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Changes in task-specific fear of movement and impaired trunk motor control by pain neuroscience education and exercise: A preliminary single-case study of a worker with low back pain

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Abstract

We report a case (a worker with low back pain) who was provided patient education and therapeutic exercise, and we performed a detailed kinematic analysis of his work-related activity over time. The subjects were one 28-year-old male worker with low back pain. In addition, to clearly identify impaired trunk movement during work-related activity in the low back pain subject, 20 age-matched healthy males (control group) were also included as a comparison subject. He received pain neurophysiology education and exercise instruction. We analyzed the subject's trunk movement pattern during a lifting task examined by a three-dimensional–motion capture system. In addition, task-specific fear that occurred during the task was assessed by the numerical rating scale. The assessment was performed at the baseline phase (4 data points), the intervention phase (8 data points), and the follow-up phase (8 data points), and finally at 3 and 8 months after the follow-up phase. No intervention was performed in the control group; they underwent only one kinematic evaluation at baseline. As a result, compared to the control group, the low back pain subject had slower trunk movement velocity (peak trunk flexion velocity = 50.21 deg/s, extension velocity = −47.61 deg/s), and his upper-lower trunk segments indicated an in-phase motion pattern (mean absolute relative phase = 15.59 deg) at baseline. The interventions reduced his pain intensity, fear of movement, and low back pain–related disability; in addition, his trunk velocity was increased (peak trunk flexion velocity = 82.89 deg/s, extension velocity = −77.17 deg/s). However, the in-phase motion pattern of his trunk motor control remained unchanged (mean absolute relative phase = 16.00 deg). At 8 months after the end of the follow-up, the subject's in-phase motion pattern remained (mean absolute relative phase = 13.34 deg) and his pain intensity had increased. This report suggests that if impaired trunk motor control remains unchanged after intervention, as in the course of the low back pain subject, it may eventually be related to a recurrence of low back pain symptoms.

Keywords

Occupational low back pain, task-specific fear of movement, impaired trunk motor control, in-phase motion pattern, lifting

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Introduction

Occupational low back pain (LBP) is the most common musculoskeletal disorder in the labor environment and is one of the most common causes of work-related disability among workers.[1] Occupational LBP is characterized by relatively mild pain,[2] but it is prone to prolongation and recurrence due to the interaction of ergonomics factors (e.g. impaired trunk movement) and psychological factors (e.g. fear of movement and pain catastrophizing).[3] Among the psychological factors, fear of movement is one of the most important risk factors for occupational LBP[4] because it has a direct negative impact on trunk movement during work-related activities;[5] fear of movement also reduces labor productivity.[6] Therefore, to improve individuals' work-related disability caused by LBP, both impaired trunk movement and fear of movement must be considered.

Impaired trunk motor control (such as the "in-phase motion pattern" and "reduced variability" between upper and lower trunk segments) has been recognized as a factor in the development of trunk movement disorders during work-related activity.[7] The in-phase motion pattern indicates spatiotemporal coincidence of movement between upper and lower trunk segments.[8] Decreased variability indicates less spatiotemporal variation of movement between upper and lower trunk segments.[8] Individuals with LBP show different characteristics of trunk motor control depending on the disease stage.[9] For example, the anti-phase motion pattern and trunk variability are increased during acute LBP, perhaps as an attempt by the body to find a new, pain-free motor control solution.[9] Subsequently, as the pain improves, the trunk coordination motion pattern and variability decrease to a normal range, but in some cases, an individual with chronic LBP learns and acquires maladaptive compensatory patterns in order to avoid pain, and this may result in an excessive in-phase motion pattern and decreased variability.[9] The trunk coordination pattern and variability may also continue as the impaired motor control status for a long time, perhaps years, in individuals with chronic LBP.

Fear of movement is reported to be involved in impaired trunk motor control and to be one of the factors in the development of an excessive in-phase motion pattern and decreased variability, which cause trunk muscle co-contraction and freezing-like behavior.[10] Such altered motor control might be beneficial to avoid pain in cases of acute-phase injury, but prolonged effects have negative consequences such as increased lumbar loading and tissue degeneration of intervertebral disks.[10] It thus appears that the impaired motor control in individuals with LBP who have a strong fear of movement may be the result of learning and acquiring maladaptive movement patterns triggered by an acute-phase back injury. Rehabilitation for fear of movement and impaired trunk movement may resolve the symptoms of LBP, so that an injured worker with LBP will not experience an exacerbation of LBP symptoms when he or she engages again in work-related activity.

The use of graded exposure therapy and patient education has been described as an effective intervention for fear of movement.[11,12] Graded exposure therapy includes patient education on pathophysiology and biomechanics based on the biomedical model, as well as psychological interventions based on the fear-avoidance model. In those studies, the subjects were asked to rate the degree of their fear of movement of physical activity, and the object of fear was clarified. The subjects then experienced the fearful behavior in a step-by-step manner designed to reduce the fear through habituation. In another intervention, pain neuroscience education (PNE)[13] was implemented, and it was reported that a combination of PNE and exercise is useful in improving work disability in workers with LBP.[14] However, there are no detailed reports on the changes over time in LBP symptoms (pain intensity, fear of movement, etc.) or trunk movement patterns, or the temporal relationships between these factors after a series of these interventions.

We provided patient education and exercise with the goals of (1) improving LBP symptoms, including the subject's fear of movement and (2) preventing the recurrence of LBP symptoms in the subject. The purpose of this case report was to describe the course of a case in which patient education and therapeutic exercise were provided, and a detailed longitudinal assessment of fear of movement and work-related activity was conducted.

Case report

Study setting and subject selection

The study period was from 2 April 2020 to 1 October 2021. The single-case subject was recruited from the cohort of a recently completed laboratory study involving people with LBP.[15] The inclusion and exclusion criteria for the LBP subject selection were as follows. The inclusion criteria were as follows: (1) pain that occurred from the lower rib edge to the gluteal fold for >1 day, (2) LBP that occurred when lifting a heavy object during work, (3) LBP duration of >3 months, and (4) a score $\geqslant 1$ on a numerical rating scale (NRS) for pain intensity during work in the past 4 weeks and $\geqslant 7$ on an NRS for fear of movement during work-related activity. The exclusion criteria were as follows: (1) a previous diagnosis of spinal disease (lumbar disk herniation, lumbar spondylolisthesis, or lumbar osteoarthritis), (2) pain in peripheral joints of pain in upper and lower limb joints, (3) the presence of neurological symptoms of a lower limb, and (4) serious spinal pathology (cancer, inflammatory arthropathy, or acute vertebral fracture) or a diagnosis of neurological disease. Thirteen people responded and completed the inclusion criteria questionnaire. Five met the criteria, and one of those consented to participate in this study.

