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ELECTROMYOGRAPHIC AND CINEMATOGRAPHIC ANALYSIS OF RISING AND LOWERING BETWEEN SITTING AND STANDING

by

©

CONNE D. ROBERTSHAW

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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ABSTRACT

Electromyographic (EMG) activity of the erectores spinae, rectus abdominis, external oblique and triceps brachii muscles was examined in 30 normal females during rising and lowering between sitting and standing. The purpose of the study was to determine if EMG activity would differ among the combinations of armrest, seat surface and no hand support, and four 5 cm increments of seat height. A descriptive analysis of the spatial characteristics of the motions was also completed using combined cinematographic and EMG techniques on two subjects.

The surface EMG signal was full wave rectified and low-pass filtered to yield a linear envelope. Quantified data from each electrode pair was normalized to a standard reference activity and then analyzed statistically using a three-way analysis of variance. Significantly higher levels of erectores spinae and rectus abdominis activity were found when rising and lowering were performed without hand support. Lower seat heights, where the individual's knee angles were less than 90°, also significantly increased EMG activity of the trunk muscles and triceps brachii. The cinematographic analysis of the activities revealed that the use of progressively lower seat heights

increased both hip flexion and the vertical displacement of the body center of mass. Since EMG activity of erectores spinae has been previously shown to be a reliable index of mechanical stresses acting on the spine; these results suggest that the use of hand support and of seat heights equal to or slightly greater than the length of the lower leg will minimize spinal stress during the transition between sitting and standing.

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CHAPTER I

INTRODUCTION

Rationale

Rising and lowering between sitting and standing are activities of daily living which are normally performed many times in the course of a day. Several studies have shown that difficulties in performing these fundamental human movements are associated with the functional capacity of the lower extremities.[1,2,3,4] The mobility, strength and stability of the lower limbs were reported to be important factors in the ability to get in and out of a chair.[1,2] However, Andersson et al[1] also found that the transition between sitting and standing subjects the lumbar spine to significant mechanical stress. Similar increases in spinal loading were found for rising and lowering, but hand support significantly reduced the load on the spine during both activities. The authors concluded that spinal loading during rising and lowering between sitting and standing may be minimized by the use of hand support, and that this information is of particular importance to patients with low back pain.

Hall[5] predicted that more than 70% of the adult Canadian population will experience significant low back pain at some time in their lives. Low back pain is considered to be one of the most costly medical problems in modern industrial societies. Contrary to commonly held belief, white collar workers have been found to be afflicted with low back pain nearly as often as heavy manual workers.[6] Spinal stresses incurred during activities of daily living and sedentary type occupations may, therefore, be contributory to the production of low back pain syndromes. Existing low back pain may also be aggravated by basic human movements, such as rising from a chair, since exacerbation of low back pain has been reported to occur when individuals subject their lumbar spines to increased mechanical loads.[6]

A complete and thorough account of the muscle activity associated with rising and lowering is not available. Portnoy and Morin[7] reported that the electromyographic (EMG) activity of erectores spinae during rising was characterized by an increase in amplitude as the center of gravity of the trunk was displaced forward, whereas Donisch and Basmajian[8] observed bursts of electrical activity of the back muscles during the movement. The effects of alterations in seat height and hand support on EMG activity of erectores spinae during getting in and out of a chair has not been previously examined. Although increased intra-abdominal pressure resulting from contraction of the abdominal muscles is known to relieve some of the load on the spine,[6] abdominal muscle activity during rising and lowering has not been previously investigated. Triceps brachii activity has also not been previously studied despite reports by several investigators[1,4,9] that hand support facilitates rising from a chair. In addition, little descriptive biomechanical data exists for the activities of rising and lowering between sitting and standing.

Rising from sitting is considered by physical therapists to be a stressful activity which may exacerbate low back pain.[10,11] However, physical therapists acting to advise patients in the prevention and treatment of low back pain, have not had sufficient information available to adequately describe the transition between sitting and standing. Information on the appropriate selection and adjustment of chairs for persons engaged in sedentary type occupations is also presently insufficient. Advice to patients, regarding getting in and out of a chair with minimal spinal stress, must have a scientific basis if patients with low back pain are to be treated in the most effective manner.

Nachemson[6] suggested that the most important task of the physical therapist in the rehabilitation of patients with low back pain, is to give ergonomic and postural advice based on present knowledge of spinal loading. Scientific evidence regarding spinal loading during rising and lowering between sitting and standing is expected to be of value in preventative and remedial back care education programs, with possible benefit to a large portion of individuals in modern industrial societies.

Objectives of the Study

1. To compare the effects of varying seat heights and varying hand support on EMG activity of the trunk muscles and triceps brachii during rising and lowering between sitting and standing, in order to determine the optimum combination of seat height and hand support which minimizes spinal stress during these activities.
2. To obtain descriptive biomechanical data on the activities of getting in and out of a chair with varying seat heights and varying hand support.
3. To obtain information regarding spinal loading during the transition between sitting and standing which may be used in back care education programs for patients and for persons engaged in sedentary type occupations.

Research Hypothesis

Mean EMG activity of the trunk muscles and triceps brachii will differ among the combinations of four positions of seat height and three conditions of hand support.

Delimitations

1. The investigation was limited to EMG and cinematography of rising and lowering between sitting and standing using armrest, seat surface and no hand support, and four 5 cm increments of seat height.
2. The study was limited to EMG activity of erectores spinae, rectus abdominis, external oblique and triceps brachii recorded with surface electrode pairs from standardized electrode sites.
3. The investigation was limited to thirty-two female subjects ranging in age from 18 to 35 years, in weight from 46.6 to 67.6 kg, and in height from 154.2 to 174.2 cm. The study was limited to normal subjects with no clinical history of chronic low back pain, back injury or significant limb pathology.

Limitations

1. Subject selection was made on a volunteer basis, and did not constitute a random sample of the population.
2. Measurement of intradiscal pressure (IDP) and EMG activity of the trunk muscles simultaneously would have provided additional information but was not feasible due to the invasive nature of IDP measurements and the risk to normal subjects.
3. Force transducers placed on the armrests and the seat surface of the chair, as well as beneath the subject's feet would have provided more complete descriptive biomechanical information, but were not economically feasible.
4. Radiographic measurements of pelvic inclination and the lumbar lordosis would have provided additional information but would have produced abnormal subject risks.
5. The investigation did not account for individual differences in habits of rising and lowering, which may have influenced EMG activity during the standardized performance of the movements.

CHAPTER II

REVIEW OF THE LITERATURE

Intervertebral Disc Pathology and Sitting

Low pack pain has been reported to be one of the most frequent and disabling conditions affecting men and women in their productive years.[12,13,14] Kelsey et al[15] found that impairments of the back and spine were the most frequent cause of limitation of activity in persons under 45 years of age in the United States and the third most frequent cause in the 45 to 64 year old age group. In modern industrial countries, the impact of low back pain is costly, both monetarily and to the quality of life.[12,15]

The sitting posture is frequently used as a work position in modern industrial societies. An increased risk of prolapsed lumbar intervertebral discs has been reported among persons who have had sedentary occupations for several years.[13] Prolonged sitting, with infrequent changes of work postures, has also been associated with the occurrence of low back pain and herniated lumbar intervertebral discs.[12,14,16]

Although degenerative disc disease is believed to be capable of producing back pain, the exact mechanism of pain production is uncertain.[17,18] Nachemson[19] suggested that disc pathology should be considered in terms of a combination of anatomic, histologic, chemical and mechanical factors. There is agreement that mechanical stresses acting on the lumbar spine are associated with the development of degenerative disc disease and low back pain syndromes.[12,13,19,20,21] Absence from work because of low back symptoms has also been found to be related to vocational factors that increase the load on the spine.[12] Sedentary work involves static loading, whereas manual work involves dynamic loading, however static work is difficult to define. In either case, the risk of developing low back symptoms is similar.[6]

During static loading conditions, such as prolonged sitting, disc deformation has been reported to depend on the magnitude of the load and the duration of loading.[22] Hirsch,[22] in a study of the mechanical properties of lumbar discs, demonstrated that axial loaded discs do not have the same ability as unloaded discs to compensate for even a minor extra strain. In addition, volume losses of lumbar discs under axial compressive loads, in vitro, have been shown to be up to 2.5 ml during a 30 min time interval.[23] Kramer[24] demonstrated that the influx and outflow of fluids through the cartilagenous end plate of intervertebral discs are proportional to the pressure gradient. A high compressive load on the disc, therefore, is accompanied by fluid outflow, whereas unloading results in a fluid influx. Since the transition between sitting and standing is known to increase the load on the spine,[1] this evidence suggests that rising from a chair after prolonged sitting subjects lumbar discs to significant dynamic loads at a time when the discs are particularly vulnerable to mechanical stress.

Surface Electromyography

Basmajian[25] reported that muscle membrane depolarization generates an electromagnetic field in the vicinity of the muscle fibers. When a recording electrode is placed in this field, a potential or voltage will be detected with respect to the ground of the EMG system. Since motor units must be repeatedly activated to sustain muscle contraction, each motor unit activated produces a sequence of motor unit action potentials which have been designated as motor unit action potential trains. The EMG signal has been reported to represent an algebraic summation of all active motor unit potential trains from all active motor units within the pick up area of the recording electrodes. The EMG signal must be amplified before it can be recorded. Although the recorded EMG signal has been reported to be proportional to the number of impulses, it does not imply that the identity of the motor unit firing is tonic or phasic.[26]

Surface electrode recording has been suggested as the method of choice where a global pick up of superficial muscle activity is desirable.[25] Komi and Buskirk[27] reported that the test-retest reliability (55 day interval) for surface electrode recording of biceps brachii was r = 0.95 for maximum isometric EMG, r = 0.91 for maximum eccentric EMG, and r = 0.97 for maximum concentric EMG. A linear relationship between surface EMG and intramuscular EMG has also been shown to exist during isometric and constant velocity isotonic contractions.[26] It was concluded that surface activity is representative of the intramuscular activity. However, because of the difficulty of re-inserting indwelling electrodes into exactly the same place in the muscle between test days, test-retest reliability of wire electrodes has been found to be poor.[27]

Recently, Perry et al[28] in a surface and wire electrode study of the calf muscles, reported that surface electrode activity represented a composite of muscle action, with subcutaneous muscles dominant but deeper muscles also contributing. Similarly, Hemborg et al[29] suggested that EMG surface electrodes placed over the external oblique would record mainly that muscle, but some internal oblique activity would also be picked up. However, since the two oblique muscles have also been reported to work together functionally in symmetric movements in the saggital plane;[29] their activity would be complementary during symmetric activities. Specificity of surface electrode recording is likely to depend on the distance between the electrodes and the surrounding muscles as well as the density and conductivity of the adjacent tissues. Also, if spacing between bipolar surface electrodes is decreased and small electrode sensors are used; localization of the signal will be increased.[25,29]

The magnitude of electrical activity in muscle, similar to the factors that determine muscle tension, has been reported to be determined by the number of muscle fibers recruited and their mean frequency of excitation.[30,31] The amplitude of EMG signal also depends on 1) the diameter of the muscle fibers, 2) the distance between the active muscle fibers and the recording site, 3) the size of the recording electrodes, and 4) impedance.[25] Thus, with surface electrode recording, muscle fibers located closer to the surface will contribute larger amplitude electrical signals than deeper situated fibers. Larger diameter fast twitch fibers will also produce larger amplitude EMG action potentials than smaller diameter slow twitch fibers. However, erectores spinae, rectus abdominis and triceps brachii have been shown, by the myofibrillar ATPase reaction, to be composed of both Type I and Type II muscle fibers with no significant differences in fiber type proportions between the deep and superficial areas.[32]

The validity of EMG as an index of muscle tension depends on the relationship of the EMG signal to muscle force. The EMG/muscle force relationship during voluntary isometric contractions and constant velocity isotonic contractions of normal unfatigued muscle has been reported to be linear.[26,33,34,35] However, EMG/force relationships are also dependent on the conditions of the experiment and the physiological properties of human skeletal muscle. Experimental conditions must therefore, ensure both the absence of muscle fatigue and standardized electrode type, placement, subject positions and test activities.

The electrical properties of the skin must be taken into account when surface recording electrodes are used.

Cleaning and light abrasion of the skin, to remove the dead surface layer and protective oils, serves to reduce skin resistance to approximately 3000 ohms.[25] Electrical contact may be further improved by the use of conductive electrode gel, and adhesive strips used to secure the electrodes provide continued pressure at the electrode sites. Impedance at the skin/electrode interface depends on the skin site, the skin preparation, the area of the electrodes and the temperature.[36,37] The range of amplitude of the EMG signal, obtained with surface recording electrodes, is 0.01 to 5 mV.[36] However, since total impedance is variable, and of unknown magnitude, the voltage information is less meaningful. Perry et al[28] suggested that the limitations of uncontrolled sampling variations such as is produced total electrical impedance with use of surface electrodes, may be circumvented by normalization of the EMG data. There is an agreement that the EMG value obtained from each electrode when expressed as a ratio of another representative value of that electrode's output (a specific test or reference activity) serves to cancel the sampling variable.[28,35,38,39].

When bipolar surface electrodes are placed over the muscle site, the voltage recorded has been reported to be the difference in potential between the two electrodes.[37] Since the voltage waveform at each electrode is almost the same, but shifted in time; the resultant EMG action potential usually has three phases. As the force output increases, several motor unit action potentials will be detected simultaneously producing a raw EMG interference pattern.[25] The raw EMG signal is frequently full wave rectified and low-pass filtered for high frequency noise.[37] The resultant linear envelope is analyzed by measurement of the area under the curve, and a quantitative value is thus derived from a composite of the signal variables of amplitude, frequency and spike shape.[25,36,37] Artifacts, which may result from lead movement,[40] are normally identified visually and excluded from the EMG analysis.[25]

Andersson et al[41] examined the EMG activity of erectores spinae during sitting with the use of bipolar surface electrodes. Surface electrode pairs were placed at the levels of the tenth thoracic vertebra and the first, third and fifth lumbar vertebrae (T_{10}, L_1, L_3, L_5) in order to obtain representative signals from a large group of muscles suitable for the detection of major functional differences. The authors concluded that when muscle activity is observed at several spinal levels, it is possible to predict spinal stress on the basis of EMG activity of back muscles, without detailed knowledge of posture (i.e. pelvic inclination). Surface electrode pairs placed 3 cm lateral and parallel to the tips of the spinous processes at the T_{10}, L_1, L_3 and L_5 levels were reported to monitor activity of the longissimus and multifidus muscles.[41,42] Since both longissimus and multifidus span several vertebral levels in interdigitating fascicules, information obtained from more than one EMG electrode site in the lumbar region may be considered to be complementary.

Previous investigators[41,43] obtained unilateral EMG recordings, with the assumption that electrical activity would be the same on both sides of the body when symmetrical postures and test activities were used. The validity of this assumption was demonstrated by Jonsson[44] who found no statistically significant differences between the EMG activity of erectores spinae on the right and left sides of the body in symmetrical postures. Sex differences in EMG activity also appear to be negligible, since no significant differences were found in EMG activity of erectores spinae between males and females during both sitting and standing.[42,45]

EMG Activity of Erectores Spinae and Spinal Loading

Linear and rotational forces were reported to be transmitted between adjacent vertebrae by the intervertebral disc, the spinal ligaments and the apophyseal joints.[46] The nucleus pulposus has been reported to be the major load carrying articulation of the lumbar spine.[47] The pressure in the nucleus, loaded in compression, has been shown to be about 1.5 times the external load per unit area.[6] Because of its semifluid composition, the nucleus normally transmits the compressive load equally in all directions.[47] The vertical stress on the annulus fibrosis has been reported to be approximately 50% of the external load per unit area, whereas the tangential tensile strain was four to five times the external load.[6] As the ratio of disc diameter to height is higher in thoracic discs than in lumbar discs; circumferential stresses are believed to be less dominant in thoracic discs.[48]

Intradiscal pressure measurement yields direct information of the load acting on the spine, but requires invasive procedures. Andersson et al[49,50] demonstrated linear relationships between EMG activity of erectores spinae, intra-abdominal pressure, and IDP with the moments acting on the spine. The measurement values were shown to increase when the trunk moment increases.[50] Similarly, Ortengren et al[51] suggested that EMG activity of the back muscles may be used to study the load on the spine in static and dynamic situations. This evidence suggests that EMG activity of erectores spinae may be used as an index of spinal stress.

Uses and Limitations of Cinematography

Winter[37] suggested that since most human movements are complex, the examination of the external mechanics of human motion requires some type of imaging system in order to capture all the data. If many images are taken at regular intervals, dynamic activities may be described over a period of time. The use of 16 mm cameras have been recommended when precise measurements must be made from the film.[52] Since the subject is less likely to be affected by the experimental protocol, filmed activities may also be more representative of the subject's normal performance. In addition, when cinematography is synchronized in time with another measurement system, such as EMG, relationships may be drawn between the data obtained from the two measures.

The major disadvantage of cinematography has been found to be the extensive time required for data extraction and analysis.[52,53] Grieve et al[54] also emphasized that the investigator using cinematographic techniques must be aware of the inherent inaccuracies of measurement, and the techniques that are available to counteract them. Several common sources of cinematographic error have been identified. It was suggested that graininess and lack of definition of the film may lead to inaccurate location of points on the body of the subject.[54] However, an understanding of the camera and filming techniques will help to ensure that the images are of good quality.[52] Markers placed on the subject's skin to indicate boney hinge points may also shift during the performance of the activity as a result of muscle contraction and skin stretching.[54] Identification of both the marker and the joint center in the data extraction process will help to minimize this source of error.

Since cinematography is a sampling process, Winter[37] noted that the sampling theorem must not be violated with respect to the filming rate. The sampling theorem was reported to state that "the process signal must be sampled at a frequency at least twice as high as the highest frequency in the signal itself." Sampling at too low a frequency may result in false frequencies being generated in the sample data which were not present in the original signal (aliasing errors). However, Winter[37] concluded that, except for higher-speed activities, standard 16 mm movie cameras will satisfy the requirements of the sampling theorem.

When assumptions have to be made concerning the weights and dimensions of body segments; it may be difficult to check how accurately they apply to a particular subject.[54] Hubbard[55] reported that in order to make measurements and comparisons based on photographic records; the major movement plane must be determined, and the camera placed perpendicular to and in the approximate center of that plane. However, human motion will involve some movement which is outside of the major movement plane.[52] Motion occurring toward and away from the camera will produce apparent changes in the dimensions of parts of the body (parallax error). Grieve et al[54] suggested that in practise a large camera to subject distance will reduce this source of error to a minimum. Although there are several possible sources of cinematographic error, Miller and Nelson[52] stated that accurate measurements can be obtained from films of subjects performing under either competitive or controlled laboratory conditions when the filming procedures developed for biomechanical research are carefully observed.

Rising and Lowering Between Sitting and Standing

The spatial characteristics of rising and lowering between sitting and standing with varying seat heights and varying hand support have not been previously reported. Previous cinematographic and biomechanical studies of rising from sitting have emphasized knee joint mechanics and muscular dynamics.[3,4,56,57] The activity of lowering from standing to sitting appears to have been almost totally disregarded. However, the main features of the activities are known, and this information may be used as a basis for further study.

Rising from sitting has been reported to be initiated by forward pivoting of the trunk.[1,3] Kelley et al[3] found large knee torques in response to the transfer of weight from the seat to the lower extremities (lift off), and peak knee extensor muscle activity was observed at that point. Similarly, Ellis et al[56] reported that peak patello-femoral forces occurred at the point of lift off. In the latter part of the motion, hip and knee torques were found to diminish gradually as hip, knee and trunk extension was completed and the body was raised to standing.[1,3] It has also been suggested that rising may be accomplished either bringing the body center of mass (C of M) over the feet or by bringing the feet back under the body C of M.[2] However, Johnston and Smidt[2] concluded that rising is normally performed by bringing the trunk over the feet. During lowering from standing to sitting, a reversal of the rising activity, the hips, knees and trunk are flexed and flattening of the lumbar lordosis occurs simultaneously.[1] After seat contact occurs (touch down), the trunk is raised to the upright position.

Andersson et al[58] demonstrated, using radiographic measurements, that the lumbar lordosis decreases by an average of 38° when an individual moves from standing to the sitting position. Donisch and Basmajian[8] also reported that posterior rotation of the pelvis is about 40° when a standing person sits down, and that this pelvic rotation is accompanied by flattening of the lumbar lordosis. It has been suggested that the hip flexion and backward rotation of the pelvis that occurs during lowering from standing to sitting brings the ischial tuberosities into a weight bearing position.[59] Since the sacrum is almost completely fixed to the pelvis, Andersson et al[41] concluded that the posture of the lumbosacral spine is directly related to the inclination of the pelvis. The lumbar spine, therefore, moves toward lordosis when the pelvis rotates forward, and toward kyphosis when the pelvis rotates backward. The position of the head may also effect the degree of lumbar curvature during getting in and out of chair, since the line of sight has been reported to influence the shape of the spine.[60]

Little information exists in the literature regarding the electrical activity of the trunk muscles during the transition between sitting and standing. Morris et al[61] suggested that erectores spinae activity occurs during saggital plane movements of the trunk in order to oppose the forces of gravity. During trunk flexion, erectores spinae has been reported to create an extensor moment equal and opposite to the flexor gravitational force.[62] Although erectores spinae contraction has been observed during rising from sitting,[7,8] the activity has not been quantified to a high degree of confidence. No information exists in the literature regarding abdominal muscle activity during rising and lowering. An increase in intra-abdominal pressure produced by contraction of the abdominal muscles has been reported to relieve some of the load on the spine in certain situations, such as during stoop lifting.[6,62] It has been suggested that stretch receptors in erectores spinae may be responsible for initiating the reflex increase in intra-abdominal pressure.[63] However, when movements of the trunk were performed without resistance in both the sitting and standing postures, the abdominal muscles were found to be inactive.[25] Trunk muscle activity during getting in and out of a chair, therefore, requires investigation.

The effects of varying hand support on EMG activity of the trunk muscles and triceps brachii during rising and lowering has also not been previously reported. Although the lower extremities appear to provide the major thrust required for rising from a chair,[3,56,57] significant reductions in knee joint contact forces and muscle forces occurred when the armrests were used.[56] Andersson et al[1] also found that hand support significantly reduced IDP at L_3 during rising and lowering. However, this finding may have been the result of the spine being relieved of the weight of the arms when hand support was used.[64] Further study is, therefore, required.

The Sitting and Standing Postures

Nachemson,[19] in a study of lumbar IDP, found that the load on the spine was 30% higher in unsupported sitting than in standing. The increase in spinal loading that was observed in sitting can be explained by the forward displacement of the trunk's C of M, which increases the weight arm relative to the pelvic base of support (moment of flexion or weight arm in sitting = trunk weight × distance from the center of rotation to the C of M of the trunk).[65] In standing, the lumbar spine moves toward lordosis and the weight arm is shortened.[65,66] However, the load on the spine during sitting may be reduced if the lumbar lordosis is maintained and back muscle activity is minimized.[65,66,67,68] The use of backrest support together with a backrest inclination of 100° to 110° were found to be of major importance in reducing IDP and EMG activity of back muscles, as a result of part of the body weight being transmitted to the backrest.[41] A further decrease in IDP at L_3 occurred when the lumbar support was increased. This evidence, therefore, provides guidelines for minimizing spinal stress during sitting.

Since most joint centers are a short distance from the line of gravity during erect standing, the force of gravity develops rotary components in many joints which must be resisted by muscular forces.[25,69] The abdominal and erectores spinae muscles have been reported to serve as stays to maintain equilibrium of the trunk during standing.[70] Accordingly, EMG studies of erectores spinae have reported only intermittent activity of these muscles in the standing position.[71,72] However, the abdominal muscles were found to be inactive during standing with the exception of the lower portion of internal oblique.[25]

In opposition to the popular belief that standing is a static position, standing has been shown to be normally composed of a series of relatively immobile postures separated by brief intervals of movement.[73] Postures of symmetrical weight bearing on both feet or with body weight borne almost entirely on either the left or right foot did not persist for longer than 1 min, with the average duration being about 30 sec. Experimental conditions, therefore, should not involve forced periods of prolonged standing.

The Chair

The sitting posture an individual assumes has been reported t[illegible]n the design of the chair, his or her sitting ha[illegible]e task to be performed.[66] The importance [illegible]ent changes of position during sitting in order to [illegible]ze fatigue and discomfort has been emphasized by [illegible]eral investigators.[66,67,74,75] The chair, theref[illegible] should allow for changes of position, and not force[illegible]e occupant into a fixed posture.

Although the effects of varying seat heights on the activity of t[illegible] trunk muscles during getting in and out of a chair is not known, previous investigators have identified relevant factors which should be considered in the selection of an appropriate seat height. Chairs with adjustable seat heights were recommended for individual use in the workplace in order to accommodate persons of different body dimensions.[66,75,76] A seat height slightly less or equal to the length of the lower leg has been suggested, so that body weight would be supported by the ischial tuberosities, and compression of soft tissues of the posterior thighs could be avoided.[64,68,77] Sitting with feet supported was found to produce pressures under the ischial tuberosities which were in excess of 30 pounds per square inch, whereas sitting with feet hanging produced similar ischial tuberosity pressures but significantly higher thigh pressures also resulted.[77] Therefore, seat heights of 41 cm were recommended in chairs designed for public use to permit the feet to reach the floor.[74]

The seat height of the chair also influences the spinal posture of the occupant. Troup et al[78] found that lumbar vertebral posture was largely secondary to the postural relationship between the trunk and the lower limbs, when the inclination of the trunk was held constant. The posture of the lumbar spine, therefore, may be altered by both changes of seat height and changes in height of the feet support. Low seats produced a sitting position with a thigh-trunk angle of less than 90° resulting in backward rotation of the pelvis and obliteration of the lumbar lordosis.[64,79] High seats, where the occupant's feet were unsupported, were found to hasten the onset of back muscle activity and early fatigue resulted.

