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Spinal posture, stiffness and motor control during pushing and pulling in flexion and active extension patterns of chronic nonspecific low back pain

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This cross-sectional study aimed to compare the change in spinal posture, mechanical stiffness, and motor control of the thoracolumbar spine in individuals who were asymptomatic and those with chronic nonspecific low back pain (LBP) of flexion pattern (FP) or active extension pattern (AEP) during pushing and pulling tasks performed in standing. The real-time thoracolumbar posture, mechanical stiffness, electromyographic amplitude and synergy between specified trunk muscle pairs (Internal Oblique and Multifidus, Rectus Abdominis and Erector Spinae, Internal Oblique and Rectus Abdominis, Multifidus and Erector Spinae) were analysed during quiet standing, standing pushing and pulling tasks against a load standardized at 15% of the individual body weight in a total of 39 individuals (asymptomatic, n = 14; FP, n = 11; AEP, n = 14). Pulling task resulted in greater lumbar posterior translation ($p = 0.009$) and Rectus Abdominis activity ($p = 0.006$), but smaller lumbar lordosis ($p < 0.001$) when compared to pushing task. Pulling task also resulted smaller lumbar lordosis ($p < 0.001$) and thoracic kyphosis ($p = 0.003$) comparing to upright standing. AEP group showed a significantly greater amplitude of their Internal Oblique activity when compared to those who were asymptomatic across all tasks ($p = 0.001$). Findings suggested that pulling manoeuvre in standing produced greater shear at the lumbar spine than that of pushing manoeuvre. Individuals with low back pain executed the low-load push/pull tasks with the motor strategy largely comparable to asymptomatic group. Future studies investigating the cumulative effect of repetitive push/pull loadings on the movement and motor control of the spine are warranted to better understand the long-term impacts on spinal health.

Keywords Classification, Low back pain, Mechanical stiffness, Motor control, Spinal posture

Low back pain (LBP) is the leading cause of musculoskeletal disability in the globe[1]. Epidemiologic studies showed that 9–20% of LBP incidence in workers are related to push/pull tasks[2,3]. Simulation biomechanical studies revealed that a higher compressive force was found during pulling task[4–6], whereas higher anterior–posterior (AP) shearing force, was identified during pushing task[6]. The increase in compressive or shearing force acting on the spine was considered to contribute to the development and recurrence of LBP. However, such causal relationship remains inconclusive.

Heterogeneity of non-specific LBP (NSLBP) related to movement impairments might partly explain the inconclusive findings mentioned above. NSLBP is defined as LBP without specific pathoanatomical origin[7]. The mechanism-based subclassification system for chronic NSLBP from O'Sullivan[8] was one of the major classification systems that had been frequently adopted in research of motor control impairment (MCI). O'Sullivan's classification categorizes patients with MCI according to their provocative movement direction(s), and the five defined groups with their prevalence rated in descending order were: flexion pattern (FP), active extension pattern (AEP), passive extension pattern, lateral shift, and multidirectional patterns[8,9].

Previous studies had identified that FP, AEP and healthy individuals displayed distinct presentation of spinal kinematics and trunk muscle activity in static sitting and functional tasks including sit-to-stand and

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reaching[10–12]. The variation in muscle recruitment patterns and spinal kinematics in different subtype of LBP had also been reviewed in earlier studies. For muscle recruitment patterns, bipolar surface electromyography (EMG) is a common technique for recording electrical signals from muscle activity[13]. Using this method, Dankaerts et al.[14] reported that AEP patients tended to co-contract their spinal stabilizers with inability to relax. In contrast, FP patients showed lower muscle activities in sitting compared to those with AEP. As for kinematics study, it was revealed that patients with LBP would present with specific movement pattern during functional movement. For instance, cyclists with LBP of FP exhibits greater lumbar flexion during cycling[15]. Therefore, it is postulated that the investigation of differential muscle activation pattern and kinematics between FP and AEP could provide explanations on the between-group differences in spinal posture and stiffness during push/pull tasks.

Segmental spinal stiffness during the execution of push/pull tasks was another important area to be investigated. Mechanical stiffness measurement of spine segment enables the evaluation of spinal stability in different functional position. For example, Häusler et al.[16] reported that lumbar and thoracic stiffness were greater in upright standing comparing with prone position because of increase in axial compression on the spine.

There is a lack of prior research on the comparison of kinematics, motor control and spinal stiffness presentations during upright standing and push/pull tasks with LBP subgroup classification, and such investigation will allow more understanding on whether pushing and pulling will exert more ergonomic risk on specific LBP subtype and inform corresponding injury prevention measures. This study aimed to examine the real-time (a) change in spinal posture, (b) motor recruitment pattern and (c) spinal stiffness when executing push/pull tasks in standing among individuals presented with LBP (either FP or AEP), as compared to those who were asymptomatic. By including both FP and AEP subgroups of LBP, results of this study would offer new insights for postural advice for respective subgroups of NSLBP patients.

It was hypothesized that:

(1) greater sagittal translation in the lumbar spine would be found during pushing task as compared to pulling task;

(2) greater loss of lumbar lordosis would be found in FP subgroup as compared to AEP subgroup and asymptomatic group during pushing and/or pulling task; and.

(3) greater stiffness of the lumbar segments would be found during pulling task as compared to pushing task and upright standing.

