

Diurnal Variation in Trunk Kinematics During a Typical Work Shift

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Summary: Diurnal variation in trunk flexibility, defined as changes in range of motion, has been previously observed and quantified. Prior studies have shown that decreased disk height occurs as the day progresses and allows the spinal ligaments to slacken, resulting in an increase in the range of motion (flexibility) and a possible reduction in the risk of injury. This risk may be accentuated under dynamic motions of the spine. This study was conducted to observe the change in dynamic trunk mobility as a function of time of the day. Trunk motions of 21 men were observed at three specific times of the day using a triaxial electrogoniometer. No variation in trunk range of motion in any of the cardinal planes was observed. However, velocity and acceleration in the sagittal plane showed significant variations, suggesting the reexamination of the "slack ligaments" hypothesis. This study asserts that identifying flexibility by only its static component, range of motion, gives only partial information about the diurnal variation experienced by the spine. Industrial injuries occurring in the early morning hours may be a result of insufficient trunk mobility. This study indicates that risk associated with diurnal variation is far more complex than originally thought. **Key Words:** Diurnal variation—Trunk mobility—Flexibility—Low-back disorders.

Low-back pain has grown to epidemic proportions in the 20th century (15). Nationally, back injury is the single most expensive health-care problem in the 30- to 50-year age group (16), with an estimated total economic cost of about \$30 billion per year (13). The risk of low-back disorder (LBD) has been shown to be related to industrial work, especially work involving manual material handling (MMH) activities (3,17). Finding an effective means of reducing the risk of back injury can be beneficial to both the worker and management.

Krag et al. (8) demonstrated that a person's body height will change throughout the waking hours. This

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has been attributed to decreased fluid volume in the intervertebral disks as a result of continued compression, and hence a reduced disk height throughout the working day. Adams et al. (1) hypothesized that reduced intervertebral separation slackens the spinal ligaments, allowing greater trunk range of motion. They observed that subjects' flexibility in the late afternoon showed an increase of $5.0 \pm 1.9^\circ$ in the range of motion of sagittal spinal flexion as compared with the early morning measurement. Both studies have quantified flexibility only in terms of its static component, namely range of motion. No one has attempted to quantify the dynamic components of flexibility. There is reason to believe that this may affect spine loading.

Under dynamic activity, the spine is expected to experience higher loading levels than those experi-

TABLE 1. Subject anthropometric information

Variable		
Age (yr)	25.03	3.80
Height (cm)	179.70	10.74
Weight (kg)	77.80	33.10

Values are means \pm SD.

enced under static condition. This is mainly due to the accelerating mass of the trunk and the increase in muscle coactivity (4,10). The viscoelastic ligamentous spine also may act to increase spinal loading under increased velocity conditions (5,6). Marras and Wongsam (12) found that velocity of motion was the only parameter capable of accurately distinguishing between patients with low-back pain and healthy individuals. They proposed that trunk velocity be used as a quantitative measure of rehabilitative progress in LBDs. In a recent clinical study, Marras et al. (11) showed how the assessment of motion capacity can be used as an effective means of diagnosis of various LBDs. In addition, recent research has shown velocity of motion to be a major contributing risk factor to occupationally related LBDs (9).

Hence, there is enough evidence to believe that quantifying changes in the dynamic components of trunk flexibility throughout the work day may be equally important, or possibly more important, than mere trunk flexibility, which up to this point has been quantified only in terms of range of motion. In this study, the term mobility shall refer to the range, maximum velocity, and maximum acceleration components of trunk motion. Thereby, mobility incorporates and expands upon flexibility to include the dynamic components associated with it. Risk and severity of injury would be expected to change throughout the day due to variation of the three dynamic parameters involved in trunk mobility. This is anticipated especially when job demands exceed the worker's ability in a given period of the day, resulting in an increase in injury risk. This study was conducted to answer the question of whether variations exist in an individual's mobility over the course of a typical work shift.

METHOD

Subjects

Twenty-one male college students volunteered to participate in the study. Selected subject anthropometric information is presented in Table 1. Subjects were

moderately active and were screened with regard to any history of back disorders.

Apparatus

The motion data were acquired using the lumbar motion monitor (LMM) developed at the Ohio State University Biodynamics Laboratory (Fig. 1). The LMM is attached via a harness system to the thorax and the pelvis with a premolded semirigid plastic material (Orthoplast). The LMM functions as an exoskeleton that mimics the motion of the spine. There are four voltage potentiometers placed at the base of the LMM that capture voltage differences corresponding to motion of the subject's back (side to side, forward/backward, or twisting). Voltage outputs from the LMM are transmitted to an A/D converter and then to a 386-based microcomputer. Voltage readings are converted into angular position in the cardinal planes using a regression (calibration) model. The angular velocity and acceleration were obtained through numerical differentiation.