Additional recommendations for chair design have been made to facilitate sitting comfort and reduce spinal stress during sitting. It has been suggested that a seat depth of 15 to 20 cm less than the sacral-calf distance would provide adequate clearance between the calf and the front of the seat.[79] Seat width should allow for clearance of the trochanters, and permit lateral movement in the chair.[79,80] The shape of the seat surface recommended was either uncontoured[75,79] or slightly concave.[68,74] Either design satisfies the principle considerations of allowing the occupant freedom of movement in the chair, and weight bearing through the ischial tuberosities. However, controversy exists regarding ideal seat inclination. Floyd and Roberts[79] recommended a horizontal seat so that there is a less acute thigh-trunk angle, and changes of position are facilitated. A seat that is inclined backward 5° has also been recommended, so that there is no tendancy to slide forward in the chair.[68,80]

The firmness of the seat also influences sitting comfort. Kroemer[75] recommended a padded, upholstered seat that does not compress more than 2.5 cm so that the seat would be firm enough to provide support. Very hard seats produced discomfort in a short time.[80] Very soft seats were not recommended as body weight is then distributed to soft tissues adjacent to the ischial tuberosities producing undue pressure and discomfort.

Conclusion

Rising and lowering between sitting are activities of daily living which are normally performed many times in the course of a day. Although getting in and out of a chair subjects the lumbar spine to significant mechanical stress;[1] the effects of varying seat heights and varying hand support on EMG activity of the trunk muscles and triceps brachii during these activities has not been previously investigated. The spatial characteristics of rising and lowering between sitting and standing with varying seat heights and varying hand support have also not been previously reported.

Nachemson[6] suggested that the most important task of the physical therapist, in the rehabilitation of patients with low back pain, is to give ergonomic and postural advice based on present knowledge of spinal loading. However, the objective basis for education of patients regarding getting in and out of a chair with minimal spinal stress is presently incomplete.

CHAPTER III

MATERIALS AND METHODS

Subjects

Thirty informed, volunteer females with no clinical history of chronic low back pain, back injury, minor scoliosis or significant limb pathology served as subjects for the study. Two additional informed, volunteer females, who were selected using similar criteria, participated as subjects in both the pilot study and the synchronized EMG/cinematography portion of the investigation. Copies of the informed consent and photography-cinematography consent forms are contained in Appendix A. Subjects were considered to have moderate activity levels in that all subjects were physical therapy and physical education students who participated in recreational physical activities on a regular basis. Subjects were required to perform a screening test of abdominal endurance consisting of 20 bent knee curl ups with feet stabilized as adapted from Quinney et al.[81] Subjects ranged in age from 18 to 35 years (mean 23 years), in weight from 46.6 to 67.5 kg (mean 57.7 kg), and in height from 154.2 to 174.2 cm (mean 164.7 cm).

The Chair

A Drabert 4002CAA stenographer's chair* was used in the study. The standardized components of the chair were: seat depth 54 cm; 5° backward inclination of the seat; seat surface covered with 2.5 cm foam padding and upholstery; pneumatically adjustable range of seat height 13 cm; upholstered backrest 61 cm in height; backrest inclination 110°; a lumbar support incorporated in the backrest of the chair; and removable high density plastic armrests 21 cm in height.

Subject Positions and Activities

1. The Sitting Position

The subjects' standardized sitting position in the study was with buttocks as far back as possible on the seat surface, trunk resting against the backrest of the chair, the lumbar support positioned in the lumbar

*Sunar, a Division of Hauserman Limited, 1 Sunshine Avenue, Waterloo, Ontario N2J 4K5 concavity, head upright, eyes fixed horizontally, and feet supported. Subjects wore stockings but no shoes.

2. Seat Height Positions

a) Position One (reference seat height) was sitting with the seat height of the chair adjusted individually for each subject such that thighs were horizontal, lower legs vertical, and knee angles 90° (Figure 1).[82] The reference seat height was, therefore, based on each subject's lower leg length.[57] The angle of the right knee was checked to ensure that it was 90° using a standard goniometer, with the long axes of the upper and lower legs as lines of reference. The soles of the feet were in contact with and resting on two 91 cm square, 5 cm thick wooden platforms. The platforms were fixed to the base of the chair to prevent any movement of the apparatus during testing.

b) Position Two maintained the seat height of the chair from Position One with the subject's feet resting on one 5 cm thickness wooden platform; resulting in a seat-to-platform height of 5 cm higher than in Position One.[82]

c) Positions Three and Four were with seat-to-platform heights of 5 cm and 10 cm lower than in Position One, respectively.[82]

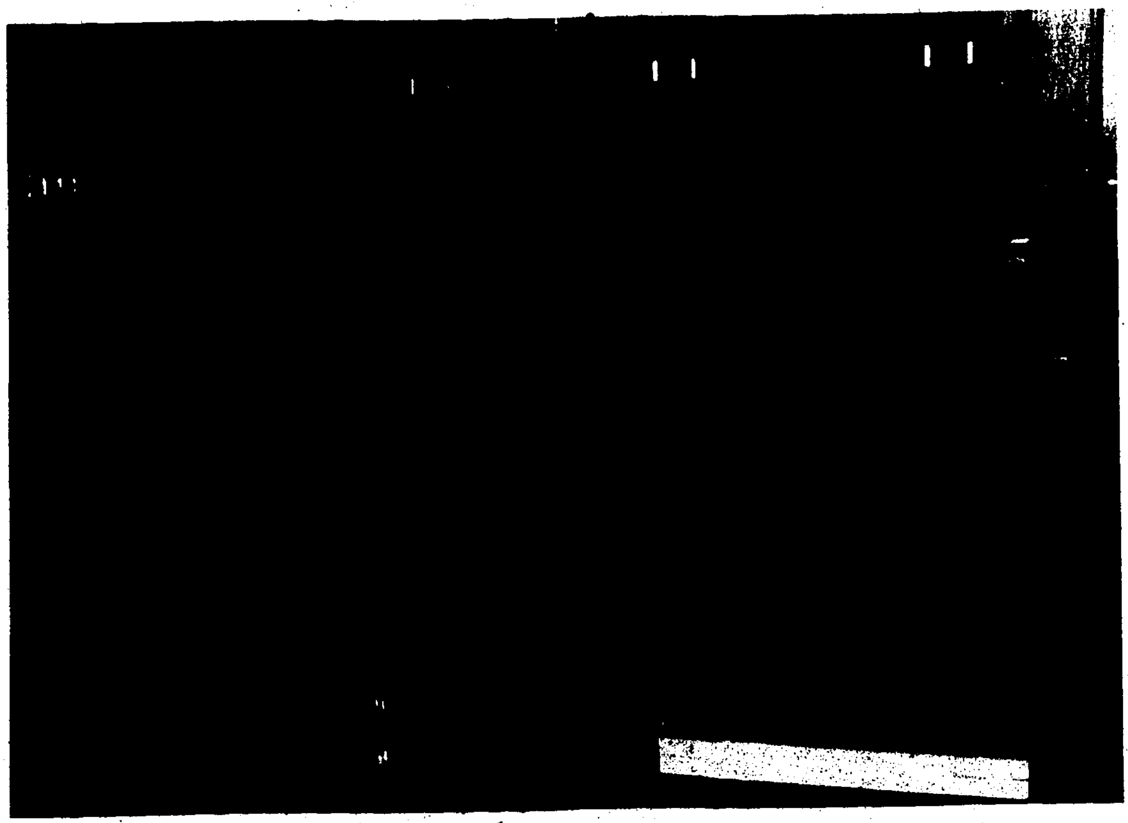

Figure 1. A subject seated in Position One

3. Hand Support Conditions

a) In the armrest hand support condition, subjects placed their hands on previously marked positions on the upper, anterior extremes of the armrests of the chair.

b) In the seat surface hand support condition, subjects placed their hands on previously marked positions on the lateral, anterior extremes of the seat surface on either side of the chair. The armrests were removed from the chair.

c) For the no hand support condition, the subjects' arms were hanging by their sides with palms facing medially. The armrests were removed from the chair.

4. The Activity of Rising From Sitting to Standing

From the backrest supported sitting position, subjects assumed one of the three hand support conditions while leaning forward in the chair, and rose from sitting to erect standing.

5. The Standing Position

The subjects' erect standing position was with weight evenly distributed on both feet, knees loosely extended, arms hanging relaxed, head upright and eyes fixed horizontally.

6. The Activity of Lowering From Standing to Sitting

From the standing position, subjects assumed one of the three hand support conditions while lowering from standing to backrest supported sitting.

7. EMG Reference Activities

Seated in Position One with upper arms adjacent to and in line with the trunk, elbows flexed to 90°, palms directed medially and grasping a 5 kg weight in each hand, subjects rose from sitting to standing. With similar hand and arm positions and grasping a 5 kg weight in each hand, subjects lowered from standing to backrest supported sitting.

Electromyography

Beckman bipolar surface electrodes, 7 mm in diameter, with a sensing element of silver-silver chloride were used to pick up EMG signals in the study. The electrode sites were thoroughly cleaned with alcohol to remove the skin's protective oils, and light abrasion was used to remove the dead surface layer of skin.[25] The gaps under the silver discs were filled with electrode gel, and the electrodes were fixed to the skin surface with double adhesive electrode collars. The electrodes and their adhesive collars were covered with Elastoplast adhesive tape to maintain pressure at the electrode sites.

The erectores spinae surface electrode pairs were placed 3 cm lateral and parallel to the tips of the spinous processes on the right side of the body at the T_{10}, L_1, L_3 and L_5 vertebral levels.[41,41,83] The upper rectus abdominis electrode pair was placed longitudinally 5 and 8 cm below the tip of the zyphoid process, 3 cm to the right of midline.[84,85,86] The lower rectus abdominis electrode pair was placed longitudinally 2 and 5 cm below the umbilicus, 3 cm to the right of midline.[84,85,86] The external oblique electrode pair was placed just below the right costal margin at the angle of the ninth rib, in an oblique line parallel with the underlying muscle fibers.[84,85,86] Interelectrode distance, measured from center to center, was 3 cm for the above electrode pairs. In order to investigate the three heads of the right triceps brachii muscle as a single entity, the triceps electrode pair was placed longitudinally in the midline of the posterior upper arm over the major bulk of the muscle, with an interelectrode distance of 4 cm. The locations of the eight surface electrode pairs are illustrated in Figure 2.

The electrodes were connected to the leads of an

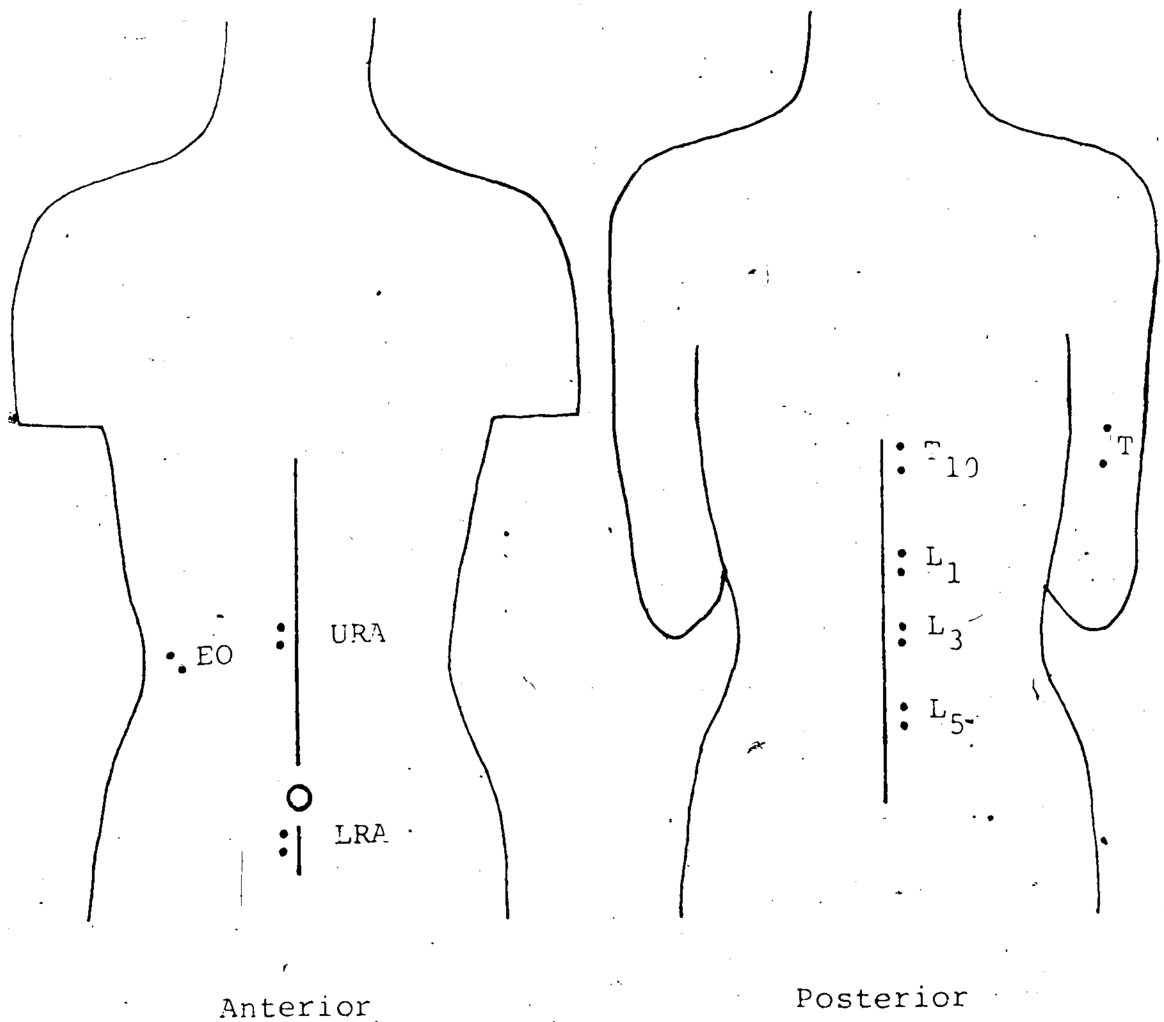

Figure 2. Positions of surface electrode pairs (EO indicates the external oblique electrode pair, URA upper rectus abdominis, LRA lower rectus abdominis, T triceps, and T_{10}, L_1, L_3, L_5 indicate the spinal levels of the erectores spinae electrode pairs).

eight channel Beckman Dynograph recorder, model R612* with a frequency response range of 5.3 to 1000 Hz. EMG potentials were full wave rectified and low-pass filtered (upper limit 100 Hz) for high frequency noise using a 9852A coupler producing a linear envelope.[36,37] Chart speed was calibrated at 11.5 mm/sec and was kept constant throughout the study. A permanent paper record (electromyogram) was produced from the Beckman ink-pen recorder.

The Experimental Procedure

Measurements of anthropometric characteristics of subjects seated in Position One were trunk height (chair seat to right acromium), knee to hip depth (right knee joint to greater trochanter), and right heel to posterior thigh distance. Upper arm length (right acromium to elbow joint) and forearm length (right elbow to radial styloid process) were measured in the standardized erect standing position. All measurements, testing, data extraction and analyses were completed by the author. A summary of subject anthropometric characteristics and reference seat heights may be found in Table I.

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*Beckman Instruments, Inc., Electronic Instruments Division, 3900 River Road, Schiller Park, Illinois 60176.

Table I. Summary of anthropometric characteristics of subjects and reference seat heights

Hand Support		Age (years)	Weight (cm)	Height (cm)	Trunk Height (cm)	Upper Arm Length (cm)	Forearm Length (cm)	Knee-Hip Length (cm)	Heel-Thigh Length (cm)	Reference Seat Height (P1)(cm)
	x̄	23.8	58.3	164.5	50.5	30.4	24.8	41.2	41.2	40.2
Armrest	s	3.4	5.2	4.7	2.3	1.2	0.7	1.9	[illegible]	2.2
n = 10	range	20.0- 31.0	47.9- 64.4	157.7- 172.4	47.0- 53.7	28.3- 32.3	23.6- [illegible]	[illegible]	[illegible]- 43.4	36.8- 42.3
Seat Surface	x̄	24.2	59.7	166.4	[illegible]	31.1	25.3	43.2	[illegible]	[illegible]
	s	4.6	5.8	4.3	[illegible]	1.3	0.8	2.5	[illegible]	[illegible]
n = 10	range	20.0- 35.0	49.6- 67.6	160.8- 174.2	47.5- 52.6	29.3- 33.7	23.7- 26.2	39.5- 47.3	[illegible]- 45.3	37.7- 43.3
	x̄	22.3	55.2	163.2	50.4	30.2	25.0	41.9	40.8	40.0
No	s	2.9	4.1	4.5	2.2	1.4	2.0	1.7	2.0	2.2
n = 10	range	18.0- 27.0	46.6- 59.8	154.2- 168.7	47.8- 55.0	27.8- 32.3	22.3- 29.4	39.0- 44.5	36.8- 43.6	36.9- 42.9

Subjects were randomly assigned to one of the three hand support conditions previously described. Each subject was given four practises of the test activities. Five EMG recordings of each test activity were obtained for each of the four positions of seat height, for each subject in the three hand support conditions. Position One was administered first, as Positions Two, Three and Four were established for each subject in reference to the seat height obtained in Position One. The position of each subject's feet was marked with masking tape in Position One, and maintained throughout the sequence of testing.[2,4] The sequence for completion of Positions Two, Three and Four was randomly assigned to each subject from a random number table.[87] Subjects relaxed in backrest supported sitting for 5 min between each change of seat height. Subjects also performed one practice, and three repetitions of each of the EMG reference activities.

Subjects maintained the standardized sitting and standing positions for a period of 30 sec prior to commencing the test activities. The durations of the test activities were determined in a pilot study of 324 trials using the two additional female subjects. Based on the mean durations calculated from the pilot study; a specified activity time of 2 sec was used for both rising and lowering.[3] Subjects performed the test activities to a metronome calibrated at one beat per sec.[3] In order to eliminate the effects of subject reaction time, subjects initiated the activities at will during a 5 sec period.

Cinematography

In order to examine the temporal, spatial and EMG patterns of the rising and lowering activities; combined EMG and cinematographic techniques were carried out using the two additional female subjects. The anthropometric characteristics of these subjects may be found in Appendix B. Since both subjects participated in all three hand support conditions in this portion of the investigation, the order of administration of the hand support conditions was also randomized. The experimental procedure was otherwise identical to that described for the main study.

Joint centers on the right side of the body were highlighted with 2 cm diameter white adhesive discs (Appendix B). A Photo-Sonics 16 mm-1PL movie camera* with a 12 to 120 mm Angenieux zoom lens was used to record the test activities on 16 mm double perforated, positive reversal, Kodak ectochrome 7250 film. The camera was

*Instrument Marketing Corporation, 820 Mariposa St., Burbank, California 91506.

situated 6.2 m from the subject. The horizontal axis of the lens was positioned at the level of L_3 during lift off, as this point formed the center of the photographic field. The test motions occurred in a plane perpendicular to the horizontal axis of the lens. The camera speed was set at 50 frames per second (fps), with a shutter opening of 30°, and film exposure time was calculated to be 0.0017 sec per frame. The filming record and graphic representation of the filming protocol are contained in Appendix B.

A Photo-Sonics Neon Timing Light Generator series TLG* was connected to both the camera and the Beckman Dynograph recorder. The internal timing light located within the camera was activated at a frequency of 10 Hz, producing a light trace on the edge of the film. The 10 Hz timing generator signal was simultaneously recorded by the Beckman EMG system using a 9852A coupler with an amplification factor of .5 V/mm. This arrangement made it possible to synchronize the film record with the EMG

*Instrument Marketing Corporation, 820 Mariposa St., Burbank, California 91506.

record. The identity of each test activity was ensured by assigning an event number to each trial in the randomized sequence. The event number for each test activity was displayed in the photographic field, as well as recorded on the corresponding electromyogram. Three synchronized EMG/film records of each test activity in each of the 24 test conditions were obtained for subject #1, whereas subject #2 performed three repetitions of the test activities using seat height Position One in each of the three hand support conditions. A total of 90 EMG/film records were thereby obtained.

Analysis

Data collection and analysis forms for both portions of the study may be found in Appendix C. In preparation for analysis, any EMG artifacts present were identified visually and excluded from the data. However, since it was not possible to distinguish between artifact and muscle activity in three of the triceps brachii records; these recordings were excluded from the analysis. As the statistical test required groups of equal size; three additional triceps brachii records were excluded by random selection to balance the groups. EMG recordings were digitized manually using a Hewlett-Packard 9874A digitizer*, and the area under the curve ($mm^2 \cdot sec$) calculated by a Hewlett-Packard 9826 desktop computer*. To exclude the sampling variation produced by total electrical impedance with use of EMG surface electrodes; mean EMG test values for each channel were normalized as percentages of the mean of three reference activities for both rising and lowering.[28,35,38,39]

In order to determine if EMG activity was significantly different among the combinations of four positions of seat height, three hand support conditions and two activities; a three-way analysis of variance with planned post-hoc multiple comparisons of means tests was carried out for each electrode pair.[88] A 0.05 level of significance was adopted.

In the combined EMG/cinematography portion of the study, trial #2 or #3 was randomly selected for analysis from the three repetitions of each test condition performed by each subject. A total of 30 synchronized EMG/film records were therefore, analyzed. The film was first examined using a Kodak Trimlite RC Reader**, and the

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* Hewlett-Packard, 3404 East Harmony Road, Fort Collins, Colorado 80525.

** Business Systems Market Division, Eastman Kodak Company, Rochester, New York 14650.

frames in which specific activity events occurred were marked (head and hand movements begin, lift off or touch down, hand contact with the chair begins or ends, and head and hand movements end). In order to determine the consistency of frame selection, the events of eight trials were selected 10 times at half hour intervals, and the number of the frame selected, in relation to the first timing generator trace for that trial, was recorded by an outside observer. A 6% error in frame selection was found for the eight trials and 28 events examined. Frame selection raw data is presented in Appendix B.

Each trial consisted of approximately 100 frames. Every fifth frame was marked, providing 21 frames per trial for analysis. The film speed was determined by counting the number of timing generator traces and the number of frames for each trial, and the frame rate was calculated using the following equation:[89]

$$\text{Frame Rate} = \frac{\text{number of frames}}{\text{number of timing traces} \times 0.01 \text{ sec}}$$

The time interval between frames was calculated as follows:

$$\text{Time Between Frames} = \frac{5}{\text{frame rate}}$$

In this manner, the film speed was found to be 50 fps, and the time between frames 0.1 sec.

The film record was analyzed using a pin registered Triad Motion Picture Analyzer* to project onto a Bendix Digitizing Board**. A Hewlett-Packard 9864A digitizer*** was used to enter the coordinates of a standard reference point, and in constant order, those of 11 subject reference points into a Hewlett-Packard 9825A computer***.[90] A custom program stored on magnetic tape then calculated body segment lengths from the digitized joint center points. Segment weights were calculated from the Humanscale anatomical data for females.[91] The horizontal and vertical displacement (x-y coordinates) of the body C of M were then determined, as well as the magnitude of hip flexion relative to the anatomical

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* Triad Corporation, 1200 Grand Ave., Glendale, California 91200.

** Bendix Corporation, Southfield, Michigan 98037.

*** Hewlett-Packard, 3404 East Harmony Road, Fort Collins, Colorado 80525.

position (the reciprocal of the trunk-thigh angle). Stick figures were also plotted, and later reduced for graphic display. The stick figures, EMG and biomechanical data were then synchronized by matching the timing generator traces for each trial.

Since the resolution of the film was good, the accuracy of the film analysis was dependent mainly on the reliability of digitizing. The computer program, therefore, also randomly selected one frame from each trial for redigitizing. Pearson Product Moment Correlation Coefficients were then calculated between the $time_1$ and $time_2$ coordinates of the 11 digitized reference points.[92] The reliability of digitizing was found to be $r = 0.99$, and the absolute differences between the coordinates did not exceed 2.4 mm.

CHAPTER IV

RESULTS AND DISCUSSION

The description of movement patterns using EMG and cinematography may provide both descriptive and quantitative information about the activities. The EMG recorded in the present study was considered to be a valid and reliable index of muscle tension in accordance with the methodological and physiological considerations reported by previous investigators.[26,28,33,34,38] Since rising and lowering are relatively slow activities,[4] and a frame rate of 50 fps was used to obtain a high quality, complete film record;[37] the 6% error in frame selection found in the present study may have been the result of the occurrence of a number of similar frames in the film record. The results and discussion of the main study will be organized around the specific muscle groups investigated, and the descriptive EMG/cinematography results will be discussed in a separate section. A summary of the discussion, as well as a discussion of clinical implications will follow.

