International Journal of Industrial Ergonomics, 6 (1990) 211–224
Elsevier

THREE DIMENSIONAL DYNAMIC MOTOR PERFORMANCE OF THE NORMAL TRUNK

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(Received February 14, 1990; accepted in revised form May 17, 1990)

ABSTRACT

Traditionally, human strength has been described in terms of the maximum force one could exert under isometric conditions. However, in the past decade ergonomists have attempted to find strength measures that better represent the dynamic aspects of occupational tasks. Recent efforts have focussed upon dynamic motor performance capabilities of the human body that go beyond the traditional measures of isometric strength. The objective of this study was to document the three dimensional dynamic motor performance capabilities of the normal human trunk as subjects flexed and extended their trunks as fast as they could under 'sagittally symmetric and asymmetric "back lifting" conditions. The results indicated that the range of motion, trunk angular velocity and trunk angular acceleration decreased in the sagittal plane as the trunk became more asymmetric. Dynamic motor performance characteristics increased in the frontal and transverse planes as the trunk became more asymmetric, however, these differences were also dependent upon the device used to measure trunk motor performance.

RELEVANCE TO INDUSTRY

This information could be used for the construction of dynamic biomechanical models, ergonomic design of work stations, pre-employment selection, quantification of low back disorders, and as a measure of rehabilitation progress in low back disorders.

KEYWORDS

Back strength, three dimensional trunk movement, biomechanical modeling, strength testing, low back disorders.

INTRODUCTION

The assessment of human strength can take many forms. Traditionally, human strength has been determined through assessment of force or torque production of the body under isometric conditions. As strength measurement instrumentation has become more sophisticated, many have tried to assess human strength characteristics under dynamic conditions in an attempt to relate strength more closely to occupational requirements. However, as these strength measurement techniques become more realistic, the traditional measures of strength (such as maximum force production capability) have changed dramatically.

Recently, Kroemer and associates (1990) have defined dynamic human strength in terms of dynamic motor performance. In this study, it was concluded that dynamic motor performance can be described in terms of many dependent variables other than force or torque. For example, displacement, velocity, acceleration, jerk, mass, or repetition could all serve to characterize dynamic human motor performance. These characteristics may very well be the limiting factors in the ability of a worker to perform a task under dynamic conditions.

Trunk strength measures

This paper concerns itself with biomechanical measures of three dimensional trunk strength. It does not address psychophysical approaches to strength assessment.

Traditionally, human strength has been defined in terms of isometric exertions. Human strength was observed as a function of the maximum force or torque one could exert with the body in a set position. For example, Garg and Badger (1986) investigated trunk strength as subjects were asked to lift weights at three asymmetric lifting angles (30, 60, and 90 deg) of the human body. Here, asymmetry was defined as the positions of the feet relative to the shoulders. They found that the maximum isometric strength decreased by 12, 21, and 31% for asymmetric lift angles of 30, 60, and 90 deg, respectively.

Many ergonomist have recognized that most industrial tasks involve the exertion of muscle force to generate body motion during the performance of an occupational task. Thus, in order to approach more realistic occupational test conditions, researchers have been exploring means to assess and document trunk strength under dynamic work conditions. It was hoped that dynamic measures of strength would more accurately simulate forces acting on the body and strength capability of the worker during occupational task performance.

Originally, dynamic strength assessments of the lumbar spine considered the ability of the trunk to exert force or torque upon a dynamometer as the trunk was moving under predetermined isokinetic velocity conditions. Marras et al. (1984) first characterized the torque production capabilities of the human torso as subjects extended their trunks during back lifting motions. The trunk velocities varied from isometric to the maximum isokinetic trunk velocity attainable in sagittally symmetric positions. They found that as trunk velocity increased, the amount of torque exerted decreased substantially until only minimal torque could be exerted under maximal dynamic conditions. Studies by Mayer et al. (1985) compared the isokinetic trunk extension strength of normal subjects to those who had suffered low back disorders. They found that quantitative measures of back strength taken under dynamic conditions could serve as a means of observing restoration of back function for those suffering from low back pain. Latter studies by Marras and colleagues (1986) tried to quantify the decrease in trunk torque performance as the trunk velocity increased over a range of static to 90 deg/s. They found that trunk torque production decreased by about 0.55 percent of maximum for every deg/s increase in trunk angular extension velocity. Marras and Mirka (1989) tested trunk isokinetic strength under three dimensional concentric and eccentric conditions. They found that as the trunk became more asymmetric trunk torque production decreased by 8 to 9 percent of maximum for every 15 deg of trunk asymmetry (defined about the lumbro-sacral junction). They also found that eccentric torque exceeded concentric torque production only when the trunk was flexed in forward bending postures.

Studies by Deutsch (1989) attempted to define dynamic trunk strength in three dimensional space using a triaxial dynamometer to monitor trunk torque and velocity as the resistance in each plane of the body was set by the dynamometer. This study showed that one could use velocity and torque production as a means to quantify disability of the spine. However, these results must be viewed in relative terms since the dynamometer used in this study imposed significant moments of inertia on the trunk.

Marras and Wongsam (1986) used a small, lightweight lumbar monitor to measure range of motion and angular velocity characteristics of the lumbar spine in both normal subjects as well as those suffering from low back disorder. The advantage of this technique of trunk motion measurement is that motion characteristics of the trunk were not controlled by the monitor but served as a dependent measure of dynamic motor performance. The dynamic motor performance characteristics were tested only in sagittally symmetric positions. They found that maximum extension velocities of normal subject averaged about 80 deg/s whereas the average velocities of the injured group were 25 deg/s. This study also showed that trunk velocity characteristics were far better indicators of lumbar spine impairment than were range of motion characteristics.

