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Electrokinesiologic measurement of trunk sagittal mobility and lumbar erector spinae muscle activity

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Abstract—Additional studies to determine intratester reliability of electrokinesiologic (EK) measures related to trunk movement and low back muscle activity are needed. EMG activity and EK records of repetitive movements at both natural and maximal speeds were computer sampled and quantified among 22 nonimpaired subjects. Significant differences were observed between group means at different speeds and trials for both kinematic and EMG measures. Predictably, maximal speed testing resulted in higher levels of EMG activity when compared to natural speed testing. Intratester reliability of measures was high at both speeds. Range of motion data correlated well between two trials for both natural and maximal speed movements, ranging from 0.81 to 0.97. Correlation of speed of movement measures ranged from 0.41 to 0.76. These data suggest that computer-analyzed EMG activity and EK signals are reliable assessment tools for trunk mobility. The application of this procedure to persons with low back pain to acquire EMG activity and mobility data appears justified.

Key words: *EMG, kinematics, kinesiology, lumbar spine, mobility measurements.*

INTRODUCTION

Electromyographic (EMG) analyses using surface or indwelling fine-wire electrode recordings have been undertaken to investigate spinal muscle activity during various postures and movements (1–6). In addition to analyzing EMG activity levels about the spine, spinal mobility can also be assessed, especially among persons with low back pain (LBP, 7–9).

Examination of EMG patterns from erector spinae muscles in subjects without LBP has revealed a period of "muscle relaxation" at about the point where the lumbar lordosis becomes flattened during forward bending (4). Persons with chronic LBP of musculoskeletal origin, however, neither accomplish relaxation in full flexion

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(8,9) nor show evidence of the normal flexion-relaxation response (10,11). Furthermore, the abilities of these individuals to alter the speed and rhythm of movement and extent of range of motion (ROM) are limited in comparison to those of pain free individuals (5,12). While back pain may not always be associated with increased muscle activity, it may result from joint or capsular irritation with concomitant protective posture (13). Marras and Wingsam demonstrated that velocity of movement was especially sensitive to detecting differences in impairment among a group of persons with chronic LBP (14).

An extensive review of research relating lumbar paravertebral EMG activity to chronic LBP revealed no consistent evidence of elevated absolute levels of EMG activity, thereby supporting the need for further investigation and development of improved assessment methods (15). Accordingly, we have developed an electrodiagnostic procedure, using surface EMG recordings and POLGON (Medelec, Ltd., Old Woking, Surrey, England) goniometry with polarized light (16) to produce an objective assessment procedure of trunk mobility (TM). This procedure, which we call electrokinesiological (EK) spinal testing, is applied during forward and backward body bending with fully extended knees (17,18). We believe that EK testing could eventually serve as a precursor to objective functional diagnosis, especially when gathered over a maximum range at different movement velocities. In this regard, at least two speeds of motion, natural (low) and maximal (fast), can contribute information about individual functional status, because they are representative of the velocity range over which individuals typically flex their trunks when bending forward, and they may elicit musculoskeletal deficits among persons with LBP. Ultimately, such measurements may, in addition to facilitating an objective assessment of spinal function for diagnosis, also lead to novel preventative and rehabilitative approaches. Our earlier findings, based upon qualitative analyses of EMG activity and POLGON records, suggested that EK testing of spinal function might objectively differentiate subjects with and without LBP (17–19). Before proceeding further with EK testing on subject groups, it is essential that the reliability and sensitivity of such testing be more precisely examined in a control sample. Accordingly, the purpose of this study was to document reliability of EK testing of trunk movement in the sagittal plane at two speeds of motion. This study, then, represents the first in a series needed to develop procedures in which kinematics and EMG data can be used in combination as a clinical assessment tool.

