RESEARCH ARTICLE

Kinematic Analysis of Pelvic and Lower Limb Joints during Stand-to-sit Movement in Individuals with Chronic Low Back Pain: A cross-sectional study

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Abstract

Objectives: It is crucial to investigate the daily functions commonly utilized by individuals with low back pain (LBP) due to their implications for recurrence and chronicity. Stand-to-sit (StTS) task is one of the more repetitive functions in human daily life. This study aims to evaluate pelvic and lower limb joint kinematics during the StTS task in individuals with Non-Specific Chronic Low Back Pain (NSCLBP) compared to a healthy control group.

Methods: Pelvic and lower limb joint kinematic data in all three planes were recorded from 20 individuals with LBP and 20 healthy individuals using a Qualisys motion capture system during the StTS task. A Functional Data Analysis statistical approach was employed to compare the kinematic data between the two groups.

Results: In the initial phase of the movement, we observed a greater anterior pelvic tilt (P=0.028) and an altered pelvic frontal plane motion pattern (P=0.029) in the LBP compared to the healthy group. The only significant differences between the lower limb joint kinematics of the two groups were a less hip external rotation position (P=0.025) and a more knee adduction pattern (P=0.002) on the right side in the LBP subjects compared to the healthy group.

Conclusion: Considering a few differences noted between the two groups across various joints and planes evaluated, it appears that the kinematic pattern of the lower limbs does not significantly differ between the NSCLBP and healthy groups during the StTS task in most comparisons. However, distinct kinematic patterns have been observed in the pelvic region, particularly in the sagittal and frontal planes, between the two groups.

Level of evidence: III

Keywords: 3D motion analysis, Kinematics, Low back pain, Lower limbs, Stand-to-sit

Introduction

Low back pain (LBP) is a medical disorder associated with socioeconomic problems.[1] Approximately 90% of the subjects with LBP in whom the cause of symptoms is unknown are classified as Non-Specific Low Back Pain (NSLBP).[2] Prior research has shown that individuals with NSLBP and healthy subjects exhibit different movement patterns in the pelvic and lower limb joints during functional activities.[3-5] This divergence in movement signatures among individuals with LBP is believed to arise from variances in underlying contributory mechanisms.[6,7]

As LBP evolves into a chronic condition, it is recognized as a biopsychosocial issue, closely intertwined with various factors.[8] The primary focus of treatment for these individuals revolves around disability prevention; however, the available evidence on interventions for symptom alleviation remains insufficient.[9] Notably, biomechanics emerges as an important biological factor in this complex interaction.[10]

Among functional activities, the stand-to-sit (StTS)

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movement emerges as an integral aspect of daily life, involving lumbar spine flexion.[11] The StTS task often occurs after walking, one of the most common forms of human locomotion.[12] Additionally, individuals with LBP frequently face challenges during daily tasks, including this movement.[13]

Prior studies on joint kinematics during the StTS in LBP individuals have yielded conflicting results. Some have reported reduced lumbar and hip range of motion (ROM) in NSLBP during the StTS task.[13,14] In contrast, other investigations have indicated no significant differences in hip motion [4] and pelvic movements between the two groups.[15,16] Additionally, some studies have identified less hip joint motion and greater pelvic tilt excursion in the LBP group.[3]

However, prior research has underscored the potential advantages of employing Functional Data Analysis (FDA) to analyze kinematic data over time.[17] in previous studies, discrete variables, such as ROM, have been commonly examined using traditional statistical methods to compare different groups.

Previous research generally interprets StTS pelvis kinematics as involving rotation, potentially resulting in anterior or posterior pelvic tilt.[18] However, pelvis kinematics may entail a complexity beyond more 2D movement in the sagittal plane.[19] Moreover, several researchers have recorded kinematic variables from a single leg, assuming that the opposing limb would behave similarly.

To the best of our knowledge, no previous study has undertaken the examination and analysis of movement patterns in pelvic and lower limb joints on both sides in all three planes during the "StTS" motion. Consequently, the objective of this study was to investigate the kinematic characteristics of the pelvic and lower limb joints on both sides and compare them between individuals with non-specific chronic low back pain (NSCLBP) and healthy subjects using the FDA approach. We hypothesized that there would be different kinematic patterns in the pelvic and lower limbs during the StTS task among patients with LBP and healthy subjects.

Materials and Methods

Participants

This observational cross-sectional study involved 20 patients with LBP and 20 healthy participants. The sample size calculation was established by the outcomes of previous similar studies,[3] which suggested that a minimum of 13 subjects per group would yield a statistical power of 0.8 at a significance level (alpha) of 0.05. However, in the current study, the sample size was increased to 20 participants in each group. The study received approval from the Ethics Committee at the University of Social Welfare and Rehabilitation Sciences (ID number: IR.USWR.REC.1400.061).

All participants completed an informed consent form and provided general demographic information. Participants with LBP also reported their current pain levels on a visual analog scale, ranging from "0" to "10". To determine the participants' dominant leg, they were asked to kick a ball.[20,21]

The LBP group comprised 20 subjects aged between 18 and 65 with a prior medical diagnosis of NSLBP. The participants had not received a specific pathology diagnosis for their LBP from a physician. They had experienced persistent pain lasting more than 12 weeks, had a body mass index (BMI) between 20 and 30, and were capable of rising on a chair unassisted. On the day of participation, each patient underwent an examination for the presence of radicular symptoms during the implementation of the Straight Leg Raise test, conducted by an experienced PhD candidate of physiotherapy with over 10 years of training in spine rehabilitation. The control group included healthy individuals aged 18 to 65, with a BMI between 20 and 30, and no prior history of LBP.

