16	0.45 ± 0.19	0.44 ± 0.14	0.44 ± 0.22	0.46 ± 0.23
LH/RH	0.96 ± 0.07	1.00 ± 0.37	1.02 ± 0.08	1.05 ± 0.21	1.03 ± 0.11

No significant differences between symptomatic groups

*$P < 0.05$, significant difference in symptomatic subjects when compared with asymptomatic subjects (Group 1)

increase in coordination between lumbar axial rotation and various hip movements including left hip flexion, right hip flexion, and adduction ($P < 0.05$, Table 4). There was also a significant decrease in coordination between lumbar flexion and right hip adduction ($P < 0.05$, Table 4).

Some lumbar and hip movements were significantly less coupled in subjects with right side back pain when they picked up from the left side. Specifically, this included lumbar flexion and right hip adduction in Groups 3 and 5; lumbar axial rotation and left hip external rotation in Group 3, and lumbar axial rotation and left hip abduction in Group 5 ($P < 0.05$, Table 4). No significant differences were found for time lags with respect to zero in all coupled movements.

Discussion

Bending from a sitting position to retrieve an object from the floor is a common everyday activity which may be difficult in the presence of low back pain. To date, the three-dimensional kinematics and inter-joint coordination of this activity has not been reported, nor has the way in which these kinematics may change with LBP. This is the first study to investigate the kinematics and coordination of spinal and hip movements in subjects with subacute LBP while picking up an object in a sitting position; and while the study did not deliberately match subjects across groups, the demographics of the groups were found to be generally similar, thus facilitating the comparisons.

Table 4 Mean (SD) of the cross-correlation coefficients (*R*) between the lumbar spine and hip during ipsilateral and contralateral reaching manoeuvres