Normalized EMG data, means, standard deviations, and summaries of the analyses of variance for the eight surface electrode pairs in the main study are presented in Appendix D. Between subject variations in EMG activity found in the present study were likely the result of the level of activity in the different muscle groups varying considerably among individuals.[48] Graphic representation of the synchronized EMG/cinematography data, and the cinematographic raw data from 0.2 sec intervals may be found in Appendix E.

Erectores Spinae

The cell means for the T_{10}, L_1, L_3 and L_5 electrode pairs are displayed graphically in Figures 3 and 4. Statistical testing for mean differences produced similar significant results for the four levels of erectores spinae monitored (Appendix D, Tables 1, 2, 3 and 4). The one exception was that greater levels of EMG activity occurred during rising than lowering at the T_{10} [$F_{(1,27)} = 5.46$, $p = 0.027$] and L_3 levels [$F_{(1,27)} = 17.08$, $p < 0.001$], whereas significance was not reached at the L_1 [$F_{(1,27)} = 3.26$, $p = 0.082$] and L_5 [$F_{(1,27)} = 4.14$, $p = 0.052$] levels. These findings may have been the result of varying degrees of saggital plane movement occurring at

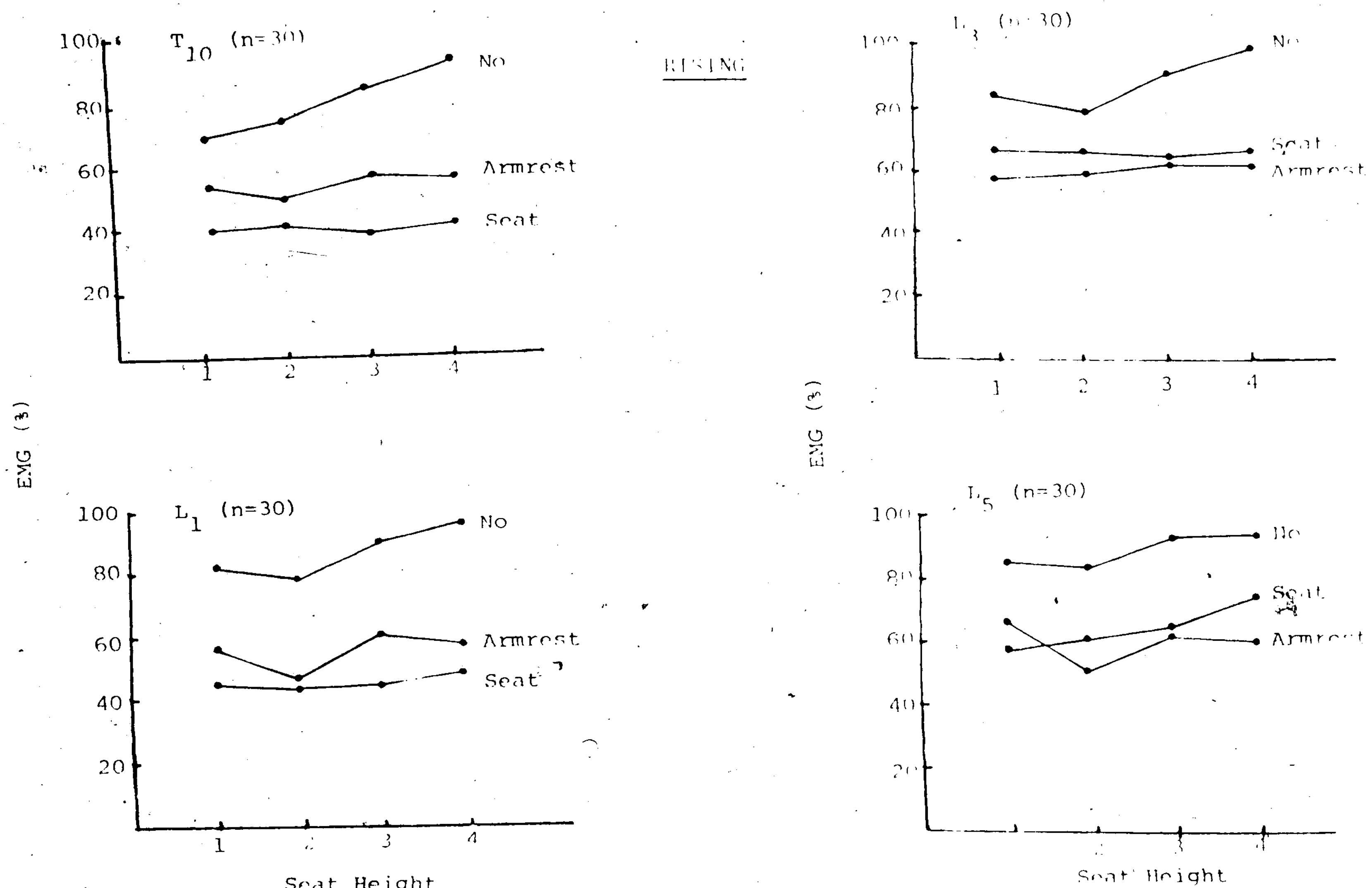

Figure 3. Mean EMG activity (%) of erectores spinae during rising with armrest, seat surface and no hand support using four levels of seat height. (One, knee angles 90°; Two 5 cm higher; Three, 5 cm lower; Four, 10 cm lower)

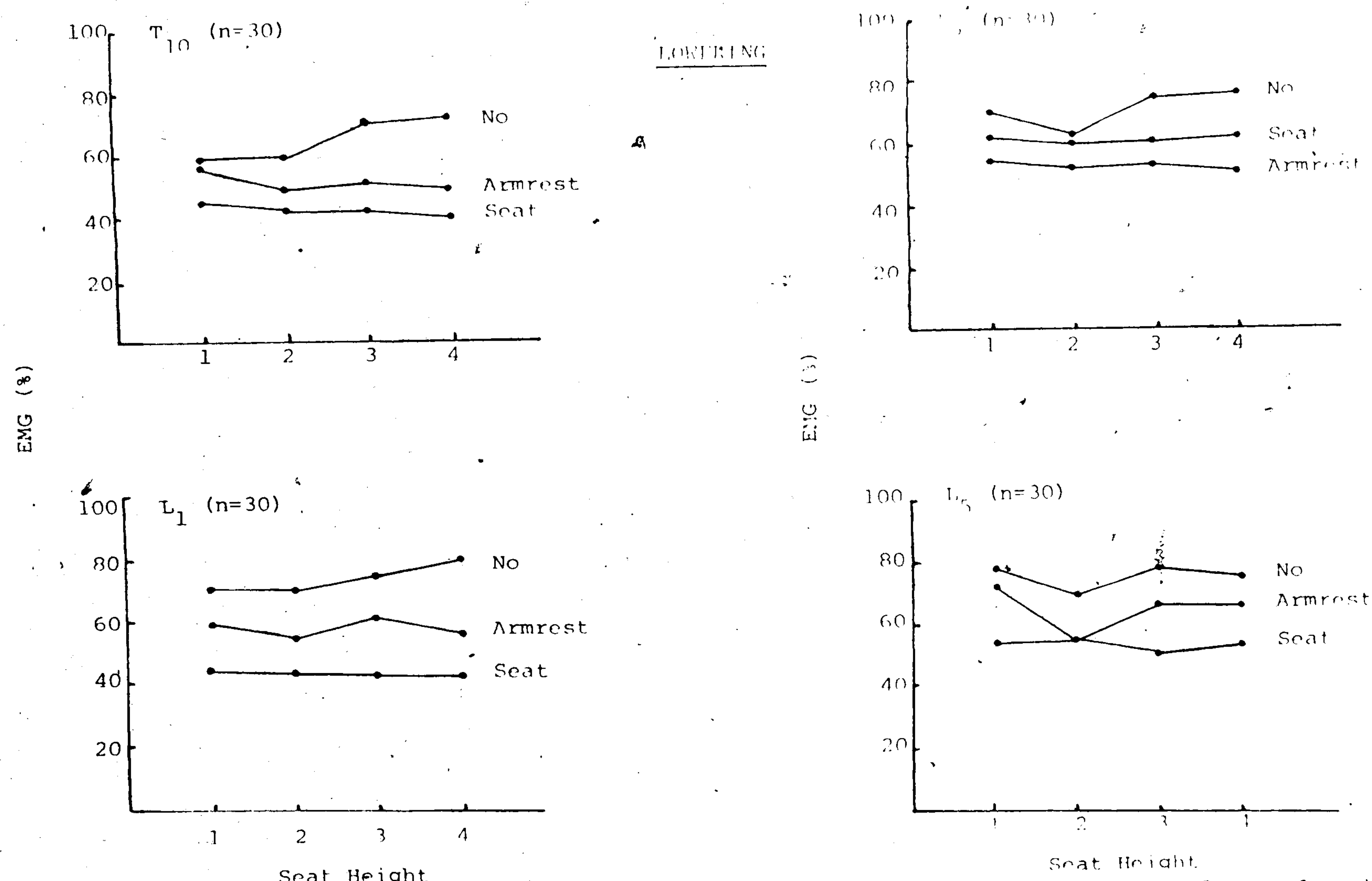

Figure 4. Mean EMG activity (%) of erectores spinae during lowering with armrest, seat surface and no hand support using four levels of seat height. (One, knee angles 90°; Two, 5 cm higher; Three, 5 cm lower; Four, 10 cm lower)

the different vertebral levels during the performance of the activities. However, a trend toward greater activity during rising is evident.

Given the complex nature of the activities, other factors may also have influenced EMG activity of erectores spinae during rising and lowering. Elevation of body weight in opposition to gravitational forces during rising would be expected to require greater muscle forces than gravity assisted lowering. In addition, erectores spinae works concentrically after lift off from the seat during rising, whereas the muscles work eccentrically prior to touch down on the seat during lowering. Larger EMG potentials, therefore, would be expected during rising.[31,33] However, it is likely that extensor muscle groups of the lower extremities provide the greater portion of the muscle forces required for vertical displacement of the body C of M during rising and lowering,[3,56,57] and that spinal loading is similar during the two activities.[1] Since EMG activity of erectores spinae has been previously shown to be a reliable index of spinal stress,[49,50,51] it may be concluded that both rising and lowering between sitting and standing increased spinal loading in the present study as evidenced by increases in EMG activity of erectores spinae.

The highest levels of EMG activity occurred when rising and lowering were performed without hand support, and significantly less electrical activity of erectores spinae was seen when hand support was used. These findings support the report of Andersson et al[1] who found that hand support significantly reduced the load on the spine during getting in and out of a chair. Since armrest and seat surface hand support produced similar activity levels of erectores spinae at the L_1, L_3 and L_5 vertebral levels, the method of hand support used does not appear to be a primary factor in the reduction of spinal stress. Andersson et al[1] also found that hand support on the thighs and on the armrests produced similar reductions in spinal loading during getting in and out of a chair. Higher levels of activity did occur at the T_{10} level when the arms were supported on the armrests as compared to the seat surface. This finding may be the result of anatomical differences in the lower thoracic region, where the erectores spinae lies deep to the trapezius and latissimus dorsi muscles. Greater activity of these muscles, which are important to arm function, may have occurred during the armrest support condition.

Significantly less EMG activity was seen with the use of seat Position One (knee angles 90°) and Two (5 cm higher) than with the use of seat heights Three and Four (5 and 10 cm lower, respectively). Lower seat heights, where the individual's knee angles were less than 90°, therefore, tended to increase erectores spinae activity and spinal loading during getting in and out of a chair. This finding was expected, since greater displacement of the body C of M would be required for the transition between sitting and standing.

The interaction between hand support and seat height was found to be significant at the T_{10}, L_1 and L_3 vertebral levels. Figures 3 and 4 demonstrate that relatively high levels of activity occurred when rising and lowering were performed with no hand support using the two lower seat heights. The use of hand support therefore, is particularly important in reducing spinal stress when lower seats are used.

The combination of the three hand support conditions and the two activities produced a differential at the L_3 and L_5 levels. Individual comparisons of means tests revealed that greater activity occurred during rising in the no hand support condition. The differences between the four seat heights and the two activities were also found to be significantly unequal at the T_{10}, L_1 and L_5 levels, since higher levels of activity occurred during rising when the two lower seat heights were used. The trend toward greater activity during rising has been discussed previously. These significant interactions provide additional support for the conclusion that higher spinal loading occurs when rising is performed either with no hand support or using lower seat heights.

Abdominal Muscles

Marked EMG activity of the rectus abdominis and external oblique muscles was observed during the rising and lowering activities; a finding which has not been previously documented. No significant difference in the magnitude of EMG activity was found between rising and lowering. It should be noted that EMG activity recorded with the external oblique surface electrode pair represents mainly external oblique since that muscle was closest to the electrodes.[29] Because the two oblique abdominal muscles lie in close proximity, some smaller amplitude internal oblique activity may also have been recorded. However, this activity is considered to be supplementary, since the ~~two~~ oblique muscles have been reported to work together functionally in symmetric movements in the sagittal plane,[29] such as were performed in the present study.

Increased intra-abdominal pressure resulting from contraction of the abdominal muscles has been reported to relieve some of the load on the spine.[6,62,93,94] Controversy exists in the literature regarding the relative importance of the contribution of the external oblique muscle to this load bearing mechanism.[29,93,94] However, it may be suggested from the present study that contraction of the abdominal muscles during getting in and out of a chair, aids in support of the spine.

In agreement with previous reports,[85,86] electrical activity of the upper and lower portions of the rectus abdominis muscle was found to be of a similar general pattern in the present study (Figures 5 and 6). Statistical testing of the main effects also produced similar results for the two electrode pairs (Appendix D, Tables 5 and 6). The results of the two rectus abdominis electrode pairs will therefore be discussed together.

Similar to the findings for erectores spinae, EMG activity of the rectus abdominis muscle was found to be greater when rising and lowering were performed with no hand support. This involuntary increase in rectus abdominis activity could represent a reflex response to

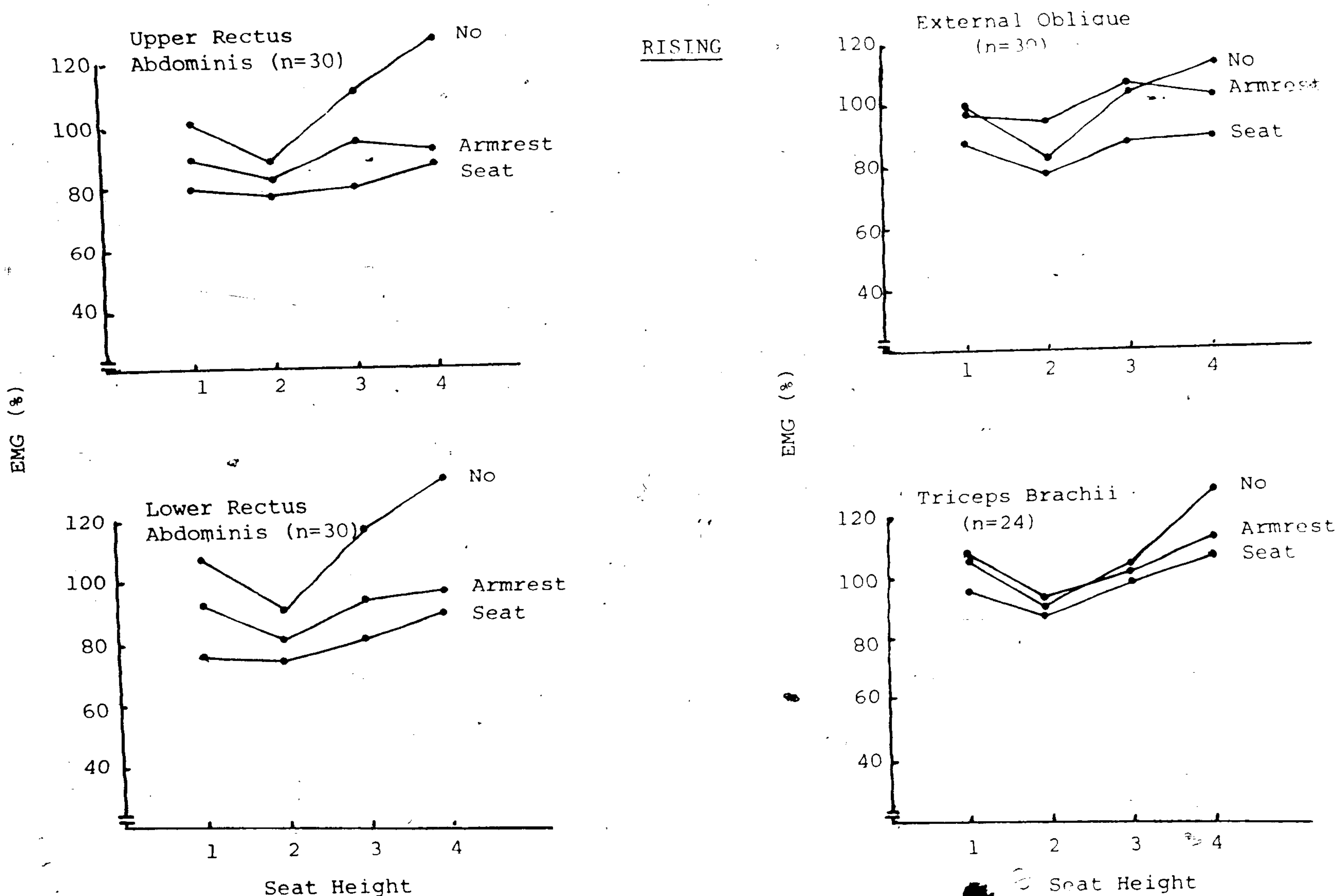

Figure 5. **Mean EMG activity (%) of rectus abdominis, external** oblique and triceps brachii during rising with three conditions of hand support and four levels of seat height

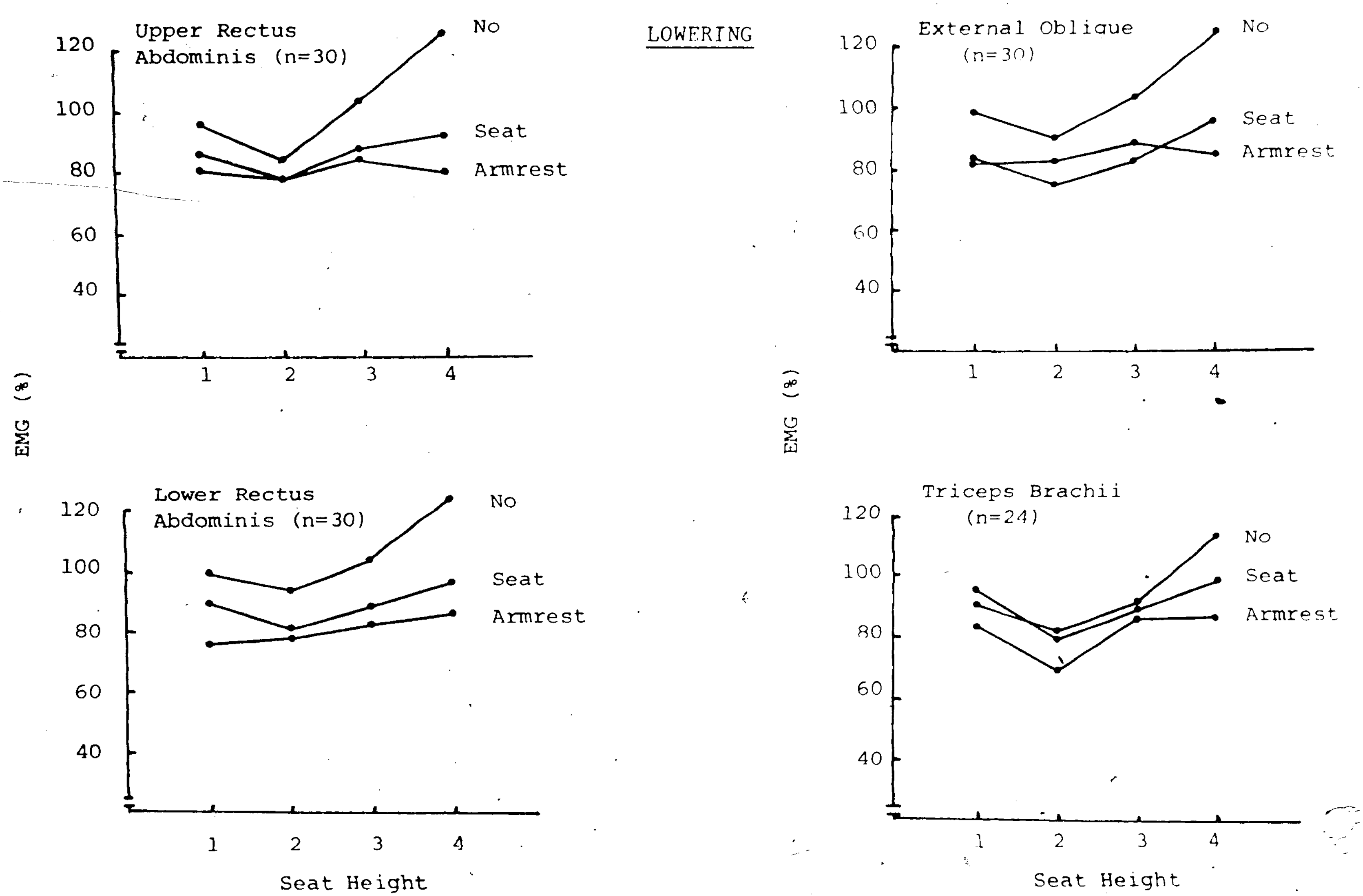

Figure 6. Mean EMG activity (%) of rectus abdominis, external oblique and triceps brachii during lowering with three conditions of hand support and four levels of seat height

the increased load on the spine that occurred in the no hand support condition.[94] EMG activity recorded from the external oblique electrode pair, however, was not significantly different among the three conditions of hand support [$F_{(2,27)} = 2.82$, $p = 0.077$]. This finding may reflect the role of the oblique abdominal muscles as stabilizers of the pelvis and trunk.[25]

Higher levels of both rectus abdominis and external oblique activity occurred with the use of the two lower seat heights. Getting in and out of a chair with lower seat heights has been reported to require a greater amount of hip flexion.[2] Sagittal plane movements of the trunk during rising were also found to be largely pivoting motions of the trunk as a whole around the hip joint axes of rotation.[3] It is suggested that with the use of lower seat heights, more forward pivoting of the upper body occurs, and more erectores spinae and abdominal muscle activity are needed to stabilize the trunk. Although gravity is believed to be the prime mover during forward bending of the trunk,[25] the abdominal muscles may also assist in rotating the pelvis posteriorly when lowering into a chair.

A differential effect between hand support and activity was found for the lower rectus abdominis.

electrode pair, since significantly more EMG activity occurred during rising with no hand support as compared to seat surface hand support. Significant interactions between the levels of seat height and the conditions of hand support were also found for all three abdominal electrode pairs. Similar to the findings for erectores spinae, multiple comparisons of means tests revealed that greater EMG activity of rectus abdominis occurred when rising and lowering were performed with no hand support using the two lower seat heights, whereas the highest levels of external oblique activity occurred during rising and lowering using no hand support and the lowest seat height. This evidence suggests that the no hand support, lower seat height test conditions, which produced the most erectores spinae activity and the highest loads on the spine, also elicited the largest abdominal muscle response.

Triceps Brachii

An unanticipated finding was that no difference was found in the activity levels of triceps brachii when the three hand support conditions, including no hand support, were compared (see Figures 5 and 6, and Appendix D, Table 8). Hand support may normally be used automatically when larger vertical displacements of the body C of M are required, such as with the use of lower seat heights. It is also possible that the arms, as represented by triceps activity, function mainly in balancing the trunk when normal subjects get in and out of a chair. Support for this interpretation is given by previous reports of large torques and vigorous accelerations at the knee joints during rising.[56,57] Vertical displacement of the body C of M during rising and lowering may therefore, be normally accomplished mainly by the muscles of the lower extremities,[3,56,57] and vertical thrust by the arms may be necessary only in the presence of lower extremity pathology.

Significantly greater triceps brachii activity occurred with the use of the two lower seat heights as compared to the highest seat height. Since greater vertical displacement of the body center of mass is required when rising and lowering are performed using lower seat heights, the two lower seat heights used in the study may have enhanced the balancing function of the arms. Higher levels of triceps activity also occurred during rising as compared to lowering at all four positions of seat height. This finding may have been the result of the gravity-resisted, concentric triceps activity required for rising as compared to the gravity-assisted, eccentric activity required for lowering.

Synchronized EMG/Cinematography

The synchronized EMG/cinematographic data, which is displayed in tables and graphs located in Appendix E, provides descriptive support for the parametric portion of the investigation. The 30 test conditions analyzed are displayed graphically in pairs, in order to illustrate some of the spatial characteristics of the test activities in relation to the EMG. Although the graphs will be discussed in relation to the findings of the main study; it should be noted that EMG linear envelopes are presented in this portion of the study whereas normalized EMG was used in the quantitative analysis.