Methods

Study design

This cross-sectional study was conducted at The Hong Kong Polytechnic University (PolyU). All procedures of this study were conducted according to the Declarations of Helsinki and ethics approval was obtained from the Institutional Review Board of PolyU (HSEARS20220913004). The report of this observational study followed the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology statement[17].

Participants

Sample size of a total of 39 subjects was calculated based on the projected effect size of medium level ($f = 0.3$, power = 0.95, alpha = 0.05) using G*Power 3.1.9.4. 21 men and 18 women were recruited by quota sampling. Participants were classified into three groups: (1) Asymptomatic group, (2) FP group and (3) AEP group, based on their self-reported LBP condition by completing a demographic survey, which was further validated via physical examination of the spine by two registered physiotherapists who had more than four years of experience (Fig. 1). Inclusion and exclusion criteria were detailed in Table 1. Informed consents were obtained from all participants prior to the commencement of the procedures.

Procedures

Participants were asked to stand with their feet at shoulder width apart. (Fig. 2) A cylindrical bar connected to a load cell was adjusted to participants' elbow height with shoulders at 45° flexion for the tasks. A force gauge was connected to a load cell to allow the standardization of a targeted load of 15% of the participants' body weight across tasks. A further increase of target load may not be appropriate as previous study recommended that the pushing and pulling load of 20% of an individual's body weight was the safety limits of acceptable exertions[6]. The participants' posture during the task was monitored such that their feet and elbows should not move, and the movement was mainly driven from the lumbopelvic region.

Clinical measurements

Clinical characteristics and self-reported scales

Demographic information was collected by interviews and surveys. Participants completed Quebec Back Pain Disability Scale (QBPDS) at baseline[20] In addition, Numeric Pain Rating Scale (NPRS) and Modified Rating of Perceived Exertion (MRPE) were asked immediately after each task. The list of questionnaires all have good validity and reliability[21–23].

Primary outcome: Spinal posture and translation

First, surface tomography was used to assess the posture and spinal translation of participants (DIERS Formetric® III 4D, Germany). Eight reflective markers were placed on the spinous processes of C7, T3, T6, T9, T12, L3 and bilateral posterior superior iliac spine (PSIS). There were three postural outcomes: kyphotic angle and lordotic angle (angular outcomes) and Flèche Lombaire (FL) (linear translation) (Fig. 3). The kyphotic angle referred to the surface tangents between the spinous process of C7 and thoracolumbar junction; the lordotic angle was quantified with the surface tangents between thoracolumbar junction and lumbosacral junction. To quantify

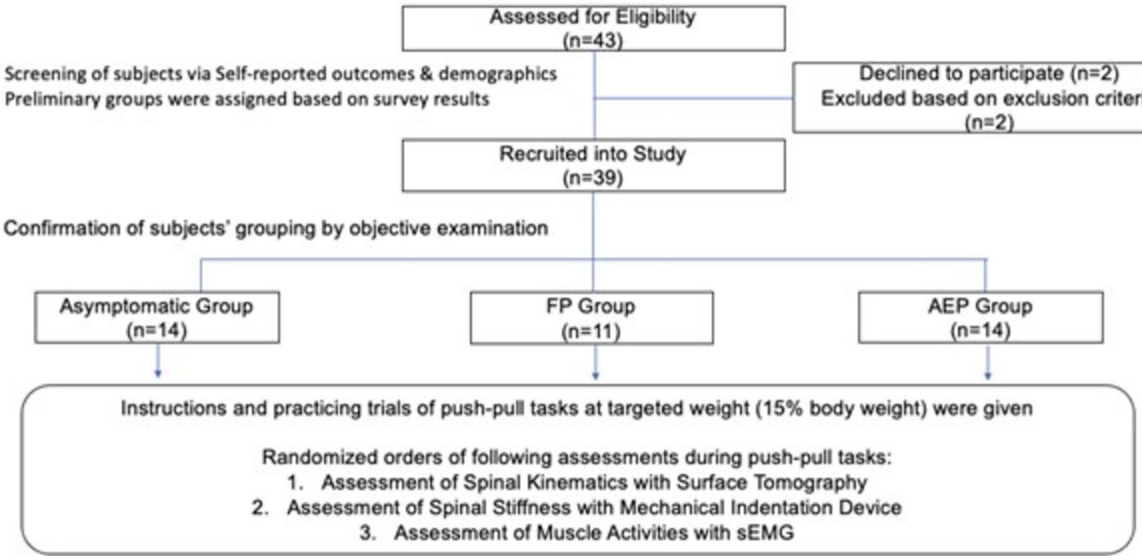

Fig. 1. Participant recruitment and study design.

