ORIGINAL

Relationship between lumbar spine motor control ability and perceptual awareness during prone hip extension movement in people with low back pain

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Abstract : Purpose : The purpose of this study was to clarify the differences in lumbar spine and hip joint motor control ability (MCA) in prone hip extension (PHE) between individuals with and without low back pain (LBP). It also aimed to determine the relationship between lumbar spine and hip joint MCA and lumbar perceptual awareness in individuals with LBP. Methods : In total, 78 university students (20 with LBP and 58 without) were included in the study. The MCA of the lumbar spine and hip joint in PHE and perceptual awareness were evaluated. The MCA of the lumbar spine and hip joint was measured using a wearable sensor. Subsequently, a comparison of the MCA of the lumbar spine and hip joints of the participants and the relationship between MCA and lumbar perceptual awareness were examined. Results : The MCA of the LBP group was higher than that of the non-LBP group in motion on the sagittal plane. In addition, perceptual awareness was negatively correlated with MCA in the sagittal plane in the lumbar spine. Conclusion : People with LBP had higher lumbar spine and hip joint MCA than those without LBP. Perceptual awareness was associated with lumbar spine and hip joint MCA in people with LBP. J. Med. Invest. 69 : 38-44, February, 2022

Keywords : *low back pain, motor control, perceptual awareness*

INTRODUCTION

Low back pain (LBP) has a high global prevalence and causes problems in many regards, including increased medical costs and frequency of medical care use, disability, and decreased working days (1, 2). It is widely known that LBP is a multifactorial condition. Thus, the evaluation of biomechanical and psychosocial factors is important in its prevention and treatment (3).

Prone hip extension (PHE) is used to evaluate biomechanical factors in LBP (4, 5). Lumbar spine and hip joint motion are closely related, and when hip joint motion occurs, lumbar spine motion also occurs via the pelvis (6). For this reason, a movement test that evaluates the angle and timing of both lumbar spine and hip joint motion during lower limb movement is often used for clinical evaluation. Among clinical tests, PHE is often used to evaluate hip extensor muscle strength, lumbar movement patterns, and musculoskeletal control during hip movement ; hence, it plays an important role in assessing LBP (4, 5). However, it is still not established whether lumbar motion increases or decreases in people with LBP (7-13). Several studies have reported that patients with LBP have less lumbar spine motion and, in compensation, more hip motion to avoid pain when performing various movement tests (7-10). Conversely, there are reports that people with LBP have a large lumbar motion angle. These are in line with the kinesiopathologic model, where LBP results from stress on the peripheral tissues of the lumbar region due to excessive motion of the lumbar spine relative to the hip joint (11, 12).

In order to solve LBP, it is important to have not only sufficient range of motion of motion but also the ability to modify the motion according to the situation, i.e., the motor control ability (MCA). People with LBP need to be able to control their lumbar movement appropriately and choose low-impact movement to prevent the exacerbation of LBP. However, there are no reports investigating lumbar MCA by lumbar motion modification, and the difference in lumbar MCA in PHE between individuals with and without LBP has not yet been clarified.

Perceptual awareness of the lumbar region is important for acquiring high lumbar MCA as it provides the proprioceptive information essential for controlling body movements (13, 14). In addition, lumbar perceptual awareness is related to LBP. It has been reported that people with chronic LBP have more abnormal perceptual awareness than those without LBP (15). Therefore, it is expected that the MCA of the lumbar spine and hip joints is closely related to lumbar perceptual awareness. However, there are no reports that have investigated the relationship between MCA of the lumbar spine and hip joints and perceived awareness of the lumbar region.

Consequently, the purpose of this study was to clarify the differences in lumbar spine and hip joint MCA in PHE between people with and without LBP and to clarify the relationship between lumbar spine and hip MCA and lumbar perceptual awareness. It was hypothesized that people with LBP would have low MCA of the lumbar spine and hip joints and that the MCA of the lumbar spine and hip joints would be related to lumbar perceptual awareness.

PARTICIPANTS AND METHODS

1. Study Design

The study was conducted with a cross-sectional observational design.

