Effect of Leg Length Discrepancy on Trunk Muscle Fatigue and Unintended Trunk Movement

ANDI ELIZABETH MINCER1), GORDON S. CUMMINGS2), PAUL D. ANDREW3), JOSEPH L. RAU4)

1) Assistant Professor, Department of Physical Therapy, School of Health Professions, Armstrong Atlantic State University
2) Associate Professor, Department of Physical Therapy, College of Health Sciences, Georgia State University
3) Professor, Division of Physical Therapy, Institute of Health Sciences, Hiroshima University School of Medicine, 1–2–3 Kasumi, Minami-ku, Hiroshima 734, Japan. TEL +81 82-257-5415
4) Professor, Department of Cardiopulmonary Care Sciences, College of Health Sciences, Georgia State University

Abstract. Asymmetry, including scoliosis compensatory to leg length difference, is commonly thought to degrade one’s performance and to predispose one to injury. We examined differences between persons with and without leg length discrepancy in ability to control motion during fatiguing trunk flexions and extensions. Loss of control was measured by the amount of unintended rotation and lateral flexion during the flexions and extensions. Fifteen subjects with leg length discrepancy and fifteen without flexed and extended their trunks with maximum effort and speed for as long as possible against resistance equal to 70 per cent of maximum isometric flexion. The excursion of flexion and extension did not include the last 15 degrees of the fully available range of motion in either direction. The two groups did not differ in variance of excursion into rotation and lateral flexion or in the number of repetitions completed to fatigue. We interpret this to mean that no difference was detected between subjects with and without leg length discrepancy in degree of neuromuscular control of the trunk during this particular testing procedure.

Key words: Leg length discrepancy, Trunk motion, Fatigue.

(INTRODUCTION) Asymmetry, including scoliosis compensatory to leg length difference, is commonly thought to degrade one’s performance and to predispose one to injury. We examined differences between persons with and without leg length discrepancy in ability to control motion during fatiguing trunk flexions and extensions. Loss of control was measured by the amount of unintended rotation and lateral flexion during the flexions and extensions. Fifteen subjects with leg length discrepancy and fifteen without flexed and extended their trunks with maximum effort and speed for as long as possible against resistance equal to 70 per cent of maximum isometric flexion. The excursion of flexion and extension did not include the last 15 degrees of the fully available range of motion in either direction. The two groups did not differ in variance of excursion into rotation and lateral flexion or in the number of repetitions completed to fatigue. We interpret this to mean that no difference was detected between subjects with and without leg length discrepancy in degree of neuromuscular control of the trunk during this particular testing procedure.

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(INTRODUCTION) When back pain arises in conjunction with leg length discrepancy, the inequality in leg length presumably gives rise to imbalance in forces, stresses, and movements in the lumbar spine, especially at the lumbosacral joint. A survey of leg length discrepancy among 1000 men in army training suggests that having a difference of 5 mm or more is associated with increased incidence of low back pain. Seventy-five percent of these soldiers with 5 mm or greater leg length discrepancy had low back pain. Friberg found that among persons with discrepancies of 5 mm or greater, those who re-
ported sciatica were symptomatic on the side of the longer limb 79 per cent of the time, while those with less than 5 mm difference showed no side of preference\(^2\). Studies of leg length discrepancy and low back pain do not provide an uncontested threshold difference for increasing the incidence of low back pain, but data support use of a 5 mm difference as the criterion\(^2-6\).

Low back pain often develops when work activities involve repeatedly bending forward in combination with rotation or lateral flexion. Although such combined movements may be intentional, as in lifting an object from the floor in a diagonal pattern, the movements often occur unintentionally, as observed by several investigators\(^7-9\).

Parnianpour et al. noted that, during attempts to repeatedly flex and extend the trunk against resistance, concomitant but unintended lateral flexion and rotation tended to increase as fatigue set in\(^7\). They attributed such extraneous movement to loss of neuromuscular control. In the lumbar spine, such loss of control due to fatigue might increase predisposition to injury, since adding lateral flexion and rotation of the movement of forward flexion reportedly puts the lumbar spine at greater risk than would forward flexion alone\(^10-13\).