Table 1. The subjects' characteristics at baseline.

	HC group (n = 20)	LBP subject
Age, years	28.1 (5.2)	28
Height, cm	172.0 (4.8)	170
Weight, kg	66.7 (9.0)	67
Occupation	Nurses 11, care workers 9	Care worker
LBP duration, years	–	5
Specific disability	–	Lifting and carrying heavy (pain NRS = 3/10, fear of movement NRS = 8/10)
Severity of LBP	–	Grade 2 (LBP that influences with work but does not cause absences)

LBP: low back pain; NRS: numerical rating scale; HC: healthy control.

For comparison with the LBP subject, we extracted the data of all healthy subjects with no history of LBP and no other diagnosed illnesses from the same data set that included the LBP subject in our previous study.[15] The mean age, height, and weight of the control group were similar to those of the LBP subject (Table 1).

This study obtained ethical approval from the Institutional Ethics Committee of Kio University (R2-01) and was conducted in compliance with the Declaration of Helsinki. We explained the study protocol to the subjects and obtained their written informed consent.

Study design

We used an experimental single-case ABA design (A-B-A'), and the intervention was performed only in the LBP subject. Phase A consisted of a 4-week baseline period with no intervention. Phase B was an 8-week period of exercises, PNE, and interviews as interventions. Phase A' was set as a follow-up period of 4 weeks. Additional follow-up evaluations were performed at 3 months (Follow-up 2) and 8 months (Follow-up 3) after the completion of Phase A'.

LBP subject description

The single-case subject selected from the above criteria was a 28-year-old male worker with chronic LBP and high fear of movement. The subject worked as a care worker and was engaged in patient transfer and carrying heavy objects. He had first experienced felt pain in his lower back 5 years before the study (around L1–L5, left < right), and the pain progressively worsened and was recently affecting his work. However, there was no change in his employment status due to LBP, and he was able to continue working.

He felt more pain-related fear when transferring patients; he reported the pain intensity was NRS 3, and the degrees of his fear of movement was NRS 8 during the past 4 weeks during his work. The range of pain was observed from the L3 spinous process to the superior posterior iliac spine. The pain appeared mainly during the lifting of a heavy an object and other heavy labor. There was no rest pain or nocturnal pain. The intensity of the pain decreased with rest. His perceptions of LBP symptoms were as follows: "I often feel anxious that moving my lower back will cause LBP" and "I'm careful not to move my lower back, to control LBP." He had never visited an orthopedic hospital or clinic for his LBP and had not received a diagnosis of LBP. In addition, he had no history of rehabilitative interventions oral medicine for his LBP.

The LBP subject was evaluated by an interview and physical examination according to the clinical practice guidelines,[16] and no red flags or neurological symptoms were identified. The LBP subject's clinical results were all negative on the nerve tension test, including the slump test, the Bragard test, and straight-leg-raising test were negative. His superficial sensation was normal. The muscle strength of his lower limbs and trunk was normal by the manual muscle testing. Muscle spasm was detected in the erector spinae and quadratus lumborum. Based on the results of these evaluations, we speculated that the subject's LBP corresponded to non-specific LBP.

Assessment timepoints

Assessments were periodically conducted to collect the recommended number of assessments for a single-case time-series analysis, that is, a total of 10–16 observations in the data stream.[17] The LBP subject was assessed by undergoing a lifting task and a task-specific fear of movement test 1×/week during the baseline phase (4 data points), the intervention phase (8 data points), and the follow-up phase (4 data points). The same assessment was also performed at 3 months (Follow-up 2) and 8 months (Follow-up 3) after the completion of the follow-up phase as follow-up assessments to confirm the medium-term effect of the interventions, with a total of 18 data points collected. In contrast, assessments of general pain-related factors were conducted for the LBP subject before and after each phase (baseline, intervention, and follow-up phase) and at 3 months (Follow-up 2) and 8 months (Follow-up 3) after the completion of the follow-up phase (5 data points).

The healthy control (HC) group was assessed only once during the study period, because the purpose of recruiting the control group was to determine whether the kinematic features of the LBP subject were normal or abnormal at baseline

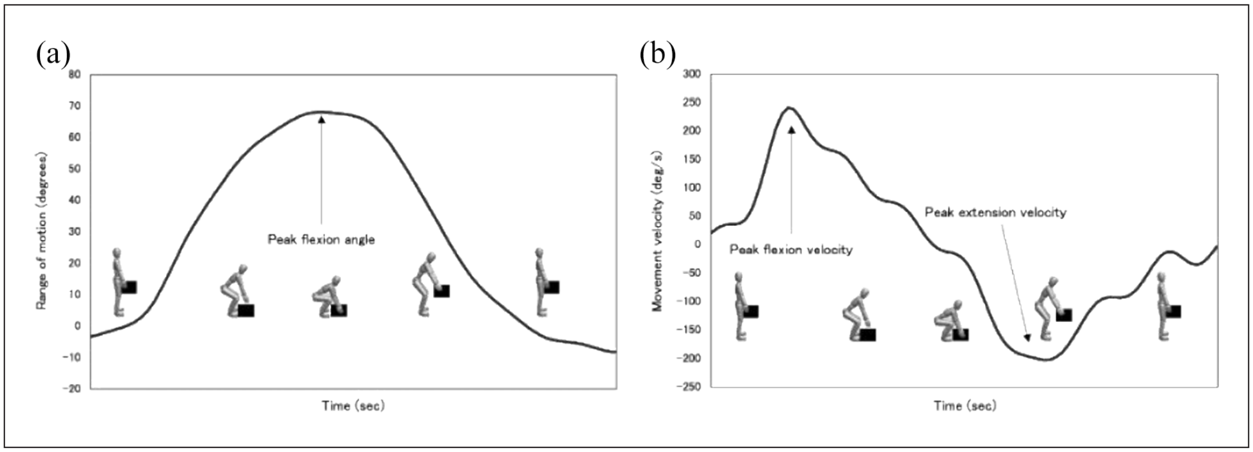

Figure 1. Time-series variation of the velocity of trunk movement during the lifting task. The kinematic data were extracted from the peak trunk flexion angle (a) and trunk flexion velocity (b) and the peak trunk extension velocity (b): (a) range of motion and (b) angular velocity.

by comparing the kinematic index between the healthy subjects and LBP subject.

