Relationships Between Trunk Movement Patterns During Lifting Tasks Compared With Unloaded Extension From a Flexed Posture

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Abstract

Objectives: The purpose of this study was to investigate between movement patterns of trunk extension from full unloaded flexion and lifting techniques, which could provide valuable information to physical therapists, doctors of chiropractic, and other manual therapists.

Methods: A within-participant study design was used. Whole-body kinematic and kinetic data during lifting and full trunk flexion were collected from 16 healthy male participants using a 3-dimensional motion analysis system (Vicon Motion Systems). To evaluate the relationships of joint movement between lifting and full trunk flexion, Pearson correlation coefficients were calculated.

Results: There was no significant correlation between the amount of change in the lumbar extension angle during the first half of the lifting trials and lumbar movement during unloaded trunk flexion and extension. However, the amount of change in the lumbar extension angle during lifting was significantly negatively correlated with hip movement during unloaded trunk flexion and extension ($P < .05$).

Conclusions: The findings that the maximum hip flexion angle during full trunk flexion had a greater influence on kinematics of lumbar–hip complex during lifting provides new insight into human movement during lifting. All study participants were healthy men; thus, findings are limited to this group. (J Manipulative Physiol Ther 2018;41:189-198)

Key Indexing Terms: *Low Back Pain; Physical Therapist Assistants; Spine; Lifting*

Introduction

With a lifetime prevalence of 38.9%, low back pain (LBP) affects a substantial proportion of individuals, and in particular, during their productive years.[1,2] In the United States, medical claims related to back injuries constituted 19% of all workers' compensation claims but were disproportionally responsible for 41% of the total injury costs.[3] Low back pain is a prevalent public health concern worldwide that not only affects individuals but also exerts a global socioeconomic burden. According to an announcement by the Japanese Ministry of Health, Labor and Welfare in 2013, LBP accounted for 60% of industrial injuries, with LBP occurring most often during manual handling activities.[4] As described earlier, it is well established that the activity of lifting is a primary risk factor for LBP.[5]

Compression force and shear force are the 2 main mechanical stresses applied to the lumbar region during lifting.[6-9] An increased compression force causes higher stress to intervertebral discs, which can result in the degeneration of intervertebral discs and/or lumbar disc herniation.[7,10] On the other hand, a shear force is applied to the intervertebral joint plane. In addition, large range of motion of the intervertebral joint causes higher stress to the intervertebral joints.[11] Therefore, increasing not only shear force but also the lumbar extension movement with high shear force can increase the stress applied to the intervertebral joints, thereby increasing the risk of intervertebral joint degeneration.[12,13] Thus, increased lumbar extension movement during lifting can increase the risk of LBP. On the basis of this information, when discussing the stress applied to the intervertebral joints, we should consider

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Table 1. *Participant Characteristics*

Variables	Mean (SD)
Age, y	24.5 (2.2)
Height, m	1.73 (0.1)
Mass, kg	66.4 (7.0)
BMI, kg/m^2	22.2 (1.7)

BMI, body mass index; *SD,* standard deviation.

not only the shear force but also the degree of lumbar extension movement during lifting. This association suggests that evaluating the lumbar movement patterns of individuals engaged in daily lifting tasks has clinical significance.

However, if patients with LBP perform lifting tasks in the clinic to evaluate their movement patterns, the lifting tasks may either cause or exacerbate LBP. Therefore, physical therapists and chiropractors usually evaluate patient lumbar-hip movement patterns during sagittal trunk rotation in the clinic, with some previous reports investigating the kinematics of the lumbar–pelvic–hip complex during sagittal trunk rotation task and/or lifting tasks.[14-18]

In 2015, Alqhtani et al[18] reported that sagittal kinematics of the hip and lumbar spine during trunk flexion are different from those observed during other functional tasks and clinicians should not be overdependent on the interpretation of flexion range of motion within the clinic to determine the degree of impairment. In their report, the lifting task consisted of stoop lifting, and the range of motions and velocities during particular phases were not analyzed. However, previous researchers reported that stoop lifting causes higher shear force on the lower back,[19,20] and lumbar movement during the initial phase of extension is associated with LBP.[21] The relationship between lifting techniques used in clinic and trunk extension from full unloaded flexion remains unclear.