METHODS

Subjects

Twenty-two nonimpaired subjects, consisting of 17 men and 5 women, aged 18 to 55 (mean 31±9), were tested using our EK method. None of the subjects had previous experience with EK testing or had experienced back or neck pain in the past 10 years. Each subject was given a brief explanation of the study before his or her informed consent was obtained.

Electrokinesiologic Equipment

An MS6 EMG system consisting of the recording unit, two AA6 Mk, high-input impedance biological amplifiers with two PA62 preamplifiers, and two integrators (time constants: 200 ms) were used (Medelec, Ltd., Old Woking, Surrey, England). The POLGON Goniometer PG6, with its associated equipment, was added to the basic EMG system to carry out movement measurements (16). All analog signals were viewed on an oscilloscope to detect and eliminate movement artifact from the analysis. The electrodiagnostic equipment was interfaced to a personal computer. EMG signals were recorded with a frequency bandpass of 8 Hz–1 kHz. Two pairs of Beckman silver-silver chloride disk electrodes (7 mm diameter; Beckman Instruments, Spinco Division, Palo Alto, CA) were attached to the skin by adhesive interfaces over the sacrospinal muscles, 3 cm bilaterally from the midline. The distal electrode was at the level of the L4 spinous process, and the proximal electrode was 3 cm above. These placements replicate those used previously (6,7,20) to quantify erector spinae EMG activity with surface electrode placements. So long as arm movements are controlled, surface electrodes placed at these sites record EMG activity correlated to EMG from the longissimus muscle group of the erector spinae (6). The ground electrode was positioned over the left calf. Skin-electrode impedances were reduced to less than 2 KΩ. While electrodes were not removed between movement trials, thereby limiting the reliability of test procedures that would be used in a clinical environment, the emphasis on this study was to examine a different source of variability for measurements. Specifically, the variability examined in this study addressed internal manifestations of muscle activation and motor control rather than external factors, such as electrode position and marker location.

POLGON, or polarized light goniometry, measures the orientation of the body part in motion to the true vertical axis. In this study, forward-backward body move-

ment, defined as an angle between the thigh and trunk, was measured between an optical projector and receivers placed sagittally on the thigh and mid-axillary line at approximately the L3–4 level. Variation in joint angle was plotted against time. POLGON receivers are easily attached because they do not require specific anatomical locations with respect to instantaneous centers of rotations of all joints contributing to movement (16). Measurement angle was sampled at 100 Hz and recorded on Kodak linograph paper (Eastman Kodak Company, Rochester, NY). Reliability was determined by comparing values to predetermined manual goniometric trunk-to-pelvis positions and values. This procedure was undertaken periodically throughout the study and yielded 95 percent accuracy in comparing values between the clinical standard (manual goniometric) and the POLGON.

Procedure for EK Testing

The EK testing was performed in two parts: the testing of maximal isometric contraction (MIC) of sacrospinal muscles in a prone position and the testing of trunk motion in the sagittal plane during standing.

For MIC testing, each subject lay in the prone position, legs strapped to the table to prevent them from moving. Manual pressure applied to the posterior bodies of the scapula prevented contributions from the upper back to lumbar extension. Each contraction was held isometrically for 10 s as EMG data were gathered. Digitized data were collected between the second and seventh seconds of contraction to control for any possible change in muscle length or reduced effort. The isometric test was repeated twice and the higher value used for normalization of EMG data during body movements taken at both trials.

Trunk motion and sacrospinal EMG activity were recorded during six successive repetitions of trunk flexion and extension with knees fully extended (**Figure 1**). A movement cycle began from a neutral standing position and progressed into full trunk flexion, extension, hyperextension, and anteflexion. For all movements, each arm supported the other at the elbow to minimize the effect of upper limb movements on low back EMG activity. The pelvis was not supported so that movements could occur naturally and without restraint. These movement repetitions were performed without pause. The first three movements were undertaken at natural speed and were followed by three movements performed at maximal speed.