Movement analysis

An experimental task that involved lifting an object was used according to our previous work.[15] A subject was asked to lift a box (520 mm × 365 mm × 305 mm) placed on the ground. The start position was standing with feet shoulder-width apart, and the centerline of the box width was placed to match the center of the subject's feet. The box was placed so that there was no space between the subject's toes and the box. The subject was asked to initiate lifting the box as quickly as possible upon hearing the start cue and to lift the box to waist height. The weight of the box was set at 25 kg, which is associated with LBP symptoms. After completing several practices, each subject performed the lifting task in five times, with a 1-min rest between each lift.

All the kinematic data collection and processing were performed according to our previous study.[15] We recorded trunk kinematic data during the above-described lifting task using a three-dimensional (3D) motion capture system of a four-charge-coupled device (CCD) camera (KinemaTracer, Kissei Comtec Co. Ltd., Matsumoto, Japan). The system recorded the displacement of color markers at a sampling frequency of 60 Hz. A total of 11 color markers (30 mm diameter) were attached to the subject's thoracic spine (Th12 spinous process), lumbar spine (L3 spinous process), pelvis (S1 spinous process), bilaterally on the iliac crest, great trochanter, lateral femoral epicondyle, and lateral malleolus. A color maker was also attached to the box.

Before the kinematic data were recorded, we applied the DLT method for the calibration of the system's CCD camera, using a control object. The recorded kinematic data were low-pass filtered with a second-order recursive Butterworth filter with a cutoff frequency of 6 Hz. To define a trunk angle, a vector was created based on the color markers placed on the Th12 spinous process and S1 spinous process, and the trunk angle was calculated using the angle between the vector and the vertical axis. We calculated the peak trunk angle, peak trunk flexion velocity, and peak trunk extension velocity (Figure 1).

An upper trunk angle was defined as a vector based on the color markers placed on the Th12 spinous process and L3 spinous process, and a lower trunk angle was defined as a vector based on the color markers placed on the L3 spinous process and S1 spinous process. Upper and lower trunk angles were calculated as the angle between each of these vectors and the vertical axis. We calculated the mean absolute relative phase (MARP) and deviation phase (DP) as trunk coordination variable–based kinematic data of the upper and lower trunk. The calculation of the MARP and DP was performed as described: we divided the time-series of trunk movement into a flexion phase (which began at the start of the subject's trunk flexion motion and ended when the box was raised) and an extension phase (which started when the box was raised and ended when the trunk had resumed an upright position).

The upper and lower trunk angular displacement and angular velocity data were time normalized to 100% in each phase, and these kinematic data were normalized to −1 to +1 intervals using the following equation

$$\text{Normalized angle: } \left(\frac{[\text{Angle} - \text{Minimum angle}]}{[\text{Maximum angle} - \text{Minimum angle}]}\right) \times 2 - 1$$

$$\text{Normalized angular velocity: } \frac{\text{Angular velocity}}{\text{Maximum angular velocity}}$$

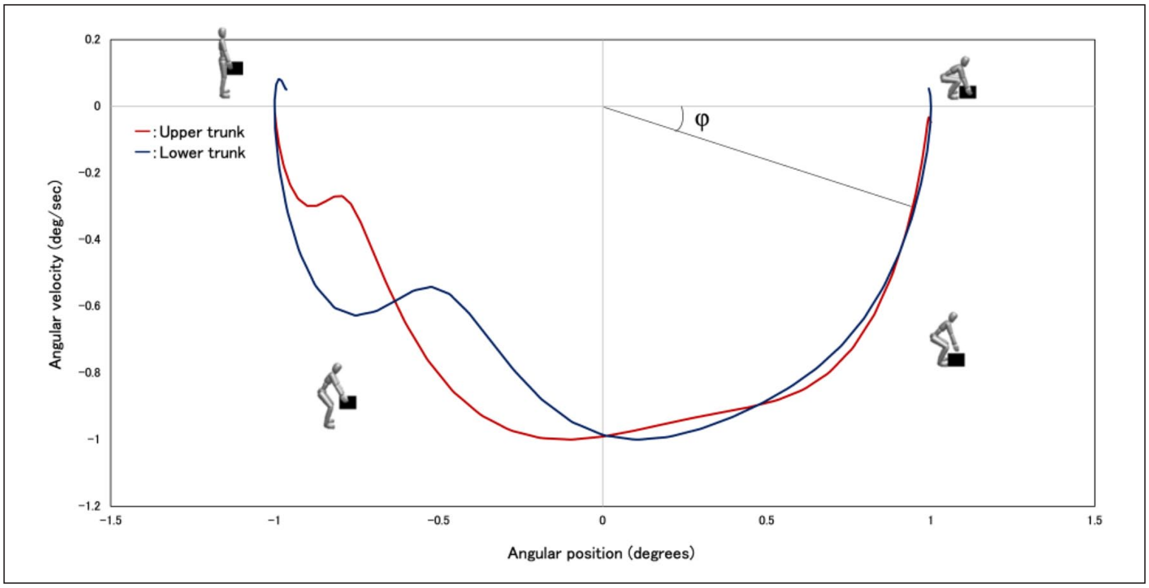

Figure 2. Phase diagram for the upper trunk segment. The phase angle, ϕ, at any point of flexion and extension can be calculated using the formula $\tan^{-1}$ (angular velocity/angle). The phase angle was calculated in this study by dividing the flexion phase and extension phase.

We generated the phase plane for each segment based on the normalized kinematic data (Figure 2). For the quantification of the phase plane trajectories, the phase angle was derived using the following equation

$$\varphi = \tan^{-1}\left(\frac{\text{Normalized angular velocity}}{\text{Normalized angle}}\right)$$

For an index of upper-lower trunk coupling, we calculated continuous relative phase (CRP) curves (i.e. ϕ lower trunk − ϕ upper trunk). The MARP was defined as the average of the CRP using the following equation

$$\text{MARP} = \sum_{i=1}^{P} \frac{|\varphi\text{CRP}|_i}{P}$$

An MARP angle closer to 0° indicates a more in-phase motion pattern between two segments, and an MARP angle closer to 180° suggests a more out-of-phase motion pattern.