Parnianpour et al. (1988) used a triaxial dynamometer to investigate three dimensional motion patterns of the spine during fatiguing sagittally symmetric flexion and extension exertions of the trunk. In this study the subjects were strapped to a Isotechnologies B-200 isodynamic dynamometer. They noted that as the trunk fatigued, the dynamic motor performance characteristics in the sagittal plane decreased in magnitude. Subjects also displayed less motor control and greater range of motion in the frontal and transverse planes of the body. They concluded that the reduction in motor performance capability was due primarily to a reduction in functional capacity of the primary muscles performing the task. They also concluded that secondary muscle groups must compensate for this capacity reduction of the primary muscle group to perform the required task.

The goal of this study is to document the manner in which dynamic motor performance characteristics change during sagittally symmetric and asymmetric trunk flexion and extension exertions. These trunk motions are commonly used in occupational tasks such as manual materials handling. Trade-offs are expected in dynamic motor performance of the trunk as one flexes and extends the trunk in various asymmetric positions. Parnianpour et al. (1988) found that the reduction in dynamic motor performance capability was due to secondary muscle groups controlling the flexion and extension task during a fatiguing sagittally symmetric exertion. It follows that if these secondary muscle groups are poor controllers of dynamic motor performance, one would also expect a reduction in dynamic motor performance if these secondary muscle groups became the predominant muscle group during an exertion, as would be the case in a non-fatiguing exertions as the trunk became more asymmetric. It is also expected that documentation of these trade-offs would facilitate ergonomic and biomechanic assessments of work and low back disorders. It is important to document these trade-offs since Parnianpour et al. (1988) concluded that "a reduction in (trunk) accuracy, control and speed of contraction would predispose an individual to injury". Therefore, the objective of this study was to define the dynamic three dimensional trunk motion characteristics as a function of trunk asymmetry and create a data base that describes these characteristics for the normal lumbar spine.

METHOD

Approach

The central focus of this study was to determine changes in trunk motion characteristics as a function of asymmetry. During symmetric lifting tasks, dynamic motion characteristics are controlled with the large, well developed erector spinae muscles. However, during asymmetric exertions, dynamic motor performance characteristics may be under the control of the latissimus dorsi, external obliques or internal obliques. A shift in control from these large well trained muscles to the thin secondary back muscles would probably affect accuracy of trunk motion as well as the motion range. Controlling an asymmetric task may be more difficult, because a high degree of muscle coactivation is required and people typically do not train the muscle control system in these postures.Thus, an experiment has been developed to investigate the manner in which three dimensional trunk motion characteristics change as the trunk flexes and extends repeatedly in symmetric and asymmetric postures. In this experiment, subjects were asked to flex and extend their trunks at a maximum velocity while their three dimensional back motion characteristics were monitored. Two back monitors were used to measure three dimensional trunk motion characteristics. One of these devices (the lumbar motion monitor or LMM) has been developed in the Biodynamics laboratory at the Ohio State University. The other device is a commercially available device used by both

Parnianpour et al. (1988) and Deutsch (1989) to measure trunk three dimensional motion. During the experiment, subjects viewed a display that indicated the amount of trunk twist (asymmetry) and target asymmetric posture windows in the transverse plane. Subjects were asked to cognitively control trunk asymmetry, or twist, while flexing and extending the trunk. In this manner, we were able to monitor three dimensional trunk motion characteristics without physically restricting trunk motion in asymmetric positions.

Subject

Eighty five subjects have been evaluated with the LMM and sixty two of the eighty five were tested with the B200. The subjects ranged in age from 20 to 53 year. There were 32 women and 58 men tested with the LMM and 22 women and 40 men tested in the B200. Anthropometric measurements were collected from all the subjects. Descriptive statistics in terms of mean and (standard deviation) are as follows: standing height, 173.4 cm (9.8), trunk length, 53.6 cm (5.1), trunk breadth, 27.8 cm (4.0), trunk depth, 19.7 cm (3.10), trunk circumference, 78.6 cm (11.4).

Experimental design

The independent variable in this study consisted of trunk asymmetry. Asymmetry was operationally defined as the amount of trunk twist in the transverse plane of the body. Asymmetry was set at five levels consisting of sagittally symmetric or zero deg twist (zero), 15 deg twist to the right (15 right), 15 deg twist to left (15 left), 30 deg twist to right (30 right), and 30 deg twist to left (30 left). These asymmetric positions are shown in Fig. 1. The initial condition for each subject was the zero condition, followed by the two 15 deg conditions, followed by the two 30 deg conditions. The order of right and left exertions were counter-balanced. Two devices were used to measure trunk motion characteristics. At least two days of rest were permitted between testing sessions.

Thirteen trunk motion characteristics (dependent measures) were quantified. These consisted of (1) the range of motion (difference between maximum to minimum position) in the sagittal plane, (2) range of motion in the frontal plane, (3) range of motion in the transverse plane, (4) peak flexion velocity in the sagittal plane, (5) peak extension velocity in the sagittal plane, (6) peak flexion acceleration in the sagittal plane, (7) peak extension acceleration in the sagittal plane, (8) peak lateral flexion velocity in the frontal plane, (9) peak lateral extension velocity in the frontal plane, (10) peak lateral acceleration (flexion or extension) in the frontal plane, (11) average of peak rotation velocities in the transverse plane, (12) average of peak return from original rotation (return rotation) velocities in the transverse plane, and (13) peak acceleration in the transverse plane.

