Abstract. The aim of this study was to investigate the kinematical movements and electromyographic activities of the trunk and hip during trunk flexion and extension at different velocities. Thirteen male subjects performed trunk flexion and extension movements for 5 times at three different velocities of 1 s, 3 s, and 5 s in the standing position. Sagittal angular displacements of the lumbar spine, pelvis, and hip as well as the surface electromyogram of the trunk and hip muscles were recorded. The kinematic characteristic was normalized, and the electromyogram was integrated and normalized separately in cycles of flexion and extension. During flexion, the lumbar spine range was significantly larger during 5 s than during 3 s and 1 s, whereas the hip range was significantly larger during 1 s than during 5 s (p<0.01). During extension, the normalized electromyogram values of the iliocostalis and longissimus were significantly greater during 1 s than during 5 s (p<0.05). Increase in the movement velocity during extension produced greater activity in the trunk extensors, while the activities of the flexors showed minimal change. The results suggest that there is a kinematic and kinetic strategy among the lumbar, pelvis and hips in order to accomplish task-oriented movements.

Key words: Trunk flexion-extension, Lumbar-pelvic rhythm, Muscle activity

INTRODUCTION

Trunk forward bending is a common pattern of movement in daily life, and it is known to induce low back pain1–5). In clinical situations, the demonstration of trunk flexion-extension, as a test movement for patients with musculoskeletal problems, is often carried out in order to assess lumbar movement or to confirm the pain. Generally, the typical pattern of trunk flexion from upright standing is considered to be initiated by the movement of the lumbar spine; then the lumbar spine and the hips move simultaneously throughout the remainder of the flexion range. In contrast, extension of the trunk is initiated in an early phase of the lumbar extension from a forward bending position, followed by sequential extension of the hips6). If the lumbar movement is restricted, excessive compensatory hip movement is often clinically observed. An opposite phenomenon can be observed
when there is restricted hip flexion during the trunk flexion.

The anatomical regions involved in forward trunk bending and extension are the lumbar spine, pelvis, and thighs. Therefore, the movement patterns of the body parts involved may be different in cases where the movement velocities are different, even when the task movement is the same. There is considerable body of research which has analyzed the kinematics and kinetics of trunk flexion-extension movements; however, the movement velocity of the whole cycle varied from 4–10 seconds or was voluntary\(^1,4,6–11\). Observations of the trunk movement are made with little consideration of movement velocity. Although the rhythm and pattern of the torso and the hip movements during flexion-extension have been investigated, the kinematic characteristics related to their movement velocity are unknown. Therefore, the determination of the different movement patterns in the lumbar region, pelvis and hips during trunk flexion-extension with varied velocity provides useful clues to the management of patients as well as assessing their motor function.

The EMG activities of the trunk extensor muscles have been investigated and a phenomenon known as “flexion-relaxation” has been identified in healthy subjects\(^2,4,12–14\). During flexion, eccentric activities in the hip and spine extensor muscles become electrically silent when these muscles are in the fully flexed position\(^3,7,10,15,16\). This phenomenon is demonstrated in patients with low back pain; in these patients, activities in the trunk extensors continued until the end of forward flexion\(^4\). There are anatomical differences in the trunk extensors between the long muscles—the longissimus (LO) and iliocostalis (IC)—and the multifidus (MF) segmental muscle. The fasciculi of the MF are arranged in one or a few segments, and the force vectors of the muscle are almost along the vertical direction\(^17\). The kinematic difference of the spine and hip movements during flexion-extension of the trunk at different velocities may be attributable to specific features of the muscular activities.

Although the activities of the trunk extensors during trunk flexion have been extensively investigated, the activities of the trunk flexors have attracted little attention\(^9\). Trunk flexors play an important role not only in flexing and rotating the trunk but also in forcing expiration and in increasing the intra-abdominal pressure\(^18\). In kinetics, the summation of all muscular activities during flexion and extension should be the same even though the durations of the movements are different. However, the details of the total activities of each of the trunk and hip extensor muscles, with respect to the movement velocity during trunk flexion-extension, have not been reported. The purpose of this study was to investigate the sagittal kinematics of the lumbar spine, pelvis and hip, and the EMG activities of the trunk and hip extensor muscles at different velocities during flexion and extension.

**METHODS**

**Subjects**

Thirteen healthy male volunteers without any history of low back pain participated in this study. Their mean age, height and weight were 25.8 (SD, 5.3 years), 172.0 (SD, 6.8 cm) and 65.5 (SD, 6.3 kg), respectively. This study was approved by the Human Research Ethics Committee of Shinshu University, Matsumoto, Japan. Before the study was initiated, the subjects were asked to read the information sheet and sign their names on the consent form.