Instruction for the flexion-extension movement in the sagittal plane was to flex forward from a fully erect posture (F), extend to the vertical position (E), extend backward (hyperextension: HE) and return to an erect posture (anteflexion: AF). The natural speed of movement was defined as natural self-pacing, elicited by the command: "Please repeat three forward-backward movements as far as you can and at your natural cadence." The maximal speed was elicited by the instruction: "Now proceed at three movement repetitions as far as you can and as fast as you can." The EK testing of trunk motion was repeated at a second trial with a pause of 5 min between the two trials.

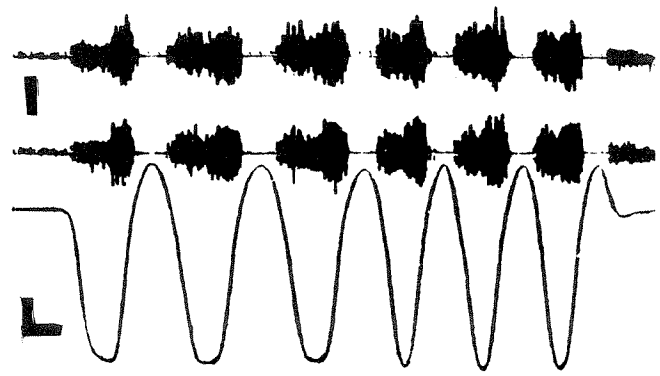

Figure 1.
Original EK recording of six body movements in the sagittal plane, first three performed at natural and next three at maximal speed. From top to bottom: surface EMG from right and left sacrospinal muscles. Calibrations: 200 μV, EMG; 20°, POLGON; 2 s time. POLGON curve of six continuous trunk movements: flexion down, extension upward direction. Starting vertical position of trunk is demonstrated by the horizontal part on the beginning of the POLGON curve.

Data Collection and Analysis

All measurements were evaluated by the same investigative team, consisting of a physiotherapist, physiatrist, and computer operator, at a room temperature of 21 °C between 8 and 11 a.m. A software package was used to obtain quantified EK measures. The computer-aided testing system for both EMG activity and POLGON records was calibrated before every MIC and movement session by a data acquisition program. Both integrated EMG activity and POLGON signals were interfaced to a computer for analog-to-digital conversion at a sampling rate of 20 Hz and stored for further quantification and statistical analyses. POLGON signals were correlated by observing the voltage value at standing to the maximal change in voltage during full trunk flexion and hyperextension. These measures defined the flexion, extension, hyperextension, and anteflexion intervals.

Kinematic variables (time, range, and speed) were calculated for both complete movement cycle and for F, E, HE, and AF segments. EMG activity was normalized and expressed as a percentage of MIC for the left and right sacrospinal muscle groups separately. EMG activity was calculated for each muscle location during F, E, HE, and AF intervals and at quiet peak values: during flexion, at maximal flexion range of motion, during extension, during hyperextension, at maximal peak range of hyperextension, and during anteflexion. For each of these intervals the data were normalized by examining EMG activity relative to values derived from previous maximal voluntary efforts.

For the purpose of this study, the first and the last of six successive movements were discarded so that four movements, two at natural and two at maximal speed movements, were used for analysis. This procedure eliminated the initial acceleration and the final deceleration components of these movements, which might impact upon EMG activity. The average value of data from two successive movements belonging to one speed and one trial was calculated for each EK measure for each subject. Thus, EK measures collected for each subject were: natural speed-trial 1; natural speed-trial 2; maximal speed-trial 1; and maximal speed-trial 2.