Therefore, investigating the relationships of lumbar–hip movement patterns between trunk extension from full unloaded flexion and lifting tasks during particular phases may provide fruitful findings to aid clinical reasoning and judgement. The purpose of this study was to investigate between movement patterns of trunk extension from full unloaded flexion and lifting techniques, which could provide valuable information to physical therapists, doctors of chiropractic, and other manual therapists. We hypothesized that lumbar–hip movement patterns were interrelated during trunk extension from full unloaded flexion and the phases of lifting tasks.

Methods

Participants

Sixteen healthy male participants were recruited (Table 1). Participants were excluded if they reported any current musculoskeletal injury or pain, previous lower extremity or lumbar surgery, a history of LBP, or a neuromuscular disease that could affect their ability to lift. Before participation, the goal of the study was explained to all participants, and oral and written consent was obtained from each participant. The study protocol was approved by the Ethics Committee of Hiroshima University Graduate School of Health Sciences prior to the study (No. 1507).

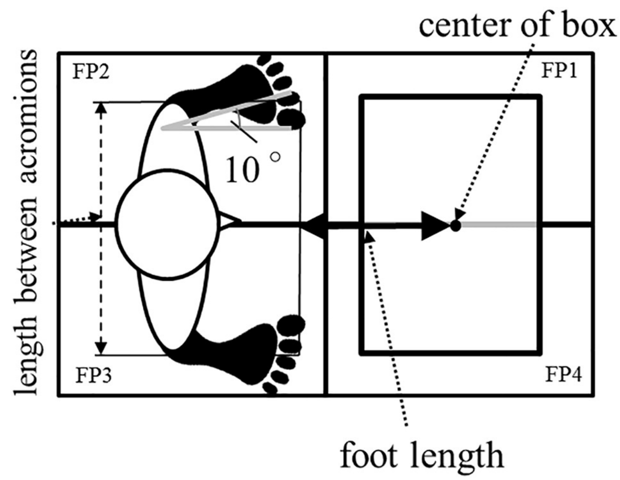

Fig 1. *Foot and box placement on force plates.* FP, *force plates.*

Data Collection

For assessment of movement patterns during lifting and unloaded trunk flexion and extension, a 3-dimensional motion analysis system (Vicon Motion Systems, Oxford, United Kingdom) equipped with 6 cameras recording at a 100-Hz sampling rate was used to capture the positions of 48 retroreflective markers attached to anatomic landmarks.

Participants were instructed to lift a box containing a 7.5-kg weight with their feet apart at the distance between both acromions from half the height of their shank to half the height of their thigh at a comfortable speed. The distance between the center of the box and the toes were set as foot length, and foot progression angle was set at a 10° toe out (Fig 1). The participants were instructed to flex their knees at 4 different knee angle magnitudes (0°, 30°, 60°, and 90°) using feedback when they reached the box, and then perform 5 lifting trials under each conditions in a randomized order (Fig 2).

Thigh and shank marker position data were streamed from the Vicon Nexus Version 2.1.1 to MatLab 2014a (MathWorks, Natick, Massachusetts) to calculate the knee flexion angle (KFA). Then KFA was displayed as a blue arrow on a screen located at a distance of a single body height from the tip of the participant's feet. The 12 o'clock direction indicated 0°, and clockwise rotation indicated an

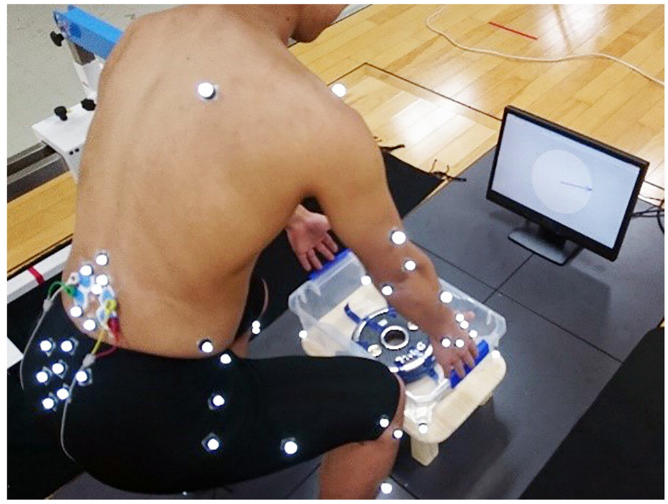

Fig 2. *The real-time feedback system used for lifting with altered knee flexion angle.*