Exclusion criteria for both groups were: 1) the presence of any symptoms (e.g., musculoskeletal disorders, neurological symptoms, or radicular pain) in the lower limbs, 2) any neurological diseases, 3) engaging in intense physical activity within 48 hours prior to study participation, 4) history of spinal surgery, 5) suffering from spinal deformities and musculoskeletal, neurological, or rheumatological disorders affecting lower limb joints, and 6) pregnancy.

Procedure

The kinematic data for the transition from standing to sitting were collected using a 7-camera Qualisys Proreflex system (version 2.7, Qualisys AB, Gothenburg, Sweden) with a sampling frequency of 100 Hz. A total of 21 passive retro-reflective markers were strategically positioned, including markers on the spinous process of the first thoracic spine (T1), bilateral anterior superior iliac spine (ASIS), bilateral posterior superior iliac spine, right and left greater trochanters, right and left medial and lateral knee epicondyles, medial and lateral right and left malleoli, right and left calcanei, and right and left first and fifth metatarsal heads. Moreover, rigid clusters consisting of four markers each were attached to the lateral aspect of both thighs and legs, positioned at the midpoint [Figure 1]. The study utilized a biomechanical model that consisted of four rigid segments: the pelvis, thigh, shank, and foot.

Figure 1. The person's status and marker placement during static "StTS" test recording

Before recording the main tasks, participants were provided adequate time to become familiar with the testing procedure. In the beginning, a three-second static position was obtained in a standing position. In the current study, the kinematic data represent the average of three "StTS" trials. To determine the seat height for each individual before commencing the main performance recording, the chair's height was adjusted so that, in the sitting position, the thigh formed a horizontal line through the greater trochanter and femoral lateral epicondyle, with the knee joint positioned at a ninety-degree angle. This adjustment was confirmed by the examiner using a goniometer. Subjects were instructed to stand barefoot in front of an adjustable chair, with their legs positioned shoulder-width apart, and to perform the motion at their preferred speed. Upon hearing the "start" command, participants were asked to sit down on a stool while maintaining a forward gaze, without using their hands for assistance. To mitigate the effects of fatigue, subjects were given sufficient rest between the tests.

The "StTS" function was divided into two phases: A) The Pre-Buttocks Contact (Pre-B_C) phase and B) the Post-Buttocks Contact (Post-B_C) phase. To achieve this, three points were defined:

1) The starting point was established as the initial moment of horizontal (x) displacement of the T1 marker.[22]
2) "Buttocks contact" was identified as the point at which the vertical linear displacement of the trochanter marker reached 90% of its peak.[23]
3) The conclusion of the movement was determined as the moment when there was no further horizontal (x) displacement of the T1 marker.

Data processing

First, the data were extracted from the Qualisys system, and then, the kinematic coordinates of markers were smoothed using a fourth-order Butterworth filter with a cutoff frequency of 6 Hz. The kinematic data were then analyzed using MATLAB (R2017b, The Mathworks Inc, Natick, MA) to characterize the movement patterns of segments over time. Utilizing the position of anatomical markers during a static trial (CAST technique), we constructed segment coordinate systems (SCSs) and anatomical planes for each segment. The kinematic data were normalized to 100% of the task. Subsequently, all StTS kinematics data were imported into Microsoft Excel for the calculation of excursion (the difference between the maximum and minimum angles) and ROM (end angle minus the start angle) separately for each phase in each group. In this study, three-dimensional joint rotations were computed using the joint coordinate system (JCS), which is derived from the SCSs.[24] For the static standing position, it was established that all joint positions were at zero degrees [Figure 1]. The feet were positioned shoulder-width apart in this static standing position in accordance with the methodology employed in the study.[25]

Statistical analysis

Statistical analysis was carried out using SPSS (SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp) and R software. The normality of the demographic data was assessed using the Shapiro-Wilk statistical test. All demographic data followed a normal distribution in this study. Additionally, all participants in the study were right-sided dominant. Descriptive statistics, including mean and standard deviation, were calculated to describe the demographic characteristics of the subjects. Regarding BMI, weight, height, age, and task duration, there were no significant differences between the control and NSCLBP groups [Table 1].

Table 1. Anthropometric data and clinical characteristics of the study population

Characteristics	NSCLBPa group (n=20) Mean(SD)	Control group (n=20) Mean(SD)	P-value
Age (year)	31.25(6.37)	27.5(5.9)	0.39
Height (cm)	168(4.38)	171(8.9)	0.19
Weight (Kg)	65.6(9.42)	67.95(8.96)	0.42
BMIb (Kg/m^2)	23.23(3.11)	23.19(1.76)	0.95
Gender	(10 males, 10 females)	(10 males, 10 females)	-
Visual analog scale (0-10)	2.9(1.1)	00.00	0.00
Duration (s)	2.48(0.43)	2.53 (0.57)	0.3

[a] Non-specific chronic low back pain
[b] Body mass index

Descriptive values for the LBP and control groups were presented as the excursion and the ROM of the pelvic, hip, knee, and ankle joints in all three planes on both sides during both phases of the task using Excel software. These values represent the averages obtained from three trials [Table 2].