Statistical Analyses

Computerized quantitative EK data for each subject formed the basis for group means and standard deviations (SD) for each speed and for each trial. Because of the high variabilities during dynamic movements, nonparametric analyses were employed. Friedman two-way analysis of variance with ranks was used to test the difference between means of EK measures obtained in the same group of subjects tested across four different conditions: natural versus maximal speed and first versus second trial. The Wilcoxon rank test for equivalent pairs was used to test the difference between two members of a corresponding pair (first trial versus second and natural speed versus maximal). Because of the more inherent homogeneity in data distribution during specifically defined MIC tests, differences between MIC values at left and right sacrospinal muscles could be tested using Student's t-test for dependent means. A Mann-Whitney test was used for comparisons between male and female subjects. Correlation of EK data between tests was assessed by Spearman's coefficient of correlation (CC). CC, as an index of the degree of association between two sets of paired measures, was used to assess the intratester reliability by correlating measures taken on the first trial with those on a second trial within the same speed of movement, by the same team of testers. All statistical analyses were considered significant if an alpha level <0.05 was achieved.

RESULTS

Sensitivity of EK Measures

Sensitivity of EK measures was assessed by the ability of the measures to discriminate the difference between two speeds of movement, natural versus maximal, in two trials of testing as well as the difference between two trials within the same speed. The latter assessment provided some insight into discriminating consistency in reproducing velocity responses to the same instruction for movement.

The means for kinematic data from body movements in the sagittal plane for the same group of subjects measured in four different conditions (natural versus maximal speed and first versus second trial) are shown in **Table 1.** Comparisons by Friedman two-way analysis of variance showed that there were significant differences between variables. Post-hoc paired comparison using the Wilcoxon rank test showed significant differences between natural and maximal speed movements at both trials for all measured kinematic measures. Specifically, time decreased and both speed and ROM at maximal speed movement increased. Paired comparison between trials within the same speed did show significantly higher values of the measures for the second trial for: 1) range of flexion movement at both speeds, natural and maximal; 2) range of total movement at natural speed; and 3) all speed measures except flexion at natural speed movements. The means and SDs for normalized EMG data for left and right sacrospinal muscles, for all four testing conditions, as well as the between-group comparisons by Friedman two-way analysis of variance and the post-hoc paired comparison using Wilcoxon rank test, are shown in **Table 2.** Comparisons by Friedman two-way analysis of variance showed that there were significant differences between corresponding EMG means with two exceptions: EMG activity at vertical position before forward bending and the maximal values of EMG activity during flexion. Paired comparison by Wilcoxon rank test showed that all EMG measures, except the two mentioned above, were significantly higher at maximal speed compared with natural speed movements. Paired comparison between trials within the same speed did show occasion-

Table 1.
Group means (±SD) for kinematic data.

Variable		Natural Speed		Maximal Speed		P
		Trial 1	Trial 2	Trial 1	Trial 2	Value
Time (sec)	Total	4.5 (0.54)	4.3 (0.54)	2.7 (0.30)*	2.7 (0.32)*	0.05
	Flex	1.5 (0.26)	1.5 (0.33)	0.9 (0.12)*	0.9 (0.15)*	0.05
	Ext	1.5 (0.22)	1.4 (0.22)	1.0 (0.12)*	1.0 (0.11)*	0.05
	Hyp Ext	0.8 (0.16)	0.7 (0.12)	0.4 (0.07)*	0.4 (0.08)*	0.05
	Anteflex	0.7 (0.09)	0.7 (0.11)	0.5 (0.07)*	0.5 (0.08)*	0.05
Speed (°/s)	Total	57 (9.8)	61 (10.9)+	99 (12.7)*	100 (12.8)*	0.05
	Flex	70 (13.1)	74 (15.9)	128 (21.8)*	128 (19.3)*	0.05
	Ext	68 (11.9)	74 (13.4)+	115 (16.1)*	112 (13.7)*	0.05
	Hyp Ext	31 (9.4)	34 (8.4)+	62 (13.8)*	65 (15.3)*	0.05
	Anteflex	34 (11.3)	37 (12.3)+	54 (11.8)*	53 (13.3)*	0.05
ROM (°)	Total	125 (13.0)	129 (14.2)+	134 (13.8)*	135 (14.8)*	0.05
	Flex	102 (11.1)	105 (12.5)+	108 (12.2)*	110 (12.1)*+	0.05
	Ext	23 (7.0)	24 (7.7)	25 (7.0)*	25 (7.5)*	0.05

P Value from Wilcoxon rank test; * significantly different from corresponding slow speed; + significantly different from corresponding first trial.

al significant differences in EMG measures (Femg natural, Fp maximal).