The 12 rising test conditions and the 12 lowering test conditions were each found to involve similar movement patterns. Rising was found to be a two part activity, first involving forward pivoting of the trunk about the hip joint axes of rotation. Maximum hip flexion occurred near the time of lift off from the seat (subject 1 $\bar{x}$ 0.88 sec, subject 2 $\bar{x}$ 0.87 sec). The magnitude of maximum hip flexion appeared to depend on the seat height of the chair (seat height Position One subject 1 $\bar{x}$ 117°, subject 2 $\bar{x}$ 95°; Position Two subject 1 $\bar{x}$ 103°; Position Three subject 1 $\bar{x}$ 119°; Position Four subject 1 $\bar{x}$ 126°). Progressively lower seat heights therefore, tended to produce more hip flexion during rising. In agreement with previous reports,[1,3] the hips, knees and trunk were gradually extended after the point of lift off, until the standing position was reached (see rising stick figures, Appendix E). In the test conditions using hand support, hand contact with the chair ended in this second portion of activity (subject 1 $\bar{x}$ 1.18 sec, subject 2 $\bar{x}$ 1.16 sec).

Lowering appeared to be a reversal of the rising activity, as flexion of the hips, knees and trunk ocurred in the first portion of the activity[1] (see lowering stick figures, Appendix E). In the test conditions using hand support, hand contact also began in this first part of the activity (subject 1 $\bar{x}$ 0.70 sec, subject 2 $\bar{x}$ 0.70 sec). Maximum hip flexion occurred near the time of touch down on the seat (subject 1 $\bar{x}$ 1.18 sec, subject 2 $\bar{x}$ 0.99 sec). The magnitude of maximum hip flexion again appeared to depend on the seat height of the chair (seat height, Position One subject 1 $\bar{x}$ 112°, subject 2 $\bar{x}$ 93°; Position Two subject 1 $\bar{x}$ 107°; Position Three subject 1 $\bar{x}$ 117°; Position Four subject 1 $\bar{x}$ 127°). Lower seats therefore, tended to increase hip flexion during lowering. After seat contact was made, a backward pivoting motion of the trunk occurred about the hip joint axes of rotation, in order to raise the trunk into the standardized sitting position.

The magnitude of hip flexion, relative to the anatomical position, that was present during sitting also depended on the seat height of the chair (seat height Position One subject 1 $\bar{x}$ 65°, subject 2 $\bar{x}$ 62°; Position Two subject 1 $\bar{x}$ 62°; Position Three subject 1 $\bar{x}$ 71°; Position Four subject 1 $\bar{x}$ 81°). Lower seat heights therefore, produced more hip flexion in the standardized sitting position used in the study. An expected moderate variation in the degree of hip flexion during erect standing was found for each subject. Subject 1's hip flexion in standing ranged from +11 to -11° (mean -3°), whereas subject 2 had a range of -22 to -12° (mean -16°). Between subject variations in the standing posture are common. Within subject variations were likely the result of the spine being subjected to a constant forward bending moment since the line of gravity usually lies ventral to its transverse axes of rotation.[25,48]

Displacement of the body C of M, relative to the standard reference point of the origin of the digitizing board, was found to occur in a characteristic pattern during rising from sitting to standing. Prior to lift off from the seat, the forward pivoting motion of the trunk resulted in gradual horizontal displacement and minimal vertical displacement of the C of M (Appendix E). EMG activity of erectores spinae and the abdominal muscles began in this phase, and the amplitude of activity increased gradually. Since forward displacement of the C of M is known to create a flexor gravitational force, the erectores spinae activity observed in this phase produced an extensor moment to balance the trunk and control the motion.[61,62] The abdominal muscle activity that occurred in this first portion of the activity aided in support of the spine. After lift off from the seat, the horizontal movement of the C of M continued in a forward direction for a brief period, and then rapidly levelled off at maximum as the standing position was approached. A narrow range of maximum horizontal displacement values were observed during the rising test activities (subject 1 $\bar{x}$ 35 cm, range 33-37 cm; subject 2 $\bar{x}$ 34 cm, range 32-36 cm). Since the standardized position of the feet used in the study restricted forward-backward movement of the whole body, this range of horizontal displacement of the body C of M may be accounted for by the postural sway that normally occurs during standing.[57]

Following lift off from the seat, rapid upward movement of the body C of M was observed, and maximum values were found when the subjects reached the standing position. Maximum vertical displacement values appeared to depend on the seat height of the chair (seat height Position One subject 1 $\bar{x}$ 23 cm, subject 2 $\bar{x}$ 27 cm; Position Two subject 1 $\bar{x}$ 24 cm; Position Three subject 1 $\bar{x}$ 31 cm; Position Four subject 1 $\bar{x}$ 34 cm). As suggested previously, greater vertical displacement of the body C of M was required when lower seat heights were used.

EMG activity of erectores spinae also occurred in the post-lift off phase of rising, in order to extend the trunk against the forces of gravity.[61] Since more trunk flexion in relation to the hip joint axes of rotation, and more vertical displacement of the body C of M were required with the use of lower seat heights; relatively more erectores spinae activity was also observed when lower seat heights were used. The magnitude of abdominal and triceps brachii EMG activity during the second phase of rising also increased with the use of lower seat heights to assist in stabilizing and balancing the trunk.

The levels of seat height which were found to produce significant differences in EMG activity in the main study are contrasted in the subject 1 rising with no Hand support and rising with seat surface hand support figures contained in Appendix E. Subject 1's data for rising with armrest hand support contrasts levels of seat height between which no significant differences were found in the main study. Similar contrasts are presented for subject 1 during lowering. Subject 1's data also demonstrates that lower levels of EMG activity of the trunk muscles occurred when hand support was used. Since rising and lowering with hand support relieves the spine of the weight of the arms,[64] less trunk muscle activity would then be required for movement and stabilization of the trunk. Data from subject 2 contrasts rising and lowering, as no conclusive differences in EMG activity of the trunk muscles were found between the two activities.

Displacement of the body C of M also occurred in a similar general pattern during the lowering test activities. Maximum horizontal displacement values, relative to the digitizer origin, were observed in the standing position (subject 1 $\bar{x}$ 34 cm, subject 2 $\bar{x}$ 35 cm). The C of M then gradually moved backward as the subject lowered into the chair, and pivoted the trunk backward into the standardized sitting position. Vertical displacement of the body C of M occurred in a downward direction, and was dependent on the seat height of the chair (seat height Position One subject 1 $\bar{x}$ 27 cm, subject 2 $\bar{x}$ 26 cm; Position Two subject 1 $\bar{x}$ 24 cm; Position Three subject 1 $\bar{x}$ 30 cm; Position Four subject 1 $\bar{x}$ 33 cm). As was found for rising, lower seat heights produced greater vertical displacement of the C of M and more trunk flexion during lowering. Since lowering is a reversal of the rising activity, EMG activity of erectores spinae observed prior to touch down served to balance the trunk against flexor gravitational forces, whereas erectores spinae extended the trunk against gravity in the post-touch down phase. Abdominal and triceps brachii muscle activity also occurred during lowering to stabilize and balance the trunk (see lowering, Appendix E).

Summary of Discussion

The purpose of this study was to determine if EMG activity of the trunk muscles and triceps brachii would differ among the combinations of armrest, seat surface and no hand support, and four 5 cm increments of seat height during rising and lowering between sitting and standing. Descriptive information on the spatial characteristics of the motions was also obtained using combined cinematographic and EMG techniques.

Statistical testing of quantified EMG data from 30 subjects revealed significant differences between the 24 test conditions which have not been discussed in previous research. The major findings of the study involved the type of hand support and the levels of seat height which maximized EMG activity of the trunk muscles and triceps brachii during rising and lowering. Since mechanical stresses acting on the spine are believed to be associated with the development of degenerative disc disease and low back pain,[12,13,19,20,21] and EMG activity of erectores spinae was found to be a reliable index of spinal stress;[49,50,51] the findings of the present study were discussed in terms of spinal loading.

Hand support was found to significantly reduce the load on the spine during the transition between sitting and standing. Rectus abdominis activity was shown to increase in proportion to spinal stress with the highest levels being observed when rising and lowering were performed with no hand support. Lower seat heights, where the individual's knee angles were less than 90°, also significantly increased EMG activity of the trunk muscles and triceps brachii during rising and lowering. It was suggested that this finding was the result of the greater displacement of the body C of M required for getting in and out of chairs with lower seat heights. Support for this interpretation was found in the results of the cinematographic analysis, where progressively lower seat heights tended to increase both hip flexion and the vertical displacement of the body C of M. The major conclusions of the study were therefore, that the use of hand support and of seat heights equal to or slightly greater than the length of the lower leg will minimize spinal stress during the transition between sitting and standing.

Clinical Implications

The findings of this study suggest important clinical considerations for both the preventative and remedial aspects of back care education. If patients with low back pain, and persons in sedentary type occupations are encouraged to develop habits of getting in and out of a chair using hand support, spinal stress may be significantly reduced on a daily basis. A further reduction in mechanical stress on the spine may be realized by the use of seat heights that are equal to or slightly greater than the length of the individual's lower legs. The resultant sitting position with thighs horizontal, lower legs vertical and knee angles 90° will facilitate the transition between sitting and standing. While both the use of hand support and the appropriate seat height should be emphasized; hand support becomes increasingly important in reducing spinal stress when lower seat heights are used.

Abdominal muscle action, by increasing intra-abdominal pressure, provides important additional support for the spine during getting in and out of a chair. Poor abdominal muscle strength would likely result in additional spinal stresses occurring during rising and lowering. The routine assessment and, if necessary, improvement of abdominal strength would therefore, also be of value in reducing spinal stress. Since patients with musculoskeletal problems involving the lower limbs likely rely on the elbow extensors and abdominal muscles to a greater extent than normal during rising and lowering; strong triceps brachii muscles should be ensured when lower extremity pathology is present.

CHAPTER V

CONCLUSIONS

1. Hand support significantly reduces EMG activity of erectores spinae during rising and lowering between sitting and standing. As EMG activity of the back muscles has previously been shown to be a reliable index of mechanical stress acting on the spine, spinal stress during rising and lowering may be reduced by the use of hand support.
2. Armrest and seat surface hand support produce similar reductions in EMG activity of the lumbar portion of the erectores spinae muscles.
3. Lower seat heights, where the individual's knee angles are less than 90°, increases erectores spinae activity and therefore, spinal loading during getting in and out of a chair.
4. Marked activity of the rectus abdominis and external oblique muscles occurs during rising and lowering between sitting and standing. This abdominal muscle action aids in the support of the spine.

5. EMG activity of rectus abdominis is greater when rising and lowering between sitting and standing are performed without hand support.
6. Getting in and out of a chair with lower seat heights increases the activity of the abdominal and triceps brachii muscles.
7. EMG activity of triceps brachii is similar whether or not hand support is used during the transition between sitting and standing. The arms therefore, function mainly in balancing the trunk when rising and lowering are performed by normal subjects.
8. A description of some of the spatial characteristics of rising and lowering between sitting and standing was provided. Progressively lower seat heights tend to increase hip flexion and vertical displacement of the body C of M during the transition between sitting and standing.

Recommendations

The findings of the current study warranted the following recommendations:

1. Further study is needed to evaluate the effects of alterations in feet positions during rising and lowering between sitting and standing.

2. The frequency of appropriate seat height adjustment, and the use of hand support during rising and lowering requires evaluation in the general population.
3. Additional studies are required to examine the spatial characteristics of rising and lowering between sitting and standing including both a larger number of subjects and the evaluation of forces.
4. A reliable, low risk method is needed to evaluate the magnitude of pelvic inclination and lumbar lordosis during various postures and activities.
5. Normative data is required for the postural characteristics of the erect standing posture, based on the variability found for two subjects in the present study.

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APPENDIX A

Consent Forms

Department of Physical Therapy
Faculty of Rehabilitation Medicine
University of Alberta
November, 1983

INFORMED CONSENT FORM FOR INVESTIGATIVE STUDY

Electromyographic and Cinematographic Analysis of Rising and Lowering Between Sitting and Standing

Outline of Procedures (retained by subject).

The purpose of the study is to determine the optimal combination of hand support and seat height to facilitate getting in and out of a chair. The entire procedure will require two hours of time, in one session. Your height, weight, arm length, trunk height and leg length will be measured. Eight pairs of surface electrodes will be placed on the skin surface of your right low back region, abdomen and upper arm attached by adhesive collars and adhesive tape.

You will be asked to perform four repetitions of rising and lowering between sitting and standing with a five kg weight in each hand; and 23 repetitions of getting in and out of the chair with either arm rest hand support, seat surface hand support or no support. Muscle activity will be monitored during the movements. On completion of the testing procedure, the electrodes and adhesive tape will be removed.

The test procedure is not considered to involve any abnormal physical risks. Getting in and out of a chair is an activity of daily living, which is commonly performed many times in the course of a day. Information gained from this study is expected to be of benefit to persons with low back problems and persons involved in sedentary type occupations.

You may withdraw from participation as a subject in this investigation at any time. Please feel free to ask any questions you may have concerning the testing procedures or other aspects of the project.

All records will be held in confidence. The reports of the study will include averages and trends for groups of subjects without identification of individuals.

Department of Physical Therapy
Faculty of Rehabilitation Medicine
University of Alberta
November, 1983

INFORMED CONSENT FORM FOR INVESTIGATIVE STUDY

Electromyographic and Cinematographic Analysis of Rising and Lowering Between Sitting and Standing

Subject Consent (retained by investigator)

I ____ agree to participate as a subject in the study entitled "Electromyographic and Cinematographic Analysis of Rising and Lowering Between Sitting and Standing" to be conducted by Mrs. Conne Robertshaw. The nature of this study has been explained to me, and I have been advised that I may withdraw from participation at any time.

Date: _______________ ________________________________

Subject's Signature

Department of Physical Therapy
Faculty of Rehabilitation Medicine
University of Alberta

Investigation: Electromyographic and Cinematographic Analysis of Rising and Lowering Between Sitting and Standing

CONSENT FOR PHOTOGRAPHY-CINEMATOGRAPHY

I ______________________________, authorize
(model)

______________________________ to take still photo-
(photographer)

graphs or moving pictures of me, as I participate as a subject in the investigative study entitled "Electromyographic and Cinematographic Analysis of Rising and Lowering Between Sitting and Standing". I understand that these photographs or moving pictures will be used for analysis of the movements, and may be used in professional publications, or for teaching purposes.

I waive the right to inspect and/or approve the still photographs or moving pictures that may be taken or their specific use, when limited to the above.

I have read the foregoing, and give my consent to those matters as stated above.

Date: ______________ Model: ______________________

APPENDIX B

Filming Records and Frame Selection Raw Data

EMG/Cinematographic Subject Anthropometric Characteristics

	Subject #1	Subject #2
Age (years)	20.0	24.0
Weight (kg)	54.2	53.4
Weight (N)	531.7	523.9
Height (cm)	158.8	157.7
Trunk height (cm)	48.5	49.0
Upper arm length (cm)	29.0	28.0
Forearm length (cm)	22.5	21.5
Knee to hip depth (cm)	41.4	40.2
Heel to posterior thigh distance (cm)	38.5	38.8
Reference seat height (Position One) (cm)	39.0	38.0

FILMING RECORD

Date: November 26, 1983 Location: 1-101B Corbett Hall

Time Started: 1030 Hours Time Completed: 1600 Hours

Camera: Photo-Sonics 16 mm - 1PL movie camera

Film: double perforated Kodak ectochrome 7250 (400 ASA)

Focal length: 60 mm focus: 60 ft. f-stop: 3.8

Frame rate: 50 fps Shutter Opening: 30°

Exposure time: 0.0017 sec/frame Camera Height: 108.5 cm

Camera-Subject Distance: 6.2 m

Background: Light blue backdrop

Artificial Lights: two 650 watts, two 1000 watts

Activity Identification: events 1-90

Subjects: #1, #2

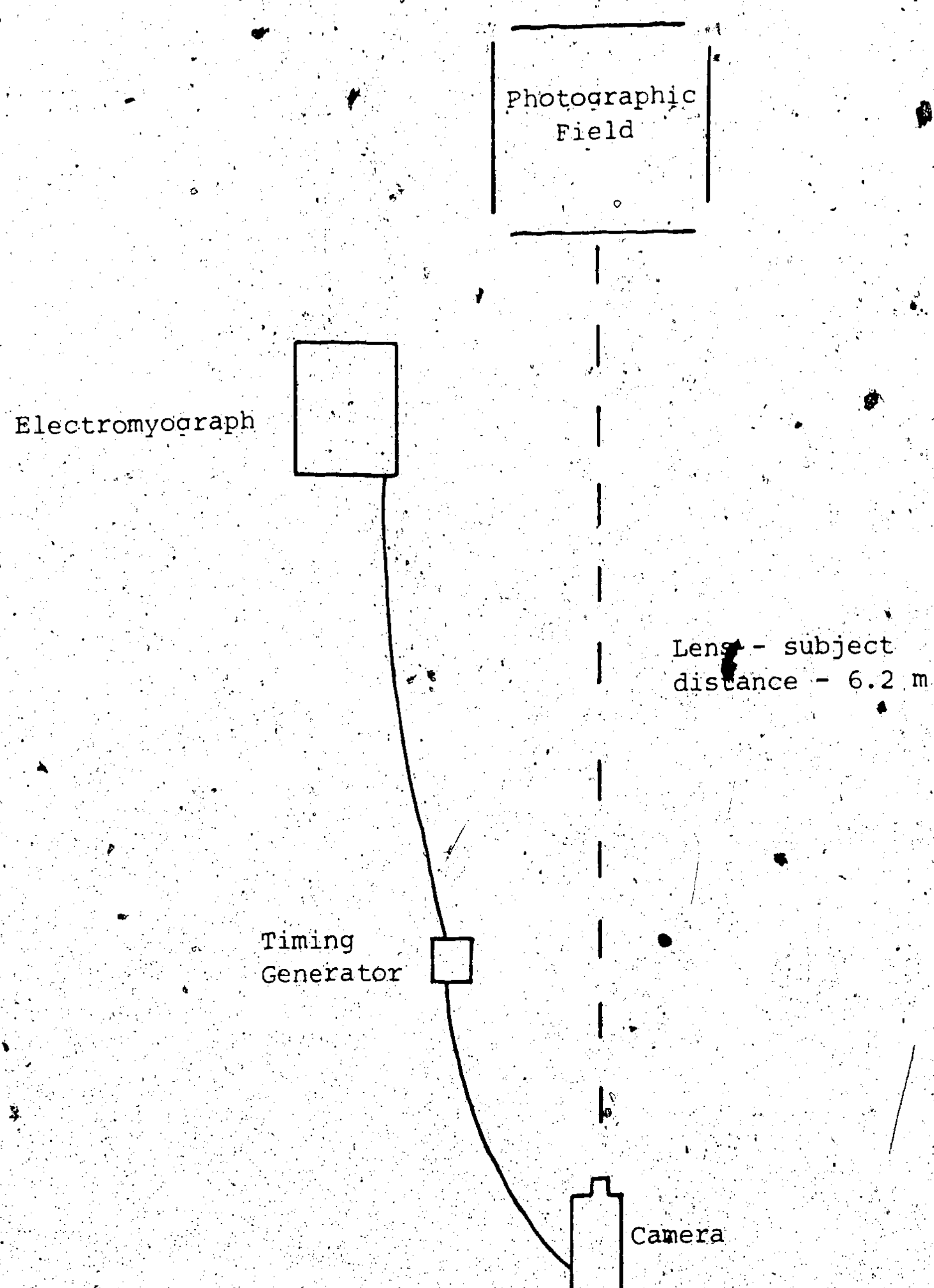
Joint Markings: right acromium, right elbow joint, right wrist joint, right greater trochanter, right knee joint, right lateral malleolus

Filming Sequence: Subject #1 - events 1-72
Subject #2 - events 73-90

Scale Object: meter stick

Horizontal and Vertical References: levelled meter stick

Schematic Representation of Filming Protocol



Frame Selection Consistency: Raw Data*

Seat Height Position One

1. Rising with no hand support

a) Frame head and hand movements begin

Subject 1: 3, 3, 3, 3, 3, 3, 3, 3, 3, 3
Subject 2: 60, 59, 60, 60, 60, 60, 60, 60, 60, 60

b) Lift off

Subject 1: 46, 47, 46, 46, 46, 46, 46, 46, 46, 46
Subject 2: 22, 22, 22, 22, 22, 22, 22, 22, 22, 22

c) Head and hand movements end

Subject 1: 98, 98, 98, 98, 98, 98, 98, 98, 98, 98
Subject 2: 98, 99, 98, 98, 98, 98, 98, 98, 98, 98

2. Lowering with no hand support

a) Frame head and hand movements begin

Subject 1: 20, 20, 20, 20, 20, 20, 20, 20, 20, 20
Subject 2: 51, 52, 52, 52, 52, 52, 52, 52, 52, 52

b) Touch down

Subject 1: 71, 71, 71, 71, 71, 71, 71, 71, 71, 71
Subject 2: 4, 4, 4, 4, 4, 4, 4, 4, 4, 4

c) Head and hand movements end

Subject 1: 98, 98, 98, 98, 98, 98, 98, 98, 98, 98
Subject 2: 45, 45, 44, 44, 44, 44, 44, 44, 44, 44

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*In relation to the first timing generator trace for each trial.

3. Rising with seat surface hand support

a) Frame head and hand movements begin

Subject 1: 6, 6, 6, 6, 6, 6, 6, 6, 6, 6
Subject 2: 47, 47, 46, 47, 47, 47, 47, 47, 47, 47

b) Lift off

Subject 1: 59, 59, 59, 59, 59, 59, 59, 59, 59, 59
Subject 2: 4, 4, 4, 4, 4, 4, 4, 4, 4, 4

c) Hand contact ends

Subject 1: 76, 76, 76, 76, 76, 76, 76, 76, 76, 76
Subject 2: 5, 5, 5, 5, 5, 5, 5, 5, 5, 5

d) Head and hand movements end

Subject 1: 106, 107, 106, 106, 106, 106, 106, 106, 106, 106
Subject 2: 49, 49, 50, 49, 50, 49, 49, 49, 49, 49

4. Lowering with armrest hand support

a) Frame head and hand movements begin

Subject 1: 38, 38, 37, 38, 38, 38, 38, 38, 38, 38
Subject 2: 28, 29, 29, 29, 29, 29, 29, 29, 29, 29

b) Hand contact begins

Subject 1: 1, 1, 2, 1, 1, 1, 1, 1, 1, 1
Subject 2: 7, 7, 7, 7, 7, 7, 7, 7, 7, 7

c) Touch down

Subject 1: 23, 23, 23, 23, 23, 23, 23, 23, 23, 23
Subject 2: 24, 24, 24, 24, 24, 24, 24, 24, 24, 24

d) Head and hand movement ends

Subject 1: 63, 63, 63, 62, 63, 63, 63, 63, 63, 63
Subject 2: 69, 70, 68, 70, 70, 70, 70, 70, 70, 70

APPENDIX C

Data Acquisition Forms

SUBJECT ANTHROPOMETRIC CHARACTERISTICS

Subject: ______________________ Date: ____________

Screening test (repetitions) ____________

Activity level ____________
____

Age (years) ____________

Weight (kg) ____________

Height (cm) ____________

Trunk height (cm) ____________

Upper arm length (cm) ____________

Forearm length (cm) ____________

Knee to hip depth (cm) ____________

Heel to posterior thigh distance (cm) ____________

Reference seat height (Position One) (cm) ____________

EMG area/time analysis ($mm^2 \cdot sec$)

Subject: ____________ Seat Height ________ Hand Support ________

	Reference Activity				Rising						Reference Activity				Lowering					
	1	2	3	$\bar{x}$	1	2	3	4	5	$\bar{x}$	1	2	3	$\bar{x}$	1	2	3	4	5	$\bar{x}$
T_{10}																				
L_1																				
L_3																				
L_5																				
EO																				
URA																				
LRA																				
Tr																				

EMG Activity (%) (mean test activity/mean reference activity × 100)

Rising

T_{10} ________ EO ________

L_1 ________ URA ________

L_3 ________ LRA ________

L_5 ________

Lowering

T_{10} ________ EO ________

L_1 ________ URA ________

L_3 ________ LRA ________

L_5 ________

CINEMATOGRAPHIC ANALYSIS

Subject: ______________________ Trial Number __________

Trial Description: ______________________________________

10 Hz	Light Trace	Frame	Events
	1.	______	
	2.	______	
	3.	______	
	4.	______	
	5.	______	
	6.	______	
	7.	______	
	8.	______	
	9.	______	
	10.	______	
	11.	______	
	12.	______	
	13.	______	
	14.	______	
	15.	______	
	16.	______	
	17.	______	
	18.	______	
	19.	______	
	20.	______	
	21.	______	
	22.	______	
	23.	______	

Time of Trial __________ Frames to be Analyzed __________

Frame Rate __________ Time Between Frames __________

Comments: ______________________________________

____

____

____

APPENDIX D

EMG Raw Data and Anova Summaries

1. Summary of analysis of variance for the T_{10} electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	116985.38	29		
Factor A (hand support)	40277.63	2	20138.81	7.09*
Subject within groups	76707.75	27	2841.03	
Within Subjects	43856.00	210		
Factor B (seat height)	2024.25	3	674.75	3.17*
Factor A × Factor B (AB)	3417.63	6	569.60	2.68*
Factor B × Subject within groups	17222.38	81	212.62	
Factor C (activity)	2134.81	1	2134.81	5.46*
Factor A × Factor C (AC)	2466.38	2	1233.19	3.15
Factor C × Subject within groups	10562.06	27	391.19	
Factor B × Factor C (BC)	815.06	3	271.69	4.38*
Factor A × Factor B × Factor C (ABC)	186.44	6	31.07	0.50
Factor BC × Subject within groups	5027.81	81	62.07	