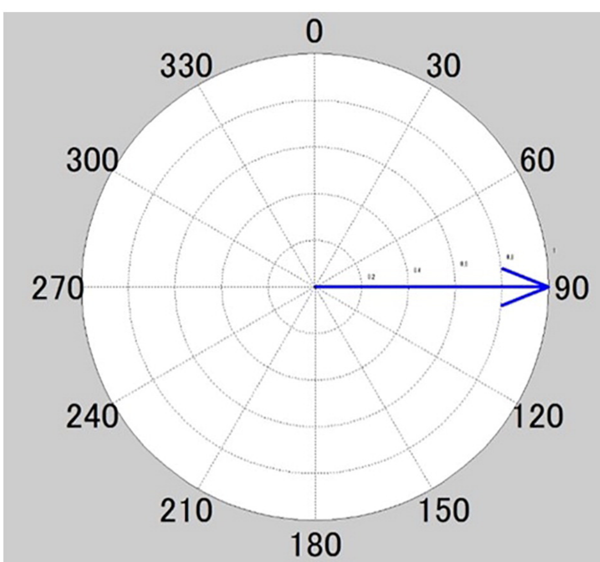

Fig 3. *The displayed knee flexion angle (clockwise rotation indicates increased knee flexion angle).*

increase in KFA (Fig 3). KFA during real-time feedback was defined as the angle between a vector from the greater trochanter to the lateral epicondyle of the femur and a second vector from the lateral malleolus to the lateral condyle of the tibia (Fig 4). The feasibility of this real-time feedback system was reported in previous studies that calculated a joint angle during a faster speed task (gait) than lifting.[22,23]

Trunk extension from full unloaded flexion was measured as follows (Fig 5): (A) stand still and upright while look straight ahead; (B) flex the trunk with knees extended as far as possible; and (C) after an oral cue, return to the original upright posture, quietly stand upright, and look straight ahead. All participants performed 5 trials and the average scores were calculated as representative values.

Data Analysis

A 15-piece, rigid-body-linked model comprising the head, thorax, pelvis, upper arms, forearms, hands, thighs, shanks, and feet was constructed using the collected data on marker coordinates.[24,25] The coordinates for the whole body center of mass (COM) and Euler angles between segments were calculated using a custom-written BodyBuilder program (Vicon, Oxford, United Kingdom) on the basis of the results of previous studies.[26,27]

The beginning and end of lifting were detected using the velocity of the markers pasted on the object that was lifted (Fig 6A). Middle of lifting was defined as the halfway point in object marker vertical displacement during lifting. The initial and final halves of the lifting motion were defined on the basis of the lifting midpoint (Fig 6B).

We detected the start and end of trunk extension from full unloaded flexion using the vertical coordinate of the COM (Fig 7). The middle of trunk extension was defined as half the change in the vertical coordinate of the COM during trunk extension. The maximum hip and lumbar flexion angles during lifting (Max hip-Lift 0, 30, 60, and 90 and Max lumb-Lift 0, 30, 60, and 90) and full trunk flexion (Max hip-FF and Max lumb-FF) were calculated. The change in the lumbar joint angles during the first half of lifting (Change lumb-Lift 0, 30, 60, and 90) and the change in the hip joint and lumbar angles during the first half of trunk extension (Change hip-Ext and Change lumb-Ext) were calculated as the differences between maximum flexion angles and the angles at the trial midpoints (Fig 8A and B).