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2. Participants

The participants were university students who were recruited and willing to participate in the study. The inclusion criteria were as follows : 1) those who did not have typical physical disabilities, such as paralysis or arthropathy ; 2) those who did not have pain, other than in the lumbar region, that interferes with daily life ; and 3) those who did not undergo surgery that affected the movement of the lumbar spine or hip joint, such as lumbar fusion or artificial hip joint. In addition to the aforementioned criteria, to verify LBP associated with lumbar extension that is not in the acute phase, the following criteria were added for LBP participants : 1) those with chronic LBP for more than 3 months at the time of measurement (16) and 2) those with LBP during lumbar extension.

3. Ethical Considerations

The purpose and methods of the study were explained orally and in writing, and written consent for "voluntary participation" was obtained before the study was conducted. This study was conducted with the approval of the Ethics Committee of Kyoto Tachibana University (Approval No. 20-09).

4. Measurement

The measurement items were the motion angle of the lumbar spine and hip joint in PHE, perceptual awareness of the lumbar region, and the degree of disability due to LBP. The Fremantle Back Awareness Questionnaire (FreBAQ) was used to assess perceptual awareness of the low back, while the Oswestry LBP disability index (ODI) (17, 18) was used to assess the degree of disability due to LBP. The FreBAQ is a nine-item questionnaire developed by Wand *et al.* (15) to assess perceptual awareness of the lumbar spine. Items 1–3 are about neglect-like symptoms, 4–5 are about intrinsic sensations, and 6–9 are on a body image index (19). A higher score on the FreBAQ indicates a decrease in perceptual awareness in the lumbar region (15). The Japanese version of FreBAQ has been developed, and its validity has been demonstrated (19, 20).

The motion angles of the lumbar spine and right hip joints in the sagittal and horizontal planes during right PHE were measured with reference to previous studies (21). A wearable sensor (TSND151 ; ATR-Promotions, Sagara, Japan) and receiving software (ARMS ; ATR-Promotions, Sagara, Japan) were used for the measurements. The sensors were attached at three locations : the thoracolumbar transition, the lumbosacral transition, and the right thigh. Specifically, the first sensor was placed in the midline of the first lumbar vertebra, the second sensor in the midline of the upper sacrum, and the third sensor in the center of the posterior right thigh (Figure 1). To keep the position of the sensor constant, it was marked beforehand and fixed sufficiently with elastic tape or an elastic band. The sensor settings were the following : acceleration range, ±8 G ; angular velocity range, ±1.000 dps ; sampling frequency, 100 Hz ; and sample average frequency, 1 time. The measurement task was PHE, which was performed in two ways : natural movement (NM) and modified movement (MM) (Figure 2). Modified movement was elicited with the instruction, "Do not move your waist as much as possible."

The participants were placed in the prone position on the bed.

Figure 1. Location of the sensor

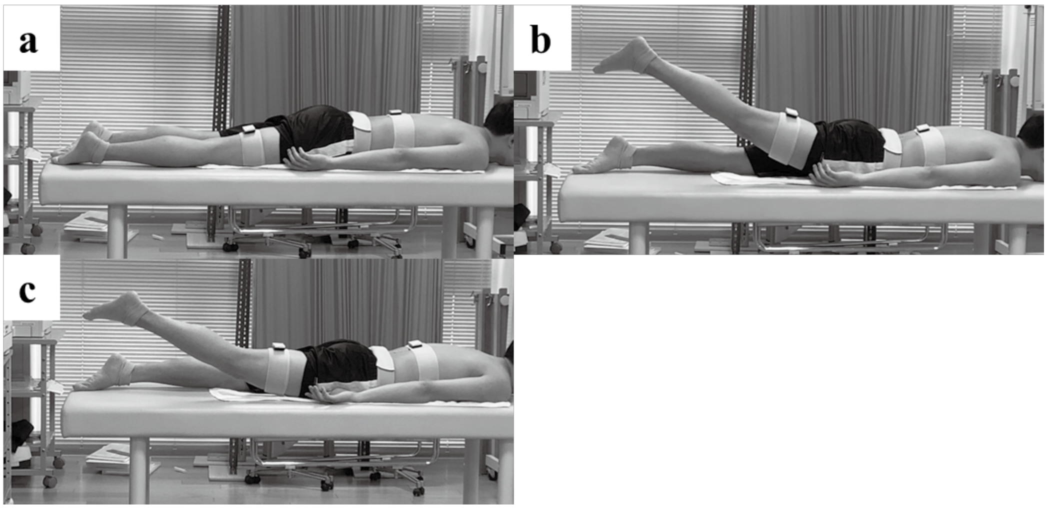

Figure 2. The movement of prone hip extension
a : starting position, b : natural movement, c : modified movement