The reported increase in unintended lateral flexion and rotation of the trunk as fatigue sets in suggests a method to quantitatively measure a possible effect of leg length discrepancy. If leg length discrepancy stresses the lumbar spine by virtue of the asymmetrical situation that it produces, fatigue may then set in relatively easily. This should be detectable by looking for relatively early or marked increases, in persons with leg length discrepancy, of lateral flexion and rotation during repeated flexion and extension of the trunk against resistance.

The purpose of this study was to investigate whether unintended lateral flexion and rotation during repetitions of resisted flexion and extension of the trunk increase sooner or to a greater degree in subjects with leg length discrepancy than in persons with equal leg lengths, and to see if subjects with unequal leg lengths reach complete fatigue at fewer repetitions of resisted flexion and extension than those with equal leg lengths. If either of these results occurs, then fatigue might be suspected as an important influence to explain why leg length discrepancy is a predisposing factor towards low back pain, as suggested by numerous correlational studies\(^1, 2, 5, 6, 10\).

**METHODS**

**Subjects**

Fifty-four subjects in the Atlanta area agreed to participate in the study. Subjects were screened by questionnaire to exclude those with history of back pain in the previous six months, or with conditions prohibiting vigorous exercise or exposure to radiography. Subjects were further screened to eliminate persons having limited or painful movement in the legs or lower trunk. Each subject received a brief orientation to the procedures of the study and signed an approved consent form. The 54 volunteers were measured roentgenographically to determine leg length discrepancy. In order to have two groups with distinct difference in leg length discrepancy the subjects were classified as having equal leg length if the difference was 2 mm or less, or as unequal if the difference was 7 mm or greater. Fifty-four subjects were accepted for X-ray measures, 10 men and 44 women. Subjects with differences of 3–6 mm were excluded from the study. This resulted in 20 subjects in the equal group and 18 in the unequal group (Fig. 1). Fifteen subjects with differences in leg length of 7 mm or greater agreed to continue in the study and are hereinafter referred to as having leg length discrepancy. Another 15 subjects, with differences of 2 mm or less in leg length, likewise agreed to participate in the study and are referred to hereinafter as having equal leg lengths.

![Fig. 1](image-url) Distribution of leg length discrepancy among 54 volunteers for the study. EQUAL indicates 20 subjects with discrepancies of 2 mm or less. UNEQUAL indicates 18 subjects with discrepancies of 7 mm or greater.
Instrumentation

To measure leg length discrepancy, an antero-posterior roentgenogram was taken of the pelvis with the subject standing, using Friberg’s method\(^{14}\). First, the difference in leg length was measured to the nearest millimeter on the roentgenographic image, and then the actual degree of leg length discrepancy was calculated according to a formula reported by Bushong to account for optical factors\(^{15}\).

All testing was performed on an Isostation B200 (Isotechnologies, Inc., Elizabeth Brady Rd., Hillsborough, NC 27278, USA), a device that simultaneously records torque, angular velocity, and range of motion in the coronal, sagittal, and transverse planes against resistance set independently and held constant for each plane of lumbar movement. The measures of torque and angular velocity in the sagittal plane have been shown to be highly reproducible\(^{16–18}\), with Spearman correlation coefficients of \(r=0.98\) and 1.0 for extension and flexion, respectively. Self-calibration was performed automatically by the B200 prior to each test session. Data were collected every 0.02 sec. The dynamometer was designed by the manufacturer to stop automatically after either 50 repetitions or two minutes. The axis of the dynamometer permitting flexion and extension was centered at the L5-S1 interspace in the standing subject. The subjects wore unrestrictive clothing with the feet bare or in stockings.

Procedures

Each subject performed movements on the dynamometer on two occasions. At the beginning of the first session, the subject flexed and extended at a comfortable speed through full range of motion against one newton-meter (Nm) of resistance for each component of motion. After three repetitions, the subject rested for one minute. These repetitions both helped familiarize the subject with the device and provided data on maximal trunk excursion.

The subject then performed a standard test following the manufacturer’s protocol for one five-second maximal isometric flexion followed by one five-second maximal isometric extension. The test was repeated once, each time with the subject upright in neutral position. In these isometric tests, the subject slowly reached maximal effort over two to three sec and then held the maximum for another two sec.