**Instruments and recordings**

Kinematical measurements of the trunk, pelvis and hip

In order to measure the sagittal movements of the trunk and hip, a three-dimensional motion analyzer (Vicon 370; Oxford Metric, London, England) was used. Infrared light-emitting, 25-mm round markers were attached with sticky tape to the skin on the spinal processes of C7, T10, L1, and L4, the sternum, the processus xiphoideus, the bilateral anterior superior iliac spine (ASIS), the posterior superior iliac spine (PSIS), the greater trochanter, the lateral epicondyle of the femur, and the external malleolus. The levels of the vertebral processes were determined by palpation. The angles of the thorax, lumbar, pelvis, and hip were measured. These angles are defined below and in Fig. 1.

**Thoracic angle (θT):** Angle between the vertical line and the line between the C7 and T10 markers

**Lumbar angle (θL):** Angle between the line perpendicular to the right
ASIS-PSIS line and the line between the L1 and L4 markers

Pelvic angle ($\theta_P$): Angle between the horizontal and right ASIS-PSIS lines

Hip angle ($\theta_H$): Angle between the line perpendicular to the right ASIS-PSIS line and the line between the right hip and knee markers

After the angles defined above were measured, the relative angles $\theta_{T_{rel}}P$ and $\theta_{T_{rel}}L$ were expressed as $\theta_T$ to $\theta_P$ and $\theta_T$ to $\theta_L$, respectively, and were calculated by the following formulas:

$$\theta_{T_{rel}}P = \theta_T - \theta_P$$
$$\theta_{T_{rel}}L = \theta_{T_{rel}}P - \theta_L = (\theta_T - \theta_P) - \theta_L$$

Since $\theta_{T_{rel}}L$ was considered as $\theta_T$; $\theta_{T_{rel}}L$, $\theta_L$, $\theta_P$, and $\theta_H$ were determined as angular variables.

Electromyographic measurement

The EMG activities of the trunk muscles and hip extensors were measured by disposable Ag-AgCl disc surface electrodes with a diameter of 10 mm (Vitorode M; Nippon Koden Corp, Tokyo, Japan). The right external oblique (EO), rectus abdominis (RA), internal oblique (IO), IC, LO, MF, gluteus maximus (GM), and biceps femoris (BF) muscles were investigated in this study. For the IC, a pair of electrodes with an inter-electrode distance of 3 cm was attached to the skin; these electrodes were aligned parallel to the line between the posterior superior iliac spine and the lateral border of the muscle at the 12th rib. The positions of the other electrodes attached to the skin were as follows: for MF, adjacent to the L5 spinal process; for LO, 3-cm lateral to the L3 spinal process; for GM, the midpoint of the line between the greater trochanter of the femur and the sacrum; for BF, the midpoint of the line between the tuber ischiadicum and the caput fibulac; for EO, the margin of the 8th rib; for RA, inferior and lateral to the umbilicus; and for IO, 2 cm inwards from the anterior superior iliac spine. The skin where the electrodes were attached was properly shaved with disposable razors and wiped with an ethanol swab. The EMG signals were processed by an amplifier (AM-511H; Nippon Koden Corp, Tokyo, Japan), filtered below 1.6 Hz (time constant of 0.01), and output through a multitelemeter system (WEB-5000; Nippon Koden Corp, Tokyo, Japan). The analog data of the EMG signals were sampled at 480 Hz, and then captured on the analog digital board of the motion analyzer in order to synchronize this data with the kinematical data. The captured signals were stored on the hard disk of a personal computer. Signals above 15 Hz were rectified by a full-wave rectifier and then filtered using a cut-off frequency of 5 Hz as a low-pass filter.

Since the EMG activity of each muscle at maximal voluntary contraction (MVC) was previously obtained based on 3 s isometric contraction by manual muscle testing, this value was adopted as the MVC for the standardization of muscular activities in this study.

Testing procedure and data analysis

The subjects were asked to stand barefoot with their legs at pelvis width on the floor, keeping their knees straight, arms by their sides, and necks in a neutral position. In the upright position, the subjects were asked to keep their eyes focused on a fixed target in order to avoid any artificial signals. At the start of the experiment, they bent their trunks forward as much as possible while keeping their necks and knees straight and their arms hanging
down freely. The subjects maintained this flexed position for 2 s, and then returned to the upright position. Trunk flexion and extension at the three different velocities were observed. The task wherein the velocity of each movement was 1 s, was defined as a FT; the task wherein the velocity of each movement was 3 s, was defined as MT; and the task wherein the velocity of each movement was 5 s, was defined as a ST. The subjects repeated each task 5 times with intervals of a few minutes between trials. The movement rhythm was paced by a digital metronome that was set at one beat per second. The order of the tasks was randomized. The subjects practiced the movements several times prior to the measurement in order to complete the movement within the assigned time frame.