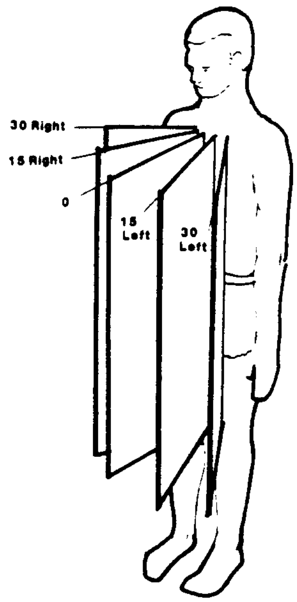

Fig. 1. Experimental task positions.

Trunk motion measurements

Two different devices were used to measure trunk motion characteristics. The first was the lumbar motion monitor (LMM) developed at the Biodynamics Laboratory (patent pending) and is shown in Fig. 2. The LMM is essentially an exoskeleton of the spine than moves in conjunction with the back. Sensors are attached to the exoskeleton that change voltage as the individual moves. These sensor voltages change as position changes. The position signals are filtered and differentiated with respect to time to determine

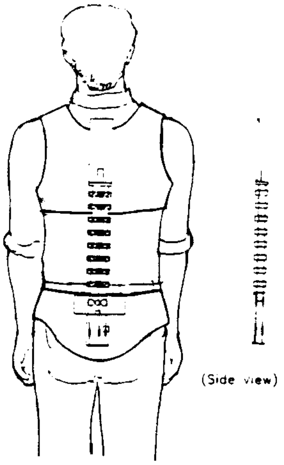

Fig. 2. Lumbar motion monitor (LMM).

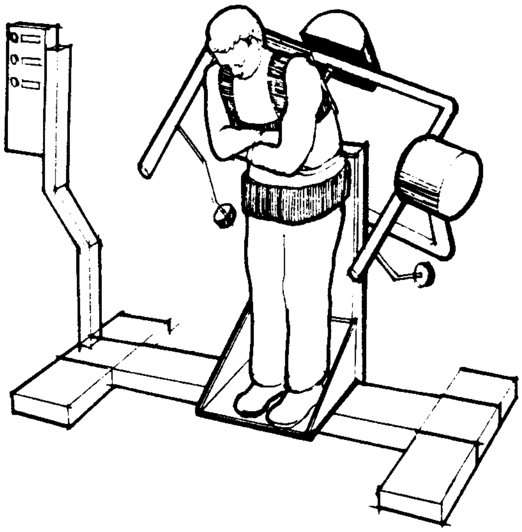

Fig. 3. B200 triaxial dynamometer.

velocity and acceleration. The LMM is aligned with the lumbro-sacral (L5/S1) junction and measures motion relative to that spine position. The LMM is strapped to the pelvis and the thorax and measures the motion between these locations. The subject is able to move freely without restriction with the LMM. There are four sizes of LMMs to ensure proper fit. All four LMMs have been calibrated and are accurate to within plus or minus 0.25 of a degree.

The second device is the Isotechnologies B200 dynamometer (Fig. 3). This is a triaxial dynamometer that physically restricts the person at the hips. All allowable motion is above the pelvic level. As with the LMM the center of rotation is aligned with L5/S1. Resistance can be independently set in each plane of the body with this device. As suggested by the manufacturer, the resistance in the sagittal plane was set at 89 N while no resistance was set in the other planes of the body.

Apparatus

The transverse plane position signal from each back monitor was sampled with a comparator circuit. The comparator circuit was used as a feedback mechanism to the subject so they could control the transverse plane motion and, thus,

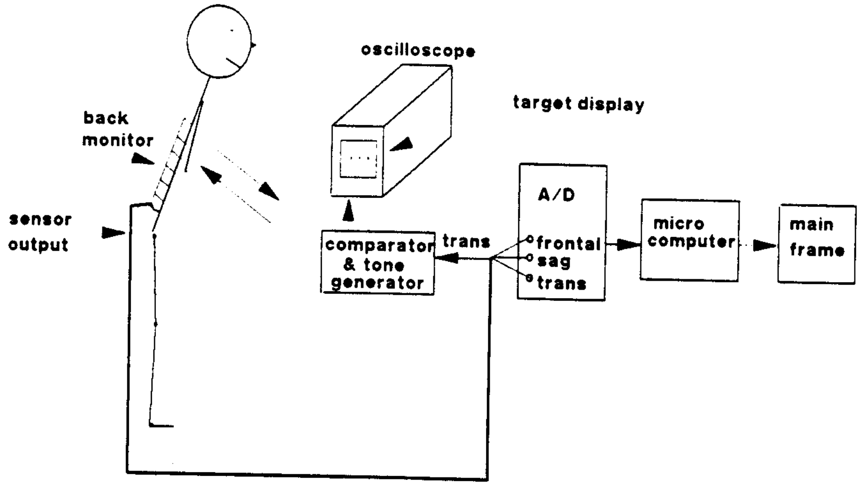

Fig. 4. Schematic representation of experimental apparatus.

control the asymmetric experimental conditions. The circuit was designed to permit a plus or minus two degree of motion window around the incoming transverse plane signal. The comparator circuit produced an auditory tone if the subject's transverse plane position fell outside the window for the specified angle. The transverse plane signal was also connected (via the comparator circuit) to an oscilloscope. The oscilloscope presented a visual display (dot) of a subject's instantaneous transverse plane position. Two additional dots were displayed, one on each side of the subject's position dot, that represent the acceptable tolerance zone or limits of the exertion. The sagittal, frontal and transverse plane signals emanating from each back monitor were also sent to an analog-to-digital (A/D) converter. This converter digitized the signals so that they could be monitored by a portable micro-computer. Figure 4 shows a schematic representation of the apparatus.