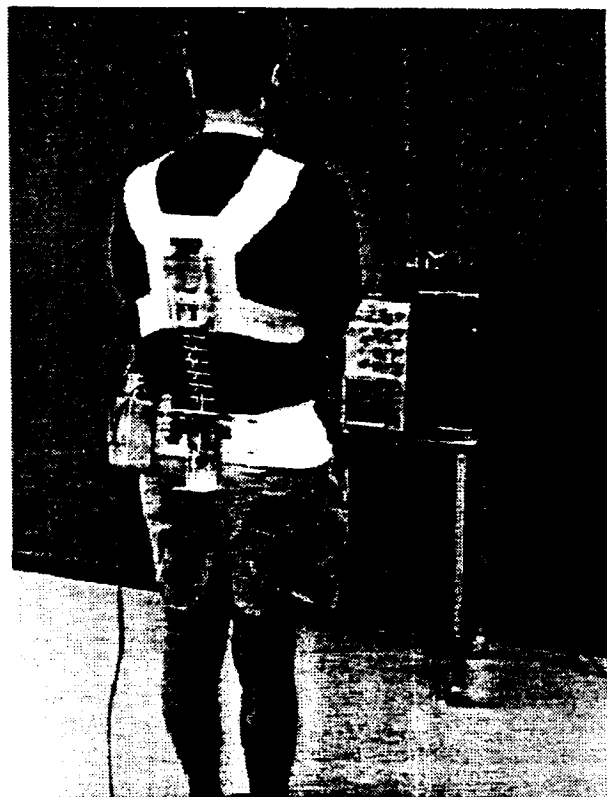


FIG. 1. The LMM worn by a subject.

Design

The experiment was a one-factor (time of the day) within-subject design. Time of the day had three levels: morning, 1 h after rising; afternoon, 5 h after rising; and evening, 9 h after rising. Time of the day was counterbalanced among three groups of subjects; hence, the starting session of the experiment varied between subjects. This was necessary to minimize bias and learning effects inherent in sequential treatment (7).

For each of the cardinal planes (sagittal, frontal, and transverse), the dependent variables were (a) percentage of maximum range of motion (PROM) for the range of motion conditions and (b) percentage of maximum velocity (PVEL) and percentage of maximum acceleration (PAC) for the maximum dynamic conditions.

Experimental Procedure

Each subject participated in an instructional practice session 1 day before the actual testing session. Written instructions were provided to the subjects that described the tasks and the expected progression of their participation. In each session (morning, afternoon, evening), subjects performed a total of six tasks. Each task consisted of moving through the maximum range of motion or moving at a maximum velocity and acceleration in one of the cardinal planes. For tasks involving range of motion, the subject was instructed to move slowly in one of the three planes until his maximum range of motion was realized. The subject then paused for 1 s and reversed the motion. For tasks involving maximum velocity and acceleration, the subject was instructed to move as quickly as possible through the range of motion, without pausing. The order of tasks over different planes was randomized to avoid ordering effects, and each task was repeated to control for outlying data.

Also, to minimize practice/learning effect between sessions, the subjects were randomly assigned to three groups (seven subjects in each group) that received three different sequences of session order (time of the day was counterbalanced). For example, subjects in the second group started with the afternoon session, followed by the evening session, and completed their experiment the following morning.

Data Conditioning

Raw data values for each subject were calculated as the percentage of the maximum observed value in

each plane for range of motion, velocity, and acceleration of all three sessions. This step was necessary to eliminate possible between-subjects effects of body size, strength, or agility on the described tasks. It should be noted that for each subject and variable, the maximum could occur at any session. This is expected because, as indicated earlier, the order of presentation of the sessions was counterbalanced among the three groups of subjects. For example, subjects who were assigned to start the experiment with the morning session would be expected to have (in addition to the treatment effect) a possible high level of practice effect at the evening session and possibly more observed maximum values (100%). However, the other two groups should counterbalance the possible practice effect of the first group, leading to the unconfounded isolation of the main treatment effect (time of the day). Hence, it is anticipated that the data would exhibit a high level of variability within each session.

Values of the two repetitions for all variables were generally in agreement (range of $\sim \pm 5\%$ difference). Hence, for each variable the percentage values for the two repetitions were averaged together.

Statistical Analysis

For the range of motion condition, analysis of variance (ANOVA) was performed on each PROM variable of each plane. This was an appropriate analysis because range of motion measurements in each plane were taken independent of the other two planes. For the dynamic conditions, because for each plane velocity and acceleration were simultaneously measured, multivariate ANOVA (MANOVA) was performed on the PVEL and PAC variables of each plane. Whenever an analysis showed a statistical significance, post hoc analysis was performed (Newman-Kuels) to determine its source.