The DP was defined as the variability of the CRP, using the following equation

$$\text{DP} = \sum_{i=1}^{P} \frac{\text{SDi}}{P}$$

DP values closer to 0° indicate lower coordination variability or more coordination stability.

The MARP and DP have been considered important variables for the analysis of multi-segment coordination in task performance.[7] It was suggested that lower MARP and DP values may represent increased protective guarding motion during a work-related activity.[18] Each variable was averaged over five trials.

Questionnaire

Task-specific fear of movement. To assess the subjects' task-specific fear of movement, we used an NRS that concerns fear of movement that occurred during the lifting task (0 = no fear and 10 = the highest possible degree of fear). The subjects were asked: "How much fear did you feel when lifting the box?" Such an assessment of task-specific fear was reported to be more useful for the prediction of a limited lumbar range of motion in patients with chronic low back pain (CLBP) than general measures of pain-related pain (e.g. the Tampa Scale for Kinesiophobia (TSK) and the Pain Catastrophizing Scale (PCS)).[19] The assessment was conducted in each trial (i.e. five times), and the subjects were asked to respond verbally at the end of each trial, based on an earlier study.[20]

General measures of pain-related factors. The state of the subjects' LBP was assessed with the use of an NRS, the TSK,[21] the PCS,[22] the Fremantle Back Awareness Questionnaire (FreBAQ),[23] the Roland-Morris Disability Questionnaire (RDQ),[24] Von Korff's grade for LBP severity,[25] and the World Health Organization's Health and Work Performance Questionnaire (WHO-HPQ).[26] These assessments were conducted before and after each phase (baseline, intervention, and follow-up phase) and at 3 months (Follow-up 2) and 8 months (Follow-up 3) after the completion of the follow-up phase.

For the determination of the subject's maximum pain in the 4 weeks prior to the study, and his pain during the movement task and rest before the movement task, the subject's pain intensity was assessed by an 11-point "Pain NRS" (0=no pain and 10=the highest possible degree of pain).

Kinesiophobia was assessed by the TSK,[21] which is scored on a 4-point scale from 1 (strongly disagree) to 4 (strongly agree), and a higher score indicates a higher degree of kinesiophobia.[27] Catastrophic thinking was assessed by the PCS[22] scored on a 5-point scale from 0 (not at all) to 4 (all the time); a higher score indicates a higher degree of catastrophic thinking.[22]

The subject's body image of the low back region was assessed by the FreBAQ[23] scored on a 5-point scale from 0 (never) to 4 (always); a higher score indicates more disturbed perception.[28] The subject's LBP-related disability was assessed by the RDQ.[24] The RDQ questionnaire is a dichotomous scoring format: yes (=item is applicable) or no (=item is not applicable). A higher score indicates a higher degree of LBP-related disability.[24] The severity of LBP was assessed by Von Korff's grade,[25] which is defined as follows. Grade 0 indicates no LBP, grade 1 is LBP that does not interfere with work, grade 2 is LBP that interferes with work but does not cause absences, and grade 3 is LBP that interferes with work, leading to sick leave.[25]

The WHO-HPQ was used to evaluate absolute and relative presenteeism.[26] This questionnaire assesses the degree to which health problems interfere with an individual's ability to perform job tasks. Absolute presenteeism is actual performance, and relative presenteeism is the ratio of actual performance to the performance of most workers in the same job. The absolute presenteeism question is as follows: "On a scale from 0 to 10 where 0 is the worst job performance and 10 is the best performance, how would you rate your overall job performance on the days you worked during the past 4 weeks?" We calculated the result by multiplying the subject's answer by 10 as the outcome of absolute presenteeism. The relative presenteeism question is as follows: "On a scale from 0 to 10 where 0 is the worst job performance anyone and 10 is the performance of a top worker, how would you rate the usual performance of most workers in a job similar to yours on the days you worked during past 4 weeks?" We calculated the outcome of relative presenteeism by dividing the actual performance (the absolute presenteeism question) by the performance of most workers in the same job (the relative presenteeism question).

Interventions

The LBP subject received a combined exercise and PNE plan created by one physical therapist (10 years of experience) with expertise in pain rehabilitation. He was interviewed immediately after the PNE and his request. All interventions were performed by the physical therapist who planned the intervention. The details of the intervention are described as follows.

Therapeutic exercise (exercise). First, his physical function (range of motion, muscle strength, and tightness) was assessed, and he then started the exercise under the physical therapist's supervision. He was instructed to perform general stretching and a standing back extension exercise at his workplace (e.g. during work and breaks). The general stretching was focused on a self-stretch of each muscle that showed reduced flexibility (erector spinae, gluteus maximus, and hamstrings). The subject was instructed to perform the stretching exercise as follows: stretch for 30 s, rest for 8 s, with 10 repetitions and three sessions per week.[29] The standing back extension exercise was performed according to the method of the One Stretch exercise developed by Matsudaira et al.[30] The One Stretch exercise is a simple daily and static back extension task, developed based on the theory of derangement syndrome proposed by McKenzie and May.[31] This exercise is widely adapted not only for LBP patients with centralization of pain but also for people with non-specific LBP. In fact, performing the One Stretch exercise was reported to lead to improvements in circulatory dynamics of the erector spinae muscle and LBP symptoms.[32] The present LBP subject was instructed to slowly extend his back for 3 s and repeat the exercise one to two times a day after lifting something heavy and performing prolonged forward bending. We hypothesized that the exercise could improve his flexibility and alleviate his erector spinae muscle spasm symptoms.

During the intervention phase, the LBP subject was checked by the physical therapist 1×/week to ensure exercise compliance, and he was also asked to record his daily exercise for an evaluation of his exercise compliance. The assessment was judged to be "Yes" if the exercise was performed ⩾1×/day.[30] The therapist informed the LBP subject that if he experienced excessive pain during the exercise, he should decrease the intensity of the exercise or stop doing the exercise. During and after the follow-up phase, the exercise was not mandatory, and the subject was autonomous.