	Group 1: able-bodied		Group2: left LBP		Group 3: right LBP		Group 4: left SLR		Group 5: right SLR	
	Ipsilateral	Contralateral	Ipsilateral	Contralateral	Ipsilateral	Contralateral	Ipsilateral	Contralateral	Ipsilateral	Contralateral
LxF-LHF	0.99 ± 0.01	0.98 ± 0.01	0.98 ± 0.02	0.98 ± 0.02	0.98 ± 0.02	0.97 ± 0.02	0.98 ± 0.01	0.98 ± 0.03	0.97 ± 0.02*	0.96 ± 0.05*
LxF-LHR	0.75 ± 0.22	0.73 ± 0.21	0.70 ± 0.28	0.70 ± 0.28	0.80 ± 0.19	0.67 ± 0.23	0.79 ± 0.16	0.76 ± 0.21	0.89 ± 0.10*	0.75 ± 0.21
LxF-LH Abd/Add	0.84 ± 0.16	0.88 ± 0.14	0.89 ± 0.14	0.94 ± 0.10	0.91 ± 0.15	0.95 ± 0.04	0.82 ± 0.22	0.92 ± 0.09	0.93 ± 0.04	0.88 ± 0.17
LxF-RHF	0.99 ± 0.01	0.98 ± 0.01	0.98 ± 0.02	0.98 ± 0.02	0.98 ± 0.02	0.97 ± 0.02	0.98 ± 0.01	0.97 ± 0.03	0.97 ± 0.02*	0.96 ± 0.04*
LxF-RHR	0.67 ± 0.22	0.78 ± 0.21	0.77 ± 0.24	0.77 ± 0.27	0.80 ± 0.21	0.75 ± 0.21	0.81 ± 0.20	0.81 ± 0.13	0.86 ± 0.16*	0.81 ± 0.23
LxF-RH Abd/Add	0.93 ± 0.08	0.82 ± 0.17	0.92 ± 0.03	0.67 ± 0.21	0.87 ± 0.11	0.63 ± 0.32*	0.85 ± 0.06*	0.68 ± 0.26	0.82 ± 0.13*	0.60 ± 0.19*
LxR-LHF	0.66 ± 0.23	0.82 ± 0.11	0.77 ± 0.20	0.79 ± 0.22	0.80 ± 0.24	0.77 ± 0.27	0.70 ± 0.26	0.79 ± 0.18	0.71 ± 0.25	0.74 ± 0.17
LxR-LHR	0.74 ± 0.21	0.83 ± 0.10	0.71 ± 0.21	0.71 ± 0.21*	0.67 ± 0.21	0.62 ± 0.20*	0.71 ± 0.21	0.80 ± 0.15	0.73 ± 0.18	0.72 ± 0.18
LxR-LH Abd/Add	0.70 ± 0.19	0.83 ± 0.13	0.71 ± 0.20	0.79 ± 0.21	0.74 ± 0.24	0.77 ± 0.25	0.63 ± 0.28	0.75 ± 0.19	0.67 ± 0.26	0.67 ± 0.20*
LxR-RHF	0.66 ± 0.23	0.82 ± 0.11	0.77 ± 0.20	0.79 ± 0.22	0.81 ± 0.24	0.76 ± 0.27	0.70 ± 0.25	0.79 ± 0.18	0.72 ± 0.24	0.74 ± 0.17
LxR-RHR	0.71 ± 0.20	0.82 ± 0.18	0.69 ± 0.24	0.76 ± 0.20	0.78 ± 0.19	0.66 ± 0.21*	0.66 ± 0.20	0.78 ± 0.15	0.70 ± 0.21	0.76 ± 0.17
LxR-RH Abd/Add	0.60 ± 0.20	0.77 ± 0.10	0.74 ± 0.19	0.69 ± 0.19	0.72 ± 0.21	0.68 ± 0.26	0.69 ± 0.21	0.70 ± 0.18	0.69 ± 0.25	0.67 ± 0.19
LxS-LHF	0.84 ± 0.16	0.72 ± 0.23	0.75 ± 0.26	0.79 ± 0.21	0.82 ± 0.19	0.82 ± 0.22	0.79 ± 0.24	0.70 ± 0.20	0.72 ± 0.25	0.88 ± 0.16
LxS-LHR	0.76 ± 0.22	0.71 ± 0.17	0.76 ± 0.22	0.72 ± 0.23	0.73 ± 0.18	0.66 ± 0.17	0.75 ± 0.14	0.75 ± 0.21	0.71 ± 0.22	0.75 ± 0.18
LxS-LH Abd/Add	0.77 ± 0.17	0.75 ± 0.19	0.70 ± 0.26	0.82 ± 0.19	0.79 ± 0.21	0.81 ± 0.21	0.65 ± 0.26	0.65 ± 0.19	0.69 ± 0.24	0.82 ± 0.20
LxS-RHF	0.84 ± 0.16	0.71 ± 0.24	0.76 ± 0.25	0.79 ± 0.21	0.83 ± 0.19	0.81 ± 0.23	0.79 ± 0.24	0.70 ± 0.20	0.72 ± 0.25	0.88 ± 0.16
LxS-RHR	0.69 ± 0.16	0.71 ± 0.18	0.72 ± 0.25	0.68 ± 0.25	0.73 ± 0.16	0.74 ± 0.23	0.71 ± 0.21	0.74 ± 0.15	0.69 ± 0.15	0.76 ± 0.16
LxS-RH Abd/Add	0.78 ± 0.14	0.71 ± 0.18	0.73 ± 0.28	0.72 ± 0.21	0.77 ± 0.17	0.68 ± 0.25	0.70 ± 0.23	0.71 ± 0.13	0.68 ± 0.22	0.72 ± 0.14

No significant differences among symptomatic groups

Lx Lumbar spine, *H* Hip, *L* Left, *R* Right, *F* Flexion, *R* Rotation, *S* Lateral flexion, *Abd* Abduction, *Add* Adduction

*$P < 0.05$, significant difference in symptomatic subjects when compared with asymptomatic subjects (Group 1)

Asymptomatic subjects picked up the object from the ipsilateral (right) side by bending the lumbar spine forwards and to the right; flexing, abducting and externally rotating the right hip, and flexing and internally rotating the left hip. Retrieving the object from the contralateral side with the right hand was more demanding, requiring four times as much as axial rotation of the lumbar spine to the left side in addition to a substantial increase in range of the other asymmetrical lumbar and hip movements. Most of these primary movements demonstrated close and consistent coupling as evidenced by cross-correlation analysis.