It was necessary to normalize the movement cycles of trunk flexion and extension because the gross range of movement and the time required for a trial differed among trials and individuals. In order to normalize the gross range of flexion and extension to their full range, each movement was represented by 101 points (100%). In order to determine one cycle of flexion, the starting and finishing points of the flexion were decided by the angle data. The period between these two points was temporarily assumed to be that of a full cycle of the movement. It was necessary to change both the starting and finishing times of the movement in order to normalize the movement and EMG data. This was because in normal subjects, the muscle activity began before the movement started and ceased after the movement ended. In order to analyze the data, the starting and finishing times of the movement were changed as follows: 20% of a full cycle of extension was added to the original starting and finishing times (Fig. 2). The same process was adopted when analyzing extension. Flexions and extensions were analyzed separately.

The obtained low-pass filtered EMG data were processed to obtain an integrated EMG (IEMG), and each IEMG was individually expressed as a standardized EMG at MVC. Finally, the amplitude of the IEMG was normalized with its mean IEMG value as %IEMG by using the procedure described above. The angular displacement data and %IEMG were analyzed by using the Body Builder application of Vicon, integ-CALC, ModifWin-2000, and the DIFF standardization program developed by the Kanagawa Rehabilitation Center in Japan. Further, these data were tested by one-way analysis of variance (ANOVA) with repeated measures. The α level was set at 0.05.

RESULTS

Kinematics of forward flexion and extension in the sagittal plane

Since the total thoracic range of motion (θTrelL) during flexion and extension was less than 2 degrees in all the subjects, the summation of the total range was defined to include θL, θP, and θH and to exclude θTrelL. In data analysis, errors were observed because the data processing ability of the 3D analyzer decreased and the variability of angular displacement increased as the recording time increased. However, in all subjects, at least 3 trials of data in FT, MT, and ST were used for the analysis.

The mean durations of the analyses of flexion and extension that were used for the analyses were 1.6 (SD, 0.2 s) and 1.6 (SD, 0.2 s) for FT, 3.8 (SD, 0.3 s) and 3.6 (SD, 0.4 s) for MT, and 6.6 (SD, 0.4 s) and 6.1 (SD, 0.6 s) for ST, respectively. Although there was no significant difference among the total range of flexion during FT, MT and ST, the total range of extension was significantly larger during MT than during both FT and ST (p<0.01). In flexion, the lumbar range was significantly larger during the ST than during MT and FT (p<0.01), whereas the hip range was significantly larger during FT than during ST (p<0.01) (Table 1). Displacements obtained by the task motions at the three different velocities varied in the lumbar, pelvis and hip (Fig. 3). The angular displacement ratios of the lumbar spine and hip were almost the same during FT, whereas the angular displacement ratio of the lumbar spine was larger than that of the hip during MT and ST in flexion. The pelvic angular displacement corresponded with the hip movement from the beginning of the movement to a half that of the entire movement during extension. The reverse action of the lumbar spine was observed at the beginning of flexion in some subjects. It was greater than 0 degrees at the lumbar spine during FT but not during ST (Fig. 4).

%IEMG of each muscle during trunk movement (Table 2)

During trunk flexion, no significant difference in the %IEMG value was observed in all muscles. During trunk extension, the %IEMG values of IC
and LO were significantly larger during FT than during both MT and ST (p<0.05). However, there was no significant difference in the %IEMG value of MF at the three velocities during extension. Moreover, during extension, no significant difference was found between the %IEMG values of the trunk extensors during MT and ST. The %IEMG values of all the flexors during the faster tasks were generally greater than those during the slower tasks.