Procedure

At the first testing session subject anthropometry was collected. Next, the subject was fitted with the proper size LMM or strapped into the B200. The subject was then permitted to become familiar with the visual display representing the transverse plane trunk position. The subject was instructed to twist so their dot moved from side to side on the oscilloscope screen. The asymmetric target zone for the five experimental conditions were then calibrated for all the experimental conditions. Subjects were given six instructions. These consisted of: (1) cross their arms in front of their chest, (2) stand with their feet shoulder width apart, and keep them in the same location for all conditions, (3) flex and extend their trunks repeatedly in the sagittal plane as fast as they can comfortably while keeping the transverse plane position dot between the target zone dots, (4) watch the dots at all times during testing, (5) if their transverse plane position fell outside the target zone a tone would sound and the trial would be repeated, and (6) move continuously until instructed to "relax". Eight seconds were permitted for each experimental run. Subjects were able to produce at least five flexion–extension cycles within this time period.

Data analysis

Custom software developed in the Biodynamics Laboratory converted the electrical signal from each back monitor into trunk position, velocity and acceleration. The software program graphically displays trunk positions in each plane of the body separately and permits one to analyze each motion component independently throughout the exertion. The first entire motion (flexion and extension) during each trial was considered a warm-up motion and was discarded for analysis purposes. The following four flexions were analyzed and averaged. Then the four matching extensions were analyzed and averaged. This process was completed for each plane of the body. The analysis program determined the average range, average peak velocity, and average peak acceleration for each plane.

The thirteen dependent measures were transferred to a data base for statistical analysis. Analysis of variance (ANOVA) techniques were used to test for statistically significant differences among the back motion characteristics. A post hoc Ryan-Einot-Gabrial-Welsch F (REGWF) test was also executed for each dependent measure to further investigate the nature of the significant differences.

TABLE 1

Summary of statistical significance for trunk motion characteristics

Dependent measure	LMM	B200
Sagittal plane		
Range	0.0001	0.0001
Flexion velocity	0.0001	0.0001
Extension velocity	0.0001	0.0001
Flexion acceleration	0.0001	0.0001
Extension acceleration	0.0001	0.0001
Frontal plane		
Range	0.0001	0.0627
Flexion velocity	0.0001	0.5723
Extension velocity	0.0004	0.1483
Acceleration	0.2052	0.4257
Transverse plane		
Range	0.0123	0.0038
Mean velocity	0.0001	0.0105
Flexion velocity	0.0006	0.0100
Extension velocity	0.0406	0.0104
Acceleration	0.0015	0.4197

TABLE 2

Descriptive statistics summary of dynamic motion characteristics as measured by the lumbar motion monitor and B200 triaxial dynamometer

	Lumbar motion monitor			B200		
	Mean	Standard deviation	Range	Mean	Standard deviation	Range
Condition: zero degrees						
Sagittal plane						
Range (deg)	37.2	14.6	65.7	42.9	11.0	57.1
Flexion velocity deg/s)	98.8	52.2	266.2	70.3	22.7	97.0
Extension velocity (deg/s)	102.4	51.5	279.3	66.4	20.5	88.1
Flexion acceleration (deg/s^2)	466.2	272.4	1323.5	218.8	103.6	439.1
Extension acceleration (deg/s^2)	477.1	283.4	1529.9	222.5	96.5	405.9
Frontal plane						
Range (deg)	3.1	2.3	16.2	1.8	1.1	6.2
Lateral flexion velocity (deg/s)	11.6	8.4	55.6	3.9	2.1	13.2
Lateral extension velocity (deg/s)	12.1	9.6	65.5	3.9	2.1	12.7
Lateral acceleration (deg/s^2)	89.8	83.5	521.6	19.4	9.4	49.8
Transverse plane						
Range (deg)	1.9	0.7	2.8	0.4	0.2	0.8
Rotation velocity (deg/s)	7.7	2.9	16.6	1.1	0.4	1.7
Return Rotation Velocity (deg/s)	7.7	4.2	25.7	1.1	0.4	1.6
Rotation acceleration (deg/s)	57.1	26.7	166.0	8.2	3.8	20.2
Condition: 15 right degrees						
Sagittal plane						
Range (deg)	28.9	12.4	51.3	29.4	9.8	42.6
Flexion velocity (deg/s)	69.1	41.0	237.2	42.1	17.8	90.5
Extension velocity (deg/s)	70.2	39.4	174.1	40.8	77.7	426.0
Flexion acceleration (deg/s^2)	301.9	210.5	1430.1	123.2	73.7	336.9
Extension acceleration (deg/s^2)	305.6	196.3	948.5	127.5	73.7	336.9
Frontal plane						
Range (deg)	6.6	4.7	21.5	2.1	1.2	4.9
Lateral flexion velocity (deg/s)	17.4	11.6	46.7	3.7	1.8	9.9
Lateral extension velocity (deg/s)	16.5	10.4	42.4	3.8	1.8	9.9
Lateral acceleration (deg/s^2)	89.7	55.1	259.7	18.7	8.1	40.0
Transverse plane						
Range (deg)	2.1	0.8	3.5	0.5	0.3	1.2
Rotation velocity (deg/s)	8.1	3.5	17.9	1.3	0.6	2.4
Return rotation velocity (deg/s)	7.5	3.2	17.4	1.4	0.6	2.4
Rotation acceleration (deg/s^2)	53.4	27.6	148.0	8.6	4.1	25.3
Condition: 15 left degrees						
Sagittal	28.4	12.74	54.5	29.1	9.7	39.1
Flexion velocity (deg/s)	70.7	42.0	221.1	42.2	19.9	91.1
Extension velocity (deg/s)	72.1	43.6	217.8	40.9	16.7	73.3
Flexion acceleration (deg/s^2)	321.6	221.0	1078.6	132.2	94.9	399.7
Extension acceleration (de/s^2)	319.3	220.6	1003.9	128.9	88.9	394.6
Frontal plane						
Range (deg)	5.2	4.1	27.5	2.3	1.4	7.3
Lateral flexion velocity (deg/s)	16.3	12.1	66.9	3.9	2.1	10.4
Lateral extension velocity (deg/s)	16.9	12.3	60.5	4.1	2.2	10.8
Lateral acceleration (deg/s^2)	90.1	64.2	316.0	17.6	8.1	39.3
Transverse plane						
Range (deg)	1.9	0.6	2.6	0.5	0.2	1.4
Rotation velocity (deg/s)	7.9	3.5	23.7	1.4	0.6	3.1
Return rotation velocity (deg/s)	7.4	2.6	12.8	1.4	0.6	3.1
Rotation acceleration (deg/s^2)	55.4	23.8	119.9	8.6	3.2	13.1