* ($p < 0.05$)

2. Summary of analysis of variance for the L_1 electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	119835.31	29		
Factor A (hand support)	49925.50	2	24962.75	9.64*
Subject within groups	69909.81	27	2589.25	
Within Subjects	33794.00	210		
Factor B (seat height)	2050.56	3	683.52	6.29*
Factor A × Factor B (AB)	1681.44	6	280.24	2.58*
Factor B × Subject within groups	8797.00	81	108.60	
Factor C (activity)	1570.31	1	1570.31	3.26
Factor A × Factor C (AC)	2073.25	2	1036.63	2.15
Factor C × Subject within groups	13010.44	27	481.87	
Factor B × Factor C (BC)	607.56	3	202.52	4.25*
Factor A × Factor B × Factor C (ABC)	141.75	6	23.63	0.50
Factor BC × Subject within groups	3863.56	81	47.70	

* ($p < 0.05$)

3. Summary of analysis of variance for the L_3 electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	71255.00	29		
Factor A (hand support)	19972.00	2	9986.00	5.26*
Subject within groups	51283.00	27	1899.37	
Within Subjects	31199.00	210		
Factor B (seat height)	1113.00	3	371.00	3.75*
Factor A × Factor B (AB)	2515.00	6	419.17	4.24*
Factor B × Subject within groups	8013.00	81	98.93	
Factor C (activity)	4156.00	1	4156.00	17.08*
Factor A × Factor C (AC)	1881.00	2	940.50	3.87*
Factor C × Subject within groups	6569.00	27	243.30	
Factor B × Factor C (BC)	232.00	3	77.33	0.98
Factor A × Factor B × Factor C (ABC)	324.00	6	54.00	0.68
Factor BC × Subject within groups	6396.00	81	78.96	

* ($p < 0.05$)

4. Summary of analysis of variance for the L_5 electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	70252.00	29		
Factor A (hand support)	26429.00	2	13214.50	8.14*
Subject within groups	43823.00	27	1623.07	
Within Subjects	52362.00	210		
Factor B (seat height)	1932.00	3	644.00	3.07*
Factor A × Factor B (AB)	1629.00	6	271.00	1.29
Factor B × Subject within groups	17009.00	81	209.99	
Factor C (activity)	2423.00	1	2423.00	4.14
Factor A × Factor C (AC)	4578.00	2	2289.00	3.91*
Factor C × Subject within groups	15798.00	27	585.11	
Factor B × Factor C (BC)	769.00	3	256.33	2.76*
Factor A × Factor B × Factor C (ABC)	710.00	6	118.33	1.28
Factor BC × Subject within groups	7514.00	81	92.77	

* ($p < 0.05$)

5. Summary of analysis of variance for the upper rectus abdominis electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	99770.00	29		
Factor A (hand support)	21422.00	2	10711.00	3.69*
Subject within groups	78348.00	27	2901.78	
Within Subjects	66100.00	210		
Factor B (seat height)	9974.00	3	3324.67	12.73*
Factor A × Factor B (AB)	6659.00	6	1109.83	4.25*
Factor B × Subject within groups	21153.00	81	261.15	
Factor C (activity)	117.00	1	117.00	0.20
Factor A × Factor C (AC)	1995.00	2	997.50	1.74
Factor C × Subject within groups	15497.00	27	573.96	
Factor B × Factor C (BC)	50.00	3	16.67	0.13
Factor A × Factor B × Factor C (ABC)	406.00	6	67.67	0.53
Factor BC × Subject within groups	10249.00	81	126.53	

* ($p < 0.05$)

6. Summary of analysis of variance for the lower rectus abdominis electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	94686.00	29		
Factor A (hand support)	25439.00	2	12719.50	4.96*
Subject within groups	69247.00	27	2564.70	
Within Subjects	75851.00	210		
Factor B (seat height)	14722.00	3	4907.33	17.29*
Factor A × Factor B (AB)	5471.00	6	911.83	3.21*
Factor B × Subject within groups	22989.00	81	283.81	
Factor C (activity)	124.00	1	124.00	0.21
Factor A × Factor C (AC)	4981.00	2	2490.50	4.21*
Factor C × Subject within groups	15963.00	27	591.22	
Factor B × Factor C (BC)	318.00	3	106.00	0.80
Factor A × Factor B × Factor C (ABC)	542.00	6	90.33	0.68
Factor BC × Subject within groups	10741.00	81	132.60	

* $(p < 0.05)$

7. Summary of analysis of variance for the external oblique electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	63453.00	29		
Factor A (hand support)	10951.00	2	5475.50	2.82
Subject within groups	52502.00	27	1944.52	
Within Subjects	63434.00	210		
Factor B (seat height)	8554.00	3	2851.33	14.49*
Factor A × Factor B (AB)	3787.00	6	631.17	3.21*
Factor B × Subject within groups	15939.00	81	196.78	
Factor C (activity)	685.00	1	685.00	0.95
Factor A × Factor C (AC)	3994.00	2	1997.00	2.76
Factor C × Subject within groups	19532.00	27	723.41	
Factor B × Factor C (BC)	689.00	3	229.67	1.88
Factor A × Factor B × Factor C (ABC)	371.00	6	61.83	0.51
Factor BC × Subject within groups	9883.00	81	122.01	

* ($p < 0.05$)

8. Summary of analysis of variance for the triceps brachii electrode pair

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Between subjects	82633.00	23		
Factor A (hand support)	2337.00	2	1168.50	0.31
Subject within groups	80296.00	21	3823.62	
Within Subjects	64731.00	168		
Factor B (seat height)	14474.00	3	4824.66	16.00*
Factor A × Factor B (AB)	3280.00	6	546.67	1.81
Factor B × Subject within groups	19003.00	63	301.63	
Factor C (activity)	6113.00	1	6113.00	12.81*
Factor A × Factor C (AC)	1539.00	2	769.50	1.61
Factor C × Subject within groups	10024.00	21	477.33	
Factor B × Factor C (BC)	151.00	3	50.33	0.33
Factor A × Factor B × Factor C (ABC)	400.00	6	66.67	0.43
Factor BC × Subject within groups	9747.00	63	154.71	

* $(p < 0.05)$

EMG (%)

T_{10} Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	91.3	33.1	93.7	35.8	100.2	38.8	62.2	26.1
	2	26.5	31.5	32.8	34.2	46.3	49.0	37.3	31.6
	3	43.8	47.9	44.2	42.5	38.4	34.1	40.9	44.3
	4	37.7	32.1	36.6	52.7	39.7	33.7	31.3	42.6
	5	43.8	36.9	30.0	43.5	45.6	51.1	57.3	52.3
	6	94.5	88.9	112.8	112.4	119.3	103.3	93.6	91.5
	7	86.1	106.4	98.8	108.0	76.8	68.9	73.5	76.3
	8	35.6	31.6	45.0	46.7	41.9	43.1	60.4	58.5
	9	42.9	52.6	58.0	62.7	38.0	34.6	36.0	45.6
	10	45.3	49.4	55.7	51.6	30.3	28.0	38.0	39.5
	$\bar{x}$	54.8	51.0	60.9	59.0	57.7	48.5	53.1	50.8
	s	25.4	26.1	30.0	28.2	30.4	22.3	20.0	20.0
Seat Surface	1	34.6	39.9	25.0	28.2	31.4	33.5	34.9	41.9
	2	30.7	28.6	34.0	32.8	44.1	43.7	45.2	37.7
	3	51.2	58.6	47.5	51.8	49.6	55.6	56.9	46.3
	4	47.4	42.4	53.9	69.2	39.3	36.7	36.2	36.9
	5	42.1	55.7	43.6	53.4	48.7	39.3	46.9	43.0
	6	47.0	43.4	36.8	49.5	37.2	47.2	24.7	23.0
	7	21.9	26.0	17.7	28.8	18.3	20.8	15.3	24.2
	8	37.2	43.1	37.5	39.6	26.1	26.4	22.0	21.1
	9	53.2	41.9	62.4	50.0	69.2	33.6	74.8	53.3
	10	45.0	38.3	41.9	35.0	78.8	91.9	66.4	71.9
	$\bar{x}$	41.0	41.8	40.0	43.8	44.3	42.8	42.3	39.9
	s	9.9	10.1	13.1	13.2	18.6	19.9	19.5	15.5
No	1	56.6	60.5	48.3	56.9	53.9	36.9	38.2	43.0
	2	73.5	62.0	88.0	115.8	36.0	36.9	75.1	92.5
	3	74.9	79.8	83.9	87.3	52.4	52.8	60.8	65.6
	4	71.3	116.6	122.8	140.0	68.6	148.4	133.7	130.7
	5	83.9	87.3	82.6	91.7	69.5	66.8	66.2	65.7
	6	73.6	85.6	99.1	93.4	79.7	60.8	68.6	79.7
	7	59.2	49.6	55.8	66.4	56.5	54.7	66.6	63.6
	8	96.7	82.6	112.6	141.4	79.3	68.8	92.4	75.7
	9	43.3	42.0	53.5	52.9	53.1	24.8	54.1	50.2
	10	63.6	72.3	75.6	100.3	49.4	57.1	63.7	55.5
	$\bar{x}$	69.7	73.8	85.2	94.6	59.8	60.8	71.9	72.2
	s	14.9	21.6	25.2	31.2	14.0	33.9	25.7	25.1

EMG (%)

L_1 Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	62.0	16.3	62.3	25.3	66.3	30.5	80.7	26.9
	2	26.9	23.6	32.8	24.2	44.1	38.1	35.7	25.7
	3	42.4	45.1	51.3	53.3	45.2	46.4	47.8	51.3
	4	24.3	27.6	28.0	31.5	46.8	39.0	39.8	50.6
	5	50.3	49.9	58.5	74.1	64.2	61.6	63.0	60.6
	6	58.7	53.0	58.0	50.0	74.4	102.3	77.2	74.9
	7	110.1	96.8	124.6	135.5	65.7	45.8	64.8	67.6
	8	117.7	71.0	95.2	112.1	100.4	109.2	121.9	126.7
	9	46.8	58.2	63.2	59.2	46.2	48.8	53.2	43.9
	10	46.8	57.5	58.3	52.0	39.0	45.5	35.0	47.7
	$\bar{x}$	58.6	49.9	63.2	61.7	59.2	56.7	61.9	57.6
	s	31.5	23.9	28.2	36.7	18.9	21.1	26.6	28.9
Seat Surface	1	66.2	63.7	56.1	58.6	63.1	54.9	57.9	72.8
	2	97.2	87.5	84.7	101.4	83.9	85.1	83.5	90.7
	3	55.0	49.3	50.7	50.1	45.3	53.8	51.3	47.2
	4	57.3	47.7	49.4	56.1	45.8	34.2	44.6	34.4
	5	30.0	35.4	38.2	45.0	34.3	48.0	51.0	47.1
	6	34.7	36.5	32.7	46.4	31.7	40.3	17.7	20.4
	7	27.2	23.0	24.9	29.7	32.9	31.1	24.6	30.8
	8	41.0	46.8	46.4	49.0	29.3	25.7	21.4	20.5
	9	36.3	39.4	40.1	45.1	50.6	37.3	44.5	50.3
	10	35.1	38.0	42.9	40.4	51.0	53.6	51.7	36.2
	$\bar{x}$	48.0	46.7	46.6	52.2	46.8	46.4	44.8	45.0
	s	21.5	17.9	16.2	19.1	16.9	17.0	19.7	22.3
No	1	75.7	59.8	69.7	69.0	72.0	65.1	77.1	70.7
	2	88.7	87.3	107.2	97.7	71.9	66.3	89.4	99.0
	3	75.2	70.1	81.5	88.3	55.5	44.3	61.4	69.9
	4	85.3	68.6	86.7	88.8	54.2	71.3	63.2	65.6
	5	82.7	95.4	109.2	98.2	69.6	72.0	63.3	81.0
	6	88.3	92.0	107.0	104.4	73.7	84.2	76.5	58.6
	7	72.1	66.1	85.9	97.7	62.0	60.0	68.0	76.0
	8	84.7	82.4	95.5	122.1	95.8	86.7	87.8	115.2
	9	80.0	94.1	103.4	118.4	84.1	91.7	92.9	100.0
	10	83.8	85.9	91.7	94.4	78.4	69.2	83.0	79.1
	$\bar{x}$	81.7	80.2	93.8	97.9	71.7	71.1	76.3	81.5
	s	5.7	12.9	13.1	15.2	12.7	13.9	11.8	17.8

EMG (%)

L_3 Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	35.2	37.6	43.3	31.0	39.2	34.9	22.3	17.3
	2	29.9	41.3	37.1	43.1	58.3	60.5	52.4	40.6
	3	75.9	59.3	71.1	55.4	72.3	57.6	61.5	55.9
	4	74.3	54.4	59.7	46.1	75.7	60.6	80.6	64.0
	5	59.6	74.4	72.2	67.7	44.7	59.8	45.7	35.6
	6	73.8	63.1	83.6	99.2	72.4	72.0	70.9	64.2
	7	51.5	59.5	65.3	58.1	49.4	32.6	54.1	51.1
	8	76.3	78.4	71.2	89.0	61.0	49.4	54.1	67.8
	9	40.0	47.8	55.0	53.6	43.0	42.8	34.3	39.3
	10	53.3	71.6	68.0	71.8	60.1	62.5	53.8	63.4
	$\bar{x}$	57.0	58.7	62.7	61.5	57.6	53.3	54.1	49.9
	s	17.8	13.8	14.2	20.9	13.2	12.9	17.1	16.4
Seat Surface	1	71.9	53.4	50.1	58.0	60.9	51.4	58.9	86.2
	2	77.5	67.2	65.2	65.5	81.6	81.6	83.3	74.8
	3	77.6	76.3	71.4	60.2	87.8	74.4	81.1	81.1
	4	57.0	49.5	48.9	51.4	63.1	65.1	43.2	51.2
	5	89.8	82.8	93.5	89.3	69.2	69.2	88.5	79.2
	6	40.0	53.5	49.4	56.1	42.4	47.1	2[illegible].1	24.4
	7	103.5	113.3	88.9	87.6	98.4	93.9	86.1	82.9
	8	65.1	72.9	81.4	80.6	57.3	87.0	75.6	87.8
	9	34.7	39.8	41.1	44.5	39.3	34.1	35.2	33.9
	10	42.6	44.6	47.7	56.3	27.5	34.3	29.0	25.3
	$\bar{x}$	66.0	65.3	63.8	65.0	62.8	62.7	60.9	62.7
	s	22.5	22.1	19.1	15.6	22.4	21.5	24.9	26.2
No	1	91.2	77.0	69.3	65.0	62.5	53.7	77.1	71.8
	2	66.3	79.1	78.3	69.3	69.7	57.4	72.9	83.4
	3	86.5	44.7	59.7	57.1	70.5	38.6	54.4	57.9
	4	94.7	76.7	104.8	92.8	58.3	71.5	72.0	77.1
	5	95.5	103.9	103.6	126.7	90.8	77.7	107.0	115.9
	6	79.9	89.0	89.0	109.1	69.7	63.4	67.1	65.0
	7	72.2	57.3	78.0	92.2	67.4	60.6	67.2	85.2
	8	74.1	79.4	91.4	126.1	68.5	57.7	102.0	71.0
	9	85.0	76.6	108.9	105.1	59.6	55.2	58.0	63.4
	10	93.4	91.8	102.4	123.4	77.3	70.0	80.9	78.0
	$\bar{x}$	83.9	77.6	88.5	96.7	69.4	60.6	75.9	76.9
	s	0.3	16.8	16.7	26.0	9.4	11.0	17.1	16.3

EMG (%)

L_5 Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	64.4	21.4	52.0	30.2	117.4	21.3	95.6	49.2
	2	55.9	64.7	51.1	51.2	55.1	33.7	31.1	34.7
	3	88.5	60.4	92.6	77.7	67.5	60.9	76.6	62.4
	4	47.9	47.9	50.2	55.2	64.3	61.6	67.9	75.2
	5	47.3	26.0	41.3	45.0	59.4	32.4	38.4	85.4
	6	34.6	35.5	56.0	39.7	58.4	71.1	70.7	73.8
	7	100.0	73.0	77.5	81.1	60.0	30.8	86.9	41.5
	8	75.8	83.5	76.2	76.5	92.9	87.7	78.1	69.4
	9	73.1	53.2	54.1	60.5	77.2	69.6	80.1	100.6
	10	54.9	66.3	62.2	72.6	69.4	75.1	53.4	69.7
	$\bar{x}$	64.2	53.2	61.3	59.0	72.2	54.4	67.9	66.2
	s	20.2	20.4	15.8	17.7	19.4	22.9	20.8	20.1
Seat Surface	1	80.7	73.0	64.9	86.3	64.0	61.6	60.2	59.2
	2	63.7	67.8	67.8	87.2	64.8	51.1	47.0	44.2
	3	91.6	82.8	93.3	95.3	95.4	83.2	67.5	84.3
	4	51.9	55.7	96.8	98.6	65.2	70.0	67.9	69.4
	5	35.5	47.7	33.6	41.6	45.2	47.9	42.5	61.0
	6	72.3	77.7	77.2	100.2	44.6	43.1	37.2	38.5
	7	48.3	43.6	40.4	52.7	49.8	43.4	46.5	41.0
	8	46.2	59.4	60.9	55.5	46.8	49.6	42.9	37.3
	9	41.3	54.5	56.7	58.0	41.2	45.4	50.8	46.1
	10	48.4	47.4	55.4	63.4	50.3	55.8	54.5	50.3
	$\bar{x}$	58.0	61.0	64.7	73.9	56.7	55.1	51.7	53.1
	s	18.3	13.7	20.4	21.8	16.3	13.0	10.6	15.2
No	1	76.5	71.1	59.4	56.9	63.8	54.0	71.2	61.4
	2	77.8	79.1	78.8	71.1	98.6	69.6	90.8	76.4
	3	101.1	76.4	137.1	89.5	97.1	72.4	106.3	86.8
	4	68.6	66.9	82.8	99.1	46.2	64.5	50.4	56.7
	5	90.2	103.2	94.2	97.4	71.2	73.0	59.9	67.9
	6	122.2	126.1	103.8	96.7	116.1	101.6	97.9	103.9
	7	73.5	67.1	67.7	73.6	51.5	62.6	47.4	37.8
	8	62.5	71.7	80.1	106.5	65.1	71.2	94.2	73.7
	9	96.3	84.9	127.7	132.4	105.3	91.8	111.0	129.8
	10	99.6	108.6	116.3	113.0	65.3	43.3	57.4	58.8
	$\bar{x}$	86.8	85.5	94.8	93.6	78.0	70.4	78.7	75.3
	s	18.3	20.3	25.9	22.0	24.2	16.8	24.0	26.2

EMG (%)

Upper Rectus Abdominis Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	125.0	128.6	116.4	134.8	111.6	117.4	125.5	111.8
	2	73.8	63.5	69.0	54.7	57.3	47.3	53.8	42.2
	3	68.5	51.2	67.0	61.2	60.0	55.6	51.4	46.2
	4	70.2	60.4	80.2	63.0	83.8	76.7	90.5	78.6
	5	58.3	48.8	63.5	69.0	65.8	103.4	72.9	58.8
	6	113.1	102.8	158.0	148.9	87.9	93.8	104.6	108.9
	7	153.3	96.7	122.0	113.2	64.2	47.6	67.8	91.2
	8	66.9	68.6	82.8	75.3	87.2	77.0	100.1	90.5
	9	71.6	119.7	65.8	78.6	93.6	79.4	93.3	89.2
	10	93.8	105.9	109.4	101.6	97.2	87.0	95.6	88.5
	$\bar{x}$	89.5	84.6	93.4	90.0	80.9	78.5	85.6	80.6
	s	31.2	29.4	31.6	32.9	18.2	23.3	23.6	24.2
Seat Surface	1	55.4	61.9	63.0	85.8	78.6	58.1	95.6	103.0
	2	86.1	89.1	90.1	88.7	77.3	88.0	84.5	88.0
	3	93.3	84.5	123.7	136.1	130.6	100.8	150.1	95.3
	4	91.3	74.2	61.2	104.3	89.0	53.4	71.6	104.2
	5	57.4	73.6	70.1	69.9	68.4	75.2	77.9	83.1
	6	87.6	76.8	85.0	76.6	84.7	72.1	103.8	106.3
	7	72.8	76.5	59.3	75.7	93.7	88.6	82.2	94.6
	8	96.1	100.2	97.5	90.7	78.1	115.0	87.6	112.7
	9	75.1	64.9	70.5	64.8	85.4	65.3	78.4	81.9
	10	82.9	67.8	69.2	75.7	75.4	64.9	60.5	53.8
	$\bar{x}$	79.8	77.0	79.0	86.8	86.1	78.1	89.2	93.3
	s	14.4	11.6	20.1	20.8	17.2	19.7	24.5	14.5
No	1	108.8	93.3	112.6	138.5	100.7	112.9	86.1	175.9
	2	81.2	96.6	94.9	94.5	106.8	88.3	106.8	128.7
	3	93.5	56.7	78.6	85.4	93.5	54.8	79.0	87.3
	4	89.8	78.9	98.2	96.9	76.1	69.3	93.0	86.9
	5	113.6	108.4	128.7	156.3	107.6	103.3	131.5	150.0
	6	128.7	100.0	125.9	118.1	96.9	80.5	101.2	100.2
	7	63.5	55.2	73.1	81.8	86.4	72.4	68.5	90.3
	8	119.9	92.4	96.4	128.8	94.9	77.7	94.0	120.2
	9	105.5	124.9	132.5	174.6	77.1	99.0	106.5	138.7
	10	106.4	82.7	151.6	157.3	133.2	108.0	167.2	184.5
	$\bar{x}$	101.1	88.9	109.3	123.2	97.3	86.6	103.4	126.3
	s	19.4	21.6	25.3	33.1	16.6	18.9	28.3	36.0

EMG (%)

Lower Rectus Abdominis Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	84.7	68.6	79.0	94.4	68.0	78.5	69.1	80.3
	2	85.8	92.6	75.4	74.7	53.1	49.8	57.1	59.7
	3	85.3	81.3	87.6	68.5	70.0	72.6	70.3	76.9
	4	71.4	53.4	81.1	79.5	76.2	71.0	97.4	85.5
	5	52.7	37.8	58.7	59.3	49.7	119.1	53.4	64.9
	6	120.7	107.5	140.1	141.1	93.8	103.0	115.4	103.9
	7	123.2	106.7	139.7	133.9	106.0	67.0	91.5	107.1
	8	87.7	100.2	102.1	84.6	100.5	93.5	128.4	104.3
	9	92.7	83.6	60.0	93.1	63.4	50.0	62.0	91.7
	10	122.1	102.7	119.4	114.4	73.2	77.7	79.7	105.8
	$\bar{x}$	92.6	83.4	94.3	94.4	75.4	78.2	82.4	88.0
	s	23.2	23.7	30.0	27.4	19.1	21.9	25.3	17.4
Seat Surface	1	77.3	61.0	71.9	85.9	67.3	52.7	66.5	93.5
	2	86.9	89.6	98.4	104.6	118.9	136.7	114.4	132.6
	3	97.0	87.4	137.4	123.6	115.5	84.0	134.3	128.0
	4	69.7	41.8	66.1	98.4	88.7	52.3	74.4	96.2
	5	70.3	95.3	94.3	68.7	80.8	80.0	91.8	88.6
	6	58.2	66.0	68.6	89.9	86.1	61.8	92.9	104.6
	7	68.7	72.3	71.1	82.1	88.0	88.5	84.4	92.2
	8	80.5	86.8	69.2	68.6	104.9	129.6	98.8	104.6
	9	78.8	72.9	75.3	66.5	86.3	69.3	83.3	76.6
	10	69.0	58.5	66.2	66.2	79.4	60.3	55.4	62.1
	$\bar{x}$	75.6	73.2	81.9	85.5	91.6	81.5	89.6	97.9
	s	11.0	16.8	22.6	19.2	16.4	30.0	22.9	21.3
No	1	143.9	71.2	155.1	174.5	85.6	65.8	95.9	173.0
	2	88.3	91.0	98.5	97.6	73.9	6[illegible].8	76.7	92.6
	3	83.5	43.9	60.3	70.4	88[illegible]	50.4	91.6	83.5
	4	105.8	92.5	110.6	124.3	113.3	110.1	127.9	119.2
	5	94.2	80.4	87.8	135.7	102.6	94.8	115.4	143.9
	6	119.5	117.5	131.9	130.6	87.7	70.5	96.0	86.1
	7	91.1	72.9	117.1	117.9	92.9	93.5	76.7	108.7
	8	123.0	108.5	115.2	109.3	120.3	78.4	102.2	152.8
	9	108.7	116.1	120.5	155.3	101.1	117.9	121.6	136.5
	10	118.6	95.0	146.4	166.9	135.2	106.1	153.0	173.7
	$\bar{x}$	107.7	88.9	114.4	128.3	100.1	85.2	105.7	127.0
	s	18.9	22.8	27.8	32.0	18.5	22.5	23.9	34.1

EMG (%)