RESULTS

As described above, two types of tasks were performed in each session, hence the results are presented in two parts: (a) range of motion (static) part and (b) velocity and acceleration (dynamic) part.

Figure 2 depicts the average PROM for each of the three sessions within a given cardinal plane. ANOVA was performed for each plane (frontal, sagittal, and transverse), coupled with the corresponding PROM.

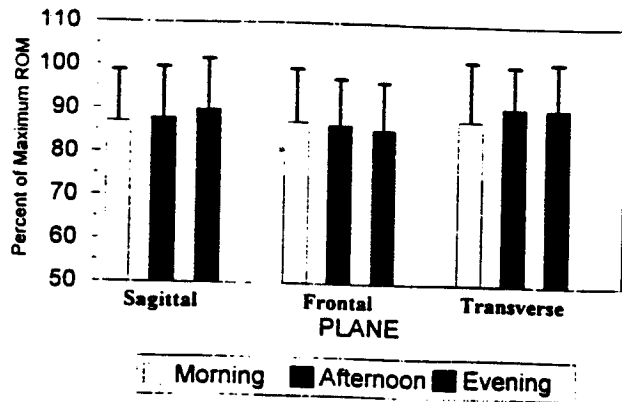


FIG. 2. Average PROM as a function of time of the day for each cardinal plane.

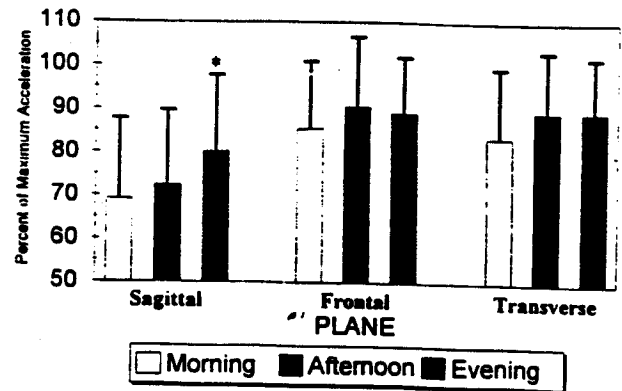


FIG. 4. Average PAC as a function of time of the day for each cardinal plane.

The analysis showed no significant difference in PROM among sessions for any of the cardinal planes ($p \geq 0.35$).

Figures 3 and 4 show the average PVEL and PAC, respectively, as a function of time of the day within each plane. MANOVA and subsequent ANOVAs were performed on the dynamic variables (PVEL and PAC) obtained during maximum motion conditions in each of the cardinal planes. Statistical significance was only observed for the sagittal plane at both the multi- and univariate levels.

Post hoc analyses were performed (Newman-Kuels) on these two conditions to compare the three time of day levels (sessions). For the sagittal PVEL, the morning session was significantly different only from the evening session ($p < 0.05$). Sagittal PAC gave similar results; the morning session showed significant difference when compared with the evening session ($p < 0.1$).

DISCUSSION

The purpose of this study was to quantify the changes in mobility of the trunk that occurred over a simulated typical 8-h work shift. Understanding the variation of mobility as a function of time may help the process of explaining and quantifying the risk and severity of low-back injury.

In their study, Adams et al. (1) measured early morning flexibility within 10 min of rising. Krag et al. (8) showed that the change in body height occurs rapidly upon rising in the morning, indicating an exponential time response. Adams et al. (2) demonstrated in vitro that a lumbar motion segment undergoes a dramatic decrease in resistance to flexion (stiffness) in the first hour of loading. These two findings coupled together offer a possible explanation of the results of Adams et al. (1), where range of motion increased in the late afternoon. Because their morning measurement was taken shortly after rising, spinal stiffness is expected to be at its highest level, and consequently range of motion at its lowest. Few people can be expected to start their work shift within 10 min of rising. The dramatic increase in flexibility reported by Adams et al. are probably not applicable to the changes experienced by most employees throughout the work shift. In our study, measurements were taken 1 h after rising to represent a more realistic situation. This might give an explanation of why PROM did not change as the day progressed. However, this also might indicate that the reduced effects of mobility would be larger when observing mobility changes first thing in the morning.