PNE. The LBP subject was given a leaflet and attended a 20-min seminar on PNE that was developed based on an earlier study.[14] The PNE focused on the following seven topics: (1) the epidemiology of occupational LBP, (2) the anatomical physiology of the nervous system concerning pain, (3) the differences in acute and chronic pain mechanisms, (4) a descending inhibition of pain, (5) central sensitization and central sensitization syndrome, (6) the fear-avoidance model, and (7) exercise-induced hypoalgesia. After attending the PNE seminar, the LBP subject was encouraged to take home the leaflet and read it several times. Our decision to use the PNE program was based on the evidence described in a recent systematic review of PNE,[11] showing that the time and frequency of interventions have varied with a shift toward shorter durations in the more recent studies. In fact, several previous studies reported that improvements in pain and disability were obtained with an intervention time and frequency comparable to those of this study.[12]

Interview. For the interview of the LBP subject, the first session was conducted face-to-face immediately after he completed the PNE, and the second and subsequent interview sessions were conducted via e-mail using a mobile phone at a time chosen by the LBP subject. The main purpose of the interview was to help improve the subject's LBP symptoms during work, and the content of the interview included a consultation on LBP symptoms, exercise, lifestyle, manual labor, and other musculoskeletal disorders. The physical therapist helped find a solution to the LBP case's LBP symptoms during work and encouraged him to control his pain without exacerbating the pain.

Statistical analyses

The statistical analysis methods applied herein are widely used for the analysis of single-case data.[33–36] These methods allowed for a more detailed analysis of the characteristics and changes over time in the LBP subject.

Comparison of the LBP subject and HC group at baseline. To investigate the LBP subject's impaired trunk motor control, we used Crawford's test[33] to compare the kinematic variables (trunk flexion angle, trunk flexion velocity, trunk extension velocity, MARP, and DP) between the LBP subject and the HC group. We used SingleBayes.exe program[33] to compare the HC group's kinematic variable data and the first data point at the baseline in the LBP subject. This program uses the Bayesian statistical methods to test whether an individual's score is significantly different from another sample. The significance level was set at 0.05.

Assessment of treatment effects. Following single-case design technical documentation,[34] the time-series data of the kinematic variables and the task-specific fear of movement were visually analyzed for the level (i.e. the stability of data within a phase), the trend (the slope of the best fitting straight line for the data), and the immediacy of the effects (the data change in each phase).

We used the following analysis methods to determine the time-series changes in the kinematic variables and the task-specific fear of movement in the LBP subject. We focused on the kinematic variables that showed a significant difference in Crawford's test.

The conservative dual-criterion (CDC) is used to determine the occurrence of a systematic change (intervention effect) between the baseline and an intervention phase.[35] A CDC analysis is performed by: (1) plotting two lines (the linear trend and the mean of the baseline data), (2) adding or subtracting (to the predicted direction) 0.25 of the standard deviation of the baseline mean from both lines and superimposing them on the intervention phase, and (3) comparing the number of data points in the intervention phase that changed more than the criterion line to the minimum number of points that defined in the guideline.[35]

We performed a non-overlap analysis (Tau-U), which is used to determine the significance of a change occurring in the intervention phase.[36] This method is the most robust non-overlap method for the analysis of single-case research data, and it is recommended because it is relatively impervious to the confounding effects of autocorrelation and can reliably detect medium-sized effects in short data sets.[34] The level of significance was set as 0.05.

Results

The LBP subject's and HC group's characteristics. Table 1 summarizes the characteristics of the 21 subjects. The results of the general measures of pain-related factors in the LBP subject and HC group are shown in Table 2. The LBP subject was able to complete the assessments and interventions as planned. No adverse events (e.g. worsening of LBP symptoms or the appearance of pain at another joint) were observed during the study period. This result was consistent with previous studies and indicated the safety of the intervention.[29] Because self-exercise is based on the active movement of an individual with LBP, adverse events (e.g. re-injury), if they occur, are expected to be mild and manageable in the natural course. The LBP subject's exercise compliance was excellent not only in the intervention phase (100%) but also in the follow-up phase (100%), whereas the compliance at Follow-up 2 (67%) and Follow-up 3 (53%) showed a slight decrease. A total of eight interviews were conducted. The content of the interviews was questions about the subject's current LBP symptoms, the relationship between his LBP and work-related activity, and the presence/absence of other musculoskeletal disorders. The LBP subject was able to control his LBP symptoms with the advice of the physical therapist.

Comparison of the baseline data of the LBP subject and HC group. Crawford's test revealed that the LBP subject's trunk flexion velocity ($p = 0.01$), trunk extension velocity ($p = 0.03$), and MARP at the extension phase ($p = 0.03$) were significantly decreased compared to those of the HC group (Figure 3(b), (c) and (e)).

Intervention effect. Table 2 shows the time-series of general measures of pain-related factors in the LBP subject. All outcomes improved from the baseline phase to the follow-up phase, and the improvement was sustained until Follow-up 2. Specifically, at 4 weeks of intervention (Intervention 1), the LBP subject's Pain NRS showed a change that was greater than the minimal clinically important change of two points.[37] His score on the TSK improved slowly, and at 4 weeks of follow-up (End follow-up), the score had risen more than the minimal clinically important change of 8 points[38] and was below the cut-off value of 37 points.[27] His PCS score also changed more than the minimal clinically important change of 15 points.[39] The subject's body

Table 2. Time-series change of each outcome measures.