TABLE 2 (continued)

	Lumbar motion monitor			B200		
	Mean	Standard deviation	Range	Mean	Standard deviation	Range
Condition: 30 right degrees						
Sagittal plane						
Range (deg)	21.1	10.0	46.2	21.5	8.8	39.1
Flexion velocity (deg/s)	53.7	30.4	149.2	27.3	13.5	54.9
Extension velocity (deg/s)	52.6	29.1	143.0	27.0	12.6	51.1
Flexion acceleration (deg/s^2)	251.9	159.9	625.0	76.4	49.7	212.1
Extension acceleration (deg/s^2)	244.8	156.4	728.4	75.9	50.6	219.3
Frontal plane						
Range (deg)						
Range (deg)	7.2	5.4	23.5	1.8	1.5	7.2
Lateral flexion velocity (deg/s)	19.5	12.2	60.2	3.9	1.8	7.5
Lateral extension velocity (deg/s)	18.8	12.4	53.5	3.9	1.9	8.2
Lateral acceleration (deg/s^2)	106.6	71.3	317.4	19.4	8.0	34.1
Transverse plane						
Range (deg)	1.8	0.8	3.6	0.4	0.2	1.1
Rotation velocity (deg/s)	6.9	3.3	17.2	1.1	0.6	3.1
Return rotation velocity (deg/s)	6.6	3.4	16.6	1.1	0.6	3.1
Rotation acceleration (deg/s^2)	48.3	25.8	115.8	8.2	3.7	21.4
Condition: 30 left degrees						
Sagittal plane						
Range (deg)	20.3	9.8	52.8	20.9	9.2	40.1
Flexion velocity (deg/s)	51.5	35.2	234.3	27.5	14.3	70.2
Extension velocity (deg/s)	52.0	35.5	230.0	27.0	13.2	64.6
Flexion acceleration (deg/s^2)	245.9	195.7	1272.8	79.1	60.2	293.2
Extension acceleration (deg/s^2)	246.2	207.8	1308.2	78.4	57.5	262.9
Frontal plane						
Range (deg)	6.1	4.7	27.8	2.2	1.2	5.1
Lateral flexion velocity (deg/s)	17.3	13.4	74.3	3.4	1.5	7.6
Lateral extension velocity (deg/s)	18.0	13.9	71.4	3.3	1.3	5.6
Lateral acceleration (deg/s^2)	98.7	74.1	339.1	17.5	6.6	27.4
Transverse plane						
Range (deg)	1.8	0.7	3.5	0.5	0.2	1.0
Rotation velocity (deg/s)	6.3	3.2	16.0	1.4	0.6	2.0
Return rotation velocity (deg/s)	6.6	3.2	16.8	1.4	0.6	2.0
Rotation acceleration (deg/s^2)	45.9	23.3	113.6	9.0	3.9	19.6

RESULTS

Motion characteristics significance

Table 1 indicates those dependent variables that demonstrated statistically significant differences in response to the experimental conditions. This table indicates that statistically significant differences (at the .05 significance level) in trunk motion characteristics were observed in every plane of the body except for frontal plane acceleration using the LMM device. When the B200 device was used, statistically significant differences were noted for all motion characteristics in the sagittal plane and for all motion characteristics except acceleration in the transverse plane of the body. However, no statistically significant differences were noted in the frontal plane of the body.

Motion characteristics description

The mean, standard deviation and range of each motion characteristic observed under each experimental condition using both the LMM and the B200 are shown in Table 2. This information

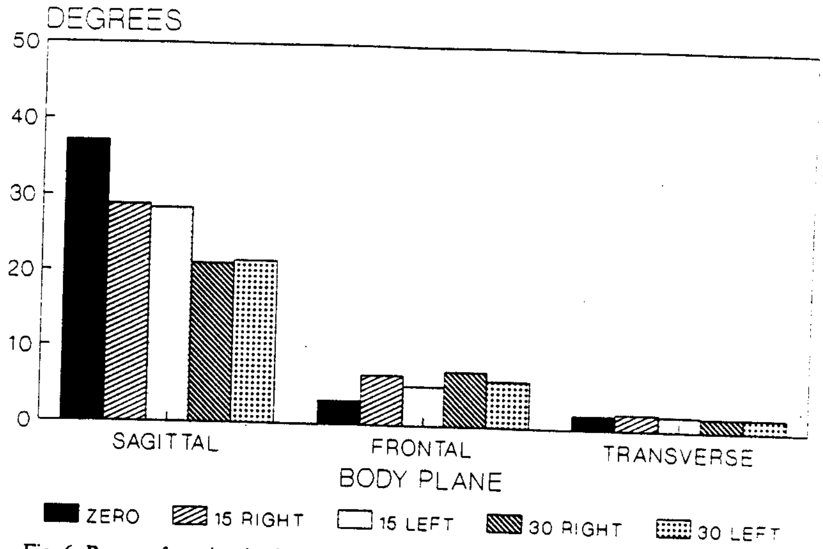

Fig. 6. Range of motion in the three planes of the trunk as measured by the B200.

was calculated from the data base in this study. Some of the more interesting results derived from this table are emphasized in Figs. 5–10.