Exclusion Criteria (applicable to all three groups)[18]	**Exclusion Criteria of LBP groups**[18,19]
● Acute or unhealed fracture ● Bones incapable of bearing body weight due to pathology ● Implantation of pacemakers and/or defibrillators ● Any red flags including neoplastic disease of the spine and certain bone diseases including infections	● Specific diagnoses for LBP disorder (e.g. severe scoliosis, spondylolisthesis, spondylitis) ● Presence of red flags ● Previous back and spinal surgery ● Pregnant at the time of study or within six months postpartum ● Presence of neurological symptoms
Inclusion Criteria of Asymptomatic group[19]	**Inclusion Criteria of LBP groups**[10,11]
● No experience of LBP within the last 12 months ● No experience of an episode of LBP lasting more than two weeks within the last two years	● History of chronic (> three months) NSLBP ● Pain localized to the lower lumbar spine (L4-L5 or L5-S1) ● Symptoms are aggravated or eased by specific postures and movements
LBP Subgroup Classification (confirmed by independent agreement by two researchers)	
FP group[10,11]	**AEP group**[10,11]
● Aggravation of symptoms with flexion of the lower lumbar spine ● Loss of segmental lordosis ● Pain relief with spinal extension	● Aggravation of symptoms with extension of the lower lumbar spine ● Excessive segmental lordosis ● Pain relief with spinal flexion

Table 1. Inclusion and exclusion criteria of participants with classification guidelines.

spinal translation, FL referred to the horizontal distance between the plumb lines of thoracic apex and lumbar apex.

Measurement was performed in standing and during push/pull tasks. Images were taken by the machine at 2 Hz for six seconds, from which a three-dimensional spinal model could be reconstructed (Fig. 4). The procedures were repeated three times for each task with a resting interval of ten seconds.

Secondary outcomes 1: Muscle activities

Secondly, surface Electromyography (EMG) (Ultium, Noraxon USA Inc., USA) were used to record the muscle activities of Lumbar Erector Spinae (ES), Rectus Abdominis (RA), Internal Oblique (IO) and Lumbar Multifidus (LM)[24]. (Table 2).

EMG signals were collected at 1000 Hz with bandwidth and common-mode rejection ratio being 20–500 Hz and greater than 80 dB respectively. Maximal voluntary contraction (MVC) data were first obtained using the method documented by Dankaerts et al.[24]. Participants then performed the push/pull tasks. EMG activity is recorded for six seconds once the targeted load was reached. Each task was repeated three times with a resting interval of ten seconds. The order of pushing and pulling task was randomised. Muscle recruitment pattern was analysed in terms of (a) mean percentage of MVC (%MVC) and (b) co-contraction index (CI). CI was defined as the percentage of mean total muscle co-activity when the muscle pairs were simultaneously activated.

The Root-Mean-Square (RMS) of the EMG activity during task was normalized with the individual MVC value. The synergy of muscle recruitment of the muscle pairs below was reported by CI:

1. Superficial and deep muscles (RA-ES and IO-LM)
2. Flexors and extensors (RA-IO and ES-LM)

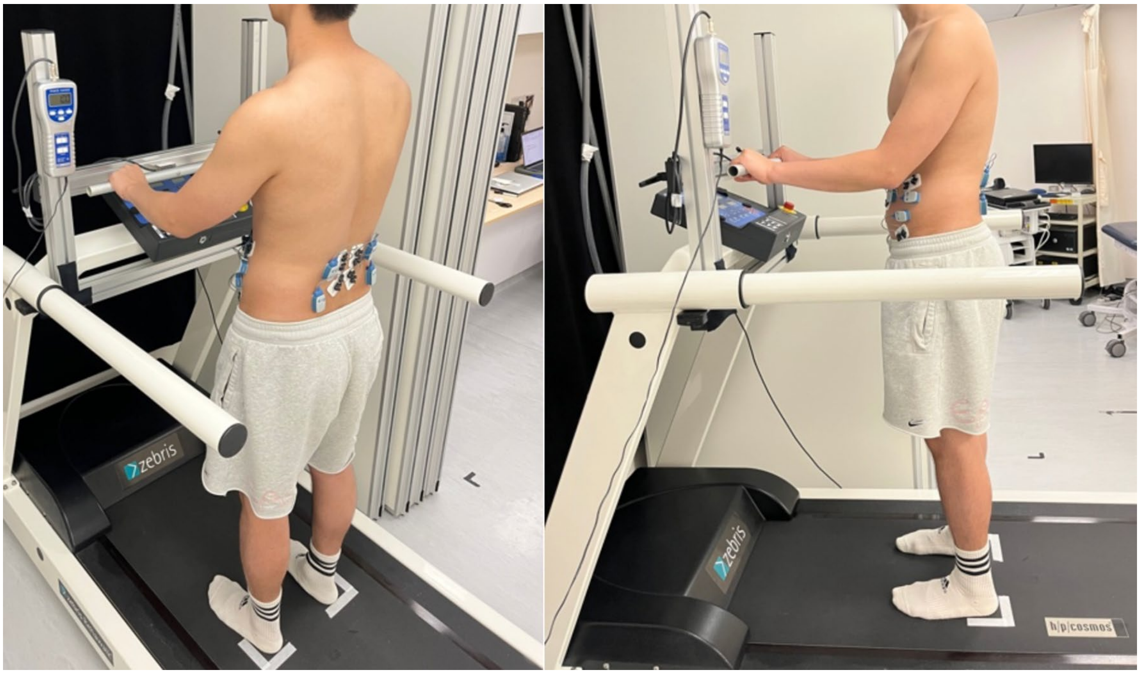

Fig. 2. Experimental setup of push/pull task procedures.