External Oblique Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	126.1	125.2	125.7	129.2	106.7	87.7	91.3	118.3
	2	107.2	133.7	129.2	135.5	60.9	55.3	68.6	64.5
	3	82.2	74.9	85.1	69.4	71.2	66.9	68.1	64.5
	4	78.4	66.5	80.4	66.3	85.5	85.1	91.6	81.4
	5	68.5	66.4	80.2	80.0	82.5	118.1	85.9	91.0
	6	126.2	136.5	126.4	141.4	84.4	83.4	100.6	91.1
	7	104.0	80.7	88.4	96.7	84.7	76.0	86.6	113.4
	8	82.3	91.1	124.4	89.5	91.6	83.5	100.4	82.3
	9	93.7	98.0	116.3	110.8	95.2	85.8	98.2	75.2
	10	110.2	92.7	97.6	94.5	74.0	90.9	104.2	87.1
	$\bar{x}$	97.9	96.6	105.4	101.3	83.7	83.2	89.6	86.9
	s	20.1	26.7	20.9	27.0	12.9	16.3	12.7	18.0
Seat Surface	1	88.5	65.1	52.8	72.2	58.3	68.8	52.7	99.3
	2	95.3	78.1	92.1	78.6	90.5	79.2	90.8	80.5
	3	132.3	85.1	145.8	119.3	82.4	79.1	115.7	100.5
	4	64.0	48.1	79.3	81.4	93.7	84.0	73.4	144.5
	5	84.3	107.8	107.1	101.9	75.3	80.0	94.0	92.0
	6	70.7	74.7	81.7	106.2	97.6	68.0	105.7	102.7
	7	70.3	76.4	69.1	78.3	86.0	86.5	72.9	95.8
	8	113.5	106.4	111.6	113.0	91.2	86.4	74.0	103.7
	9	83.4	75.4	74.1	71.5	90.5	74.1	85.4	87.7
	10	77.3	66.4	64.4	64.9	76.2	59.8	62.0	63.4
	$\bar{x}$	88.0	78.4	87.8	88.7	84.2	76.6	82.7	97.0
	s	21.1	18.1	27.4	19.5	11.6	8.8	19.5	20.7
No	1	127.4	90.0	1140.0	162.9	137.9	137.9	97.2	158.9
	2	87.4	90.3	103.4	97.6	95.9	79.0	101.7	110.4
	3	85.3	55.0	76.8	78.2	94.9	51.6	81.0	91.9
	4	113.8	84.5	110.4	117.3	109.4	93.0	107.4	107.4
	5	108.0	84.4	108.2	113.9	104.3	98.3	123.7	140.3
	6	99.4	92.6	101.1	100.9	83.1	72.4	99.1	90.6
	7	59.7	62.8	64.3	78.1	79.2	58.8	70.0	94.8
	8	97.2	67.7	68.1	87.9	86.6	111.1	85.6	123.7
	9	102.3	114.9	127.0	162.1	83.9	106.5	109.6	145.5
	10	114.0	93.5	127.9	122.4	114.5	109.6	159.2	170.6
	$\bar{x}$	99.5	83.6	102.7	112.1	99.0	91.8	103.5	123.4
	s	18.9	17.5	25.9	30.6	18.1	26.5	24.9	29.0

EMG (%)

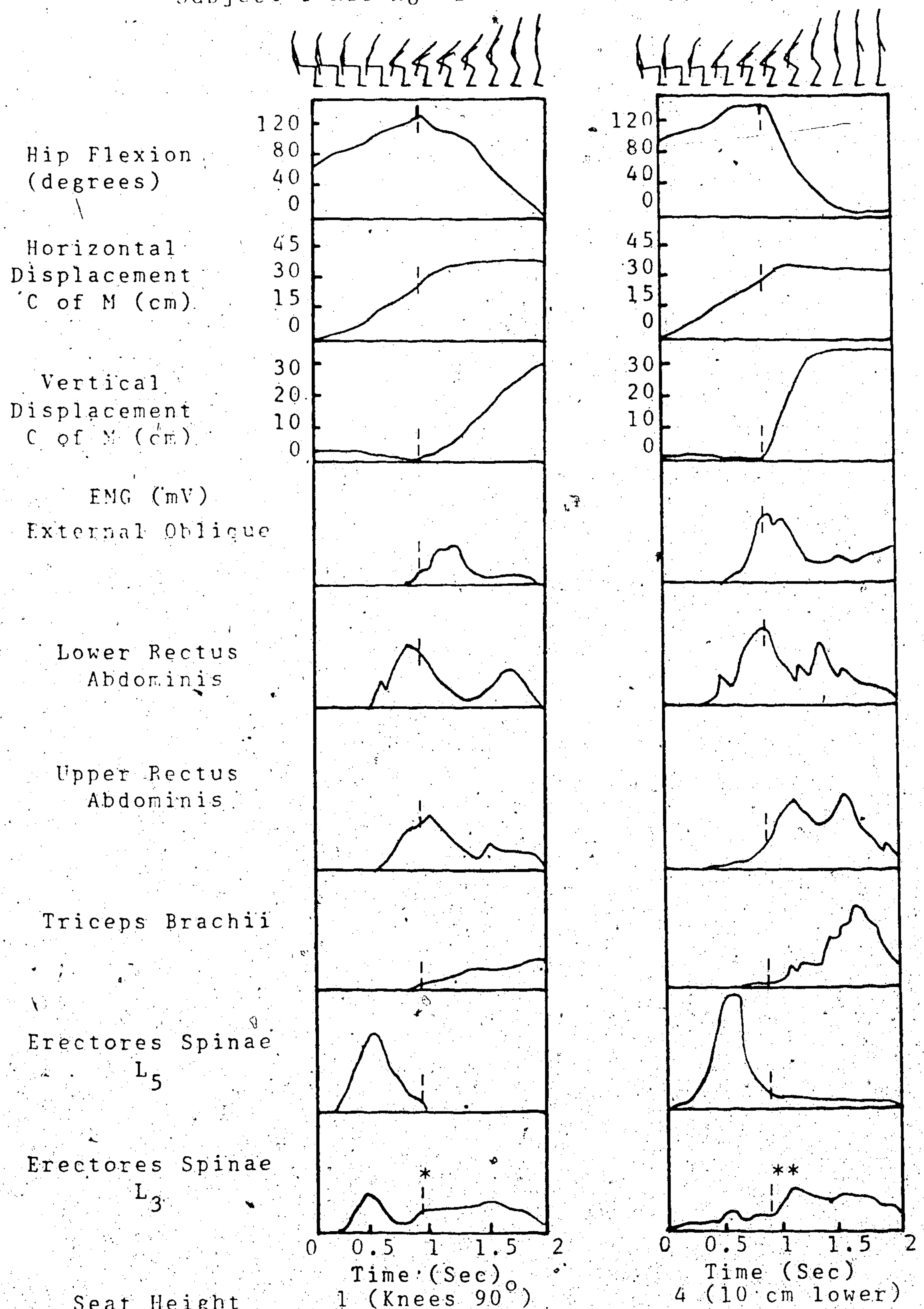
Triceps Brachii Electrode Pair

Hand Support	Subject	RISING Seat Height 1	2	3	4	LOWERING Seat Height 1	2	3	4
Armrest	1	122.8	110.7	147.2	129.7	116.0	92.7	89.9	113.0
	2	74.0	58.0	64.0	63.5	75.4	63.4	72.1	62.9
	3	87.6	71.0	88.0	79.4	71.3	58.2	63.8	69.3
	4	145.1	117.2	121.0	147.7	118.4	92.1	105.5	96.9
	5	97.2	99.5	111.4	120.7	73.4	31.8	99.8	88.9
	6	131.3	135.9	123.7	156.8	122.0	111.2	121.3	114.2
	7	90.7	70.3	91.7	86.4	64.9	81.9	93.8	91.7
	8	99.7	85.4	79.5	96.0	36.4	37.4	55.5	59.1
	x̄	106.1	93.5	103.3	110.0	84.7	71.1	87.7	87.0
	s	24.4	26.9	27.3	33.7	30.8	28.1	22.3	21.4
Seat Surface	1	100.4	83.2	95.1	70.6	94.7	62.2	68.4	70.7
	2	119.9	102.9	111.1	177.8	147.5	123.3	141.3	171.3
	3	85.3	82.2	106.2	113.6	72.6	67.1	93.7	82.1
	4	99.3	110.0	110.0	117.7	79.6	60.9	81.4	93.4
	5	76.1	82.8	74.2	81.4	81.2	84.1	71.7	88.1
	6	125.5	85.8	133.3	132.2	127.2	121.5	149.7	153.2
	7	83.8	71.4	81.3	82.1	74.1	64.8	70.9	70.4
	8	81.9	67.5	73.3	74.5	83.7	58.0	65.7	72.0
	x̄	96.5	85.7	98.1	106.2	95.1	80.2	92.9	100.2
	s	18.2	14.4	21.0	36.8	27.5	27.2	33.8	39.5
No	1	85.6	97.3	100.3	99.4	83.1	74.3	89.3	95.4
	2	111.1	73.1	101.1	110.3	82.4	47.6	62.9	78.3
	3	106.7	84.4	111.4	115.2	81.3	71.9	97.7	92.6
	4	100.0	85.6	98.2	133.2	103.4	96.2	112.2	153.6
	5	120.4	77.6	106.6	162.4	119.7	114.6	53.2	113.3
	6	111.8	95.6	86.8	121.2	89.9	75.2	79.7	105.2
	7	89.7	99.8	107.0	141.0	79.1	89.7	97.4	130.0
	8	116.6	93.0	132.5	150.1	98.4	96.4	152.0	160.5
	x̄	105.2	88.3	105.5	129.1	92.2	83.2	93.1	116.1
	s	12.5	9.7	13.2	21.4	14.1	20.4	30.6	29.5

APPENDIX E

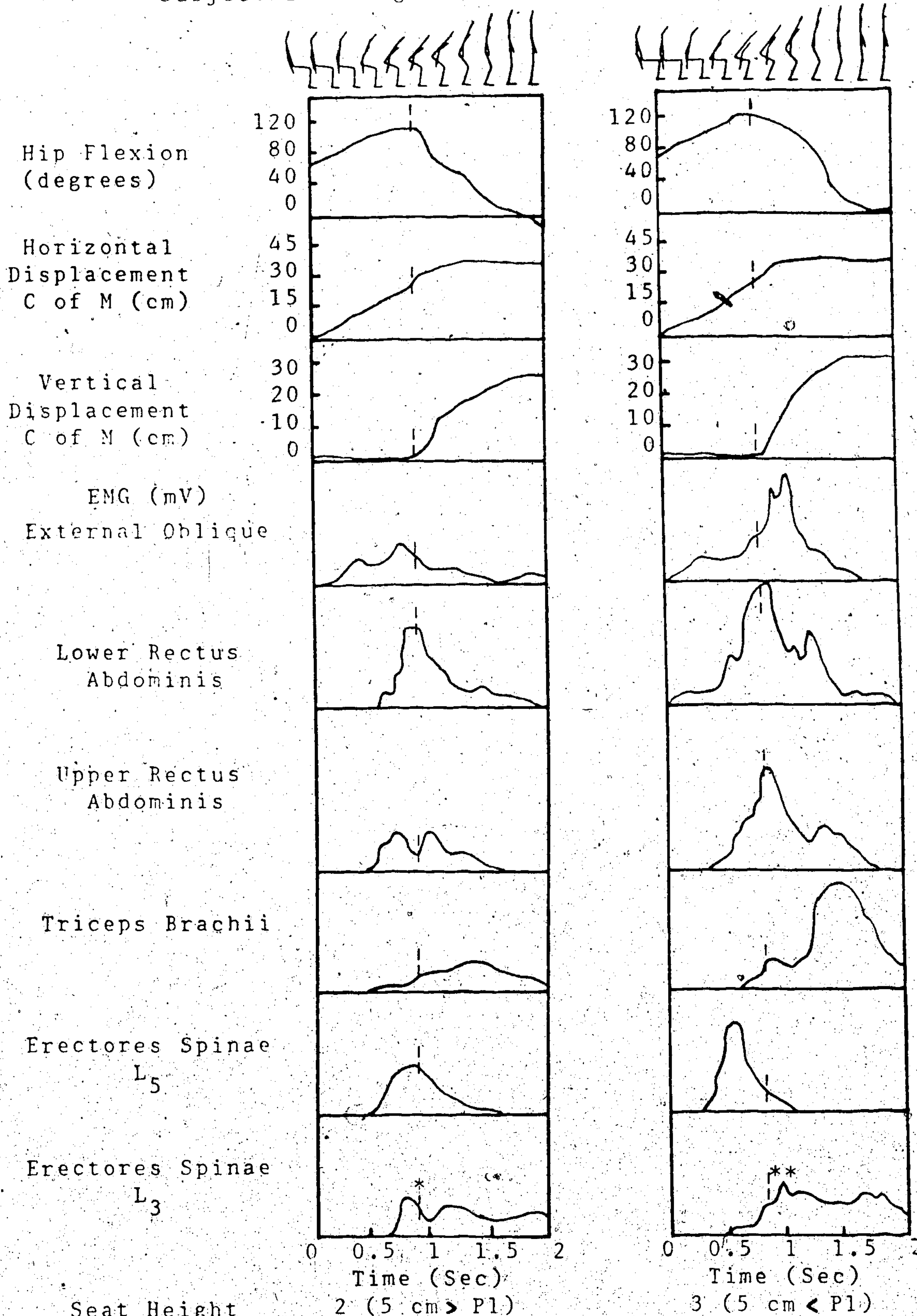
Synchronized EMG/Cinematography Data

Subject 1 Rising With No Hand Support



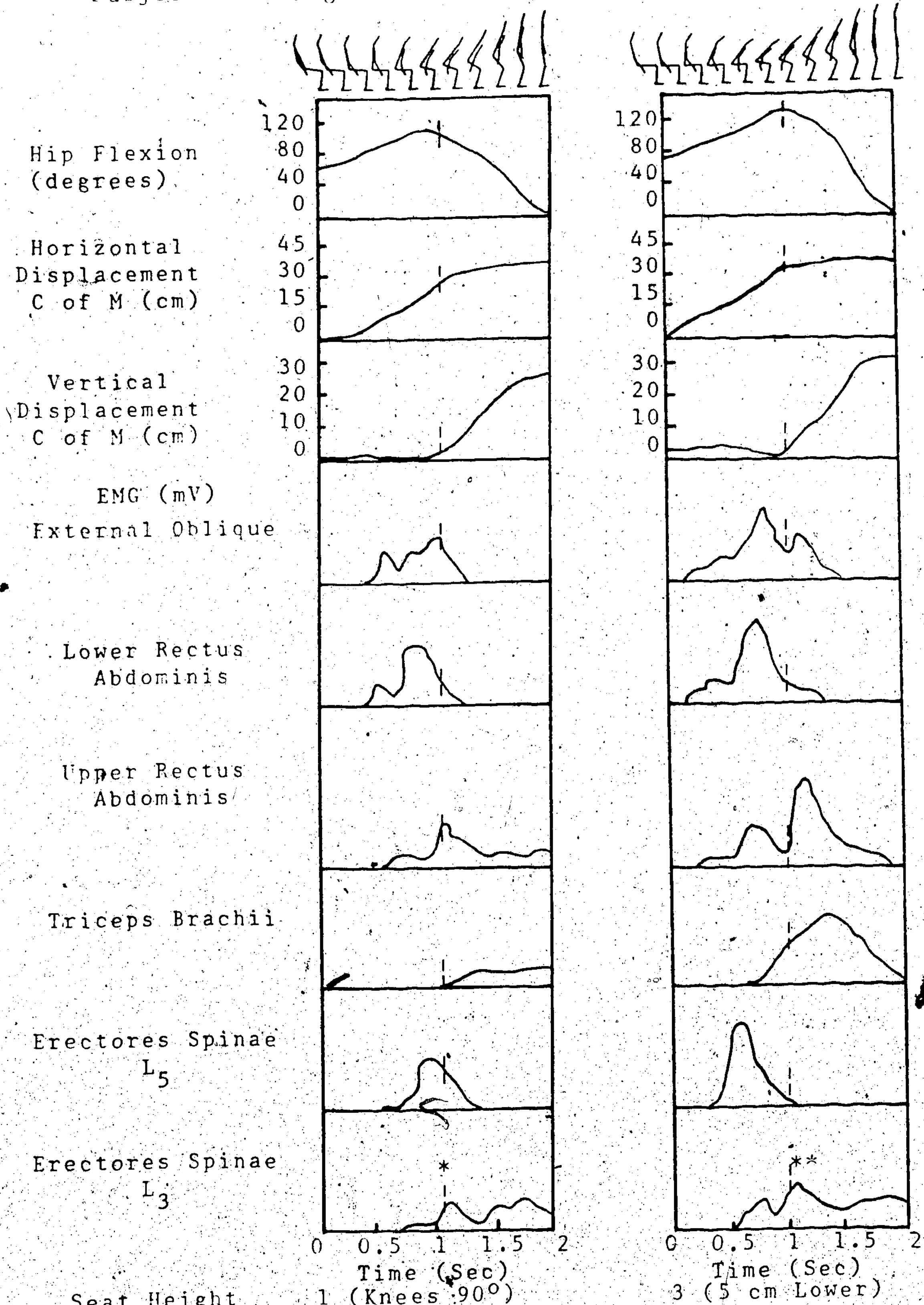
*Lift off 0.96 sec
**Lift off 0.84 sec

Subject 1 Rising With No Hand Support



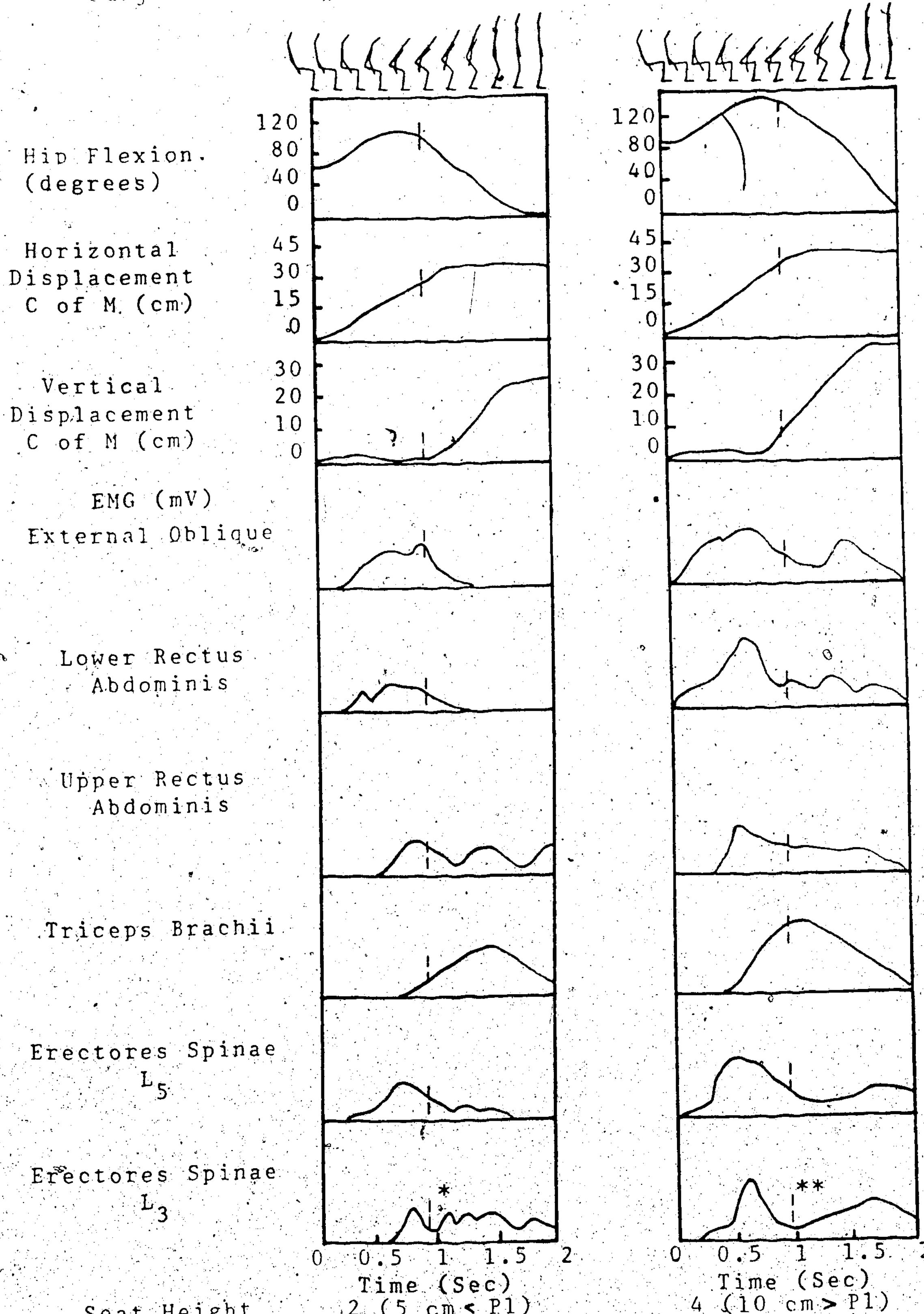
*Lift off 0.84 sec
**Lift off 0.80 sec

Subject 1 Rising With Seat Surface Hand Support



*Lift off 1.06 sec
**Lift off 0.96 sec

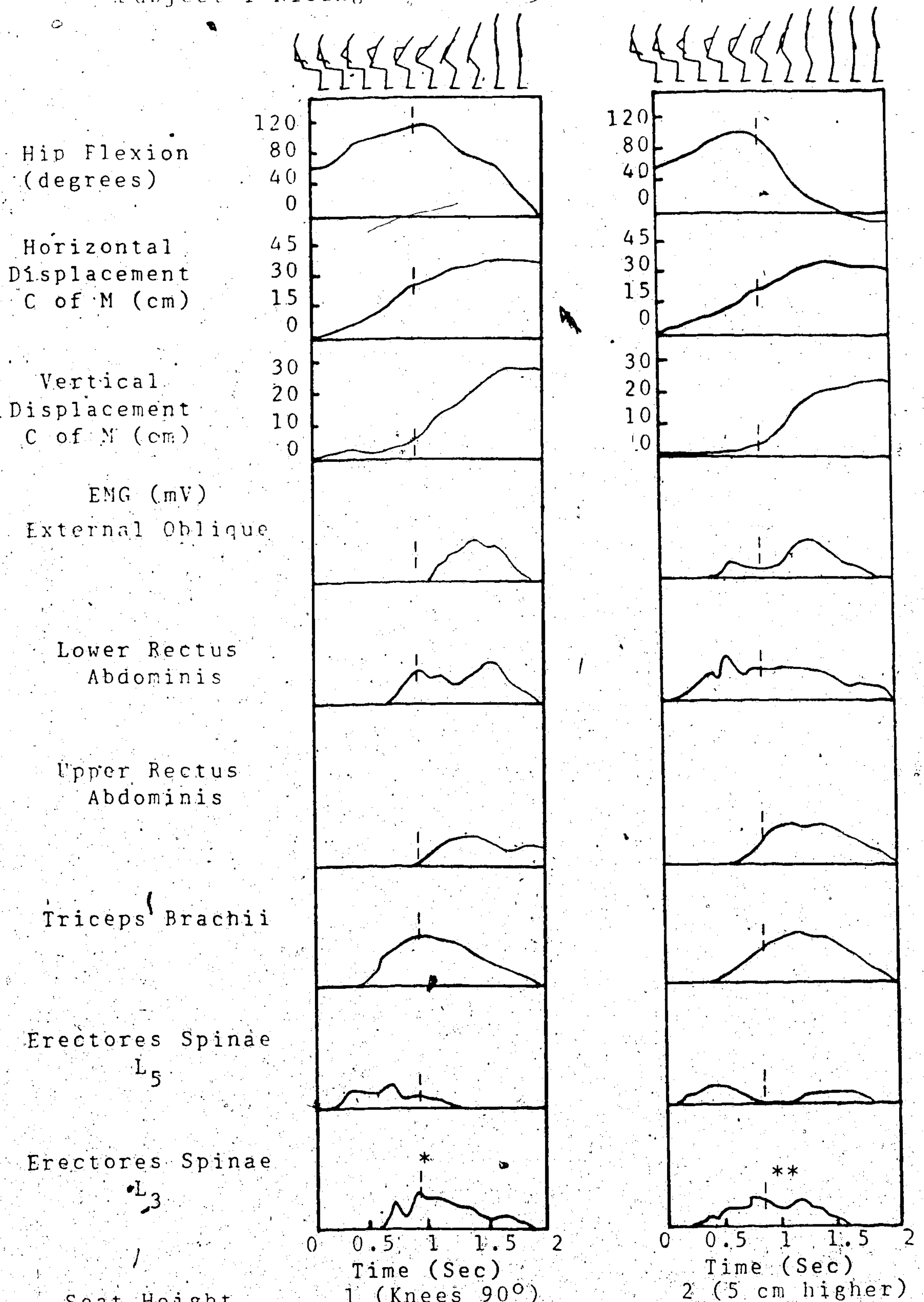
Subject 1 Rising With Seat Surface Hand Support