After another minute of rest in this first session, a dynamic practice run was performed to help the subject become better able to achieve a stable performance during the second session. The subject performed 15 repetitions of flexion and extension and was verbally exhorted to exert maximal effort. An audible signal to cue the subject to change direction was emitted from the dynamometer when the subject was at vertical and when at 85 per cent of the subject’s active range of motion for flexion. The dynamometer was set to resist flexion and extension at 70 per cent of the subject’s maximum isometric flexion. Resistance to rotation and to lateral flexion of the trunk were each set to 7 Nm.

The second session followed the first by two or three days. In this session, the subject began with five minutes of warming up on a stationary bicycle. The subject was then placed in the testing device. We were interested in determining whether leg length discrepancy causes deviation in the relaxed standing position as well as during flexion and extension of the trunk. Prior to dynamic testing the subject was instructed to stand in the dynamometer with the trunk upright and facing forward, and this position was recorded to register the degrees of rotation and lateral flexion that the subject perceived to be midline orientation. The subject was then placed in this midline orientation of lateral flexion and rotation and asked to perform the same flexion and extension task as at the end of the first session. He or she was asked to exert maximum effort and to continue until unable to perform full range with maximal effort, or until undue discomfort was perceived by the subject or investigator. In addition, the investigator instructed the subject to stop if the subject consistently failed to complete the excursion in either direction, as indicated by absence of the cueing tone from the dynamometer. Each subject was exhorted throughout the test to produce maximal effort.

Data analysis

The fatigue point chosen to indicate the end of the test was the point at which peak flexion angular velocity fell to and remained below 85 percent of maximal peak angular velocity. Because we could not be assured that all subjects were sufficiently familiar with the device to produce maximal effort in the first few repetitions, we decided to analyze the data separately with each of two starting points.
The number of repetitions was counted from the repetition in which maximal flexion angular velocity was noted, and also from the third repetition in the test. Differences between the two groups were compared using unpaired Student’s t tests.

To obtain an indication of variability of rotation and of lateral flexion without having to be concerned about the location of midposition of these motions for each subject, the variance was calculated for each subject over all data points collected (every 0.02 sec) throughout the fatigue test, for both rotation and lateral flexion. The variances of the subjects were pooled for each group, thus essentially leading to average group variances for the subjects with leg length discrepancy as well as for the subjects without. The magnitudes of these variances of lateral flexion and of rotation were compared between groups by means of an F statistic as described by Daniel\(^{19}\), with 14 degrees of freedom for the subjects with leg length discrepancy and 12 degrees of freedom for the subjects without leg length discrepancy.

A significance level of 0.05 was used for all comparisons between groups.

**RESULTS**

Data collection was prematurely stopped by the dynamometer’s limit of 50 repetitions or two minutes during tests of four subjects with leg length discrepancy and three without. Two of the subjects with leg length discrepancy had not fatigued to 85 per cent of maximum flexion angular velocity after 50 repetitions, so their data could not be fully analyzed.

The two groups exhibited no significant difference (\(p>0.05\)) in number of repetitions completed either from the third repetition or from the repetition with maximal angular velocity (Fig. 2).

Variances of trunk rotation and lateral flexion throughout the fatigue test did not significantly differ (\(p>0.05\)) between groups (Fig. 3). During the fatiguing flexion and extension test, the patterns of unintended lateral flexion and rotation varied considerably from subject to subject. Thirteen subjects demonstrated marked unintended motions primarily at or near the end of the test, whereas five others demonstrated more at the beginning. The remaining subjects showed either very little such movement at all or a great deal of it throughout the entire test. Both groups of subjects were represented equitably in each of these categories.

**DISCUSSION**

In this study, we expected the asymmetry imposed by leg length discrepancy to give rise to a mechanically unfavorable situation in the lumbar spine. This, we supposed, would result in earlier or greater fatigue in subjects with leg length discrepancy than in subjects without. It certainly did not happen under the circumstances of our study.