	HC group (n = 20)	LBP subject						
		Baseline phase (0–4 weeks)		Intervention phase (4–12 weeks)		Follow-up phase (12–16 weeks)	Follow-up 2 (28 weeks)	Follow-up 3 (48 weeks)
		Baseline 1 (0 week)	Baseline 2 (4 weeks)	Intervention 1 (8 weeks)	Intervention 2 (12 weeks)	End follow-up (16 weeks)		
Pain NRS	0 (0)	6	7	2	1	1	1	4
TSK	19.1 (5.1)	43	43	40	38	32	32	33
PCS	5.5 (4.7)	26	30	14	12	5	4	6
FreBAQ	2.7 (4.3)	13	16	12	11	1	0	2
RDQ	0 (0)	2	2	0	0	0	0	1
Severity of LBP, grade	0	2	2	1	1	1	1	1
WHO-HPQ								
Absolute	83.2 (11.1)	50	50	90	80	90	90	70
Relative	0.96 (0.19)	0.63	0.63	1.13	1.0	1.13	1	0.88
Exercise compliance	–	–		100%	100%	100%	67%	53%

HC: healthy control; LBP: low back pain; NRS: numerical rating scale; TSK: Tampa Scale for Kinesiophobia; PCS: Pain Catastrophizing Scale; FreBAQ, Fremantle Back Awareness Questionnaire; RDQ: Roland-Morris Disability Questionnaire; WHO-HPQ: World Health Organization's Health and Work Performance Questionnaire.

perception disturbance was mild (FreBAQ) compared to the cases in previous studies.[40,41] His FreBAQ score improved slowly over time, eventually reaching a score of zero. The RDQ did not change much more than the minimal clinically important change of 2.5 points[24] (because the LBP subject had a low disability level at baseline), but the score reached 0 points at 4 weeks of intervention (Intervention 1). The severity of LBP grading improved from Grade 2 (LBP that interferes with work but does not cause absences) at baseline to Grade 1 (LBP that does not interfere with work) at 4 weeks of intervention (Intervention 1). The WHO-HPQ showed improvement, and the subject's relative presenteeism in particular exceeded the cut-off value of 0.8 points at Intervention 1.[42]

However, at 8 months after the end of the follow-up phase (Follow-up 3), the LBP subject's Pain NRS, TSK, PCS, RDQ, and WHO-HPQ scores had worsened. Most notably, his pain NRS rating showed a significant worsening of pain symptoms, as the rating changed more than the minimal clinically important change of 2 points.[37]

The LBP subject never experienced pain during the movement task or when at rest before the movement task. The visual analysis and CDC revealed that the LBP subject's task-specific fear of movement was reduced at the second data point in the intervention phase (Figure 4(a) and Table 3). The Tau-U index indicated that a large proportion of the data from baseline and the intervention phase were non-overlapping and phase-dependent (Table 3). These results mean that the subject's task-specific fear of movement improved significantly in the intervention phase. We also visually confirmed a constant trend at 3 months and at 8 months after the end of the follow-up phase (Figure 4(a)).

The visual analysis and CDC showed different progress according to each kinematic variable. The subject's peak trunk flexion velocity was increased at the fourth data point in intervention phase (Figure 4(b) and Table 3). His peak trunk extension velocity showed an increased at the third data point in the intervention phase (Figure 4(c) and Table 3). The Tau-U index indicated that a large proportion of the data from the baseline and intervention phase were non-overlapping and phase-dependent (Table 3). These results indicated that the subject's slower trunk movement improved significantly in the intervention phase.

In contrast, his MARP at the extension phase did not significantly progress during any of the phases (Figure 4(d) and Table 3). The Tau-U index revealed that a large proportion of the data from the baseline and intervention phase were overlapping and phase-independent (Table 3). These results showed that the subject's impaired trunk motor control was not improved by the intervention.

Discussion

This study provides an informative case report that suggests the necessity of assessment and intervention focusing on impaired trunk motor control for the prevention of a recurrence of LBP, based on a kinematic analysis of work-related activity. In the LBP subject's course, PNE and exercise improved the task-specific fear of movement and trunk movement (i.e. slow trunk movement). However, the subject's impaired trunk motor control (i.e. in-phase motion pattern) was not changed by the interventions, and the symptoms of LBP had worsened at 8 months after the end of the follow-up.