We evaluated the intra-rater reliability and the standard error of measurement for the maximal ROM variable across all kinematic measurements [Table 3].

Table 2. Descriptive values for kinematic parameters of the pelvic and right and left hips, knee, and ankle joints during StTS[a] in NSCLBP[b] subjects and healthy participants

Region	Group		Variables											
			Excursion*(Degree) Mean /(SD)[d]						ROM[c](Degree) Mean /(SD)					
			Pre-B_C [e]			Post-B_C [f]			Pre-B_C			Post-B_C		
			sagittal	*frontal*	*transverse*	*sagittal*	*frontal*	*transverse*	*sagittal*	*frontal*	*transverse*	*sagittal*	*frontal*	*transverse*
Pelvic	*Healthy*	**Mean**	22.40	3.40	3.76	29.26	1.9	3.23	12.63	1.97	2.12	32.1	1.19	2.13
		SD	(14.5)	(1.65)	(1.9)	(15.29)	(1.22)	(2.04)	(5.89)	(1.32)	(2.06)	(7.21)	(1.03)	(1.92)
	LBP [a]	**Mean**	24.93	4.25	5.19	28.36	2.64	2.87	10.21	2.17	3.11	28.3	2.23	2.18
		SD	(13.3)	(3.49)	(3.91)	(16.07)	(1.88)	(2.19)	(10.76)	(2.00)	(2.64)	(16.25)	(2.07)	(2.01)
Dominant hip	*Healthy*	**Mean**	84.93	8.86	4.93	28.12	4.89	2.06	87.87	6.84	2.58	24.75	3.73	2.55
		SD	(20.24)	(4.46)	(4.37)	(14.74)	(3.56)	(1.55)	(12.7)	(4.29)	(2.59)	(7.92)	(3.24)	(1.23)
	LBP	**Mean**	86.21	9.36	3.91	24.8	4.3	2.4	83.61	8.38	4.85	24.71	3.79	2.51
		SD	(14.59)	(5.99)	(3.1)	(9.62)	(3.97)	(2.27)	(9.41)	(4.52)	(3.12)	(9.55)	(3.39)	(1.35)
Non-dominant hip	*Healthy*	**Mean**	86.31	12.36	14.76	27.86	5.69	8.24	90.06	10.48	9.19	24.78	3.13	6.75
		SD	(22.62)	(6.13)	(11.72)	(14.64)	(7.29)	(7.67)	(12.34)	(6.14)	(7.74)	(7.29)	(2.98)	(4.43)
	LBP	**Mean**	87.84	10.8	12.73	25.59	4.44	4.44	85.05	7.95	9.36	25.36	3.9	6.57
		SD	(23.31)	(5.77)	(9.73)	(7.37)	(3.64)	(3.46)	(25.34)	(4.3)	(7.56)	(7.32)	(3.44)	(5.28)
Dominant knee	*Healthy*	**Mean**	83.77	9.75	13.15	7.76	5.94	5.62	87.24	8.26	9.43	2.31	3.04	2.93
		SD	(19.79)	(4.65)	(6.99)	(3.13)	(4.41)	(3.27)	(7.2)	(4.03)	(1.38)	(1.99)	(2.56)	(1.33)
	LBP	**Mean**	81.86	10.12	13.16	4.34	4.24	6.51	81.39	7.99	11.34	3.04	2.57	5.6
		SD	(10.98)	(6.65)	(11.34)	(3.32)	(2.7)	(4.04)	(18.57)	(6.66)	(8.53)	(2.18)	(1.45)	(2.08)
Non-dominant knee	*Healthy*	**Mean**	84.5	14.2	15.22	9.65	7.41	7.07	87.48	8.97	11.34	3.61	4.51	4.87
		SD	(6.93)	(3.54)	(4.60)	(20.25)	(5.62)	(5.49)	(6.02)	(5.84)	(5.59)	(1.59)	(3.01)	(3.63)
	LBP	**Mean**	82.47	13.02	15.93	5.0	4.42	4.11	81.93	10.03	12.9	3.69	2.85	2.74
		SD	(10.14)	(6.29)	(7.06)	(4.4)	(2.04)	(2.9)	(10.99)	(5.58)	(7.40)	(1.99)	(2.01)	(2.40)
Dominant ankle	*Healthy*	**Mean**	14.74	5.22	5.39	7.88	3.53	4.62	12.06	3.31	3.23	8.57	2.3	2.12
		SD	(4.7)	(2.94)	(3.14)	(3.69)	(2.84)	(3.36)	(4.15)	(2.45)	(2.6)	(4.17)	(1.94)	(1.75)
	LBP	**Mean**	14.14	4.66	3.95	7.85	4.12	4.30	10.99	3.21	3.89	7.3	3.39	3.94
		SD	(5.21)	(3.24)	(2.07)	(2.88)	(3.78)	(1.89)	(3.82)	(2.85)	(3.04)	(3.18)	(4.8)	(3.11)
Non-dominant ankle	*Healthy*	**Mean**	20.49	5.62	6.37	9.62	2.91	6.53	18.47	3.14	4.72	9.44	2.06	5.45
		SD	(10.32)	(3.93)	(2.10)	(6.55)	(2.15)	(2.63)	(7.39)	(3.25)	(3.7)	(6.08)	(1.89)	(3.27)
	LBP	**Mean**	14.82	4.96	4.62	7.63	2.52	2.89	11.09	3.64	2.49	7.32	1.74	1.17
		SD	(5.06)	(1.46)	(2.70)	(2.81)	(2.33)	(1.85)	(5.67)	(1.52)	(3.2)	(3.01)	(1.68)	(1.11)