Among the volunteers for this study, the distribution of degree of leg length discrepancy (Fig. 1)
agreed well with previous surveys of large samples\textsuperscript{2, 4). The present sample of subjects thus appears to represent the general population with regard to leg length discrepancy. Important differences between our study and that of Parnianpour et al.\textsuperscript{7) require exploration. The findings of Parnianpour et al. suggested that unintended rotation and lateral flexion would increase appreciably with fatigue, but this happened for only 13 (43 per cent) of our subjects. That we did not find consistent increases in extraneous movements with fatigue may be a function of experimental conditions and methods.

Did a faulty experimental design prevent detection of an earlier fatigue by subjects with leg length discrepancy that really should have happened, or do persons with and without leg length discrepancy actually have equal footing?

**Possibility 1: True differences went undetected**

Mechanical disadvantages of asymmetry due to leg length discrepancy might not come into play until the end of joint excursion, where the structures involved have little leeway in how they fit together. In this study the subjects were tested at less than the full limit of excursion in both flexion and extension of the trunk. The fact that our subjects performed sagittal movement of the trunk that fell 15 degrees short of full flexion and approximately 15 degrees short of full extension may have weakened our ability to detect potential differences between the groups.

Unlike our study, the test by Parnianpour et al. did require the full excursion of trunk flexion\textsuperscript{7). The limit for trunk extension, on the other hand, was the same in both studies. Had our subjects not been cued by the audible tone to begin full extension until reaching full available flexion, more movements into rotation and lateral flexion might have appeared.

Another consideration is that many of our subjects were generally not as fatigued as had originally been anticipated. Had the resistance to sagittal trunk motion been set to a value higher than 70 per cent of maximal isometric effort, the results might have been different.

Our subjects may have had unusually high anaerobic capacities. Seven subjects reached the automatic limit imposed by the apparatus before reaching fatigue as defined by Parnianpour et al.\textsuperscript{7), that is, a 30 per cent reduction in flexion angular velocity. Five of these seven subjects were fatigued by only 15 per cent when the dynamometer automatically stopped. We thus adopted, \textit{post hoc}, the 15 per cent decline in angular velocity as our definition of fatigue and as the end point for data analysis. Persons with high endurance may require higher resistance to achieve ostensible fatigue.

**Possibility 2: The groups were not really different**

Despite these considerations, leg length discrepancy may in fact not really have influenced trunk flexion or extension at all. Both groups of subjects, for example, tended to rotate the trunk toward the midline in conjunction with large, abrupt movement into lateral flexion. This is consistent with coupled movements normally seen in the upper lumbar spine\textsuperscript{20). Since this coupling was seen in subjects both with and without leg length discrepancy, the compensatory scoliosis of those with leg length discrepancy appears to have not tangibly altered this normal mode of coupling.

**Where is the midline?**

By using the variance, calculated over all data points collected, of the actual positions of lateral flexion and of rotation to indicate the quantity of unintended motion, we chose to ignore the mean value of rotation or of lateral flexion for that purpose. We did not consider zero degrees of the apparatus to necessarily reflect the functional midposition of the subject during flexion and extension of the trunk.

When asked to assume midline, seven of our nine subjects with shorter right legs oriented themselves to the dynamometer’s neutral position in the transverse plane, whereas all six of those with shorter left legs oriented themselves left of the neutral position. No such dependence was found between the side of the shorter leg and the position of orientation in the frontal plane.

**Suggestions for further study**

In this study, subjects with leg length discrepancy performed fatiguing trunk flexion and extension at levels of endurance and control comparable to subjects with equal leg lengths. Future investigation might be directed at differences between the two groups near the end points of range in spinal motion, at higher fatigue levels, in older subjects, or in different patterns of movement.
CONCLUSION

Subjects with and without leg length discrepancy exhibited no difference either in fatigue, as reflected by the number of repetitions required to achieve fifteen per cent fatigue, or in neuromuscular control exhibited during trunk flexion and extension, as reflected by unintended rotation or lateral flexion by the trunk. This study suggests that young healthy subjects can compensate for the effect of leg length discrepancy on trunk flexion and extension that does not include the last 15 degrees of flexion.

REFERENCES