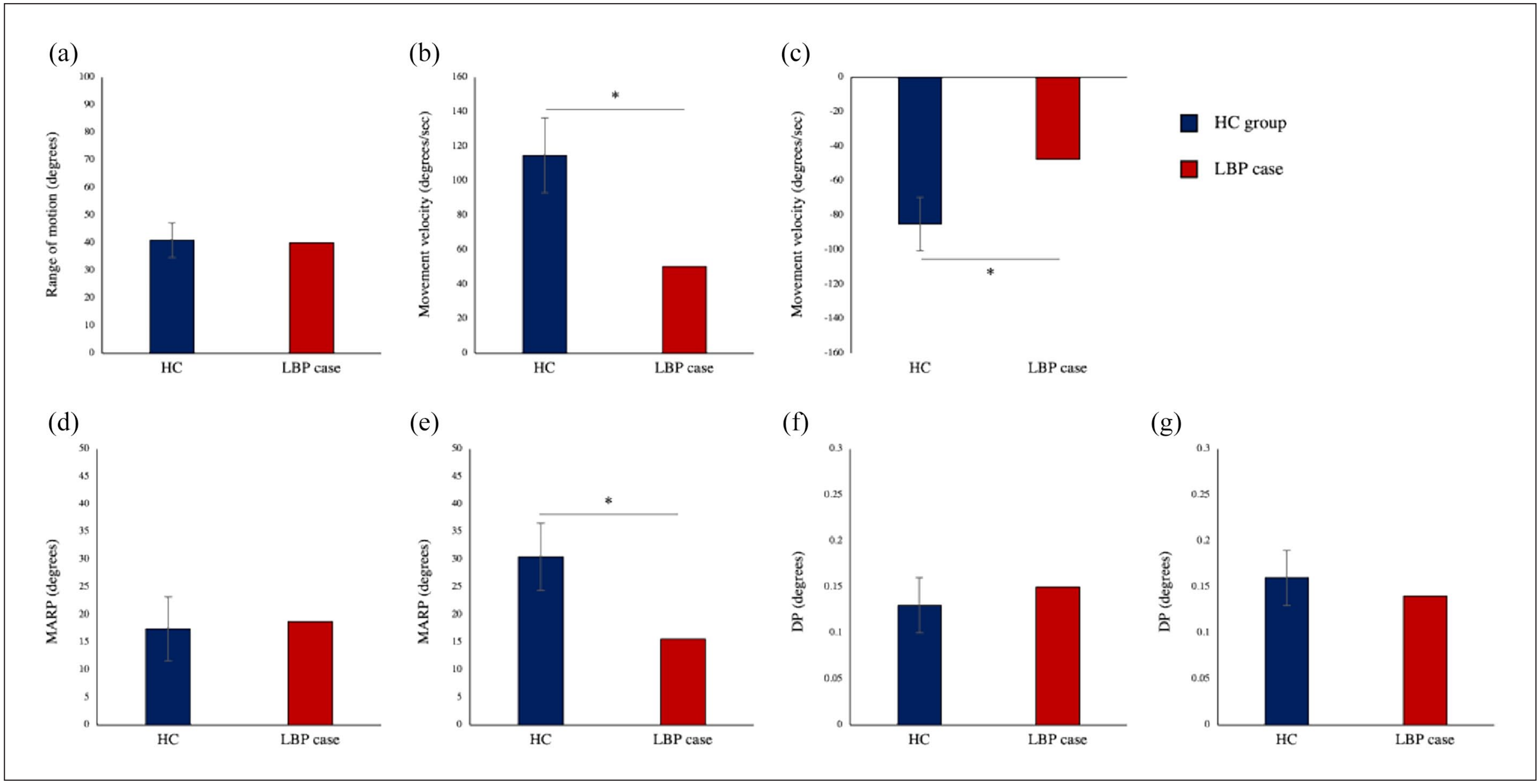

Figure 3. Comparison of the baseline data of the kinematic variables in the HC group and LBP subject. Data are mean value (SD). (a) Peak trunk flexion angle. (b) Peak trunk flexion velocity. (c) Peak trunk extension velocity. (d) MARP: flexion phase. (e) MARP: extension phase. (f) DP: flexion phase. (g) Extension phase.
*$p < 0.05$.

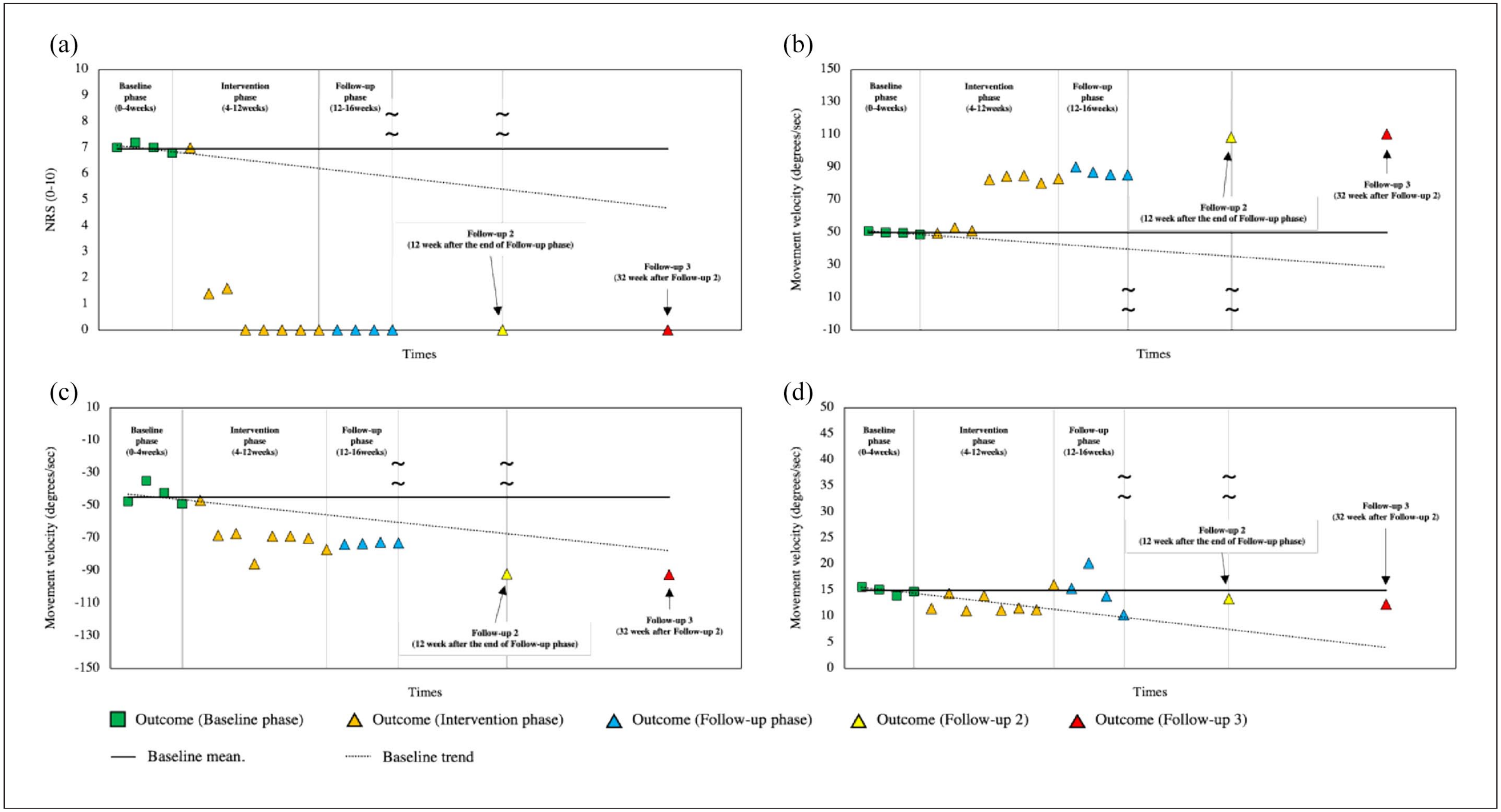

Figure 4. Change of task-specific fear of movement and kinematic variables. Outcome (baseline phase): baseline data points (4 weeks). Baseline mean: mean of the baseline data points ±0.25 SD of its mean plotted across the intervention phase. Baseline trend: linear trend ±0.25 SD of the baseline mean plotted across the intervention phase using a linear equation—both the baseline trend and the baseline mean to determine the predicted direction which the data would follow should no intervention take place, or if the intervention had no effect. Outcome (intervention phase): intervention data points (8 weeks). Outcome (follow-up phase): follow-up data points (4 weeks). Outcome (Follow-up 2): 12 weeks after the end of the follow-up phase: Outcome (Follow-up 3): 32 weeks after the end of the follow-up phase. (a) Task-specific fear of movement. (b) Peak trunk flexion velocity. (c) Peak trunk extension velocity. (d) MARP: extension phase.

Table 3. Statistical analysis of the intervention effect on task-specific fear of movement and kinematic variables.