[a] Stand-to-sit
[b] NSCLBP: Non-specific chronic low back pain
[c] ROM: Range of motion
[d] SD: Standard deviation
[e] Pre-buttock contact
[f] Post buttock contact

Table 3. Reliability values (intraclass correlation coefficient) and standard error of the measurement for kinematics parameters during the "Stand-to-sit" test

Kinematic variable	Intra-class reliability	*First phase*			*Second phase*		
		Plane of motion			Plane of motion		
Maximum ROM[a]		sagittal	frontal	transverse	sagittal	frontal	transverse
pelvic	ICC[b]	0.95	0.65	0.61	0.86	0.69	0.58
	(95% CI[c])	(0.89, 0.98)	(0.17, 0.88)	(0.31, 0.91)	(0.68, 0.95)	(0.41, 0.70)	(0.15, 0.70)
	SEM[d] (°)	1.71	1.6	1.65	4.51	0.97	4.5
hip	ICC	0.96	0.86	0.88	0.91	0.67	0.91
	(95% CI)	(0.90, 0.98)	(0.66, 0.95)	(0.71, 0.96)	(0.80, 0.97)	(0.22, 0.89)	(0.79, 0.97)
	SEM (°)	3.12	2.23	2.24	3.26	2.75	2.06
knee	ICC	0.94	0.90	0.84	0.73	0.84	0.80
	(95% CI)	(0.85, 0.98)	(0.77, 0.96)	(0.62, 0.94)	(0.36, 0.90)	(0.63, 0.94)	(0.53, 0.93)
	SEM (°)	2.9	1.51	2.53	2.03	1.11	2.35
ankle	ICC	0.83	0.54	0.96	0.67	0.62	0.79
	(95% CI)	(0.60, 0.94)	(0.31, 0.74)	(0.92, 0.98)	(0.23, 0.89)	(0.18, 0.86)	(0.50, 0.92)
	SEM (°)	2.42	3.55	0.72	2.21	2.08	1.01

[a] Range of motion
[b] Intraclass correlation coefficient
[c] Confidence interval
[d] Standard error of measurement

In this paper, we employed the FDA statistical method to compare kinematic data between two groups. This method enables the representation of any function as a linear combination of a set of curves. FDA involves converting discrete data into a functional format prior to conducting any analysis.[26] Calculations were conducted using MATLAB software, specifically utilizing the R-package named "Simultaneous Confidence Bands" SCBmeanfd [Table 4].

Results

In the present study, all of the maximal ROM variables exhibited moderate to excellent levels of intra-rater reliability,[27] as indicated by the reliability values (intraclass correlation coefficient) and standard error of the measurement for kinematics parameters during the "Stand-to-sit" test [Table 3].

The comparison of movement patterns between the LBP and control groups revealed significant differences in the pelvic region. Patients in the LBP group exhibited a more anterior pelvic tilt pattern in the sagittal plane (P=0.028) and a greater counter-clockwise (CCW) rotation in the frontal plane during the first phase of the StTS motion (Pre-B_C phase). This indicates that in the LBP group, the left ASIS was positioned higher in the frontal plane during the initial phase of the motion compared to healthy subjects (P=0.029) [Table 4].

On the right side, the only significant difference within the hip joints was a more internal rotation pattern observed in the first (P=0.025) and the second phases (P=0.003) of the motion when compared to the control group. Regarding the knee joint on the right side, there was a distinct greater adduction pattern in the frontal plane during the first (P=0.002) and second (P=0.005) phases when compared to the control group [Table 4].

There were no significant differences between the two groups in ankle motion patterns on both sides.

In the lower extremity joints (hip, knee, and ankle) on the left side, no significant differences were observed between the two groups in terms of movement patterns in all three planes during the execution of the StTS motion [Table 4]. Graphs and P-values for between-group comparisons of the pelvic and lower limb joints using the FDA approach are presented in Table 4.