After resting for 5 s while listening to a metronome of 60 bpm, the participants were instructed to lift their right lower limb to the maximum hip extension position for 3 s by an active movement. In this study, the lower limb was raised for 3 s to avoid an increase in the maximum hip extension angle due to acceleration of the lower limb raising. The motion angle of the lumbar spine was defined as the difference in tilt angle between the sensor at the thoracolumbar transition and the sensor at the lumbosacral transition. The motion angle of the hip joint was defined as the difference in tilt angle between the sensor at the lumbosacral transition and the sensor at the thigh (21). For the sagittal component, positive values were defined as extension and negative values as flexion. For the horizontal component, positive values were defined as internal rotation (front rotation of the right pelvis) and negative values as external rotation (backward rotation of the right pelvis). The 3 s after the start of the movement were divided into 0.3-s segments, and the mean value of the movement angle for each segment was calculated. The lumbar and hip motion angle difference between NM and MM (NM-MM) was calculated as an index of MCA.

The ability to modify the movement, seen as the change caused by the modification, was used as an index of MCA. The calculation of the change due to modification was based on the difference in lumbar and hip motion angles between NM and MM (NM-MM). This was used as the index of MCA since the ratio of MM to NM lumbar and hip motion angles has a negative angle, and the convergence of one value to zero has the disadvantage of changing the value substantially.

5. Statistical Analysis

SPSS version 27 (IBM SPSS Statistics, Japan IBM, Tokyo, Japan) was used for statistical analysis. The comparison of the motion angles of the lumbar spine and hip joints and the difference in motion angles between participants with and without LBP was made using an unpaired t-test. The relationship between the lumbar spine and hip motion angles and the FreBAQ and ODI scores was examined by calculating Pearson's product rate correlation coefficient. The significance level for all statistical analyses was set at 0.05, and the results are presented as mean ± standard deviation, where applicable.

RESULTS

There was a total of 78 participants in this study. Table 1 shows the general characteristics of the participants and their scores on the FreBAQ and the ODI. Figure 3 shows an example of the temporal changes in a typical lumbar and hip motion

Table 1. General characteristics of the subjects (Mean ± SD)

	Overall (78)	Low back pain group (20)	Non-low back pain group (58)
Sex (n)	Male, 37 Female, 41	Male, 8 Female, 12	Male, 29 Female, 29
Age (years)	20.1±1.1	20.1±0.9	20.2±1.2
Height (cm)	165.6±8.7	164.7±7.9	166.0±8.9
Weight (kg)	56.8±9.6	57.5±9.0	56.6±9.8
NRS (score)	—	2.1±1.3	—
FreBAQ (score)	—	3.1±2.1	—
ODI (score)	—	4.4±2.8	—

NRS, numeric rating scale ; FreBAQ, Fremantle Back Awareness Questionnaire ; ODI, Oswestry low back pain disability index ; SD, standard deviation