Effects of Gender on the EK Data

The Mann-Whitney test, applied to male and female groups, did not show significnt differences for tested kinematic data or for the majority of EMG measures. Specifically, the only between-group differences were: a sporadic occurrence of significantly higher values among female subjects in right sacrospinal muscles during extension at both natural and maximal speed movements; for average EMG activity on the right during flexion; and for peak flexion on the left at natural speed movements only.

EMG Activity during Maximal Isometric Contraction of Sacrospinal Muscles

Digitalized EMG activity during MIC of sacrospinal muscles ranged from 54.24 to 121.72 μV for right and from 57.72 to 146.94 μV for left muscles. The group mean (SD) of absolute values of MIC EMG activity of the left sacrospinal muscle, 91.61 (±21.93), was significantly higher than the right sacrospinal muscle, 86.66 (±17.59); $P<0.01$, paired t-test, $t=3.01$ DF 43.

The MIC EMG activity correlation between left and right muscles was high (Pearson coefficient of correlation: 0.87). MIC EMG activity of the right muscle did show both lower levels of activity and higher intersubject homogeneity as compared to the left sacrospinal muscle.

Comparison of MIC EMG activity between left and right sides in individual subjects showed higher values in left muscles in 13 subjects (10 male and 3 female) and vice versa in 9 subjects (7 male and 2 female). Men did have significantly higher absolute values for MIC EMG activity than women for both right (men 90 μV/s, women 75 μV/s) and left (men 96 μV/s, women 77 μV/s) sacrospinal muscle groups.

Reliability Study

Spearman's coefficient of correlation between measures at two trials to indicate retest reliability was calculated for kinematic data as well as for averaged EMG activity measures at both testing conditions, natural and maximal speed. ROM data correlated highly between two trials for both natural and maximal speed movements, ranging from 0.81 to 0.97, followed by the speed data, ranging from 0.41 to 0.76. There was a significant correlation for four of five time measures at maximal speed, and for only one of five measures at natural speed, ranging from 0.50 to 0.70. Coefficient of correlation of EMG data between the two trials ranged from 0.66 to 0.96 (**Table 3**).

DISCUSSION

Following earlier studies that demonstrated the value of lumbar paravertebral EMG assessment

Table 2.
Single and averaged activity (%MIC in μV) of left and right sacrospinal muscles recorded during movements at natural and maximal speed in two successive trials.

EMG Variable		Natural Speed		Maximal Speed		P Value
		Trial 1	Trial 2	Trial 1	Trial 2	
VPF	lf	13 (10)#	14 (9)#	15 (10)#	15 (9)#	NS
	rt	10 (9)	11 (8)	11 (8)	13 (9)	NS
Fm	lf	37 (11)	36 (12)#	37 (14)	38 (14)	NS
	rt	34 (13)	36 (15)	33 (14)	36 (18)	NS
Fp	lf	13 (7)#	12 (8)#	24 (13)*#	20 (11)*#	0.05
	rt	9 (6)	8 (7)	20 (12)*	15 (10)*+	0.05
Em	lf	88 (27)	89 (25)	102 (30)*	99 (33)*	0.05
	rt	94 (34)	93 (31)	105 (35)*	105 (39)*	0.05
VPE	lf	42 (20)	42 (19)	53 (20)*	52 (18)*	0.05
	rt	40 (19)	43 (18)	49 (20)*	52 (22)*	0.05
HEm	lf	43 (21)	43 (19)	54 (21)*	52 (18)*	0.05
	rt	41 (20)	44 (19)	50 (20)*	53 (22)*	0.05
HEp	lf	14 (12)#	14 (12)#	22 (10*#	23 (10)*#	0.05
	rt	10 (12)	11 (14)	17 (9)*	19 (10)*	0.05
AFm	lf	17 (12)#	18 (12)#	23 (11)*#	24 (10)*#	0.05
	rt	13 (12)	15 (13)	18 (9)*	20 (11)*	0.05
Femg	lf	23 (9)#	21 (8)#	24 (11)*#	25 (10)*#	0.05
	rt	19 (9)	18 (7)	20 (10)*	22 (10)*	0.05
Eemg	lf	56 (15)	53 (14)	70 (20)*	66 (19)*	0.05
	rt	57 (18)	54 (17)	69 (22)*	67 (23)*	0.05
HEemg	lf	24 (15)	24 (12)	37 (15)*#	37 (15)*	0.05
	rt	20 (14)	22 (13)	32 (14)*	34 (17)*	0.05
AFemg	lf	10 (7)#	10 (6)#	16 (8)*#	16 (8)*#	0.05
	rt	6 (7)	7 (7)	11 (7)*	12 (8)*	0.05