Discussion

The results of the current study, align with some prior research findings,[12] indicated that there were no significant differences between the two groups in terms of task duration. The greater amount of anterior pelvic tilt position observed during the "Pre-B_C" phase of the task in individuals with LBP may be a consequence of movement restrictions in the lumbar spine and hip joints.[13,14] This finding was in line with earlier research that reported increased pelvic excursion during the initial phase of this motion.[3] It is conceivable that during the first phase of the "StTS" movement when lumbar ROM is limited, the pelvis compensates for this restriction in lumbar spine mobility by increasing anterior tilt. Moreover, the observed anterior pelvic tilt position during the first phase of the task in CLBP subjects may be attributed to the hyperactivity of the quadriceps muscles and the inefficiency of the abdominal muscles.[28]

Table 4. Kinematic curves and P-value for the pelvis, dominant and, non-dominant hip, knee, and ankle in the three anatomical planes between two groups. ▪▪▪▪▪▪ CLBP ▬▬▬ Control, * P value < 0.05

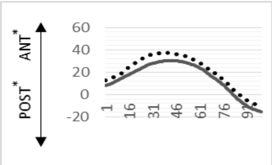
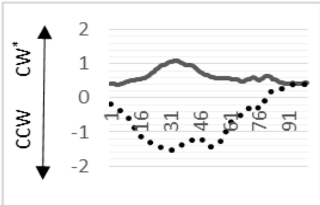
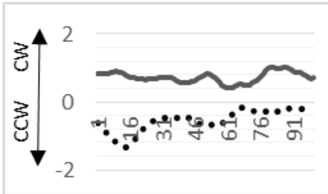
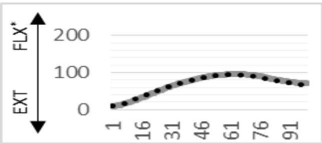
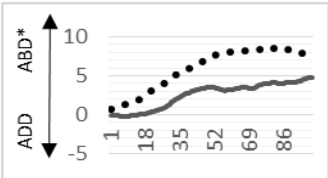
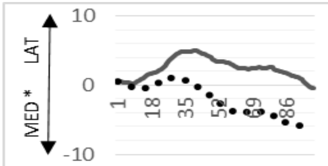
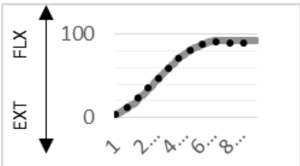
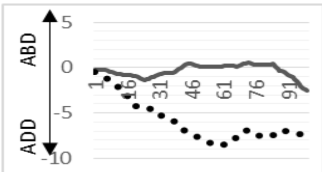
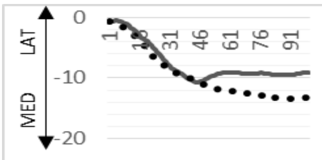
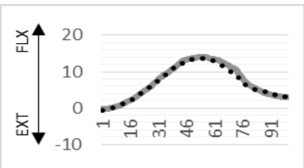
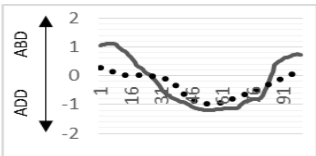
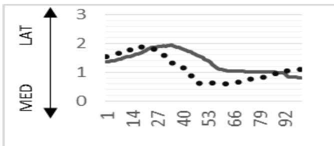
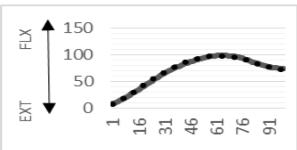
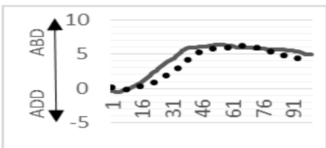
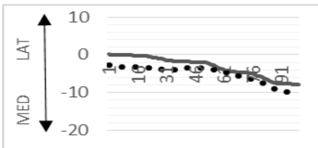
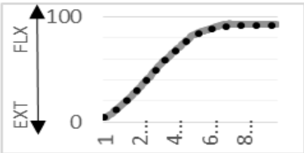
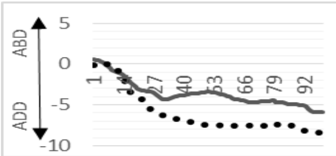
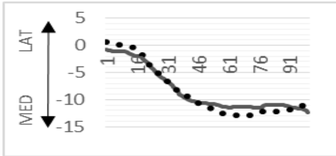
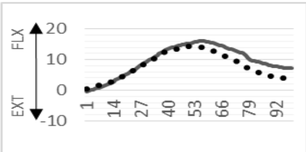
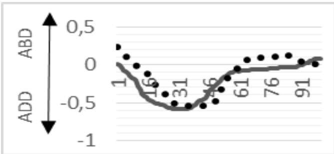
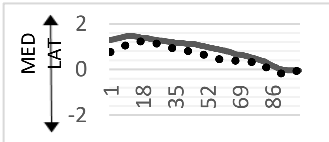
	Sagittal	Frontal	Transverse
Pelvic	 *P-value: 0.03**	 *P-value: 0.03**	 *P-value: 0.06*
Dominant side			
Hip	 *P-value: 0.95*	 *P-value: 0.05*	 *P-value: 0.03**
Knee	 *P-value: 0.85*	 *P-value: 0.00**	 *P-value: 0.55*
Ankle	 *P-value: 0.93*	 *P-value: 0.28*	 *P-value: 0.18*
Non-dominant side			
Hip	 *P-value: 0.86**	 *P-value: 0.80*	 *P-value: 0.51*

Table 4.Continued

	Sagittal	Frontal	Transverse
Knee			
	P-value: 0.98	*P-value: 0.75*	*P-value: 0.20*
	Sagittal	**Frontal**	**Transverse**
Ankle			
	P-value: 0.44	*P-value: 0.29*	*P-value: 0.39*