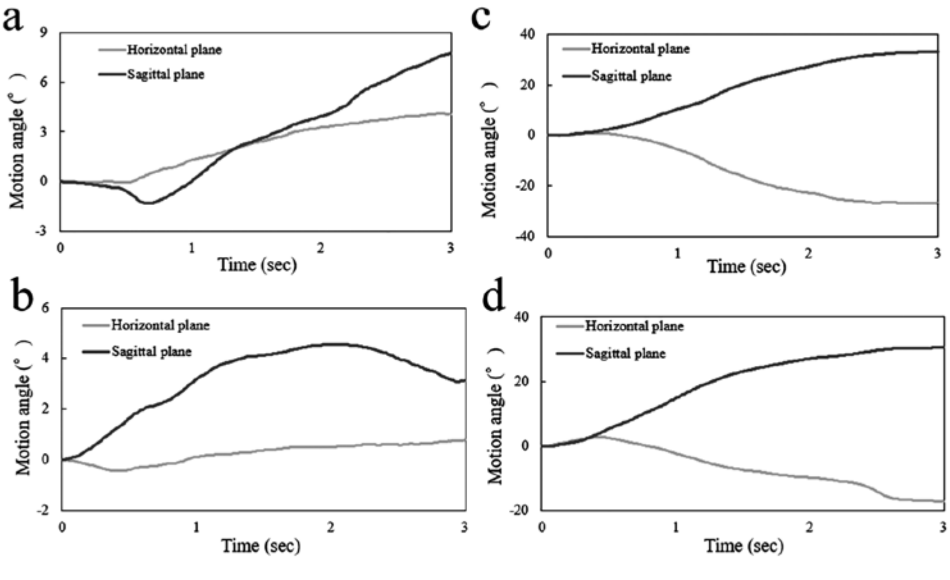

Figure 3. Typical motion angle.
a : lumbar spine in natural movement, b : hip joint in natural movement, c : lumbar spine in modified movement, d : hip joint in modified movement

angle.

Table 2 shows the motion angles of the lumbar spine and hip joints in NM and MM, and the motion angle differences between the NM and MM in the sagittal plane. In the sagittal plane, the lumbar extension angle was significantly smaller in the second half of the movement (after 1.8 sec) in the MM for the LBP group (1.8-2.1 sec : LBP group 2.2±5.0 / non-LBP group 4.7±4.4 ; 2.7 -3.0 sec : LBP group 4.2±5.1 / non-LBP group 7.2±5.0) (Table 2). The motion angle differences between NM and MM in the lumbar spine was significantly greater in the LBP group in all sections, except for the early stage of motion (0.6-0.9 sec : LBP group 0.5±2.1 / non-LBP group 1.4±2.1 ; 2.7 -3.0 sec : LBP group 5.9±3.0 / non-LBP group 5.4±4.1) (Table 2).

Table 3 shows the motion angles of the lumbar spine and hip joints in NM and MM, and the motion angle differences between the NM and MM in the horizontal plane. In the horizontal plane, the hip external rotation angle of the LBP group was significantly smaller in the section of 0.9-1.5 sec, which is the middle range in NM (LBP group : -2.4±3.8 / non-LBP group -5.0±4.6 ; 1.2 -1.5 sec : LBP group -4.9±5.0 / non-LBP group -8.1±5.5) (Table 3). The lumbar spine contralateral rotation (ipsilateral pelvic rotation) angle was significantly smaller in the LBP group in the middle range of 1.8-2.4 sec (1.8-2.1 sec : LBP group -0.1±2.2 / non-LBP group 1.2±1.8 ; 2.1 -2.4 sec LBP group 0.1±2.4 / non-LBP group -1.2±1.9) (Table 3).

Table 4 shows the correlation coefficients between the FreBAQ, the ODI and the motion angle difference in the lumbar and the hip between NM and MM. The FreBAQ was significantly negatively correlated with the motion angle difference between the NM and MM of the lumbar spine in the sagittal plane (r=-0.45 to 0.53) in all sections in the second half of the movement (after 1.2 s) (Table 4). The ODI showed a significant negative correlation with the lumbar motion angle difference in the sagittal plane at 1.2-1.5 sec (r=-0.45) and in the horizontal plane at 0.9-1.2 sec (r=-0.46) (Table 4).

DISCUSSION

This study investigated the differences in the MCA of the lumbar spine and of the hip joint during PHE of individuals with and without LBP. This was evaluated as the angular difference between the natural and modified motion on PHE at the two joints. This study also examined the relationship between the MCA of the lumbar spine and hip joints and lumbar perceptual awareness.

The results indicate that people with LBP have higher lumbar MCA in the direction of pain than people without LBP and that there is a negative correlation between lower lumbar perceptual awareness and lumbar MCA in people with LBP. These suggest the importance of considering the evaluation and treatment of lumbar perceptual awareness when providing lumbar motor control training to people with LBP to avoid pain and tissue loading, which may contribute to the solution of LBP.