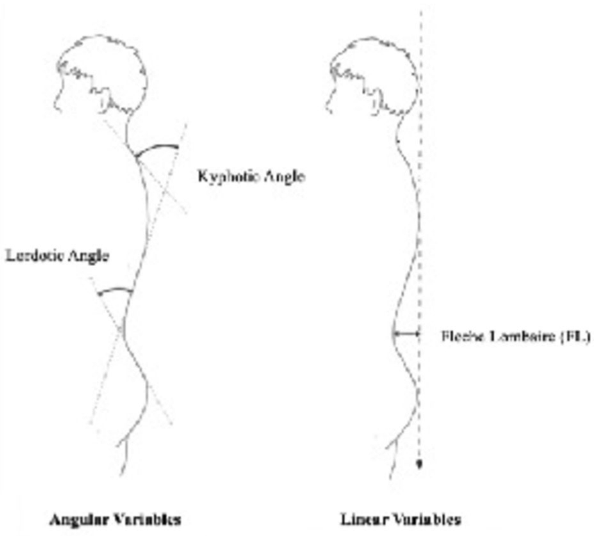

Fig. 3. Outcomes of spinal posture and translation measured by the surface tomography.

CI was calculated using the formula shown below[25], whereas area A and B referred to the areas under the EMG curve for muscle A and B respectively.

$$Co - Contraction\, Index = 2\, x\, \frac{Common\, Area\, A\, \&\, B}{Area\, A\, +\, Area\, B}\, x\, 100\%$$

Secondary outcomes 2: Spinal stiffness
Lastly, the mechanical indentation device (Pulstar G3 system, USA) was used to measure the spinal stiffness of participants between T9 and S1 on each spinous process. A posteroanterior pressure was applied manually by the operator using the circular-shaped applicator[26] (Fig. 5) during standing, pushing or pulling task. Each task was repeated three times with the order of pushing and pulling task randomised. The spinal segmental resistance was captured from cephalic (T9) to caudal (S1). For analysis, the target segments were stratified into three spinal

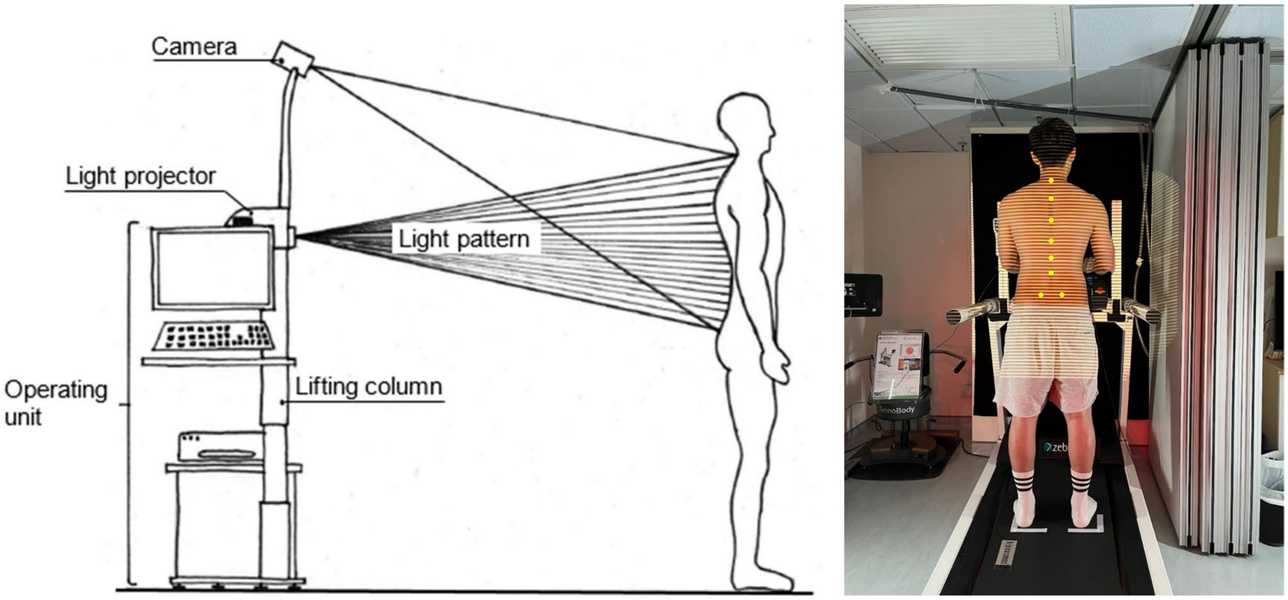

Fig. 4. Schematic illustration of spinal posture and translation measurement using the surface tomography.

Targeted Muscles	Electrodes placement
Erector Spinae (ES)	Over the largest muscle mass found by palpation, 4 cm from midline of the spine at the third lumbar vertebrae (L3)
Lumbar Multifidus (LM)	L5 level and aligned parallel to the line between the posterior superior iliac spine (PSIS) and the L1–L2 interspinous space
Rectus Abdominis (RA)	1 cm above the umbilicus and 2 cm lateral to the midline
Internal Oblique (IO)	1 cm medial to the anterior superior iliac spine (ASIS) and beneath a line joining both ASISs

Table 2. EMG electrodes placement.