*The p-values reported in the table are for the first phase of the StTS movement.
*Post (posterior), Ant (anterior), CCW (counter-clockwise), CW (clockwise), Ext (extension), Flx (flexion), ADD (adduction), ABD (abduction), MED (medial), LAT(lateral)
In each graph, the vertical axis indicates the angle of the joints (Angle (degree), and the horizontal axis indicates the percentage of the StTS motion cycle over time (during both phases)

The increased CCW rotation of the pelvis in the frontal plane on the right side observed in the LBP group may be attributed to the weakness of the hip abductor muscles on the same side. This result was in agreement with previous research demonstrating that weakness in the gluteus medius muscle is linked to the manifestation of NSCLBP.[29]

Regarding hip joint kinematic patterns, our study showed a greater internal rotation pattern of the hip joint in the LBP group on the right side; however, there were no significant differences between the two groups on the left side hip joint in all the three planes. The results of past studies on the rotation of the hip joint in the transverse plane in the LBP group compared to healthy individuals were contradictory. Some previous pieces of research have reported a higher amount of internal hip rotation in the subjects with LBP than in the healthy group during an active hip test.[30] Other researchers reported a reduction in the ROM for the internal rotation of the hip joint among individuals with LBP.[31] It is worth noting that in their study, this decrease in hip internal rotation ROM was evident in athletes with LBP who were consistently engaged in rotational sports, such as golf. [31] In these LBP patient athletes accustomed to repetitive rotation movements on one leg, it was found that the hip external rotator muscles exhibited greater stiffness and a more cross-sectional area compared to non-athlete LBP subjects.[32] Consequently, it is conceivable that the kinematics of the hip joint in this group of LBP athletes may differ from those of non-athletes participating in the current study. In a recent study evaluating hip rotation in the horizontal plane during the "StTS" task, the results showed no significant differences in the mean values for hip rotation between the two groups.[3] In our study, we observed a greater amount of CCW rotation of the pelvis in the transverse plane, which was associated with increased hip internal rotation on the right side in the LBP group compared to healthy subjects. One potential explanation for these kinematic patterns during the first phase of the StTS motion could be related to the need for more stability to reach controlled motion in the LBP group. Other studies have supported similar findings, indicating postural instability during StTS maneuvers owing to decreased lumbar spine and trunk flexion in individuals with NSCLBP.[16] This diminished trunk flexion has been associated with a shorter period during which the center of mass remains within the base of support during StTS.[33] Therefore, it is plausible that individuals with NSCLBP, experiencing a reduced capacity for trunk flexion, may rely more on pelvic CCW rotation (internal rotation) and hip internal rotation to provide additional passive stability in the dominant side lower limb,[34] facilitating controlled movement during the initial phase of the StTS maneuver.

The only significant difference in the knee joint between the two groups was observed on the right side, where a more adduction position of the knee joint was evident in both phases within the LBP group. This altered knee frontal plane kinematic aligns with findings from previous studies that have reported increased knee motion in the frontal plane in the CLBP group during functional tasks.[35,36] This observation could be attributed to gluteal muscle weakness in the LBP subjects who rely more on their hamstrings and hip flexors, as opposed to their gluteal muscles.[29]

The current study did not reveal significant differences in most of the parameters related to lower limb joint kinematics on both sides and three planes between the two groups. A significant finding in the current study was the altered kinematic patterns of the pelvic region during the execution of the "StTS" function. These altered movement patterns of the pelvic region could potentially result in excessive mechanical loads on the lumbar spine. Such excessive stresses applied to the lumbo-pelvic region have been associated with spinal pathology and the development of LBP.[37] additionally, it is noteworthy that the pelvic region plays a crucial role in integrating the movements of the lumbosacral region and lower limb joints.[38, 39, 40, 41] Therefore, during routine daily activities, impaired pelvic movements could have an impact on both of these areas. Understanding the altered strategies employed by LBP individuals to perform the "StTS" function can contribute to the improvement of functional diagnostic criteria and aid in the development of targeted treatment approaches within their physical therapy plans.

In this study, the results revealed that, in contrast to the right side, there were no significant differences between the two groups on the left side across all joints in all three planes. This suggests that in the CLBP group, compensatory mechanisms may develop more on the one side over time due to increased reliance on and utilization of the one side. Taking into account this finding, it is essential for clinicians and researchers to consider the potential side-specific differences in kinematic alterations.

The present study has several limitations. Firstly, our study focused on joint kinematics, and the inclusion of electromyography recordings could have provided additional insights into the musculoskeletal activity of the subjects. Additionally, the use of skin markers may have introduced potential kinematic inaccuracies due to soft tissue artifacts, which were not accounted for in our analysis. Lastly, our participants experienced mild lumbar spine pain for a duration exceeding three months. We are not sure whether similar outcomes would manifest in individuals with more severe LBP.

Conclusion

According to the results of our study, pelvic kinematic patterns in all three planes should be a focal point in both research and rehabilitation programs when addressing this function in NSCLBP subjects. It seems that in NSCLBP subjects, the kinematic patterns of the lower limb joints are not sufficient to distinguish the LBP group from the healthy one. As a result, it is necessary to pay attention to other factors, such as psychosomatic disorders and muscle activation during the StTS performance, in LBP subjects.