Although all subjects were able to complete the tasks, the LBP groups, particularly those with a positive SLR sign, did so by reducing trunk and hip motions, but did not change the ratio of lumbar to hip movement. It should be noted that all participating LBP patients were symptomatic during the experiment. Group 5 subjects (right SLR) exhibited the most distinct response, especially when reaching to the contralateral side. There was a significant reduction in lumbar axial rotation to the left but compensated through an increase in lumbar left-side bending and left hip abduction. We suggest that this compensatory movement re-orientates the whole trunk, thereby decreasing tension on the spinal nerve roots and on the soft tissues of the hip, especially in demanding situations like picking up from the contralateral side. This study also revealed that during contralateral reaching, all subjects with right-side LBP exhibited reduced coupling between lumbar flexion and hip movements.

The findings of this study correlate well with previous studies in which the LBP subjects have demonstrated restricted spinal movements, the nature of the restriction being related to the pathology [2, 23]. Previous work has also shown that the relationship between the lumbar spine and hip movements will be altered [13, 28]. Avoiding extremes of lumbar and hip flexion, and reducing velocities and accelerations, will minimize pain and protect injured tissues, but will necessitate compensatory changes in kinematics.

Subjects with positive SLR signs have demonstrated greater restriction in lumbar and hip flexion during sit-to-stand and stand-to-sit [30], physiological movements [26], and during dressing activities [31]. This may be due to increased stiffness and stretch tolerance of the hamstring muscles [16] or to abnormal tension in the sciatic nerve or its composing nerve roots [15]. Tafazzoli and Lamontagne [33] found that the passive elastic moment and the stiffness of the hip joint of back pain subjects were significantly greater during the SLR test when compared with asymptomatic subjects.

During these reaching activities, however, subjects maintained their knees in flexion, which would suggest that the tension on the sciatic nerve was less than that elicited during the SLR test and should not have been the principal limitation to movement. This suggests that the changes in range of motion and lumbar spine–hip coordination may not be primarily a function of the compliance of the sciatic nerve and its related soft tissues. We hypothesize that these changes may be due to posture-related loading acting across the lumbar spine and hips. We propose to conduct further studies to investigate these mechanisms.

The change in spine–hip coordination may also be due to imbalance between the lumbar extensors and the abdominal muscles, and be a manifestation of a change in muscle function due to back pain [1]. Changes in muscle activation patterns and the muscle moments exerted by the antagonist and agonist [34] may be pain adaptive [21], and might also result from subtle postural adjustments that developed during the acute phase [24].

Changes to the mechanical properties of the lumbar spine and hip, and the role of interactive torques in the production of the specific movement pattern when picking up an object may also contribute to altered joint coordination. Previous studies [8, 9, 10] have suggested that in case of a multi-joint control, the leading joint (in this case the lumbar spine) is controlled differentially to the subordinate joint (in this case the hip) with the leading joint generating interactive torque at the subordinate joint to substitute passive control for active control. This may help explain the altered lumbar–hip coordination during picking up activities, in which low back pain subjects would preferentially increase the hip movements in the frontal and horizontal planes and limit movements of the lumbar spine and hips in the sagittal plane.

Our study included only middle-aged male subjects with sub-acute low back pain. The sample size, although small, was sufficiently statistically powered to determine a clinical effect and the observations were highly consistent. The sample does, however, represent only a portion of the total LBP population. The findings may not be generalizable to other groups, including those suffering from chronic low back pain. At this stage we cannot say whether the findings observed in sub-acute LBP subjects would eventually become established, compensatory movement patterns for subjects with chronic low back pain. Our study did not examine the loads acting on the lumbar spine and hips, and the power transfer between segments. Further investigation of these factors, currently underway, may allow us to explain the alterations in kinematic patterns in subjects with low back pain.

Conclusion

Our study has demonstrated that individuals with low back pain have limited range and velocity of segmental motions as well as altered lumbar–hip coordination. Moreover, the LBP patients with positive SLR signs demonstrated some additional limitation and compensatory movement pattern. For example, the LBP subjects were still able to manage picking up activity by increasing lumbar and hip movement in the frontal and horizontal planes of motion, while limiting the movement of the lumbar spine and hips in the sagittal plane. Clinicians should be aware of the compensatory pattern and to offer the most appropriate treatment and advice to restore the movements of the lumbar spine and hips. The information obtained in this study enable us to have a better understanding of the mechanisms of LBP and restricted SLR signs. Restoration of normal function in LBP patients may require recognition in not only the primary kinematic variables, but also in the coordination of movements between lumbar spine and hips.

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