Range of motion

Figures 5 and 6 show the range of motion observed during the experimental tasks with the LMM and B200 trunk motion monitors, respectively. Increased range of motion is observed with the B200 monitor only in the sagittal plane when no asymmetry is present. Mean trunk motion range is 43 deg for the B200 monitor, whereas it is 37.2 deg for the LMM. Range of motion characteristics in the sagittal plane do not vary significantly between the LMM and B200 as the trunk is twisted by 15 deg during flexion and extension. Average range of motion in the sagittal plane is between 28.4 and 29.4 deg regardless of the device used for measurement or the direction of twist. As the trunk twisted to 30 deg the sagittal range of mo-

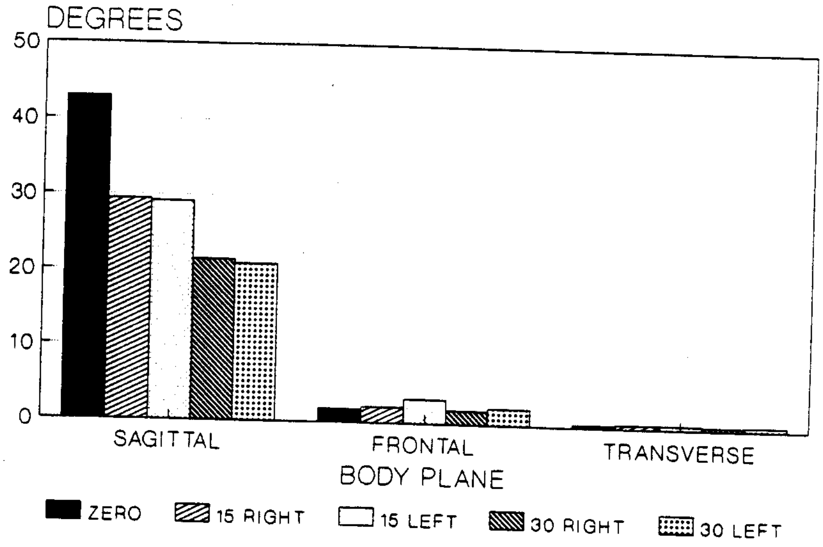

Fig. 5. Range of motion in the three planes of the trunk as measured by the LMM.

tion decreased to 20 to 21.5 deg regardless of the monitor or the direction of twist.

Figures 5 and 6 also indicate the range of motion in the frontal plane of the trunk under the various experimental conditions. Motion range in the frontal plane using the B200 was under 2.3 deg regardless of the amount of trunk twist and were not significantly different between conditions. However, with the LMM, significant increases in frontal plane motion were noted as trunk asymmetry increased. Frontal range of motion in the sagittally symmetric positions was about 3 deg throughout the exertion. However, as the trunk became more twisted, this range of motion increased to 6.6 and 7.2 deg for the 15 deg and 30 deg twists, respectively, on the right side of the body and 5.2 and 6.1 deg for twists of 15 and 30 deg to the left, respectively. Thus, the more asymmetric the motion, the more frontal plane range of motion was involved.

When transverse plane range of motion was considered, about 2 deg range of motion was observed with the LMM. About 0.5 deg of range was observed with the B200. However, there were no patterns apparent with either device.

Trunk velocity

Trunk velocity characteristics are shown in Figs. 7 and 8 for both the LMM and the B200 monitors, respectively. These figures indicated significant trunk flexion and extension velocity was present in all planes of the trunk when the LMM was used to measure the motion. Regardless of the device used for measurement, velocity characteristics in the sagittal plane decreased substantially in both flexion and extension as the trunk became more asymmetric. Mean trunk velocities in the sagittal plane ranged from 51 to 102 deg/s for the LMM and from 27 to 70 deg/s for the B200. When frontal plane velocity characteristics were observed, no statistically significant differences between the various trunk twist conditions were observed with the B200 monitor. However, when the LMM was used more velocity in the frontal plane was noted as the trunk became more asymmetric. The greatest incremental difference between consecutive conditions was observed when the trunk went from a sagittally symmetric to a 15 deg twisting condition. Under sagittally symmetric conditions, frontal plane velocity was about 12 deg/s. When the trunk was twisted 15 deg, frontal plane velocity increased to about 17 deg/s, regardless of the direction of twist. Finally, when the trunk was twisted to 30 deg, frontal plane velocity increased to around 18 and 19 deg/s.

Transverse plane trunk velocity was about 7 deg/s using the LMM device and about 1.5 deg/s for the B200, however, the degree of twist was

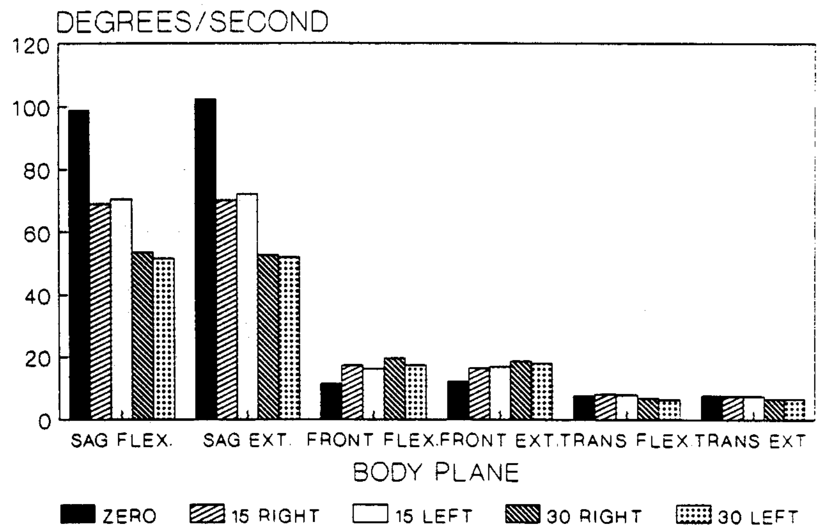

Fig. 7. Trunk flexion and extension velocity characteristics in the three planes of the trunk as measured by the LMM.