The results also indicate that natural motion in the sagittal plane did not differ significantly between the LBP group and the non-LBP group ; however, there was a greater difference in the motion angle of the lumbar spine in the LBP group compared with the non-LBP group on modified motion. This contradicts the hypothesis as it signifies that the LBP group has more MCA than the non-LBP group. It is speculated that people with LBP develop motor control of the lumbar spine as they modify

Table 2. Motion angles and angular differences of the lumbar spine and hip joints in the sagittal plane

Time segment (s)	Affected joint	Low back pain group			Non-low back pain group		
		NM	MM	NM-MM	NM	MM	NM-MM
0–0.3	Lumbar spine	-0.1±0.2	-0.1±0.2	0.0±0.3	0.0±0.2	0.0±0.3	0.0±0.4
	Hip joint	0.2±0.5*	0.1±0.1	0.1±0.4	0.0±0.3	0.0±0.3	0.0±0.3
0.3–0.6	Lumbar spine	-0.4±1.0	-0.3±0.8	-0.1±1.1	0.1±1.2	-0.3±1.0	0.4±1.2
	Hip joint	1.3±2.1	0.8±1.0	0.5±1.7	1.0±1.8	0.8±1.2	0.2±1.5
0.6–0.9	Lumbar spine	0.0±2.2	-0.4±2.1	0.5±2.1*	1.1±2.7	-0.3±2.3	1.4±2.1
	Hip joint	4.4±3.2	3.8±2.4	0.6±2.5	4.4±3.5	3.4±2.6	1.0±3.5
0.9–1.2	Lumbar spine	1.8±3.4	0.1±3.3	1.7±2.7*	3.1±3.6	0.5±3.1	2.6±2.8
	Hip joint	9.1±3.8	7.8±3.7	1.3±3.2	9.4±4.8	7.6±4.3	1.8±5.0
1.2–1.5	Lumbar spine	3.8±4.4	0.9±4.0	2.9±3.0*	5.4±4.3	1.9±3.5	3.5±3.3
	Hip joint	14.3±3.5	11.4±4.3	2.9±3.3	14.5±5.4	11.7±5.2	2.8±5.7
1.5–1.8	Lumbar spine	5.4±5.2	1.6±4.6	3.8±3.2*	7.6±4.8	3.3±4.0	4.3±3.7
	Hip joint	17.9±3.8	14.1±4.5	3.8±3.6	18.0±5.4	14.9±5.9	3.2±5.5
1.8–2.1	Lumbar spine	7.0±5.7	2.2±5.0*	4.8±3.2*	9.5±5.3	4.7±4.4	4.8±3.9
	Hip joint	20.3±4.1	15.9±4.2	4.4±3.8	20.3±5.3	16.9±6.3	3.4±5.1
2.1–2.4	Lumbar spine	8.5±5.8	2.8±5.1*	5.6±3.2*	11.0±5.5	5.8±4.7	5.1±4.0
	Hip joint	21.9±4.1	17.4±3.8	4.5±3.2	21.9±5.3	18.2±6.2	3.7±4.9
2.4–2.7	Lumbar spine	9.4±5.8	3.6±5.0*	5.8±3.1*	12.0±5.5	6.6±4.8	5.4±4.0
	Hip joint	23.0±4.0	18.7±4.0	4.3±2.9	23.1±5.5	19.1±6.3	3.9±4.9
2.7–3.0	Lumbar spine	10.2±5.7	4.2±5.1*	5.9±3.0*	12.7±5.6	7.2±5.0	5.4±4.1
	Hip joint	23.8±4.2	19.3±4.0	4.5±2.8	23.6±5.5	19.5±6.5	4.1±4.9

*Significant difference compared to the non-low back pain group
NM, natural movement ; MM, modified movement

Table 3. Motion angles and angular differences of the lumbar spine and hip joints in the horizontal plane