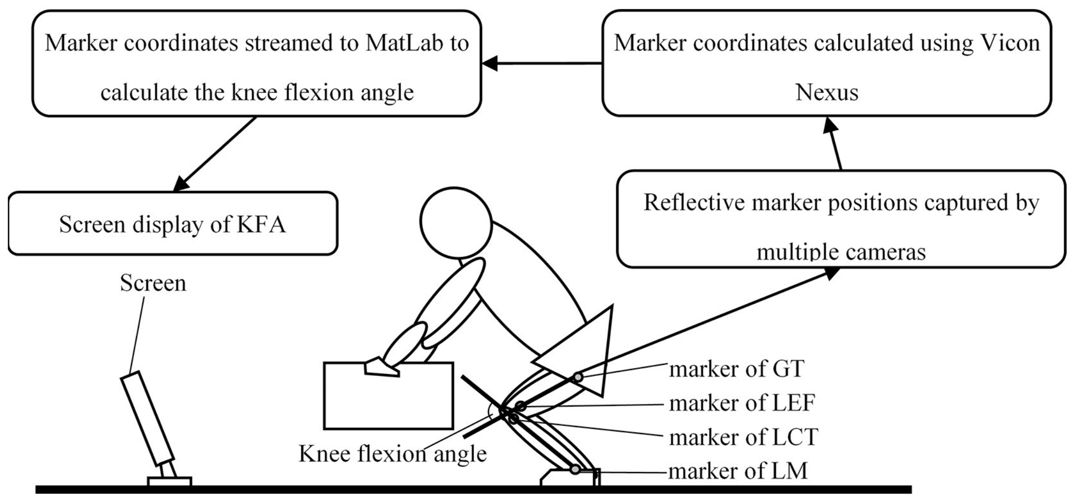

Fig 4. *The definition of KFA and the processing flow of real-time feedback.* GT, *greater trochanter;* KFA, *knee flexion angle;* LCM: *lateral condyle of the tibia;* LEF: *lateral epicondyle of the femur;* LM: *lateral malleolus.*

Fig 5. *The evaluation task measured in this study: (A) stand still and upright, (B) flex the trunk with knees extended as far as possible, and (C) after an oral cue, return to the original upright posture, quietly stand upright, and look straight ahead.*

Statistical Analysis

Pearson correlation coefficients were calculated to evaluate the relationships between the change in lumbar extension angles during the first half of each lifting condition and Max hip-FF or Max lumb-FF. Pearson correlation coefficients were also used to evaluate the relationships between the maximum lumbar and hip flexion angles during lifting and Max hip-FF. All statistical analyses were performed using SPSS Version 22.0 statistical software (IBM Corp, Armonk, New York). Statistical significance was accepted for a P value of <.05.

Results

Tables 2 and 3 show the mean and standard deviation of each variable. There was no significant correlation between Change lumb-Lift 0, 30, 60, and 90 and Max lumb-FF and Change lumb-Ext (Table 4). However, Change lumb-Lift 0, 30, and 60 were significantly negatively correlated with Max hip-FF ($P < .05$; Table 4). In addition, Change lumb-Lift 0 and 60 were significantly and negatively correlated with Change hip-Ext ($P < .05$; Table 4). Max hip-FF was significantly and negatively correlated with Max lumb-Lift 0, 30, 60, and 90 ($P < .05$; Table 5). It was also positively correlated with Max hip-Lift 0, 30, and 60.

Discussion

The purpose of this study was to investigate movement relationships between movement patterns of trunk