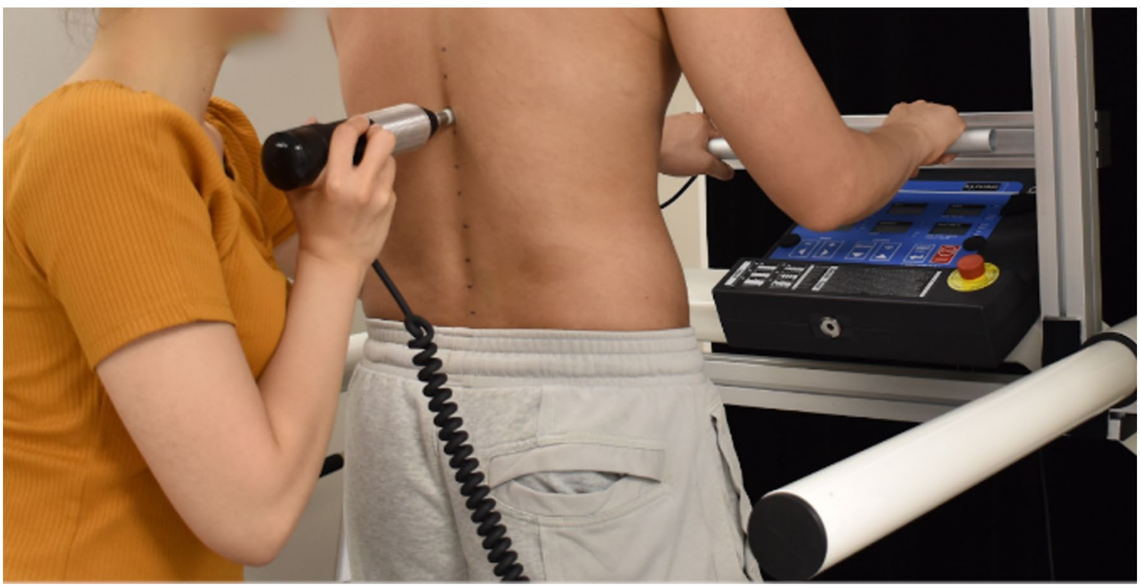

Fig. 5. Set up of spinal stiffness measurement using mechanical indentation device.

regions anatomically: T9-T12 as the lower thoracic region, L1-L3 as the upper lumbar region and L4-S1 as the lower lumbar region.

Statistical analysis

Normality of the data and homogeneity of variances were assessed using Kolmogrov-Smirnov test, and Levene's test respectively. Baseline variables were compared using Pearson's Chi-Square for categorical variables and one-way ANOVA for continuous variables. For the clinical measures, two-way ANOVA was used to analyse between-group and between-task differences and interaction effect in spinal posture and translation. One-way ANOVA was used for examining the between-task difference of spinal stiffness and between group difference of the EMG parameters. Independent T-test was used to analyse difference of EMG activity between pushing and pulling tasks. Kruskal–Wallis test and Man-Whitney U test were used when the data did not fulfil the criteria of parametric statistics. The level of statistical significance was set at 0.05 for all the above tests. Multiple independent T-test and Mann–Whitney U test with Bonferroni adjustments (significant level of 0.017) were used respectively as post-hoc analysis when significant results were found.

Internal consistency of primary and secondary outcome measures was also assessed using the intraclass correlation coefficient (ICC). Besides, the formula of the standard error of measurement (SEM) was:

$$\mathrm{SEM}_{\mathrm{consistency}} = \mathrm{SD}_{\mathrm{diff}}/\sqrt{2}$$

SEM could be calculated by dividing the standard deviation (SD) of the mean differences between measurements by $\sqrt{2}$[27]. The relative reliability was assessed using the ICC. The degree of reliability of the respective outcome measures was considered to be poor, fair, moderate or excellent if the value of ICC < 0.4, 0.4–0.7, 0.7–0.9 and ≥ 0.9 respectively[28].

Results

Demographics & self-reported scales

Participants' demographics and baseline level of disability were similar across all groups. No experience of pain was reported by all participants during data collection (Table 3).

Reliability of outcome measures

For spinal kinematics assessment, the ICC(3,3) for FC, FL and Kyphotic angle were excellent (ICC: 0.921–0.960), while lordotic angle yielded good reliability (ICC: 0.831). For spinal stiffness, the ICC(3,3) were excellent for lower thoracic spine region (T9-T12) and upper lumbar spine region (L1-L3) (ICC:0.963–0.968), and good to excellent reliability for lower lumbar spine region (L4-S1) (ICC:0.797). For EMG, the ICC(3,3) showed perfect reliability for %MVC of RA, ES, IO, LM (ICC:0.951–0.970) and CI of IO-LM, RA-ES, IO-RA, LM-ES (0.918–0.966).

Spinal posture and translation

Kyphotic angle was significantly higher in standing than that in pulling task (45.2° vs 38.4°, $F = 4.416$, $p = 0.003$) (Table 4). The kyphotic angle was also higher in pushing than pulling task (44.2° vs 38.4°), though it did not reach statistical significance ($p = 0.017$). In addition, lordotic angle was significantly smaller in pulling task than that of standing and pushing (36.1° vs 44.6° vs 44.6°, $F = 8.448$, $p < 0.001$). There were no statistically significant differences for between-group comparisons or interaction effect.