N = 22; all values = mean (SD); **VPF** = EMG activity in vertical position before forward bending; **Fm** = Maximal value of EMG activity during flexion phase of movement; **Fp** = EMG activity at peak forward flexion; **Em** = Maximal value of EMG activity during extension phase of movement; **VPE** = EMG activity at vertical position during extension; **HEm** = Maximal value of EMG activity during backward movement (Hyperextension); **HEp** = EMG activity at peak of hyperextension; **AFm** = Maximal value of EMG activity during forward movement from the maximal backward bending to the vertical positon (anteflexion); **Femg** = Average value of EMG activity during flexion phase of movement; **Eemg** = Average value of EMG activity during extension phase of movement; **HEemg** activity = Average value of EMG activity during backward movement (hyperextension); **AFemg** activity = Average value of EMG activity during forward movement from the maximal backward bending to the vertical position (anteflexion); P = Significance value using Friedman two-way analysis of variance; NS = Non significant; Wilcoxon rank test : * significantly different from corresponding natural speeds, + significantly different from corresponding first trial, # significantly different from corresponding right muscle.

(7,11,17), we intended to document the reliability of a diagnostic technique that uses kinematic data from the trunk and pelvis and EMG activity of lumbar spinal muscles simultaneously. We propose that the measures obtained in EK testing allowed insight into body mobility and sacrospinal EMG activity levels, thus providing a set of data that may potentially be used as a quantitative diagnostic tool. The applied technique demonstrates that our use of electrophysiologic recordings is reliable and should be considered as a vehicle to contribute objective analyses in functional spinal assessments.

We emphasize that this work is important as an initial stage of validating the testing procedures in terms of accessing the reliability and sensitivity of EK parameters to changes in muscle function associated with speed and direction of movement. In reality, objective measurements of spinal function are still insufficient in proportion to the magnitude of spinal disorders in the general population.

If people with nonimpaired and impaired lumbar spines differ in vertebral movement velocity as well as in flexibility (14), what is the impact of different speeds of movement on kinematic and EMG levels of impaired and unimpaired spines? In the present study, analysis of selected kinematic and EMG measures during specific sequences of flexion-extension body movement did show

Table 3.
Spearman coefficient of correlations for intrarater reliability of kinematic and EMG measures.