Time segment (s)	Affected joint	Low back pain group			Non-low back pain group		
		NM	MM	NM-MM	NM	MM	NM-MM
0–0.3	Lumbar spine	0.0±0.1	0.0±0.1	0.0±0.1	0.0±0.2	0.0±0.2	0.0±0.2
	Hip joint	0.1±0.3	0.0±0.3	0.1±0.2	0.1±0.3	0.2±0.4	0.0±0.4
0.3–0.6	Lumbar spine	0.1±0.7	0.0±0.5	0.2±0.7	0.0±0.7	-0.1±0.5	0.1±0.6
	Hip joint	0.6±1.8	0.7±1.7	-0.1±1.8	0.7±1.3	1.1±1.2	-0.4±1.4
0.6–0.9	Lumbar spine	0.2±1.5	-0.2±1.0	0.4±1.1	0.3±1.1	-0.1±1.0	0.4±1.0
	Hip joint	0.0±2.8	0.7±2.8	-0.7±2.3	-1.1±3.1	0.7±2.4	-1.8±2.9
0.9–1.2	Lumbar spine	0.2±1.9	-0.3±1.3	0.5±1.2	0.6±1.3	-0.1±1.4	0.7±1.0
	Hip joint	-2.4±3.8*	-1.1±3.2	-1.3±3.2*	-5.0±4.6	-1.4±3.9	-3.6±4.0
1.2–1.5	Lumbar spine	0.1±2.1	-0.3±1.5	0.5±1.3	0.9±1.5	-0.1±1.5	1.0±1.3
	Hip joint	-4.9±5.0*	-2.8±3.4	-2.1±4.9	-8.1±5.5	-4.0±4.7	-4.0±5.2
1.5–1.8	Lumbar spine	0.1±2.2	-0.5±1.6	0.6±1.4	1.2±1.8	0.0±1.7	1.2±1.7
	Hip joint	-7.1±6.3	-4.5±3.6	-2.6±5.9	-10.0±6.1	-6.0±5.4	-4.0±5.8
1.8–2.1	Lumbar spine	0.1±2.2*	-0.6±1.6	0.7±1.6	1.2±1.8	0.0±1.7	1.3±1.7
	Hip joint	-8.5±6.8	-5.6±3.9	-2.9±6.2	-11.1±6.6	-7.4±5.7	-3.7±5.8
2.1–2.4	Lumbar spine	0.1±2.4*	-0.6±1.8	0.8±1.8	1.2±1.9	0.0±1.7	1.3±1.7
	Hip joint	-9.6±6.9	-6.6±4.4	-3.0±6.3	-12.0±6.9	-8.2±5.9	-3.8±5.7
2.4–2.7	Lumbar spine	0.2±2.5	-0.6±1.9	0.8±1.9	1.2±1.9	0.0±1.7	1.2±1.9
	Hip joint	-10.6±7.1	-7.5±4.8	-3.1±6.4	-12.6±7.1	-8.8±6.0	-3.8±5.8
2.7–3.0	Lumbar spine	0.2±2.5	-0.7±1.9	0.8±1.8	1.2±2.0	0.0±1.8	1.1±1.9
	Hip joint	-11.2±7.2	-8.1±5.1	-3.1±6.6	-12.8±7.3	-9.1±6.3	-3.7±5.8

*Significant difference compared to the non-low back pain group
NM, natural movement ; MM, modified movement

Table 4. Correlation coefficients between angle difference of motion and FreBAQ and ODI

Time segment (s)	Affected joint	Sagittal plane		Horizontal plane	
		FreBAQ	ODI	FreBAQ	ODI
0–0.3	Lumbar spine	0.01	0.00	0.12	0.35
	Hip joint	-0.20	-0.04	-0.10	-0.13
0.3–0.6	Lumbar spine	-0.17	-0.17	-0.06	-0.03
	Hip joint	-0.12	0.02	-0.26	-0.16
0.6–0.9	Lumbar spine	-0.32	-0.26	-0.32	-0.28
	Hip joint	-0.33	-0.27	-0.11	-0.19
0.9–1.2	Lumbar spine	-0.39	-0.40	-0.53*	-0.46*
	Hip joint	-0.30	-0.18	0.10	0.03
1.2–1.5	Lumbar spine	-0.47*	-0.45*	-0.45*	-0.34
	Hip joint	-0.12	-0.01	0.04	0.06
1.5–1.8	Lumbar spine	-0.53*	-0.41	-0.39	-0.26
	Hip joint	0.00	0.06	0.06	0.10
1.8–2.1	Lumbar spine	-0.54*	-0.33	-0.31	-0.14
	Hip joint	-0.08	-0.02	0.10	0.12
2.1–2.4	Lumbar spine	-0.53*	-0.27	-0.23	-0.07
	Hip joint	-0.12	-0.11	0.13	0.16
2.4–2.7	Lumbar spine	-0.48*	-0.23	-0.16	-0.02
	Hip joint	-0.03	-0.19	0.11	0.17
2.7–3.0	Lumbar spine	-0.45*	-0.25	-0.10	0.04
	Hip joint	-0.08	-0.20	0.13	0.18

*Statistically significant correlation ($p < 0.05$).
FreBAQ, Fremantle Back Awareness Questionnaire ; ODI, Oswestry low back pain disability index

their movements on a daily basis due to fear of pain associated with motion (22) and as a protective mechanism against tissue damage (23). It is also possible that as a result of obtaining information and guidance on how to reduce or prevent LBP, the participants with LBP may have practiced control of smaller lumbar movements. However, it is not clear whether the LBP group has a higher MCA than the non-LBP group in other directions or tasks, as this study was limited to evaluating natural and modified lumbar spine movements on hip extension.