	Overall	Subgroup		
	Total	Asymptomatic	FP	AEP
	n = 39	*n* = 14	*n* = 11	*n* = 14
Demographics				
Age (years)	33.8 ± 9.9	30.6 ± 7.8	35.1 ± 12.0	36 ± 9.9
Gender (M:F, n)	21:18, 39	8:6, 14	6:5, 11	7:7, 14
Height (cm)	166.9 ± 9.1	167.2 ± 8.9	165.5 ± 6.3	167.6 ± 11.4
Weight (kg)	61.2 ± 11.0	59.6 ± 9.9	59.3 ± 7.8	64.3 ± 13.8
BMI (kg/cm²)	21.9 ± 2.5	21.2 ± 2.4	21.6 ± 1.6	22.7 ± 3.0
Self-reported Scales				
QBPDS score (0–100)	7.6 ± 8.1	4.1 ± 4.9	9.4 ± 8.0	9.7 ± 9.8
MRPE (0–10)				
Pushing task	4.1 ± 1.1	4.14 ± 0.950	4.2 ± 1.5	3.9 ± 0.920
Pulling task	3.7 ± 1.2	3.7 ± 0.910	3.4 ± 1.0	4.0 ± 1.6

Table 3. Descriptive statistics of demographics and self-reported scales. Data presented by Mean±SD unless otherwise specified. Remark: FP: Flexion Pattern; AEP: Active Extension Pattern; QBPDS: Quebec Back Pain Disability Scale; MRPE: Modified Rating of Perceived Exertion.

Spinal posture and translation		Task		
	Standing	Pushing	Pulling	Sig. (Between tasks)
Flèche Lombaire (mm)	43.6 ± 11.1	32.7 ± 18.0	21.4 ± 18.6	*p* < 0.001* *p* < 0.001** (standing and pulling) *p* = 0.009** (pushing and pulling)
Kyphotic Angle (°)	45.2 ± 10.1	44.2 ± 11.45	38.4 ± 9.4	*p* = 0.014† *p* = 0.003†† (standing and pulling)
Lordotic Angle (°)	44.6 ± 11.0	44.6 ± 9.6	36.1 ± 10.9	*p* < 0.001† *p* < 0.001†† (standing and pulling) *p* < 0.001†† (pushing and pulling)

Table 4. Mean ± Standard Deviation, test statistics for between-task comparisons of the spinal posture and translation. *:p<0.05 (Kruskal–Wallis test);**:p<0.017 (Multiple Mann–Whitney U test); †: p<0.05 (Two-way ANOVA); ††: p<0.017 (Multiple independent T-test).

Muscle	Task			
	Pushing	Pulling	Sig. (between tasks)	Sig. (between groups)
Erector Spinae (ES)				
	16.5 ± 9.24	16.0 ± 9.7	*p* = 0.686	*p* = 0.111
Lumbar Multifidus (LM)				
	16.8 ± 10.4	19.0 ± 13.0	*p* = 0.621	*p* = 0.486
Rectus Abdominis (RA)				
	10.1 ± 10.0	18.7 ± 16.8	*p* = 0.006†	*p* = 0.363
Internal Oblique (IO)				
	25.7 ± 18.5	19.4 ± 14.1	*p* = 0.107	*p* = 0.010*

Table 5. Mean ± Standard Deviation, test statistics for between-task comparisons of the muscle activation (%MVC). *: p<0.05 (Kruskal–Wallis test); †: p<0.05 (Mann–Whitney U test).

Internal Oblique (IO)	Groups			
	Asymptomatic	FP	AEP	Sig
Asymptomatic vs FP	17.5 ± 14.0	25.2 ± 23.6	/	*p* = 0.545
FP vs AEP	/	25.2 ± 23.6	25.4 ± 11.0	*p* = 0.123
Asymptomatic vs AEP	17.5 ± 14.0	/	25.4 ± 11.0	*p* = 0.001*

Table 6. Mean ± Standard Deviation, post-hoc test statistics of between-group comparison of IO. *: p<0.0017 (Multiple Mann–Whitney U test).

Spinal translation was the largest in pulling task such that FL was significantly smaller for pulling task when compared to standing (21.4 mm vs 43.6 mm, $p < 0.001$) and pushing (21.4 mm vs 32.7 mm, $p = 0.009$) (Table 3). Additionally, there were no statistically significant differences for between-group comparisons of FL.

EMG

For analysing the amplitude of muscle activity, there was no significant between-task difference for the %MVC of ES, LM and IO. Pulling task resulted in a significantly higher %MVC of RA than pushing task (18.7% vs 10.1%, $p = 0.006$) (Table 5).

For between-group comparison of %MVC, there was no significant between-group difference in ES, LM and RA. For IO, significant difference was only found in comparison between asymptomatic and AEP groups, with the AEP group having higher IO muscle activation (25.4% vs 17.5%, $p = 0.001$) (Table 6).

For analysing the synergy of muscle recruitment, no between-task and between-group difference of CI in all muscle pairs was found (Table 7).

Spinal stiffness

For spinal stiffness among lower thoracic, upper and lower lumbar regions, there were no between-task differences (Table 8).