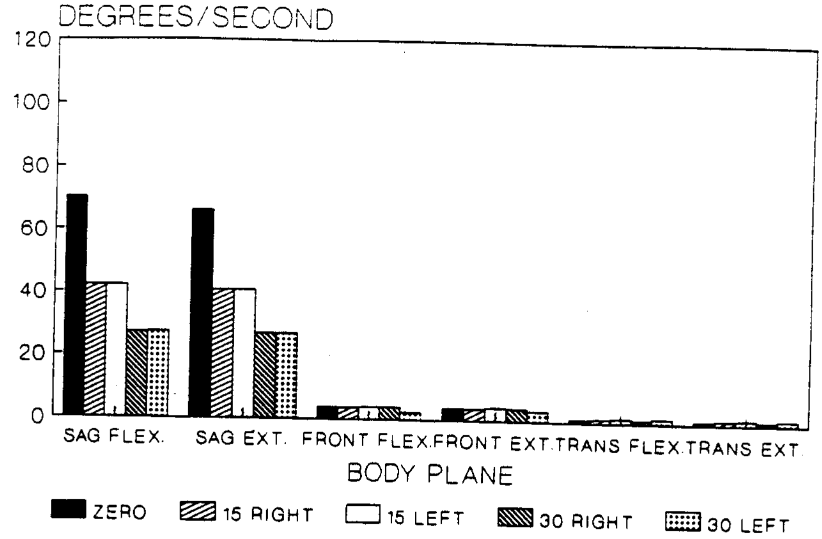

Fig. 8. Trunk flexion and extension velocity characteristics in the three planes of the trunk as measured by the B200.

controlled in this experiment, therefore, no trends among the various asymmetry conditions are obvious.

Trunk acceleration

Trunk acceleration characteristics for the various experimental conditions are shown in Figs. 9 and 10 for the LMM and B200, respectively. Trunk flexion and extension accelerations in the sagittal plane of the trunk with no trunk twisting averaged about 470 deg/s^2 as measured by the LMM. As with trunk range of motion and velocity in the sagittal plane, trunk acceleration decreased as the trunk became more asymmetric. Accelerations were about 300 deg/s^2 when the trunk was twisted 15 deg and about 245 deg/s^2 when the trunk was twisted 30 deg. Acceleration characteristics as measured by the B200 displayed a similar pattern, however, the magnitude of the accelerations varied from 220 deg/s^2 for sagittally symmetric positions

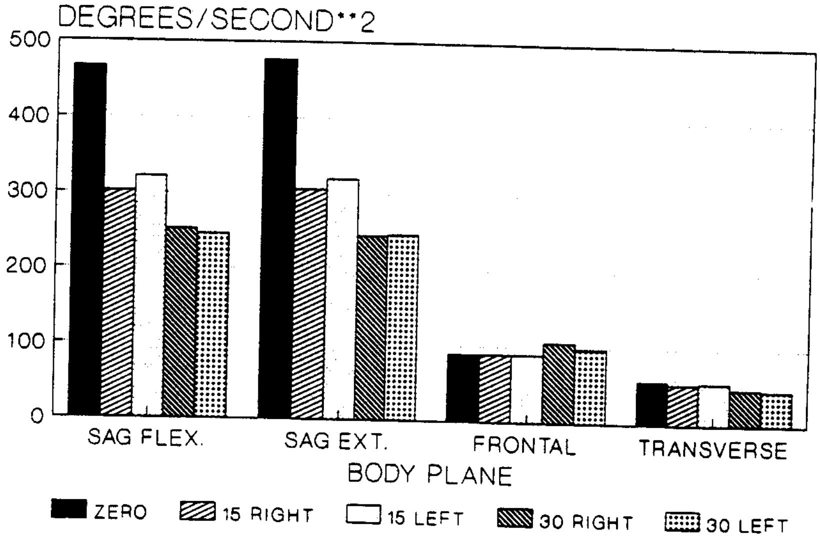

Fig. 9. Trunk flexion and extension acceleration characteristics in the three planes of the trunk as measured by the LMM.

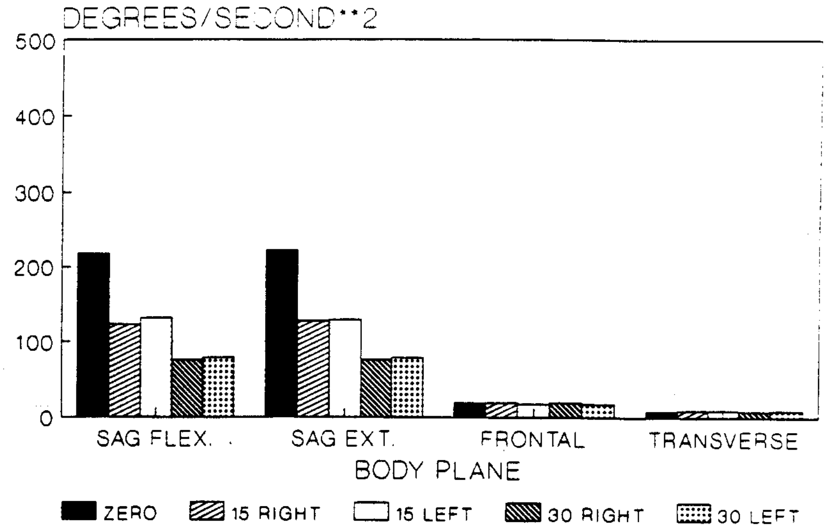

Fig. 10. Trunk flexion and extension acceleration characteristics in the three planes of the trunk as measured by the B200.

to about 77 deg/s^2 under the 30 deg twist condition.