Regarding the difference between the LBP group and the non-LBP group in the early part of the movement, Lee *et al*. (24) reported that the contribution of the lumbar spine was greater in the early part of the movement during forward and backward bending of the trunk. Their results (24) are not surprising, given that forward and backward bending movements of the trunk are initiated cranially and spill over caudally. On the contrary, the motion in PHE is initiated from the caudal side and spills over to the cranial side ; thus, it is assumed that the contribution of the hip joint is larger in the early phase of motion. Therefore, the motion angle of the lumbar spine, which tends to be different due to LBP, did not differ between the LBP and non-LBP groups in the early phase.

In the horizontal plane, the lumbar contralateral rotation (pelvic ipsilateral rotation) angle of the LBP group was smaller than that of the non-LBP group in the middle segment of natural motion. As in the sagittal plane, the LBP group may have controlled the lumbar spine and minimized the movement in order to avoid pain. However, there are fewer phases of motion where significant differences between the two groups. This may be due to the lower amount of rotational motion of the lumbar spine when in the horizontal plane (24). Additionally, the difference in motion in the horizontal plane may not be as important as that in the sagittal plane during PHE. This result emphasizes the significance of PHE for the evaluation of motion in the sagittal plane. It also suggests that it may be desirable to use movements other than PHE to assess motion on other planes.

Regarding the relationship between the MCA of the lumbar spine and hip joint and perceptual awareness, FreBAQ showed a significant negative correlation with motion angle difference in the sagittal plane in the lumbar spine. This result indicates that the smaller the FreBAQ score, the greater the change due to the movement modification. In other words, for people with LBP, the better the lumbar perceptual awareness, the greater the change in MCA due to correction. Motor control involves the adjustment of output based on sensory information obtained, and proprioception, which detects the position and movement of the body, is considered to be particularly important (25). Therefore, it is natural that lumbar perceptual awareness is related to the MCA of the lumbar spine. A systematic review by Laird *et al*. (10) reported that individuals with LBP had decreased proprioception due to repositioning compared with individuals without LBP. In this study, the evaluation of the sensory system associated with perceptual awareness is not based on an objective evaluation of proprioception. However, they indicate that perceptual awareness is related not only to pain (15), but also to biomechanical factors, and that improving perceptual awareness to improve motor control of the lumbar region may be one clue to the treatment of LBP.

This study has other limitations. First, the speed of motion was not constant in this study, although the hip extension motion was performed by all subjects in 3 s. The motion angle of the initial phase is expected to be larger when the motion speed is faster and the motion is completed earlier. Thus, it is necessary to consider the velocity and phase in the analysis in future studies. In addition, 3 s was set to avoid excessive hip extension angle due to the effect of acceleration associated with lower limb elevation ; however, movements in ordinary exercises are often performed in short periods of about 1 s. Therefore, the motion angles of the lumbar spine and hip joint when the duration of hip extension is varied should also be examined. Third, PHE was performed only on the right side, but depending on the pathology of LBP, the appearance of symptoms may differ between PHE on the left side and PHE on the right side. Since this point was not investigated in this study, it is recommended to examine the appearance of symptoms on Kemp's test and bilateral PHE in the future, as well as to limit and verify the participants accordingly. Furthermore, the present study was conducted using a very limited age group of university students, but there is a possibility that the results will be different for the elderly. Therefore, it is necessary to consider the elderly as a population of interest for this research topic.

In conclusion, this study clarified the differences in lumbar spine and hip joint MCA in PHE between people with and without LBP and examined the relationship between lumbar spine and hip joint MCA and lumbar perceptual awareness. The results showed that in the sagittal plane, the lumbar spine motion was smaller in the LBP group than in the non-LBP group when the participants were instructed to maintain a small lumbar motion. In addition, perceptual awareness was negatively correlated with MCA in the sagittal plane in the lumbar spine. Therefore, people with LBP have higher MCA in the direction of pain than people with non-LBP, and lumbar MCA is related to perceptual awareness.

CONFLICT OF INTEREST

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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