*Lift off 0.90 sec

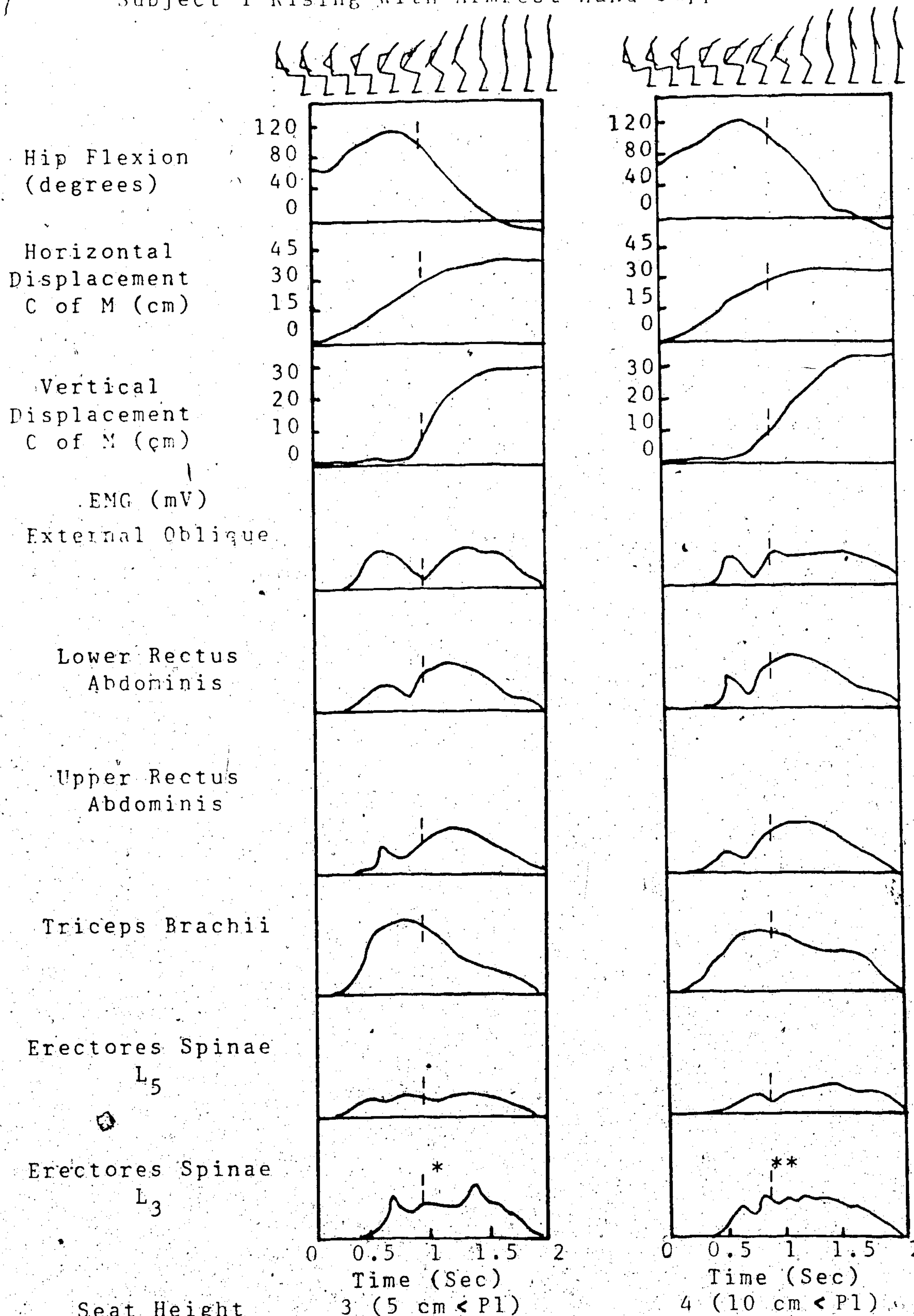
**Lift off 0.96 sec

Subject 1 Rising With Armrest Hand Support



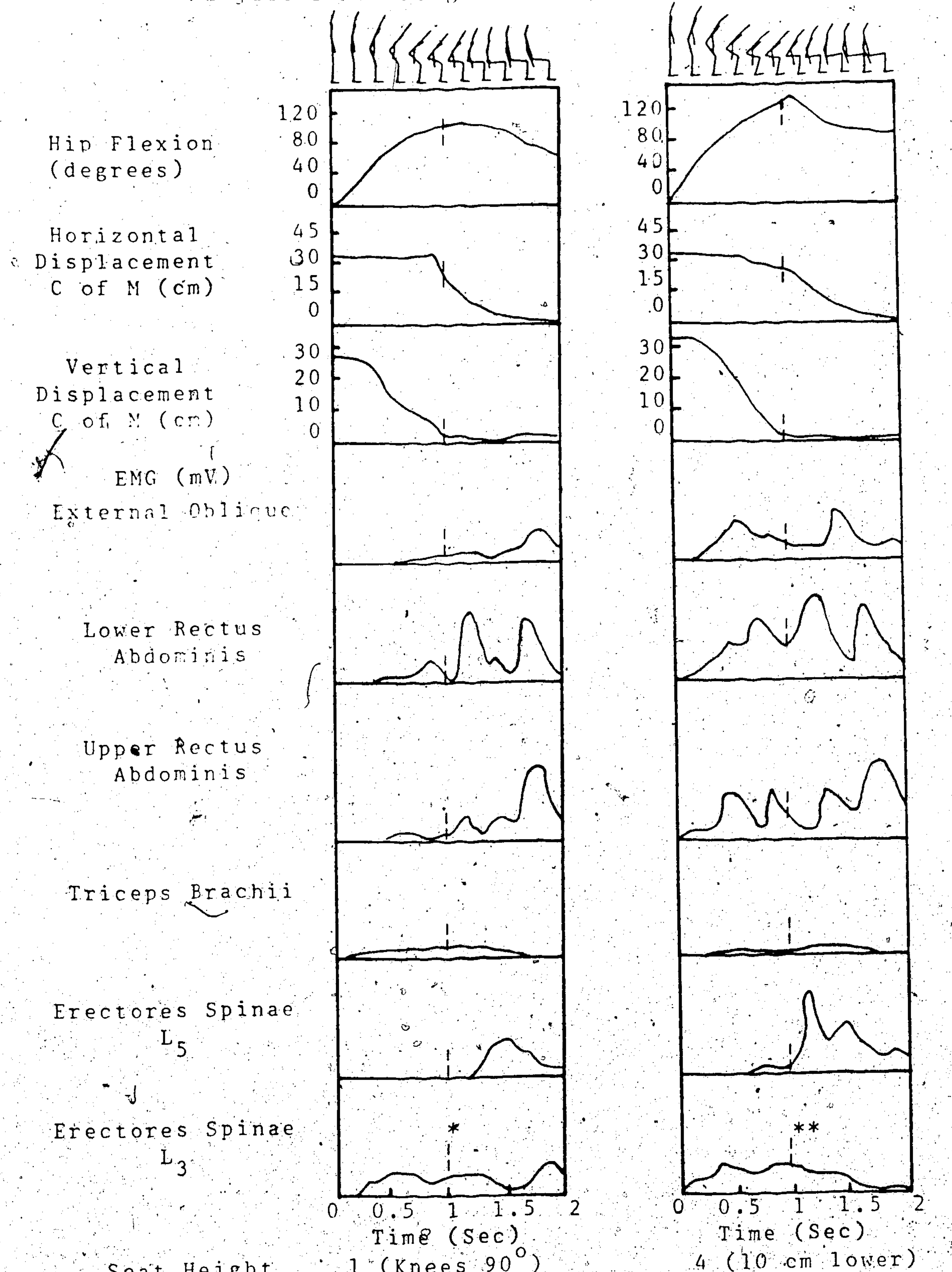
*Lift off 0.86 sec
**Lift off 0.76 sec

Subject 1 Rising With Armrest Hand Support



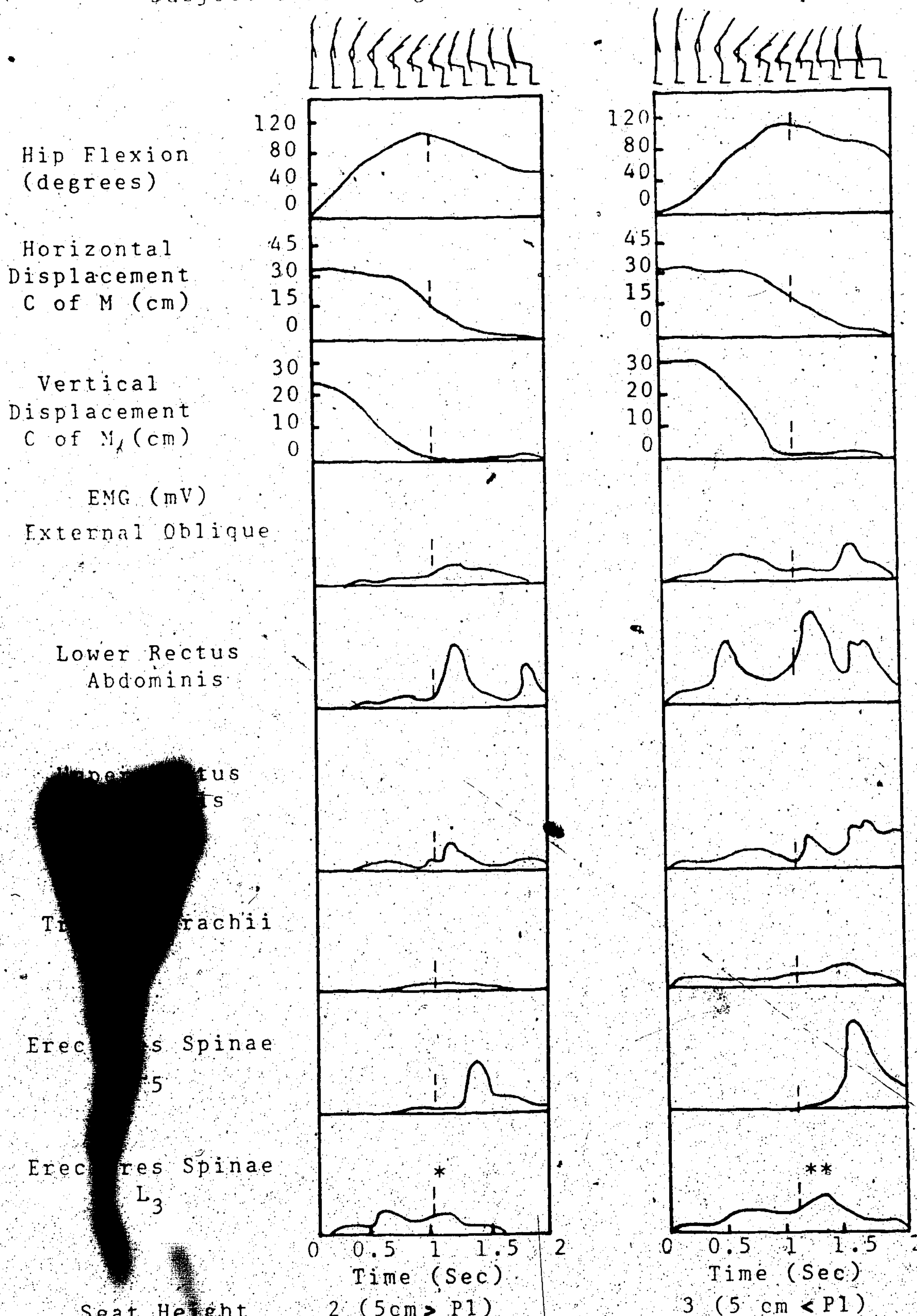
*Lift off 0.88 sec
**Lift off 0.76 sec

Subject 1 Lowering With No Hand Support



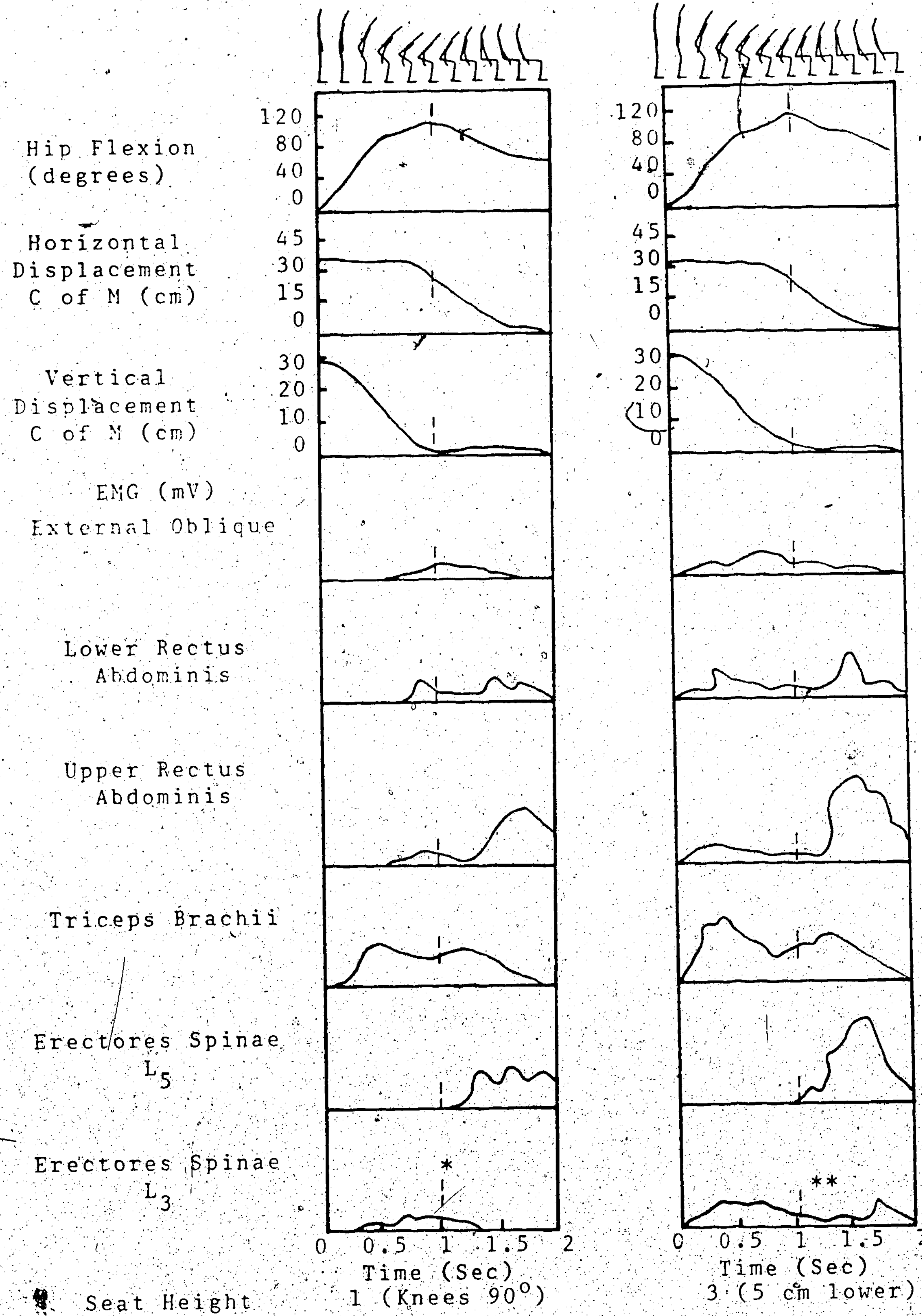
*Touch down 1.02 sec
**Touch down 0.96 sec

Subject 1 Lowering With No Hand Support



*Touch down 1.02 sec
**Touch down 1.18 sec

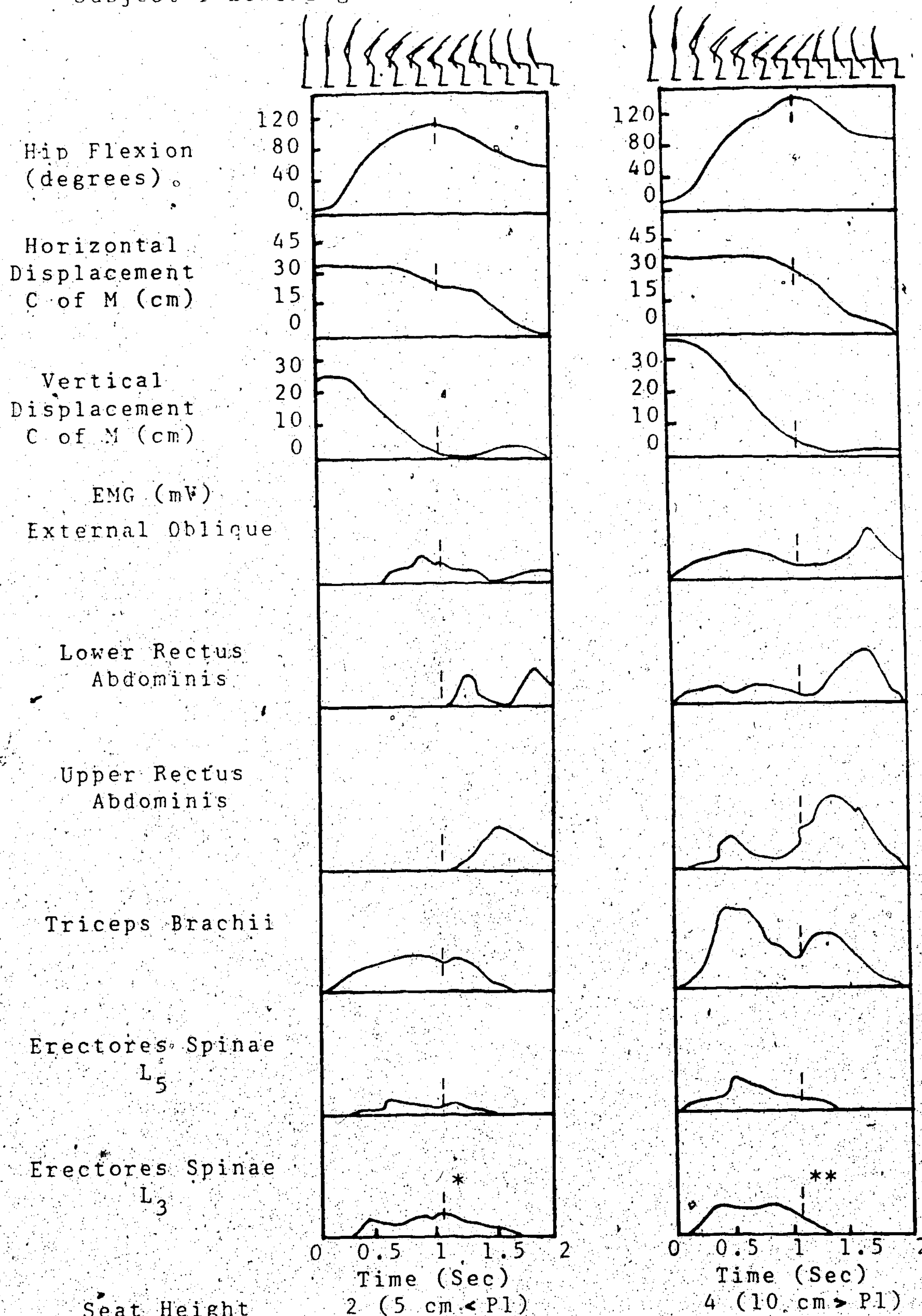
Subject 1 Lowering With Seat Surface Hand Support



*Touch down 1.06 sec

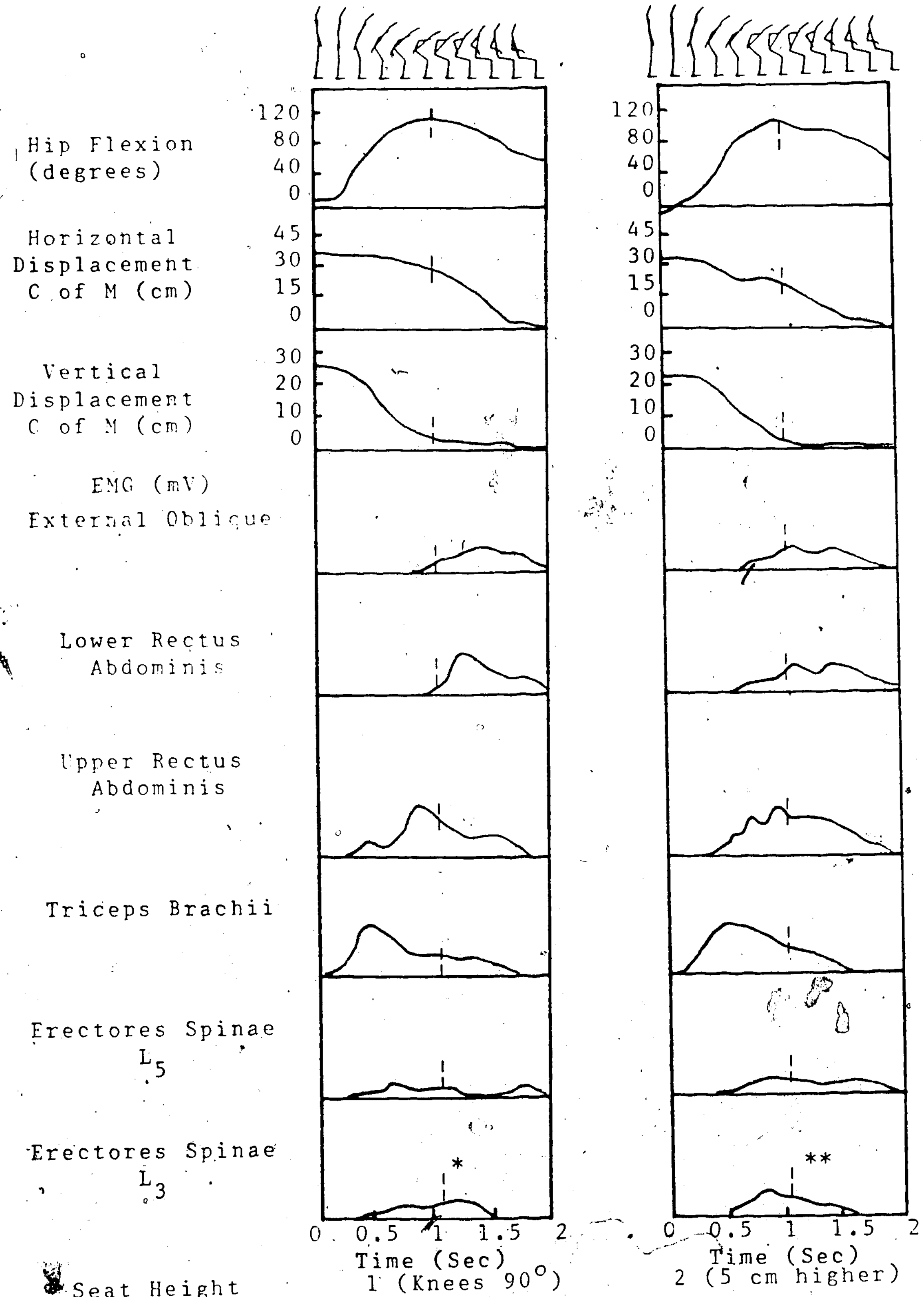
**Touch down 1.04 sec

Subject 1 Lowering With Seat Surface Hand Support



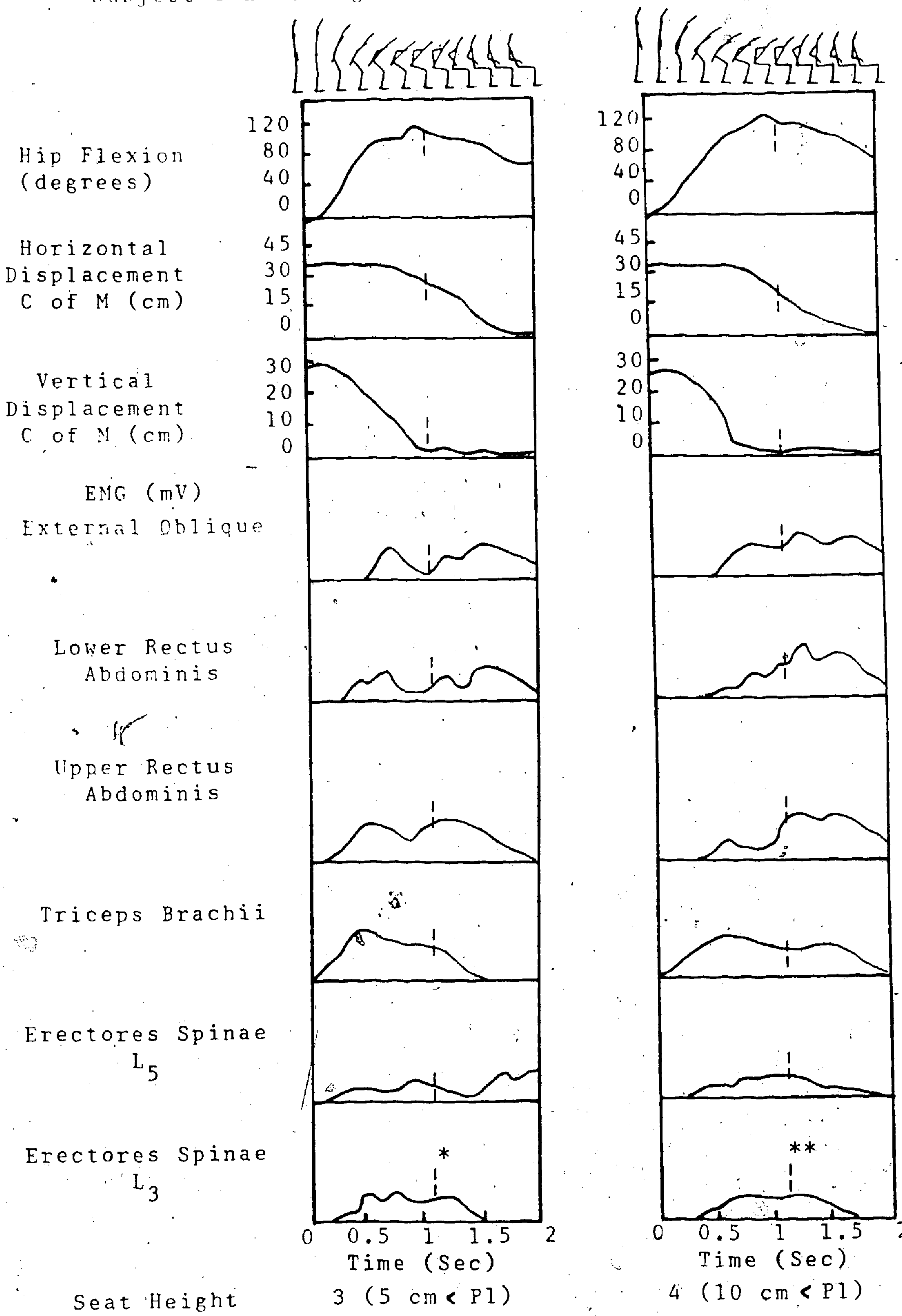
*Touch down 1.16 sec
**Touch down 1.18 sec