Acceleration in the frontal plane did not vary significantly among experimental conditions. Accelerations were about 90 deg/s^2 for the sagittally symmetric and 15 deg asymmetric conditions as measured by the LMM and increased to about 100 deg/s^2 when the trunk was twisted to 30 deg. Frontal plane acceleration remained at about 18 deg/s^2 regardless of trunk asymmetry when measured by the B200.

When transverse plane accelerations were considered, slightly less acceleration was produced as the trunk became more asymmetric (about 10 deg/s^2 reduction) as measured by the LMM. A constant transverse plane acceleration of about 8.5 deg/s^2 was noted under the various conditions as measured by the B200.

DISCUSSION

In this study, we have been able to characterize dynamic motor performance components of the trunk as a function of changing trunk asymmetry. This study has established a data base that characterize these components. It has shown that there are significant differences in dynamic motor performance that occur as the trunk becomes more asymmetric. The general trend in this performance is characterized by differences in trunk range of motion, velocity and acceleration. As the trunk becomes more asymmetric by increasing the degree of twist in the transverse plane of the trunk, the trunk range of motion, velocity and acceleration decrease rather systematically in the sagittal plane. Range of motion and velocity increase in the frontal plane as the trunk becomes more asymmetric and this trend is also fairly systematic. Even though there are some significant responses that occur in the transverse plane, these differences are difficult to identify since the magnitude of the differences are small. Also differences in the transverse plane were most likely forced due to the experimental design. Thus, generally there appears to be trade-offs associated with motion in the various planes of the body at these maximum levels of exertion. As the trunk becomes more asymmetric, motion component magnitudes decrease in the sagittal plane of the trunk and increase in the frontal plane of the trunk. It is also evident that the degree of differences seen in this trend are also a function of the device that is used for measurement.

The trade-off of the range of motion with asymmetry mentioned above may be due to several factors. First, as the trunk becomes more asymmetric, flexion and extension must be controlled more by the thin oblique, abdominal and latissimus dorsi muscles of the trunk and less by the large erector spinae muscles. Once control shifts from the erector spinae muscle to the smaller trunk muscles, a significant degree of co-operation must occur among the muscles to perform the task within the restrictions of the experimental design. When more muscles are involved more time is needed by the body's control system to determine when each muscle must activate or turn off in order to perform the task. This increased time would result in slower motion and less moment of inertia, which would decrease the range of motion. Second, since the task must be controlled by these smaller muscles that are not optimally designed for trunk extension and flexion, the control system does not have a well developed mental model for the task as would occur in a sagittally symmetric exertion that employs the erector spinae muscles primarily. Thus, trial and error must occur to perform the task that would reduce the speed of the exertion. Finally, the inherent range of motion of the individual muscles and vertebral joints employed during the exertion may be smaller when a person bends asymmetrically, thus, smaller ranges of motion and a smaller distance to build up acceleration and velocity is available.

It should also be emphasized that fewer changes in transverse plane motion components were observed during the experimental task. This does not necessarily mean that this plane of motion is not important in dynamic asymmetric motion. It may simply reflect the control inherent to the experimental design.

This information could be used for several purposes. First, it could be used to produce dynamic models of the human body during tasks such as three dimensional manual materials handling. This information could be used to set limits on model parameters or could be used in a probability sense to show the chances that a worker will assume a given motion characteristic while performing a task.

Second, this data base could be used for task design. This data base represents dynamic limits of performance for the back in three dimensional space. Thus, for jobs requiring the types of asymmetric motions studied here, this information could be used to design the jobs such that the task requirements fall within the range of motion and motion capabilities of most people.

Third, this data base could be used as a basis for rehabilitation. We have defined the limits of normal trunk asymmetric dynamic motor performance capabilities in this study. Performance characteristics of those suffering from low back disorders could be compared to this data base so that the degree of disability can be assessed.

Finally, this information could be used for pre-employment selection purposes. We have defined the range of motion characteristics for normal subjects in this study. Hence, potential workers who possess the greatest capabilities in terms or dynamic motor performance can be identified for particularly demanding jobs where no other ergonomic solutions are possible.

We have also shown that many differences in dynamic motor performance characteristics are a function of the type of device used to measure the dynamic performance. These devices were designed for different purposes and are quite different in construction. The LMM was intended to be a portable device that could evaluate subjects in terms of absolute measures of motion components on the job, in the laboratory or in the clinic. The B200, on the other hand, was designed exclusively for clinical use and was intended for relative comparisons in performance. The inherent mass of the B200 and the triaxial design were created to control subject motion and most certainly would impose different range of motion and motion characteristics compared to the LMM. It is not the objective of this study to judge the merits of the individual back monitors that were used in this study. The objective was simply to develop data bases that describe motion characteristics based upon available technology.

Future studies are currently underway based upon this study. These studies are designed to increase the size of the data base as well as to investigate the types of trunk motion characteristics that are associated with various types of low back disorders. It is expected that this expanded data base could eventually be used as a workplace tool as well as a low back disorder diagnostic device that is safe and does not suffer the traditional risks of such techniques such as radiation exposure.

ACKNOWLEDGMENT

This work was supported, in part, by a Rehabilitation Engineering Center Grant No. H133 E90017 from the Department of Education.

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