Kinematic Data		Natural Speed	Maximal Speed
Time	T	0.30	0.68*
	F	0.37	0.50*
	E	0.31	0.59*
	HE	0.70*	0.32
	AF	0.27	0.64*
Speed	T	0.51*	0.76*
	F	0.65*	0.34
	E	0.41*	0.73*
	HE	0.74*	0.64*
	AF	0.65*	0.65*
ROM	T	0.94*	0.94*
	F	0.97*	0.94*
	HE	0.85*	0.81*

EMG data	lf	rt	lf	rt
VPF	0.79*	0.81*	0.78*	0.68*
Fm	0.84*	0.82*	0.79*	0.82*
Fp	0.66*	0.81*	0.77*	0.81*
Em	0.93*	0.95*	0.87*	0.93*
VPE	0.86*	0.75*	0.83*	0.87*
HEm	0.85*	0.83*	0.85*	0.88*
HEp	0.91*	0.89*	0.86*	0.87*
AFm	0.95*	0.92*	0.85*	0.85*
Femg	0.87*	0.86*	0.81*	0.86*
Eemg	0.85*	0.87*	0.84*	0.84*
HEemg	0.87*	0.79*	0.89*	0.87*
AFemg	0.90*	0.88*	0.76*	0.86*

N = 22; * $p < 0.05$.

changes of EK measures in relation to speed of movement, evoked by self-pacing natural and maximal efforts in nonimpaired subjects. Reliability and sensitivity of such measurements is a necessary precursor to using EK testing in subjects' studies.

EMG activity and POLGON signals, when subjected to computer analysis, might be used for reliable assessment tools of body movement in the sagittal plane. The obtained measures of natural and maximal speed movements are potentially useful, as evidenced by the wide range of normal values among nonimpaired subjects of both sexes. We demonstrated that increased speed of movement would result in increased EMG activity levels. Test repetition did not influence EMG data recorded at the same speed. Ahern et al., using surface EMG recordings, have demonstrated the reliability of lumbar paravertebral EMG assessment in persons with chronic LBP (8). Our interest in eventually using EMG activity and goniometric measures for spinal diagnosis was influenced by the early report on normative data on low back mobility and activity level (7). The present study confirmed the repeatability of measures of both spinal mobility and muscle activity during flexion-extension movements and highlighted the fact that EK testing of both natural and maximal speed movements could yield reproducible, quantitative data.

EK testing in the present context uses trunk motion as a proxy measure for low back mobility, which, presumably, is restricted to lumbar vertebral joint segments and the lumbosacral region. Additional bending occurs at the hip joints, so that flexion of the spine and pelvic rotation are simultaneous (12). Flexibility of back and hamstring muscles, as distinguished from spinal and hip motion, is not possible in this EK test, but the test is intended to measure global body mobility in the sagittal plane with selected monitoring of EMG activity of lumbar extensor muscles.

A question of interest is whether EK measures reflect changes due to speed of motion. EMG activity levels in sacrospinal muscles increased in 10 of 12 measurements during maximal speed compared to natural speed movements. The only unchanged measures were EMG activity in a vertical position before forward bending and maximal value of EMG activity during the flexion phase of movement. Lower EMG activity levels during natural speed movements corresponded to the expectation that when individuals are free to choose their frequency of motion, they chose one that results in lower energy costs (21). Lower and more variable EMG measures might be related to the lower energy costs and less recruitment and discharge rates of motor units for muscle contraction during natural speed movements versus maximal speed movement. The study of surface EMG signal profiles during different walking cadences in humans revealed significant changes in magnitude, which could be related to the mechanical function of the muscles involved (22). In the present study, the significant increase of normalized EMG activity of sacrospinal muscles during movement at maximal speed compared to the natural speed movement should relate to the greater extent of muscle activity during individual efforts at maximal speed movement.

Using EK testing, a significant difference between measures obtained under natural and maximal movement speeds occurred in a predictable direction. Significant changes in a precise direction obtained at maximal speed

supports the view that the EK test measured what it presumes to measure. These changes in maximal speed movements compared to natural speed movements were: decreased time, increased speed of movement and increased EMG activity. In addition, an increase of ROM at maximal speed compared with natural speed movements was observed in our control sample. Our sample was too small for definite conclusions and requires replication with a larger sample size, but the data do suggest that trunk movements in the sagittal plane differ, with a tendency to increase at maximal speed movements compared with natural speed movements. The value of these observations for clinical situations can only be realized if similar directional trends are observed in persons with LBP.