**DISCUSSION**

The forward bending of the trunk involves the thoracic spine, the lumbar spine, and hip flexions, and is caused by the anterior tilt of the pelvis on the
femurs. However, the relative contribution of the spine and pelvic movements has been controversial. It has been described that lumbar spine flexion occurs exclusively in the initial phase of trunk flexion, and is followed by a forward pelvic tilt in the later phase. It has also been reported that during extension toward the upright position, the sagittal movements of the spine and hip occur in the reverse order, with the pelvis tilting backward, followed by an extension of the lumbar spine. In previous research, the range of spinal flexion had been examined from the upright position to the forward bending position. An almost linear increase was found in both the pelvic and lumbar motions during progressive gross flexions of up to approximately 90 degrees at different velocities.
Table 2. Comparison of the %IEMG of each muscle during trunk flexion and extension at different velocities

<table>
<thead>
<tr>
<th>Movement</th>
<th>Task</th>
<th>BF Mean ± SD</th>
<th>EO Mean ± SD</th>
<th>GM Mean ± SD</th>
<th>IC Mean ± SD</th>
<th>IO Mean ± SD</th>
<th>LO Mean ± SD</th>
<th>MF Mean ± SD</th>
<th>RA Mean ± SD</th>
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<tbody>
<tr>
<td>Flexion</td>
<td>FT</td>
<td>5.0 ± 2.0</td>
<td>14.3 ± 13.7</td>
<td>6.1 ± 6.3</td>
<td>9.3 ± 2.9</td>
<td>26.0 ± 34.8</td>
<td>9.3 ± 4.0</td>
<td>13.4 ± 5.9</td>
<td>8.8 ± 9.0</td>
</tr>
<tr>
<td></td>
<td>MT</td>
<td>6.6 ± 2.9</td>
<td>8.4 ± 7.3</td>
<td>5.7 ± 6.3</td>
<td>7.9 ± 2.0</td>
<td>18.5 ± 26.8</td>
<td>9.3 ± 2.2</td>
<td>14.6 ± 6.0</td>
<td>4.7 ± 6.4</td>
</tr>
<tr>
<td></td>
<td>ST</td>
<td>7.8 ± 3.2</td>
<td>7.3 ± 6.2</td>
<td>5.1 ± 5.1</td>
<td>7.8 ± 1.6</td>
<td>17.1 ± 21.7</td>
<td>9.2 ± 2.6</td>
<td>13.0 ± 5.1</td>
<td>3.9 ± 4.9</td>
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<tr>
<td>ANOVAa</td>
<td>F value</td>
<td>0.826</td>
<td>0.901</td>
<td>1.045</td>
<td>0.589</td>
<td>0.142</td>
<td>0.045</td>
<td>0.131</td>
<td>0.648</td>
</tr>
<tr>
<td>Tukey</td>
<td>p value (FT vs MT)</td>
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<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
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<td>n</td>
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<tr>
<td>Extension</td>
<td>FT</td>
<td>20.7 ± 9.9</td>
<td>7.1 ± 5.2</td>
<td>16.9 ± 12.2</td>
<td>29.3 ± 5.7</td>
<td>18.1 ± 2.6</td>
<td>31.8 ± 6.8</td>
<td>39.3 ± 10.0</td>
<td>3.6 ± 2.5</td>
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<tr>
<td></td>
<td>MT</td>
<td>14.3 ± 7.4</td>
<td>6.2 ± 4.8</td>
<td>10.3 ± 7.7</td>
<td>21.2 ± 3.5</td>
<td>14.8 ± 11.5</td>
<td>24.0 ± 4.4</td>
<td>30.6 ± 7.8</td>
<td>2.9 ± 2.4</td>
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<tr>
<td></td>
<td>ST</td>
<td>13.4 ± 5.5</td>
<td>5.8 ± 4.7</td>
<td>8.7 ± 6.3</td>
<td>17.4 ± 4.0</td>
<td>14.1 ± 11.8</td>
<td>20.5 ± 4.6</td>
<td>26.4 ± 7.3</td>
<td>2.6 ± 1.9</td>
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<tr>
<td>ANOVAa</td>
<td>F value</td>
<td>1.022</td>
<td>0.102</td>
<td>0.726</td>
<td>0.009†</td>
<td>0.025*</td>
<td>4.111</td>
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<tr>
<td>Tukey</td>
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<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td></td>
<td>p value (MT vs ST)</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
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<td>n</td>
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</tr>
<tr>
<td></td>
<td>p value (FT vs ST)</td>
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<td>n</td>
<td>n</td>
<td>n</td>
<td>0.008†</td>
<td>n</td>
<td>0.022*</td>
<td>n</td>
</tr>
</tbody>
</table>

*: Analysis of variance was performed on the %IEMG values by Tukey’s HSD multiple comparison test. SD = standard deviation, FT: 1 s, MT: 3 s, ST: 5 s. *p<0.05, †p<0.01, df: 2 (inter-task), 36 (intra-task).