	CDC		Tau-U	
	n criterion (criterion = 7)	Effect (Y/N)	Tau-index	p-value
Task-specific fear of movement	7	Y	−0.88	0.02
Kinematic variables				
Peak trunk flexion velocity	7	Y	0.81	0.03
Peak trunk extension velocity	7	Y	−0.88	0.02
MARP: extension phase	6	N	−0.56	0.13

Criterion: minimum number of data points required to reach a systematic change; n criterion: the identified number of data points below the criterion lines, effect: presence (Y) or absence (N) of a systematic change; CDC: conservative dual-criterion; MARP: mean absolute relative phase.

Combinations of PNE and exercise have been reported to improve the pain intensity, fear of movement, LBP-related disability, and presenteeism of individuals with LBP.[14,43] In this study, we used a combination of PNE and exercise to correct the LBP symptoms, including subject's fear of movement and to prevent a recurrence of LBP for him. PNE is a cognitive-based intervention that helps individuals reconceptualize their approach to pain and corrects their maladaptive belief (fear of movement and catastrophic thinking) toward pain.[13] Although the effect of PNE alone is ambiguous, its benefits can be enhanced when combined with exercise.[44] His progress showed consistent improvement in overall LBP symptoms, including task-specific fear of movement, which supports the results of previous studies.[14,43]

The results of our kinematic analysis and assessed fear of movement revealed that the progress differed among the variables. The subject's peak trunk flexion and extension velocity, which are indices of impaired trunk movement, were improved by our interventions. For example, impaired trunk movement limits the movement range and velocity in individuals with LBP and is considered to be a behavioral change based on fear of movement.[45] Graded-level exercise improves musculoskeletal disorders by providing a decreased fear of movement.[46] Our results suggest that the decrease in the subject's task-specific fear changed aspects of the subject's avoidance belief-based fear such as "avoiding rapid trunk movement," which resulted in faster trunk movements. In contrast, the subject's MARP, an index of impaired trunk motor control, was not changed, and the in-phase motion pattern remained. Hodges et al. proposed a theory of trunk motor control in LBP: the disorders are adaptive behaviors acquired through reinforcement learning and are based on complex changes in the central nervous system, rather than mere conscious behavioral changes.[47] In fact, there are many cases in which the experience of pain leads to the learning of incorrect trunk motor control, resulting in residual impaired trunk motor control even after pain remission.[48] There are two types of fear of movement assessments: generalized fear of movement as assessed by the TSK and task-specific fear of movement as assessed by the NRS. Because the arousal of fear in general daily life and fear about specific movements differ, the results of each assessment are not correlated.[49] An earlier study showed that task-specific fear, rather than generalized fear of movement, is useful in predicting motor behavior.[49] In this study, the TSK and the NRS were completed by the LBP subject, and his NRS score decreased more immediately in the intervention phase. Therefore, among aspects of fear of movement, the improvement of task-specific fear might have contributed to the improvement of impaired trunk movement in the LBP subject. This case report suggests that more detailed and individualized assessment and intervention is needed for impaired trunk movement and fear of movement, as they consist of a variety of mechanism.

The trunk tight control strategies including the in-phase motion pattern influence muscle fatigue, increase spinal tissue loading, and decrease sensory feedback, which may lead to reorganization of the sensory and motor cortex and impaired proprioceptive sensory.[9,47] Such secondary consequences based on impaired trunk motor control might lead to negative long-term consequences such as recurrence and chronicity of LBP. We observed herein that the subject's in-phase motion pattern was not changed consistently throughout the study period, and the symptoms of LBP eventually worsened. In light of these results, we speculate that even if the correction of fear of movement improves an individual's impaired trunk movement, if the motor control behind the movement disorders is not improved, it is not true improvement and it may lead to the recurrence of LBP. Our present findings suggest that for interventions for LBP with high fear of movement, we need to focus on maladaptive trunk motor control patterns, rather than improving the impaired trunk movement.

This study has several limitations. First, as the study has a single-case design, the generalizability of our findings to all individuals with LBP is limited. In particular, the LBP subject had relatively mild body perception disturbance and LBP-related disability. Second, the assessment of task-specific fear of movement was measured by a subjective NRS, and we did not use a physiological index. Subjective bias could thus have affected our results. Third, the assessment of exercise compliance was based on a question that asked the subject about past situations, and recall bias was thus a possibility. Fourth, the kinetic assessment of the lifting task was conducted in a laboratory setting, not in an actual working setting, and it may thus have been insufficient to assess the true work performance for the LBP subject. Fifth, physical function (range of motion, muscle strength and tightness) was assessed only at baseline, because the assessment was conducted to help develop exercise plans, not to determine the effects of the intervention. However, physical function could influence LBP symptoms,[29] and it may thus be clinically important to examine temporal changes in physical function. Sixth, the evaluation of the implementation status of exercise was based only on whether or not it was performed. The intensity/repetitions of the exercise/repetitions of the exercise were left to the LBP subject's and were not recorded or controlled. The detailed information about the implementation status of exercise might be important for explaining intervention effects. Seventh, we used the TSK and PCS for psychological assessment of pain. These assessments are globally used to evaluate fear of movement and catastrophic thinking. However, in order to assess behavioral change based on pain (i.e. fear-avoidance behavior), an evaluation of the Fear Avoidance Beliefs Questionnaire (FABQ) may be necessary.[50] Eighth, the kinematic assessment of the control group was performed at baseline only. To robustly evaluate the relationship between intervention and symptom improvement, it might also be necessary to evaluate a control group over time, as well as the LBP subject. Finally, the LBP subject could not be blinded to the study, due to the study's design.

Conclusion

In this study, education and therapeutic exercise elicited positive effects on the subject's fear of movement and trunk velocity. However, his trunk motor control continued to show the in-phase motion pattern, which eventually worsened the pain intensity. These results suggest that as in this LBP subject, residual impaired trunk motor control (i.e. remained in-phase motion pattern) despite the improvement in impaired trunk movement (i.e. increased trunk movement velocity) can lead to the recurrence of pain.

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Author contributions

RF, HS, and RI designed the study. RF, RI, and ST collected, analyzed, and interpreted the data. RF and SM wrote and prepared the manuscript. All authors read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

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Informed consent

We explained the study protocol to the subjects and obtained their written informed consent.

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