Discussion

Our results showed that task-specific impacts were present in spinal posture, translation and muscle activation. Significantly smaller lordotic angle, smaller FL (greater translation) with greater RA activation was found in pulling task as compared to pushing task. Pulling task also showed smaller lordotic and kyphotic angles compared

	Task		
Muscle Pair	Pushing	Pulling	Sig. (between task)
IO-LM	52.9 ± 15.8	57.5 ± 14.0	*p* = *0.324*
RA-ES	45.8 ± 18.8	49.4 ± 15.6	*p* = *0.343*
IO-RA	44.0 ± 18.4	47.9 ± 17.1	*p* = *0.580*
LM-ES	68.6 ± 11.1	68.9 ± 11.1	*p* = *0.646*

Table 7. Mean ± Standard Deviation, test statistics for between-task comparisons of the muscle activation (CI). *: $p<0.05$ (Mann–Whitney U test).

		Task		
Spinal Region		Standing	Pushing	Pulling
Lower Thoracic	35.6 ± 5.9	33.7 ± 7.0	33.1 ± 6.7	*p* = *0.224*
Upper Lumbar	31.6 ± 7.3	29.5 ± 8.1	29.8 ± 7.6	*p* = *0.424*
Lower Lumbar	27.9 ± 6.9	25.4 ± 6.8	25.9 ± 7.2	*p* = *0.236*

Table 8. Mean ± Standard Deviation of spinal stiffness among spinal regions, groups and tasks. *$p<0.05$ (One-way ANOVA).

with upright standing. AEP group demonstrated greater IO recruitment across tasks. For spinal stiffness, there was no between-task difference.

Spinal control between pushing and pulling tasks

Based on our results, pulling task yielded the lowest FL which demonstrated higher lumbar linear translation than pushing task. Higher linear translation might induce higher risk on the spine. Clinically, these findings suggested that people could prioritize pushing task over pulling task in manual handling.

This finding was, however, contradictory to the previous study done by Knapik et al.[6], which suggested that the AP shearing force was higher in pushing task than pulling task in all lumbar levels except L5/S1. One of the possible reasons for the different findings might be due to the use of different measurement tool. Knapik et al.[6] adopted EMG-assisted biomechanical model, which deduced the AP shearing force using EMG information[29]. However, such method was not a direct measurement of the spinal motion and could be confounded by individual variability of muscle recruitment patterns.

The electromyographic amplitude was higher in RA during pulling task than pushing task, while there was no between-task significant difference among extensor muscles (LM and ES). Provided that spinal posture measurement also reflected a significantly lower lordotic angle in pulling task when compared to pushing task and standing, the EMG findings were coherent with findings of spinal posture.

Spinal control between the LBP subgroups

Findings of the present study did not show significant between-group differences in all spinal posture, translation and EMG parameters, except for %MVC. It was interesting to find that %MVC of IO was higher in the AEP group than the asymptomatic group. This finding was consistent with the results reported by Dankaerts et al.[10] examining for a seated position. However, the pattern differed from O'Sullivan's proposed pattern in the AEP group, which suggested that AEP group tended to excessively activate ES and ML instead. Given the absence of pain during the task executions and lack of between-group difference in spinal posture and translation, the underlying reason might be that the active muscle system of the symptomatic groups utilized different recruitment strategies to enable the accomplishment of the task without symptom provocation.

Spinal stiffness between pushing and pulling tasks

Contrary to our hypothesis, the data revealed no task-specific differences in spinal stiffness with a high individual variability was observed (Fig. 6). The high variability could imply a "wash-out" effect by individual variation of neuromuscular strategies. Our finding revealed that there was a smaller lordotic angle and higher RA activation in pulling task. When the spine adopted a less lordotic posture, the zygapophyseal joints in the lumbar spine would be in a less close-packed position[30]. With higher intersegmental translation allowed, the spinal stiffness measured would be less. On the other hand, higher RA activation would increase axial compression resulting in greater spinal stiffness supposably. The two effects on spinal stiffness might therefore potentially cancel out mutually during the task.

Limitations

In this study, the participants' pain-induced motor control patterns could not be observed, which was attributed by the low experimental task demand. Hodges et al.[31] had proven that changes of motor control pattern could be induced by pain. However, no participant reported pain before and immediately after the tasks in this study. In addition, the similar level of disability among the symptomatic and asymptomatic groups could contribute to the similar findings between groups in the study. In addition, our findings obtained from a small sample size of