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References

1. Hoy D, Bain C, Williams G, et al. A systematic review of the global prevalence of low back pain. Arthritis Rheum. 2012; 64(6):2028-37. doi: 10.1002/art.34347.
2. Koes BW, Van Tulder M, Thomas S. Diagnosis and treatment of low back pain. BMJ. 2006; 332(7555):1430-4. doi: 10.1136/bmj.332.7555.1430.
3. Orakifar N, Shaterzadeh-Yazdi MJ, Salehi R, Mehravar M, Namnik N, Haghpanah SA. Comparison of Kinematic

Movement Patterns between 2 Subgroups of Females with Low Back Pain and Healthy Women during Sit-to-Stand and Stand-to-Sit. J Appl Biomech. 2022; 38(5):346-354. doi: 10.1123/jab.2022-0064.
4. Sadeghisani M, Manshadi FD, Kalantari KK, Karimi MT, Azimi H, Aghazadeh A. Kinematics of the Lumbar Spine and Hip Joints in People with Persistent Low Back Pain during Sit to Stand and Stand to Sit Activities. Med J Islam Repub Iran. 2021:35:165. doi: 10.47176/mjiri.35.165.
5. Rahimi A, Arab AM, Nourbakhsh MR, Hosseini SM, Forghany S. Lower limb kinematics in individuals with chronic low back pain during walking. J Electromyogr Kinesiol. 2020:51:102404. doi: 10.1016/j.jelekin.2020.102404.
6. Van Dillen LR, Sahrmann SA, Norton BJ, Caldwell CA, McDonnell MK, Bloom NJ. Movement system impairment-based categories for low back pain: stage 1 validation. J Orthop Sports Phys Ther.2003; 33(3):126-42. doi: 10.2519/jospt.2003.33.3.126.
7. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. Man Ther. 2005; 10(4):242-55. doi: 10.1016/j.math.2005.07.001.
8. Kamper SJ, Apeldoorn AT, Chiarotto A, et al. Multidisciplinary biopsychosocial rehabilitation for chronic low back pain: Cochrane systematic review and meta-analysis. BMJ. 2015:350:h444. doi: 10.1136/bmj.h444.
9. Foster NE, Anema JR, Cherkin D, et al. Prevention and treatment of low back pain: evidence, challenges, and promising directions. Lancet.2018; 391(10137):2368-2383. doi: 10.1016/S0140-6736(18)30489-6.
10. Negrini S, Pollet J, Ranica G, et al. Movement analysis could help in the assessment of chronic low back pain patients: Results from a preliminary explorative study. Int J Environ Res Public Health. 2022; 19(15):9033. doi: 10.3390/ijerph19159033.
11. Kerr KM, White JA, Barr DA, Mollan RA. Analysis of the sit-stand-sit movement cycle in normal subjects. Clin Biomech (Bristol, Avon).1997; 12(4):236-245. doi: 10.1016/s0268-0033(96)00077-0.
12. Sadeghi H, Allard P, Prince F, Labelle H. Symmetry and limb dominance in ablebodied gait: a review. Gait Posture. 2000; 12(1):34-45. doi: 10.1016/s0966-6362(00)00070-9.
13. Shum GL, Crosbie J, Lee RY. Effect of low back pain on the kinematics and joint coordination of the lumbar spine and hip during sit-to-stand and stand-to-sit. Spine (Phila Pa 1976). 2005; 30(17):1998-2004. doi: 10.1097/01.brs.0000176195.16128.27.
14. Pourahmadi MR, Takamjani IE, Jaberzadeh S,et al. Test-retest reliability of sit-to-stand and stand-to-sit analysis in people with and without chronic non-specific low back pain. Musculoskelet Sci Pract.2018:35:95-104. doi: 10.1016/j.msksp.2017.11.001.
15. Claeys K, Dankaerts W, Janssens L, Brumagne S. Altered preparatory pelvic control during the sit-to-stance-to-sit movement in people with non-specific low back pain. J Electromyogr Kinesiol.2012; 22(6):821-8. doi: 10.1016/j.jelekin.2012.04.007.
16. Jangjoo N, Alijanpour E, Khodabakhsh S, Shojaedin SS, Naemi R. Comparison of Spine–Pelvis Kinematics Variability during Sit-to-Stand and Stand-to-Sit in People with & without Chronic Low Back Pain: A Vector Coding and Statistical Parametric Mapping Approach. Applied Sciences. 2022; 12(22):11796.doi: 10.3390/app122211796.
17. Ryan W, Harrison A, Hayes K. Functional data analysis of knee joint kinematics in the vertical jump. Sports Biomech.2006; 5(1):121-38. doi: 10.1080/14763141.2006.9628228.
18. Lazennec JY, Brusson A, Rousseau MA. Hip–spine relations and sagittal balance clinical consequences. Eur Spine J.2011;20 Suppl 5(Suppl 5):686-98. doi: 10.1007/s00586-011-1937-9.
19. Kim Y, Vergari C, Girinon F, Lazennec JY, Skalli W. Stand-to-sit kinematics of the pelvis is not always as expected: hip and spine pathologies can have an impact. J Arthroplasty.2019; 34(9):2118-2123. doi: 10.1016/j.arth.2019.04.059.
20. Guerrero-Henriquez J, Mendez-Rebolledo G, LLancaleo L, Vargas M. Effects of dominance and vision on unipedal balance tests in futsal players using a triaxial accelerometer. Sports Biomech.2024:1-10. doi: 10.1080/14763141.2024.2301987.
21. Gabbard C, Hart S. A question of foot dominance. J Gen Psychol.1996; 123(4):289-96. doi: 10.1080/00221309.1996.9921281.
22. Tully EA, Fotoohabadi MR, Galea MP. Sagittal spine and lower limb movement during sit-to-stand in healthy young subjects. Gait Posture.2005; 22(4):338-45. doi: 10.1016/j.gaitpost.2004.11.007.
23. Mourey F, Grishin A, d'Athis P, Pozzo T, Stapley P. Standing up from a chair as a dynamic equilibrium task: a comparison between young and elderly subjects. J Gerontol A Biol Sci Med Sci. 2000; 55(9):B425-31. doi: 10.1093/gerona/55.9.b425.
24. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng.1983; 105(2):136-44. doi: 10.1115/1.3138397.
25. Leardini A, Benedetti MG, Catani F, Simoncini L, Giannini S. An anatomically based protocol for the description of foot segment kinematics during gait. Clin Biomech (Bristol, Avon).1999; 14(8):528-36. doi: 10.1016/s0268-0033(99)00008-x.
26. Ramsay J, Hooker G, Graves S. Introduction to functional data analysis. In: Functional data analysis with R and MATLAB. New York, NY: Springer; 2009
27. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016; 15(2):155-63. doi: 10.1016/j.jcm.2016.02.012.
28. Behdarvandan A, Shaterzadeh-Yazdi MJ, Negahban H, Mehravar M. Differences in timing and magnitude of lumbo-pelvic rotation during active and passive knee extension in sitting position in people with and without low back pain: A cross-sectional study. Hum Mov Sci. 2019:64:338-346. doi: 10.1016/j.humov.2019.02.012.
29. Cooper NA, Scavo KM, Strickland KJ, et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. Eur Spine J.2016; 25(4):1258-65. doi: 10.1007/s00586-015-4027-6.
30. Sadeghisani M, Manshadi FD, Kalantari KK, et al. A comparison of the lumbopelvic-hip complex movement