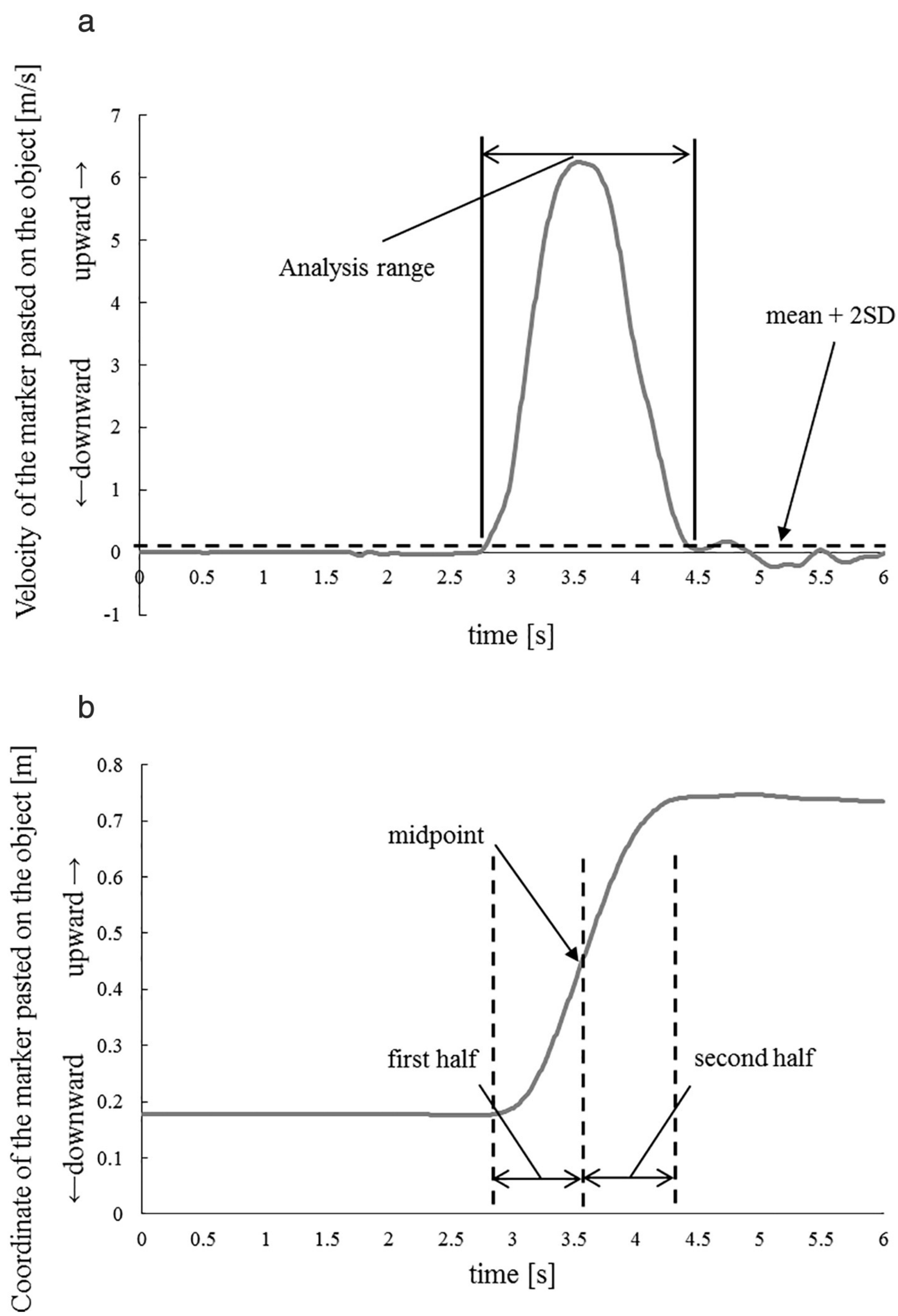

Fig 6. *(A) The start of lifting was detected as the velocity of marker pasted on the object became larger than mean +2 SDs during standing, and the end of lifting was the time when the velocity became smaller than mean +2 SDs. (B) Before half was defined as from start to middle of trial, and after half was defined as from the middle to end of trial.* SD, *standard deviation.*

extension from full unloaded flexion and lifting techniques, which could provide valuable information to physical therapists and chiropractors. This study identified significant correlations between hip movement during trunk extension from full unloaded flexion and lumbar movement during lifting under conditions of 0°, 30°, and 60° knee flexion, which was consistent with the initial hypothesis. However, contrary to this hypothesis, lumbar movement during trunk extension from full unloaded flexion was not correlated with lumbar movement during lifting under any lifting conditions. Hip movement during trunk extension from full unloaded flexion was also not significantly correlated with lumbar movement during lifting under the condition of 90° knee flexion.

These results suggest that Max hip-FF and Change hip-Ext can serve as useful indices for physical therapists

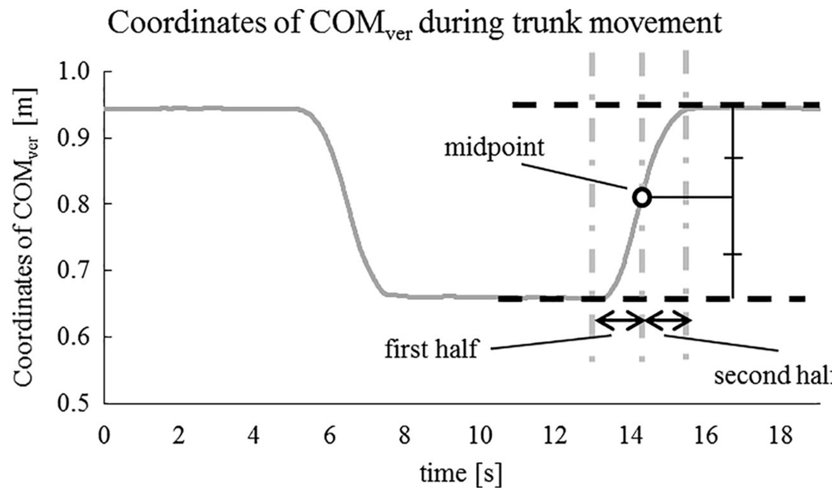

Fig 7. *The definition of the midpoint during trunk movement.* COM_{ver}, *vertical coordinate of the center of mass.*