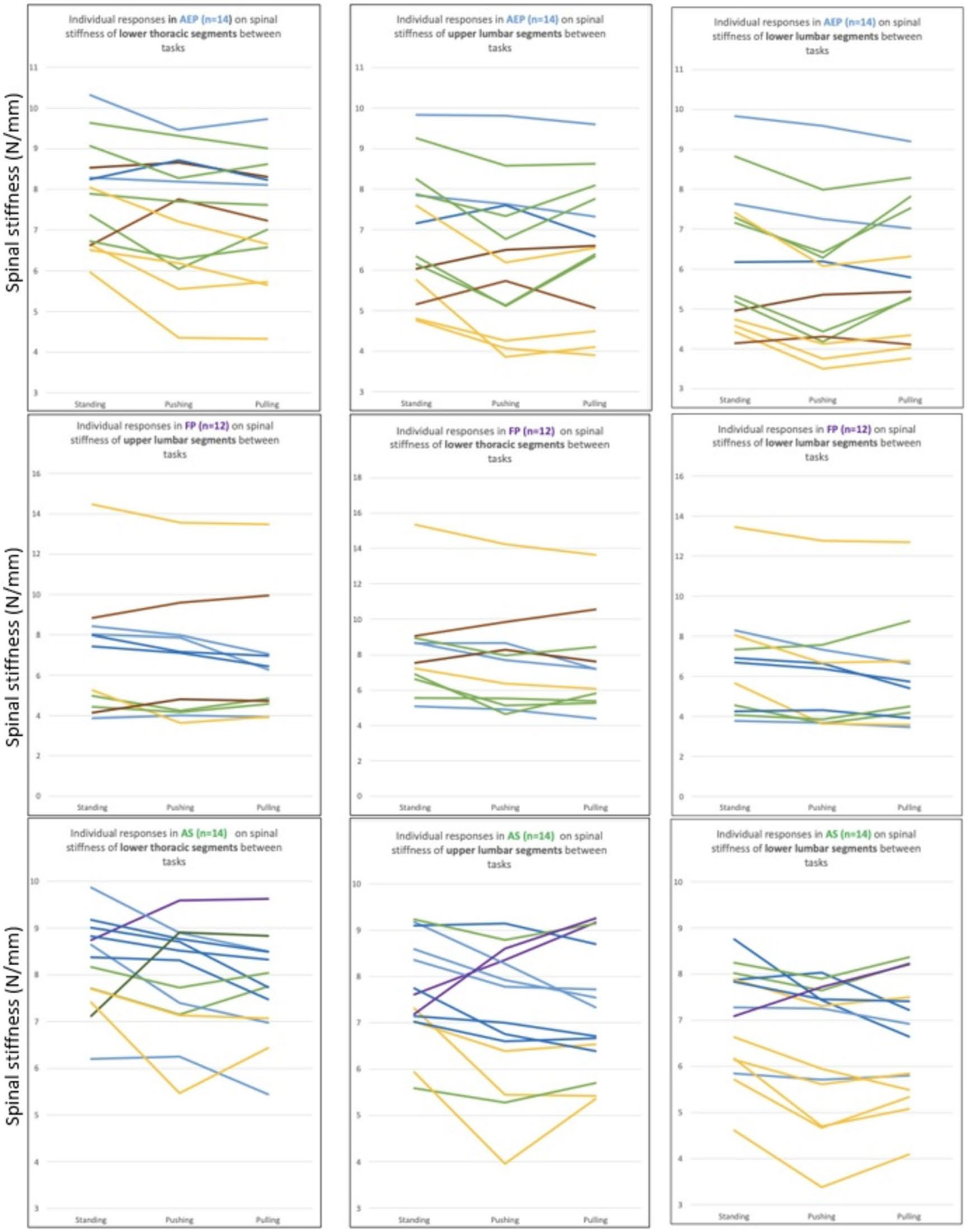

Fig. 6. Individual responses (as indicated by respective coloured line) of spinal stiffness (N/mm) measured during standing, pushing and puling tasks, presented by groups of participants and respective spinal regions formed by a) lower thoracic, b) upper lumbar and c) lower lumbar segments.

relatively young and fit adults may not be generalizable to those presented with more prevalent demographics related to LBP i.e., middle-aged and higher BMI[7].

Future studies to address the effect of repetitive push/pull loadings on participants with FP/AEP through the random sampling method with a greater sample size based on power analysis are warranted to optimise the representation of the LBP subgroups before the valid clinical implications can be generated[32]. A further increase of target load may not be appropriate as a previous study recommended that the push/pull load at 20% of body weight was the safety limit of exertions[6]. Cumulative loading on the spine from repetitive movement was known to be associated with incidence of LBP with minimal or even without weight[33]. Further studies examining the presentation of posture and motor control with repetitive push/pull tasks would provide insight for the understanding of LBP. Furthermore, the use of traditional bipolar EMG did not allow the appreciation of spatial variation of EMG activity in the muscles[13], recent study used advanced protocol of high-density surface EMG to examine back extensors and abdominal muscles in chronic LBP population during concentric and eccentric trunk flexion and extension tasks[34]. Future studies may use such technological advancement to further the understanding of maladaptive motor control in LBP with different functional assessment.

Finally, caution is required when interpreting or integrating the present findings for which only two LBP subtypes within the MCI classification (i.e., FP and AEP) were included in this study with the screening procedure adopted. While present findings are only confined to those with either FP or AEP subtypes, it is recommended that future studies should investigate those who are classified with MCI of passive extension, lateral shift or multidirectional subtype to holistically inform the kinematics and motor recruitment patterns across the wide spectrum of MCI in chronic nonspecific LBP.

Conclusion

This study provided new insight for spinal posture, translation, motor control and segmental stability in pushing and pulling tasks specifically. Moving objects by pushing instead of pulling manoeuvre could reduce shearing on the lumbar spine, irrespective of the symptoms and classification of LBP. Further studies investigating the cumulative effect of repetitive push/pull loadings on spinal motor control are needed to address the practical demand in daily living activities. Inclusion of participants suffering LBP with specific level of disability would optimize the comparability of results to other studies on LBP.

Data availability

The data that support the findings of this study are openly available in Zenodo at https://doi.org/https://doi.org/10.5281/zenodo.11115066 . Further enquiries can be directed to the corresponding author.

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