patterns in people with and without non-specific low back pain during an active hip test. Journal of Mechanics in Medicine and Biology. 2017; 17(01):1750004. doi:org/10.1142/S021951941750004X.

31. Murray E, Birley E, Twycross-Lewis R, Morrissey D. The relationship between hip rotation range of movement and low back pain prevalence in amateur golfers: an
and the relationship with postural stability in aging. Gait Posture. 2021:86:292-298. doi: 10.1016/j.gaitpost.2021.03.025.

34. Levangie PK, Norkin CC. Joint structure and function: a comprehensive analysis. Fifth edition. Philadelphia. FA Davis; 2011.

35. Gombatto SP, D'Arpa N, Landerholm S, et al. Differences in kinematics of the lumbar spine and lower extremities between people with and without low back pain during the down phase of a pickup task, an observational study. Musculoskelet Sci Pract.2017:28:25-31. doi: 10.1016/j.msksp.2016.12.017.

36. Papi E, Bull AM, McGregor AH. Alteration of movement patterns in low back pain assessed by Statistical Parametric Mapping. J Biomech.2020:100:109597. doi: 10.1016/j.jbiomech.2019.109597.

37. McGill SM. The biomechanics of low back injury: implications on current practice in industry and the clinic. J Biomech.1997; 30(5):465-75. doi: 10.1016/s0021-9290(96)00172-8.

38. Cho M. Correlations among pelvic positions and differences in lower extremity joint angles during walking in female

observational study. Phys Ther Sport.2009; 10(4):131-5. doi: 10.1016/j.ptsp.2009.08.002.

32. Neumann DA. Kinesiology of the hip: a focus on muscular actions. J Orthop Sports Phys Ther.2010; 40(2):82-94. doi: 10.2519/jospt.2010.3025.

33. Jeon W, Whitall J, Griffin L, Westlake KP. Trunk kinematics and muscle activation patterns during stand-to-sit movement university students. J Phys Ther Sci.2015; 27(6):1941-4. doi: 10.1589/jpts.27.1941.

39. Pourahmadi M, Barejahri AM, Sahebalam M, Bagheri R. Relationship of impaired lumbar spine-hip coordination during sit to stand and stand to sit with functional disability in chronic nonspecific low back pain patients. Archives of Bone and Joint Surgery. 2022;10(10):892. doi: 10.22038/abjs.2022.56903.2822.

40. Khanzadeh R, Mahdavinejad R, Borhani A. The effect of suspension and conventional core stability exercises on characteristics of intervertebral disc and chronic pain in office staff due to lumbar herniated disc. Archives of Bone and Joint Surgery. 2020;8(3):445. doi: 10.22038/abjs.2019.40758.2102.

41. Azadinia F, Ebrahimi-Takamjani I, Kamyab M, Asgari M, Parnianpour M. Immediate effects of lumbosacral orthosis on postural stability in patients with low back pain: a preliminary study. Archives of Bone and Joint Surgery. 2019;7(4):360. doi: 10.22038/abjs.2019.34753.1912