and chiropractors to evaluate lumbar extension movement during lifting conditions involving knee flexion from 0° to 60°. In other words, when a participant performs a smaller hip movement during trunk extension from full unloaded flexion, the participant may undergo greater lumbar movement during those specified lifting conditions.

There are 2 possible explanations for these observations. First, participants who cannot use their hip extension movement well during the first half of trunk extension may not be able to adequately use their hip extensors. Therefore, the lumbar extensors may endure greater kinetic demands than the hip extensors during lifting, resulting in more lumbar motion during the first half of lifting. The function of the hip has large effects on lumbar movement during lifting because the hip extensors work in coordination with the lumbar extensors during lifting.[28] Second, hamstring muscle stiffness and a change in motor control during trunk extension can work to decrease the maximum hip flexion angle during trunk extension. Participants with these factors had to increase their initial lumbar flexion angle during lifting; therefore, larger lumbar extension movement might be required to return to an upright standing position.

Most activities of daily living (eg, lifting as measured in this study) do not require the full range of joint motion.[29-31] Hence, relative joint stiffness (ie, 1 joint might move with a relatively smaller or larger angle compared with another joint) has an important role in the coordination between these joints accomplishing the daily task.[29-31] Interestingly, not only under a 0° lifting condition, which is a posture similar to trunk extension but is also applicable to other lifting conditions, the maximum lumbar flexion angle during lifting increased and the maximum hip flexion angle during lifting decreased as Max hip-FF decreased. This finding suggests that participants with a small Max hip-FF may not only have tightened hamstrings but may also alter their lumbar–hip movement patterns to a pattern that allows greater lumbar movement relative to hip movement. This may explain why the lumbar movement during lifting conditions that did not include a 0° angle correlated with Max hip-FF. On the basis of this discussion, it is possible that the maximum hip flexion angle during trunk extension can serve as an index of the relative stiffness present between the lumbar region and the hip during lifting. Previous studies have reported that mechanical stress becomes concentrated in the joint that moves more often relative to other joints.[29,31,32] Therefore, altering a movement pattern involving frequent lumbar movement to another pattern that can protect the lumbar region may have clinical significance. Our assumption is consistent with previous reports that patients with LBP have shortened hamstrings and that they move their lumbar region more often than their hips.[15,31,33,34]

However, not all of the present results support our hypothesis. There was no significant correlation between lumbar movement during trunk extension from full unloaded flexion and lumbar movement under all lifting conditions. To decrease lumbar mechanical stress, trunk extension movement was started by hip extension, followed by initiation of lumbar movement.[35] In addition, Kang et al[36] reported that lumbar movement during stoop lifting decreased when lifting was performed after hamstring stretching. These previous studies and the results of this study suggest that hip extension movement is a primary and important movement during the first half of lifting, with greater lumbar extension movement during first half of lifting potentially occurring as compensation for less hip extension movement. Therefore, Max lumb-FF and Change lumb-FF were not significantly correlated with lumbar movement during the lifting trials evaluated in the present study. Moreover, there was no significant correlation between hip movement during trunk extension and lumbar movement under the 90° KFA lifting condition. This result might be explained by the change in mechanical loading of knee joint.