The repeatability of measures between two trials provided information about the reliability of the measurements. The correlation coefficients were greater than 0.81 for the ROM measures, greater than 0.79 for average EMG activity measures and greater than 0.66 for single EMG activity measures at both natural and maximal speed testing. This finding is in agreement with earlier studies (7,8). Correlation coefficients of speed and time measures varied from 0.30 to 0.76, with most of them being significant, except for time measures at natural speed. The explanation for lack of correlation for time measures at natural speed may lie in the physiologically greater variability among nonimpaired subjects when they move at natural self-pacing rhythm compared to a self-pacing rhythm at maximal speed. Before significant value can be attached to the reliability of these measures across trials, however, repeat measures must be separated by greater time intervals and repeated preparation of subjects for data acquisition. Because a good correlation coefficient does not mean that the results of two measurements are the same, differences were tested using the Wilcoxon rank test. The differences between trials were significant for flexion ROM at both speeds of movement (**Table 1**). We believe that this finding might be explained by changes in either connective tissue or tendon elasticity seen in repetitive motions with gravity, as is often observed when bringing fingertips close to the floor during repeated forward flexion. The total ROM and speed of movement in the sagittal plane were lower at first trial for natural speed movements only. The first trial of natural speed movements was the first in a sequence of repetitions and may explain why it contained lower values of total ROM and velocity at natural speed movements. Contrary to the ROM and speed measures, the mean values of time (**Table 1**) and EMG measures (**Table 2**) were not significantly different between either trials for natural or maximal speed of movement. Time and EMG measures were associated with higher coefficient of variations. Thus, the increased variation is the time course over which a movement is performed, and the EMG activity that is generated is consistently observed irrespective of the specified speed of movement requested or the range of motion over which that speed is demonstrated.

Comparison between EK data of men and women in this study demonstrated that the kinematic and normalized EMG data could not be differentiated on the basis of gender. EMG digital data for MIC measures were significantly higher in men than in women. This finding corresponds to the expected difference in muscle mass between men and women. Alternatively, higher MIC values in men might be due to greater effort undertaken by men than by women during the testing, but this possibility was not systematically studied.

The significant differences in MIC between left and right sides during MIC is more difficult to explain. Although we did not measure the actual torque being generated during this isometric activity, a larger value from the left sacrospinal muscle group might be due to a rotational torque to the right, away from the sagittal plane during MIC efforts.

In the evaluation of individual subjects, we noticed that six movement repetitions, the first three at natural followed by the next three at maximal speed, ensured objective evidence of both the subject's mobility and cooperation during testing. In the evaluation of body mobility of individual subjects, there are not only physiological but also psychological prerequisites that may influence muscle activity and mobility patterns. Individual repeatability of these measurements is our next concern in comprehending intrasubject variability and promoting normative data. The present study did demonstrate the contribution of speed, repetition of movement and gender to group means on EK measures.

CONCLUSION

Paired comparisons by Wilcoxon rank test showed significant differences in kinematic and EMG measures between natural and maximal speed movements at both trials. In this study, intratester reliability and sensitivity of EK testing were provided for both natural and maximal speed movements. Intratester reliability was good for

ROM, speed, and EMG measures. The correlations for time measures were less impressive compared with ROM and EMG measures.

Reproducible measures were obtained when a group of nonimpaired subjects was retested at the same speed. The repetition of testing did show some systematic changes in kinematic data, such as increase in both ROM and speed of movement, probably because of viscoelastic changes or because subjects learned to perform the test better during repeated motions. This effect was evident in ROM and speed measures between the first and second trial at natural speed motions and only for ROM trunk flexion at maximal speed movements. There was no repetition effect on EMG measures. MIC EMG activity was influenced by gender, but normalized EMG measures and kinematic measures during movements were not influenced by gender.

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