The insignificant change in mobility in the transverse and the frontal planes might have a biomechanical basis. Motion in the frontal and transverse planes

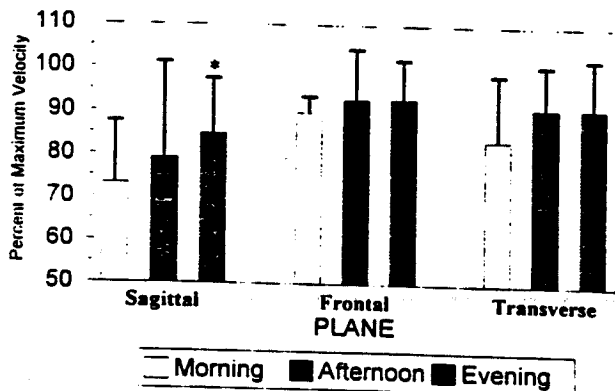


FIG. 3. Average PVEL as a function of time of the day for each cardinal plane.

is partially generated by the internal and external obliques and by the latissimus dorsi muscles. The vector directions of the lines of action of muscle forces do not lay in any one of the three principal planes of the body. Consequently, the forces generated by these muscles result in a velocity (and acceleration) proportional to the cosine of the anatomical angle between the muscles and the plane of interest. Because the obliques and the latissimus dorsi muscles are the prime movers in the frontal and transverse planes, variation in mobility in these planes is caused by larger variation in the mobility of the muscles. Thus, one would not expect to observe a large variation in mobility in these planes over the course of the work day. In contrast, major contributors to motion in the sagittal plane are the erector spinae and the rectus abdominus muscles. The lines of action of these muscles lay parallel to the sagittal plane. Hence, the variation in the mobility of these muscles is directly reflected in the variation in the motion in this plane. In addition, major motion limiters in the frontal and transverse planes are muscles (obliques and latissimus dorsi), whereas in the sagittal plane the longitudinal ligaments play a dominant role in limiting the motion, especially at extreme positions. This might be a factor in making the motion components in the transverse and frontal planes relatively constant as the day progresses.

Ligaments are passive components and therefore serve to limit motion rather than initiate it. Consequently, the condition of "slack ligaments" should show up in the range of motion rather than in the velocity and acceleration. This study showed that only the dynamic components of mobility in the sagittal plane were significantly influenced by time of the day. Hence, it would be logical to assume that the influence of changing disk height due to recumbency is only a small part of mobility. The viscoelastic property of spinal ligaments and other passive tissues causes variation in the dynamic components of motion and is expected to affect the responses and loading of these tissues (5,6,14). At this time, it is unknown how the change in these components would affect spinal loading patterns (e.g., compression, lateral shear), which warrants further research. In addition, spinal stability might be affected by variation in mobility. The relationship between mobility and spinal stability should be addressed in further investigations. Because this is a relatively new area of interest, there is a wide array of relationships that remain to be investigated, such as examining mobility immediately after prolonged periods of sitting, standing, and lying.

The Americans with Disability Act (ADA) of 1991 dictates that a preemployment test must accurately reflect the skills and other performance indicators being measured. This study showed that some dynamic trunk motion variables change in magnitude depending on the time of day. This might raise the question with regard to biomechanical performance or functional evaluation measures (e.g., agility tests, strength test, etc.). Time of the day might be a confounding factor in determining accurate levels of these measurements. Normative databases that account for diurnal variation in performance measures may be a way of approaching such a possible problem.

Limitations

In this study, the testing times were chosen to approximate a typical working day where a person is expected to start work ~1 h after rising and end the work shift 8 hours thereafter. Hence, the results of this study should be viewed within this context. If, for instance, the first session was started at a different time (e.g., shortly after rising), the results might show different patterns. In addition, because the measurements were collected at three discrete intervals, the exact progression of mobility with time cannot be obtained. Therefore, the analysis focused on comparing mobility among three points in time. In addition, it should be noted that the group who participated in this study was drawn from a college population. It is possible that the results may change if the sample was drawn from an actual population of full-time industrial workers. Lastly, this study did not consider gender and age effects, which warrant further investigation.

CONCLUSIONS

No significant changes in trunk range of motion occurred in any of the three planes of the body under these conditions. However, significant increases in trunk mobility, as evidenced by increased PVELs and PACs, were found only in the sagittal plane. Trunk mobility in the sagittal plane significantly increased 9 h after rising as opposed to 1 h after rising.

Because no significant changes in trunk flexibility were seen during the course of the three test periods, industrial injuries that occur during the early morning may stem from causes other than trunk flexibility. The results of this study indicate that significant increases in the dynamic components of trunk mobility in the sagittal plane occur several hours after rising.

Consequently, this suggests that industrial injuries occurring during the early morning hours may result from insufficient trunk mobility. Certainly, the relationship between trunk mobility and incidence of industrial injury warrants further research. The study also raises the issue of diurnal variation in biomechanical performance measures and its possible consequences to the ADA. Lastly, it is evident that the relationship between the spinal structure and its biomechanical risk factors are more complex than originally thought, warranting further research.

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