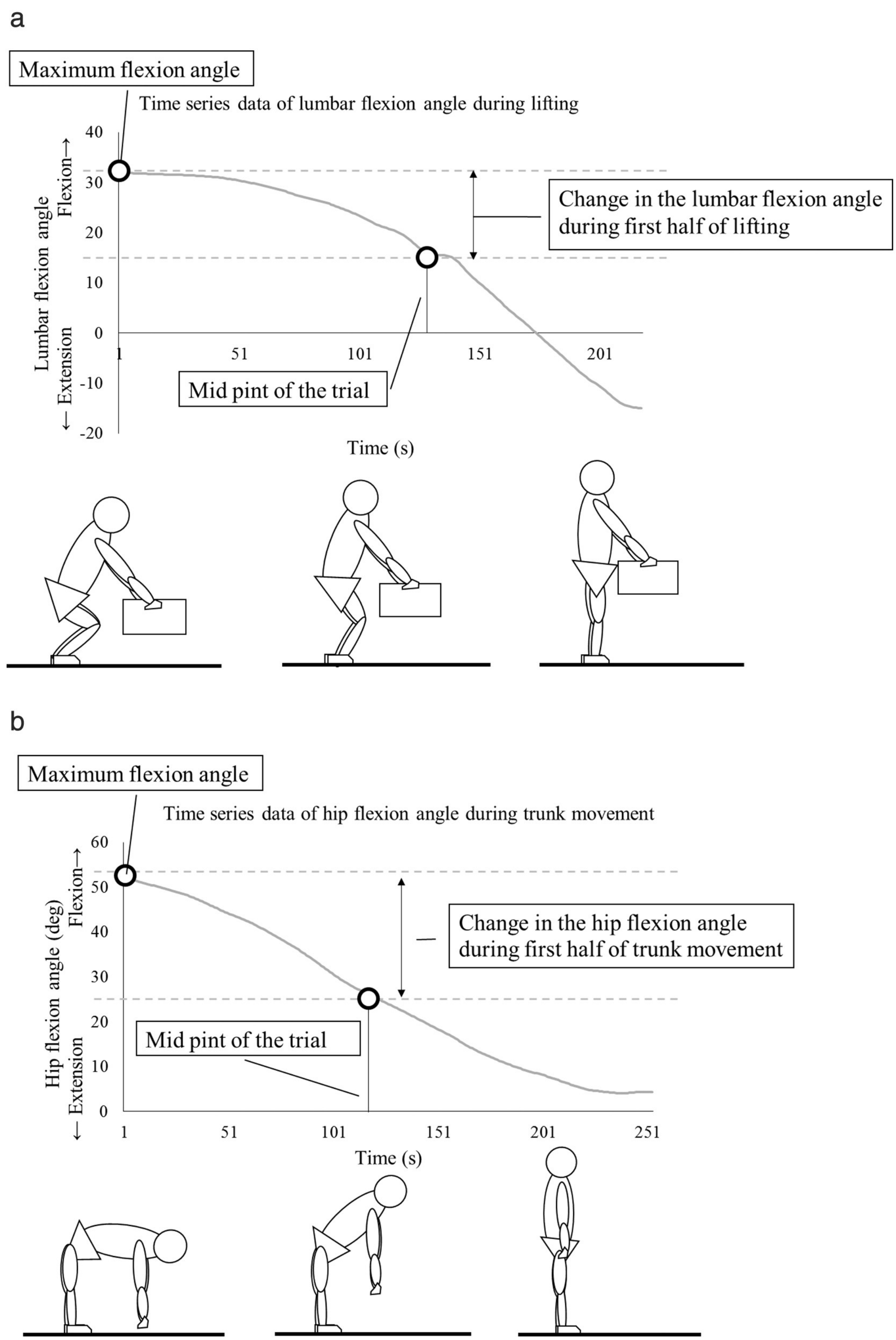

Fig 8. *Calculation of the amount of change in hip flexion angle during first half of lifting (A) and trunk movement (B).* deg, *degree.*

The change can cause higher activity of the rectus femoris muscle acting as a hip flexor and of reciprocal inhibition of the hamstrings muscle acting as a hip extensor; that is, there may be altered motor control of the biarticular muscles

Table 2. *Means and SDs of Maximum Joint Angles During Lifting or Trunk Extension From Full Unloaded Flexion*

Maximum Joint Angles (°)	Conditions				
	Unloaded Full Flexion	Lift 0	Lift 30	Lift 60	Lift 90
Lumbar joint angle	45.0 (9.0)	36.4 (10.8)	37.1 (12.8)	33.1 (12.6)	31.6 (12.5)
Hip joint angle	59.2 (10.1)	47.1 (8.3)	57.4 (9.0)	64.5 (9.8)	71.2 (9.1)

SD, standard deviation.