Subject 1 Lowering With Armrest Hand Support



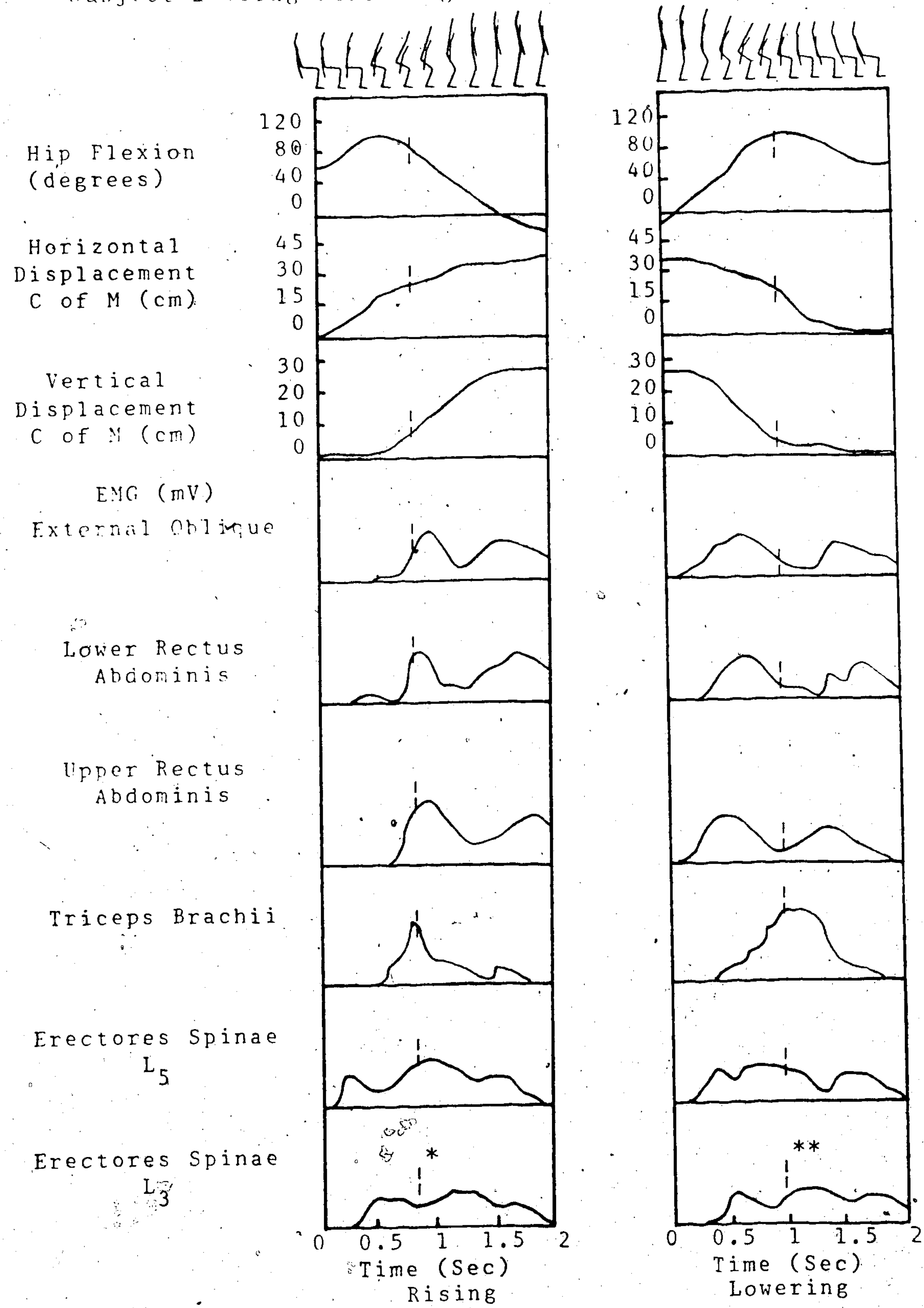
*Touch down 1.20 sec
**Touch down 1.14 sec

Subject 1 Lowering With Armrest Hand Support



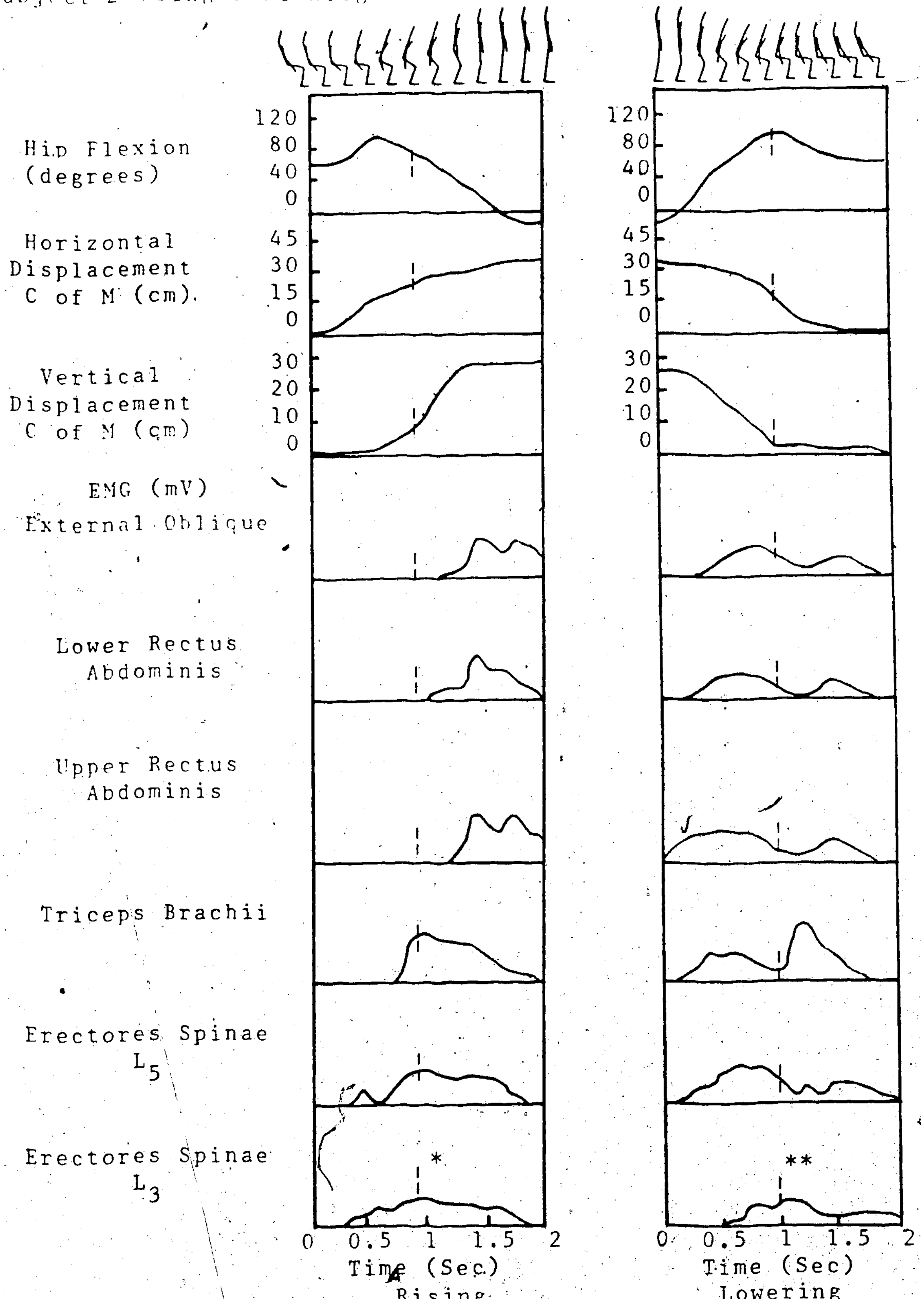
*Touch down 1.22 sec
**Touch down 1.24 sec

Subject 2 Using Seat Height 1 and No Hand Support



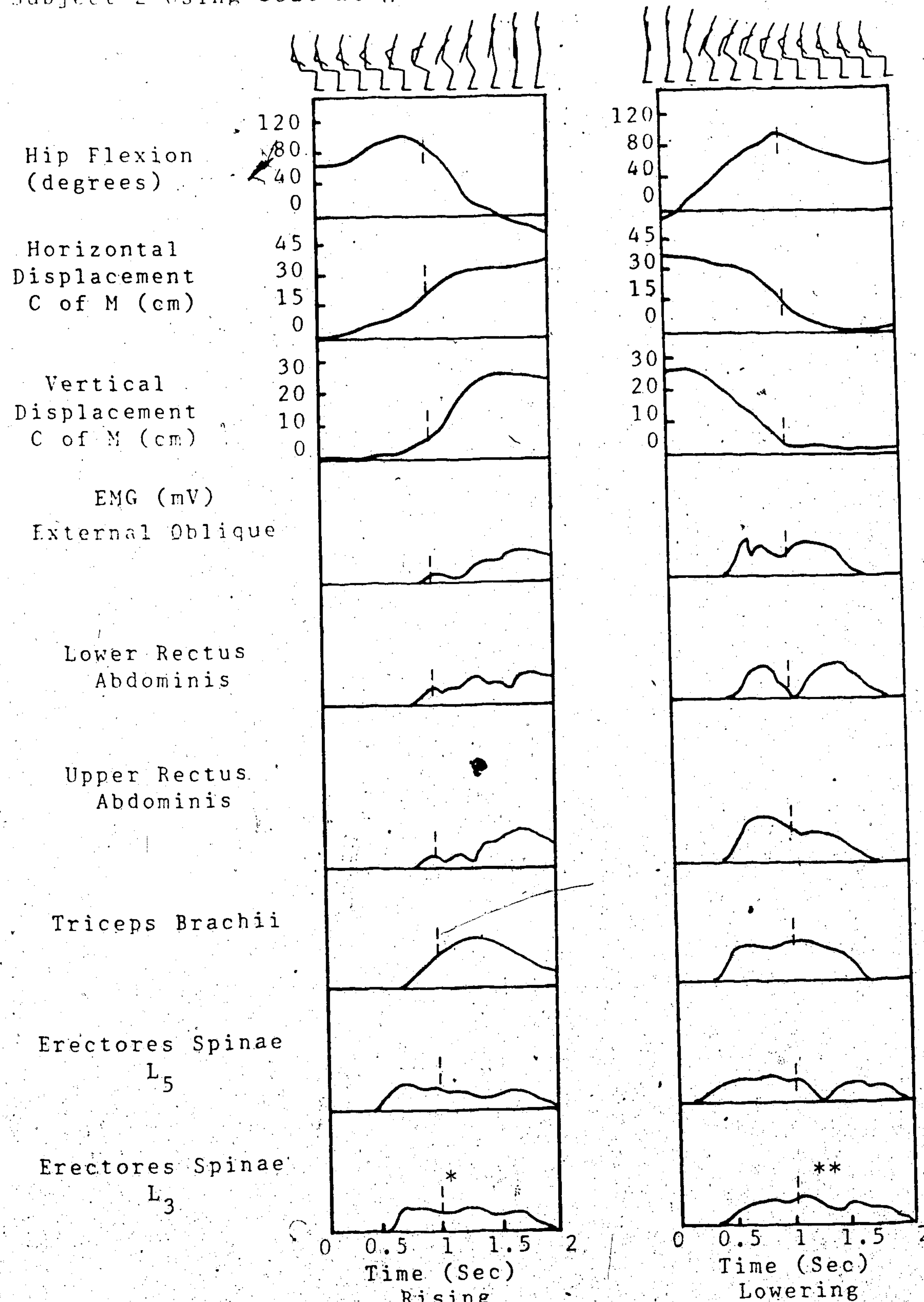
*Lift off 0.76 sec
**Touch down 0.96 sec

Subject 2 Using Seat Height 1 and Seat Surface Hand Support



*Lift off 0.84 sec
**Touch down 0.98 sec

Subject 2 Using Seat Height 1 and Armrest Hand Support



*Lift off 1.00 sec
**Touch down 1.04 sec

Subject 1 Rising With No Hand Support

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm) x	y
1	0	0.0	67	0	4
	10	0.2	76	3	4
	20	0.4	87	7	4
	30	0.6	104	13	2
	40	0.8	119	21	0
	50	1.0	129	27	0
	60	1.2	112	33	4
	70	1.4	88	35	12
	80	1.6	59	36	20
	90	1.8	34	36	26
	100	2.0	11	35	30
2	0	0.0	61	0	2
	10	0.2	69	3	2
	20	0.4	86	9	1
	30	0.6	99	15	0
	40	0.8	107	23	0
	50	1.0	103	30	3
	60	1.2	76	34	12
	70	1.4	46	37	18
	80	1.6	18	36	23
	90	1.8	0	36	25
	100	2.0	-6	35	25
3	0	0.0	73	0	1
	10	0.2	84	4	1
	20	0.4	101	10	1
	30	0.6	120	18	0
	40	0.8	121	25	1
	50	1.0	102	31	8
	60	1.2	72	34	18
	70	1.4	39	34	27
	80	1.6	15	35	31
	90	1.8	4	33	31
	100	2.0	-3	33	31
4	0	0.0	88	0	1
	10	0.2	100	5	1
	20	0.4	114	13	1
	30	0.6	133	20	0
	40	0.8	133	28	1
	50	1.0	110	32	8
	60	1.2	76	35	21
	70	1.4	37	35	32
	80	1.6	7	34	37
	90	1.8	5	33	37
	100	2.0	5	32	37

*In relation to digitizer origin.

Subject 1 Rising With Seat Surface Hand Support

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm)	
				x	y
1	0	0.0	61	0	0
	10	0.2	68	1	0
	20	0.4	75	4	1
	30	0.6	90	9	0
	40	0.8	107	15	0
	50	1.0	113	23	0
	60	1.2	103	29	4
	70	1.4	80	32	11
	80	1.6	52	34	20
	90	1.8	19	34	26
	100	2.0	6	34	27
2	0	0.0	62	0	1
	10	0.2	66	4	2
	20	0.4	89	9	2
	30	0.6	96	15	1
	40	0.8	107	22	0
	50	1.0	100	29	3
	60	1.2	75	35	11
	70	1.4	46	35	18
	80	1.6	16	36	23
	90	1.8	1	35	25
	100	2.0	-1	34	25

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm)	
				x	y
3	0	0.0	75	0	3
	10	0.2	81	4	3
	20	0.4	96	9	3
	30	0.6	115	15	2
	40	0.8	126	23	0
	50	1.0	124	30	1
	60	1.2	105	35	7
	70	1.4	90	36	12
	80	1.6	43	36	27
	90	1.8	18	34	31
	100	2.0	3	33	32
4	0	0.0	81	0	2
	10	0.2	87	4	2
	20	0.4	104	9	2
	30	0.6	122	15	1
	40	0.8	133	23	0
	50	1.0	129	30	2
	60	1.2	105	35	10
	70	1.4	65	37	23
	80	1.6	26	37	32
	90	1.8	8	35	36
	100	2.0	1	34	36

*In relation to digitizer origin.

Subject 1 Rising With Armrest Hand Support

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm) x	Displacement C of M* (cm) y
1	0	0.0	63	0	0
	10	0.2	69	2	1
	20	0.4	86	7	2
	30	0.6	102	14	1
	40	0.8	107	23	2
	50	1.0	109	24	5
	60	1.2	79	31	12
	70	1.4	61	33	18
	80	1.6	42	33	24
	90	1.8	2	34	28
	100	2.0	−3	34	28
2	0	0.0	57	0	0
	10	0.2	66	2	0
	20	0.4	82	7	1
	30	0.6	94	15	1
	40	0.8	84	23	5
	50	1.0	66	29	11
	60	1.2	38	31	18
	70	1.4	14	33	20
	80	1.6	1	32	22
	90	1.8	−10	32	22
	100	2.0	−10	32	22

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm) x	Displacement C of M* (cm) y
3	0	0.0	66	0	0
	10	0.2	74	2	0
	20	0.4	86	6	1
	30	0.6	107	13	0
	40	0.8	110	25	4
	50	1.0	97	29	8
	60	1.2	69	33	17
	70	1.4	26	35	26
	80	1.6	5	35	29
	90	1.8	−4	36	30
	100	2.0	−8	35	30
4	0	0.0	74	0	0
	10	0.2	86	3	1
	20	0.4	105	8	1
	30	0.6	120	17	1
	40	0.8	115	26	4
	50	1.0	89	30	13
	60	1.2	55	33	22
	70	1.4	23	32	30
	80	1.6	4	32	33
	90	1.8	−7	31	33
	100	2.0	−11	31	33

*In relation to digitizer origin.

Subject 1 Lowering With No Hand Support

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm) x	y
1	0	0.0	2	33	27
	10	0.2	19	32	27
	20	0.4	47	32	23
	30	0.6	76	32	16
	40	0.8	97	34	8
	50	1.0	109	24	3
	60	1.2	106	16	1
	70	1.4	100	7	0
	80	1.6	78	4	2
	90	1.8	71	1	2
	100	2.0	67	0	2
2	0	0.0	0	33	24
	10	0.2	22	33	23
	20	0.4	50	32	19
	30	0.6	77	31	12
	40	0.8	100	28	4
	50	1.0	105	22	0
	60	1.2	100	14	0
	70	1.4	94	8	0
	80	1.6	76	3	1
	90	1.8	64	1	2
	100	2.0	61	0	1

*In relation to digitizer origin.

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm) x	y
3	0	0.0	-4	31	30
	10	0.2	9	32	31
	20	0.4	33	31	29
	30	0.6	67	31	22
	40	0.8	95	30	12
	50	1.0	113	27	4
	60	1.2	117	23	0
	70	1.4	105	25	1
	80	1.6	92	6	1
	90	1.8	83	2	1
	100	2.0	75	0	0
4	0	0.0	5	32	36
	10	0.2	35	32	34
	20	0.4	74	31	25
	30	0.6	104	31	13
	40	0.8	123	29	3
	50	1.0	130	24	0
	60	1.2	123	17	1
	70	1.4	108	10	2
	80	1.6	98	6	1
	90	1.8	90	2	1
	100	2.0	83	0	1

Subject 1 Lowering With Seat Surface Hand Support

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm)	
				x	y
1	0	0.0	0	34	28
	10	0.2	21	34	27
	20	0.4	59	33	21
	30	0.6	89	33	11
	40	0.8	110	31	4
	50	1.0	117	26	0
	60	1.2	104	19	1
	70	1.4	90	12	2
	80	1.6	75	7	2
	90	1.8	69	3	2
	100	2.0	67	0	1
2	0	0.0	4	32	24
	10	0.2	8	32	25
	20	0.4	42	32	22
	30	0.6	84	31	11
	40	0.8	101	30	5
	50	1.0	112	25	0
	60	1.2	108	21	1
	70	1.4	93	12	2
	80	1.6	79	6	3
	90	1.8	66	2	3
	100	2.0	65	0	2

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm)	
				x	y
3	0	0.0	5	31	29
	10	0.2	25	31	29
	20	0.4	64	31	22
	30	0.6	92	30	12
	40	0.8	110	28	4
	50	1.0	118	23	0
	60	1.2	113	17	0
	70	1.4	102	10	1
	80	1.6	89	5	1
	90	1.8	80	2	0
	100	2.0	69	0	1
4	0	0.0	2	36	36
	10	0.2	19	36	35
	20	0.4	60	36	29
	30	0.6	96	35	17
	40	0.8	118	34	8
	50	1.0	130	29	3
	60	1.2	130	21	0
	70	1.4	111	11	2
	80	1.6	91	6	2
	90	1.8	84	2	2
	100	2.0	82	0	2

*In relation to digitizer origin.

Subject 1 Lowering With Armrest Hand Support

Seat Height	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm)	
				x	y
1	0	0.0	-8	36	25
	10	0.2	8	35	24
	20	0.4	43	35	20
	30	0.6	15	34	13
	40	0.8	97	32	7
	50	1.0	111	27	3
	60	1.2	110	21	1
	70	1.4	99	13	0
	80	1.6	83	4	1
	90	1.8	73	2	0
	100	2.0	64	0	0
2	0	0.0	-9	31	22
	10	0.2	0	31	22
	20	0.4	29	30	20
	30	0.6	78	27	10
	40	0.8	88	27	6
	50	1.0	105	22	1
	60	1.2	99	18	0
	70	1.4	91	11	0
	80	1.6	81	6	0
	90	1.8	70	2	0
	100	2.0	63	0	0
3	0	0.0	-5	35	29
	10	0.2	12	35	29
	20	0.4	49	34	24
	30	0.6	86	33	15
	40	0.8	102	31	8
	50	1.0	117	26	3
	60	1.2	112	20	2
	70	1.4	101	11	0
	80	1.6	82	5	1
	90	1.8	70	1	0
	100	2.0	65	0	0
4	0	0.0	-5	33	26
	10	0.2	12	33	27
	20	0.4	51	32	22
	30	0.6	85	32	17
	40	0.8	110	30	9
	50	1.0	121	24	3
	60	1.2	118	19	1
	70	1.4	111	14	1
	80	1.6	97	7	1
	90	1.8	84	2	0
	100	2.0	76	0	0

*In relation to digitizer origin.

Subject 2 Rising Using Seat Height 1

Hand Support	[illegible]	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm)	
				x	y
No	[illegible]	0.0	64	0	0
	[illegible]0	0.2	73	4	1
	20	0.4	90	8	1
	30	0.6	97	17	1
	40	0.8	87	24	5
	50	1.0	58	28	14
	60	1.2	26	31	22
	70	1.4	3	33	26
	80	1.6	-12	33	27
	90	1.8	-19	34	27
	100	2.0	-22	36	26
Seat Surf[illegible]	0	0.0	59	0	0
	10	0.2	64	2	0
	20	0.4	73	5	0
	30	0.6	94	15	1
	40	0.8	80	22	6
	50	1.0	65	25	9
	60	1.2	32	29	20
	70	1.4	1	30	27
	80	1.6	-13	31	27
	90	1.8	-17	32	27
	[illegible]00	2.0	-16	32	27
Armrest	0	0.0	66	0	0
	10	0.2	68	0	0
	20	0.4	74	2	1
	30	0.6	85	5	1
	40	0.8	95	10	2
	50	1.0	87	18	6
	60	1.2	61	26	14
	70	1.4	25	31	23
	80	1.6	2	33	27
	90	1.8	-17	34	27
	100	2.0	-19	35	26

*In relation to digitizer origin.

Subject 2 Lowering Using Seat Height 1

Hand Support	Frame	Time (sec)	Hip Flexion (degrees)	Displacement C of M* (cm) x	y
No	0	0.0	-13	35	26
	10	0.2	2	33	26
	20	0.4	31	31	21
	30	0.6	65	29	13
	40	0.8	87	25	6
	50	1.0	93	19	2
	60	1.2	88	10	2
	70	1.4	75	5	1
	80	1.6	69	1	0
	90	1.8	60	0	0
	100	2.0	58	0	0
Seat Surface	0	0.0	-12	33	27
	10	0.2	7	31	26
	20	0.4	37	30	21
	30	0.6	64	27	13
	40	0.8	84	24	7
	50	1.0	92	18	3
	60	1.2	87	9	3
	70	1.4	78	4	2
	80	1.6	68	1	1
	90	1.8	63	0	1
	100	2.0	62	0	0
Armrest	0	0.0	-12	38	26
	10	0.2	0	36	26
	20	0.4	39	32	22
	30	0.6	63	30	15
	40	0.8	81	25	8
	50	1.0	93	17	4
	60	1.2	88	11	2
	70	1.4	78	5	2
	80	1.6	68	1	2
	90	1.8	62	0	0
	100	2.0	61	0	0

*In relation to digitizer origin.