Nelson et al. examined the relative lumbar and pelvic sagittal motions under a load condition and found that the movement patterns of the lumbar spine and pelvis tended to be similar and appeared simultaneously during flexion; however, they tended to appear sequentially during extension. They also reported that there was considerable variation in the lumbar-pelvic rhythm between subjects.

With regard to the lumbar-to-hip flexion ratio, a phasic analysis of the ratio may be clinically useful because trunk flexion and extension are functional movements that may be used to visually assess the movement of the reference region. However, a method for the quantitative analysis of spine and hip movements is required to establish a more accurate and appropriate method of measurement. A previous study showed that there was no single movement sequence in the segmental lumbar spine during flexion in young healthy people. In this study, a partial analysis of trunk flexion and extension was performed on the thoracic spine, lumbar spine, pelvis and hip. Although almost the same angular displacement of the pelvis and the hip was observed from the beginning of the movement until when one-third the entire movement was completed, it differed when the hip started to move backward during extension. This hip movement may be required in order to maintain adequate equilibrium for balanced standing. The curves of the pelvic and hip displacements indicate that the timing of the hip sway is different between flexion and extension (Fig. 3). Values greater than 0 degrees were observed at the beginning of fast flexion, which appears to be the reverse of the pelvis posterior tilt and hip extension. Although there was no significant difference in the total range of motion among the three velocities of flexion, the hip moved to a greater extent during fast flexion and the lumbar moved to a greater extent during slow flexion. In order to perform task-oriented movements, a kinematic strategy may exist for the movements of the lumbar spine, pelvis and hip. Here, it was observed that an increase in the velocity of trunk flexion and extension tended to reduce the relative time of the entire lumbar extension. This result is in agreement with a previous study.

The automatic protective system present in the human lumbar spine may be employed in critical situations. Of the trunk flexors, IO had a larger %IEMG value than EO and RA; however the difference was not significant. The muscular activities of the trunk flexors did not change even during fast flexion. This result supports the experimental results of Takahashi et al.
muscle activity must be accurately analyzed because there is a possibility that the electrocardiogram signals are involved in the whole EMG of the trunk muscles. In this study, the higher frequency band of the EMG was not obtained since the sampling rate of the EMG signals was relatively low. The activities of the hip flexors and rectus femoris should be measured to confirm the contribution to the larger hip displacement in the fast task during flexion. Table 2 shows that during extension, the %IEMG values of the larger trunk extensors IC and LO were greater during fast movement than during slow movement. Biomechanical knowledge helps us to understand that strong extensor activity lifts up the trunk in large quantity in a short time. A full lumbar flexed position changes the line of action of the largest lumbar extensors, such as IC and LO, compromising their role in supporting the anterior shear forces on the spine\(^{30}\). These results suggest that when the movement of the trunk extension is faster, the trunk extensor activities and kinetic energy increase and consequently, higher mechanical stress may be loaded onto the lumbar spine. In the lower lateral part of the deeper posterior layer of the thoracolumbar fascia, LO, and IC are connected to IO and the transversus abdominis via the lateral raphe\(^{31}\). These trunk extensors and deep flexor muscles may function cooperatively to contribute to the stability of the spine and pelvis during trunk movement. Spinal stability is influenced by posture\(^{32}\).

The phenomenon of excessive flexion of the lumbar spine at the beginning of forward trunk bending was observed in several cases during this research. Troup described excessive lumbar flexion in the initial phase of trunk flexion as occurring when a load weighing 1.7 times as much as the body was applied to both feet\(^{33}\). Moreover, the same author reported that the phenomenon was observed in two thirds of the subjects when they performed lifting tasks using a 9.5-kg weight, suggesting that the load on the lumbar spine throughout the trunk flexion movement could influence the movement\(^{6}\). Regarding the difference in the muscular activities between hip extensors and trunk extensors, it was shown that during weight-lifting tasks, hip extensors act before the trunk extensor activity begins\(^{14,34}\). In the present study, the task movements were performed with no load other than the upper body on the lumbar spine and no consideration was taken of the initiation of activation timing in the referencing muscles. However, these are concerns that should be examined in the future. In forced excessive lumbar flexion in the fully flexed trunk position, even in cases with no load on the lumbar spine, there is the potential risk of damage to the lumbar spine. This finding may be useful in clinical situations. Further study is required to examine the effect of knee bending or a combined direction of trunk movements throughout the tasks.

The present study provides evidence for the importance of the avoidance of sudden movement from full trunk flexion to extension since this movement compromises human lumbar spine safety.

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