Table 3. *Means and SDs of Change in Joint Angles During Lifting or Trunk Extension From Full Unloaded Flexion*

Change in Joint Angles (°)	Conditions				
	Unloaded Extension	Lift 0	Lift 30	Lift 60	Lift 90
Lumbar joint angle	19.1 (10.4)	15.5 (2.4)	13.8 (2.1)	12.9 (2.5)	12.8 (3.3)
Hip joint angle	26.6 (7.0)	17.8 (3.2)	22.7 (2.7)	24.4 (3.0)	25.3 (4.7)

SD, standard deviation.

Table 4. *Correlations Between the Change in Lumbar Extension Angle During First Half of Lifting Trials and the Evaluation Indexes During Trunk Extension*

	Conditions			
Variables	0° KFA	30° KFA	60° KFA	90° KFA
Max lumb-FF	0.10 (.71)	0.43 (.09)	0.33 (.21)	0.11 (.69)
Change lumb-Ext	0.21 (.43)	−0.06 (.84)	0.28 (.30)	0.13 (.64)
Max hip-FF	−0.61 (.01) [a]	−0.56 (.03) [a]	−0.61 (.01) [a]	−0.31 (.24)
Change hip-Ext	−0.64 (.01) [a]	−0.47 (.07)	−0.50 (.04) [a]	−0.27 (.31)

Ext, extension; *FF,* full trunk flexion; *KFA,* knee flexion angle; *lumb,* lumbar; *Max,* maximum.
[a] Correlation coefficient (*P* value), a significant correlation.

Table 5. *Pearson Correlation Coefficients Between Maximum Hip Flexion Angle During Trunk Extension and Initial Joint Angles Under Each Lifting Condition*

Conditions	Max Hip-FF
Max lumb-Lift 0	−0.55 (.026) [a]
Max lumb-Lift 30	−0.53 (.036) [a]
Max lumb-Lift 60	−0.49 (.049) [a]
Max lumb-Lift 90	−0.53 (.034) [a]
Max hip-Lift 0	0.75 (.000) [a]
Max hip-Lift 30	0.58 (.019) [a]
Max hip-Lift 60	0.57 (.022) [a]
Max hip-Lift 90	0.42 (.101)

FF, full trunk flexion; *lumb,* lumbar.
[a] Correlation coefficient (*P* value), a significant correlation.

between the hip and knee joints. Therefore, additional motion evaluations should be performed to help physical therapists and chiropractors predict the consequences of lifting with >60° knee flexion.

Limitations

First, we did not assess other specific factors that can also affect human movement. Muscle stiffness, muscle strength, and central nervous system motor control all contribute to human movement.[37] The motion evaluated in this study can be affected by all of these factors. To improve clinical application, further study, including the evaluation of all of these factors, is required to identify what factors affect lifting movements. A second limitation is that all study participants were healthy men. Previous studies have reported sex differences in lifting motions[38] and that patients with LBP change their lifting movement patterns.[39,40] Further studies that target specific participant groups are needed to elucidate whether hip movement during trunk extension can serve as a clinical index that reflects lumbar–hip complex motor control. However, we determined that hip movement but not lumbar movement during trunk extension can reflect lumbar movement during first half of lifting. These findings provide useful insight for future studies investigating motor control in patients with LBP and the clinical treatment of LBP.

Conclusions

The findings that Max lumb-FF has a greater influence on kinematics of lumbar–hip complex during lifting provide new insight into human movement during lifting. These results suggest that Max lumb-FF should be considered when assessing the lumbar–pelvic–hip complex of patients with LBP. Further studies are necessary to clarify the motor control of patients with LBP and establish an evaluation index for LBP.

Practical Applications

- This study reported that a lumbar extension movement during the first half of lifting was correlated with hip movement during trunk extension but not lumbar movement during trunk extension.
- Trunk extension might be inadequate for predicting lumbar movement during lifting involving knee flexion angle of >60° because of the change in kinematic demands.
- It is possible that the maximum hip flexion angle during trunk extension can serve as an index that reflects motor control of the lumbar–hip complex during lifting.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): Y.O., M.T., K.S.

Design (planned the methods to generate the results): Y.O., M.A., T.T., K.T., T.S., K.S.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): Y.O., M.A., M.T., T.S., K.S.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): Y.O., T.T., K.T.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): Y.O., M.A., M.T., T.T., K.T., T.S., K.S.

Literature search (performed the literature search): Y.O.

Writing (responsible for writing a substantive part of the manuscript): Y.O.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): M.A., M.T., T.T., K.T., T.S., K.S.

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