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A STUDY OF ELECTROMYOGRAPHIC SIGNALS DURING ISOMETRIC HAND PUSHING AND PULLING IN A FREE POSTURE

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ABSTRACT

Two sets of isometric pushing and pulling experiments were performed by two male and two female subjects. One set of experiments involoved isometric hand pushing and pulling in a standing erect posture, in which the thigh and pelvic regions of the subjects were braced to achieve the greatest strength. Another set of experiments involved isometric hand pushing and pulling in a free posture, in which the subjects elected their preferred postures to attain the largest strength at each of three handle heights (low-66 cm ; mid-109 cm ; and high-152 cm).

It was shown from isometric pushing and pulling experiments in a standing erect posture that the rectus abdominis and the erector spinae muscles were acting as an antagonistic pair with respect to the L5/S1 intervertebral joint, and that the integrated EMG and the muscle force were linearly related. However, the relationships between the integrated EMG and the muscle force during isometric pushing and pulling in a free posture were not well-correlated. It is proposed that the integrated EMG results should be carefully interpreted for tasks of pushing and pulling at various handle heights.

INTRODUCTION

Although many jobs are becoming automated today, workers are still required to perform manual materials handling tasks in many occupational situations. Performing such tasks repetitively can lead to low back stress, pain or degeneration of the lumbosacral disk [8]. According to statistics compiled by the National Safety Council, lifting, lowering, pushing, pulling and carrying of objects are the principle source of work injuries in the United States. Again, statistics from the Liberty Mutual Insurance Company [15] indicate that 79% of the manual handling injuries are low back injuries.

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Several researchers [10, 14, 18, 19] have investigated the electromyographic (EMG) activity as an indirect measurement of the muscle forces, It was concluded that the EMG amplitudes are reasonably proportional to the corresponding muscle forces with submaximal tension. Therefore, the RMS values of EMG measurements were used as an indicator of muscle forces [1, 6, 18, 19].

In this paper, study of the forces applied in the lumber region of the spine was limited to situations involving isometric pushing and pulling of a cart at three varying handle heights. The calculation of the loads on the lumber spine was modified from an earlier biomechanical model [7] to take into account the tension exerted by the rectus abdominis muscles in pushing and pulling tasks. It was hypothesized that the rectus abdominis muscles and the erector spinae muscles were alternately active when a person pushed or pulled an object.

Hence, these two muscles were postulated to be arranged in an antagonistic pair with respect to the L 5/S 1 intervertebral joint. To verify this hypothesis, the EMG activity of both the rectus abdominis and the erector spinae was monitored in relation to the isometric hand pushing and pulling forces in various standing postures.

REVISED BIOMECHANICAL PUSH/PULL MODEL

An earlier biomechanical model for analysis of symmetric sagittal plane lifting [7] was revised for use in this study. To use the model in pushing and pulling studies as well, a few more assumptions were added to the earlier model and the calculation of the loads on the L 5/S 1 region was modified to take into account the tension developed by the rectus abdominis muscles.

Additional Assumptions

The revised biomechanical push/pull model incorporates the following additional assumptions :

(1) A person pushes or pulls with two hands.
(2) Both horizontal and vertical external forces act in the sagittal plane.
(3) The lower extremities may be non-symmetric when a person pushes or pulls (i.e. with two feet apart).
(4) The erector spinae is inactive when the rectus abdominis is active and vice versa.

Input and Output

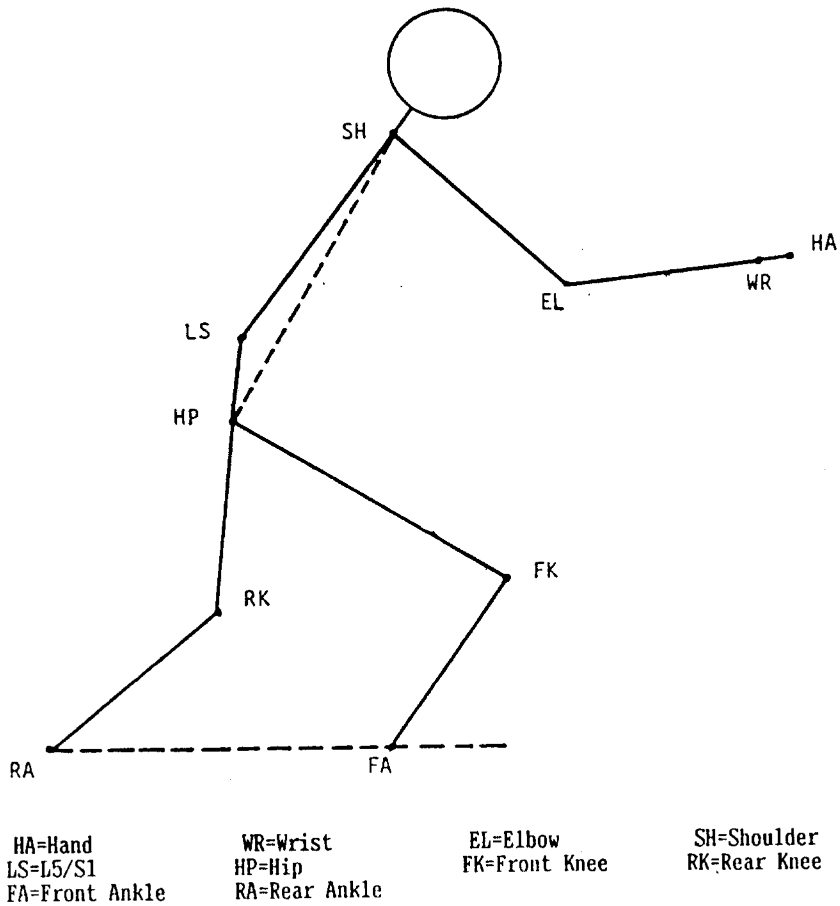
The program of the revised biomechanical push/pull model was written in FORTRAN IV computer language, requires several inputs, including :

(1) body weight of the subject ;
(2) horizontal and vertical forces exerted at hand ; and
(3) body postures during the task (x, y-coordinates of 10 major joints (Figure 1)).

Given these input, the model produces the following output :

(1) angles at 10 joints ;
(2) positions of center of mass for 9 body segments ;
(3) torques at 10 major joints ;
(4) muscle force of the erector spinae or the rectus abdominis ; and
(5) compressive force at the L 5/S 1 disc.

Figure 2 shows the flow chart of the revised biomechanical push/pull model.



Frgure 1. A Diagram of 10 Joints and 9 Body Segments

EXPERIMENTAL METHODS

Subjects

Two male and two female students, who were healthy and had no history of back pain or previous back trauma, participated in the experiments. All subjects understood the purpose of the experiments. They were instructed about the procedure of the experiments and were informed of possible injuries. Table 1 provides anthropometric data taken from four subjects. The link lengths of the subjects, measured using the linear-dimension method [16], are given in Table 2.

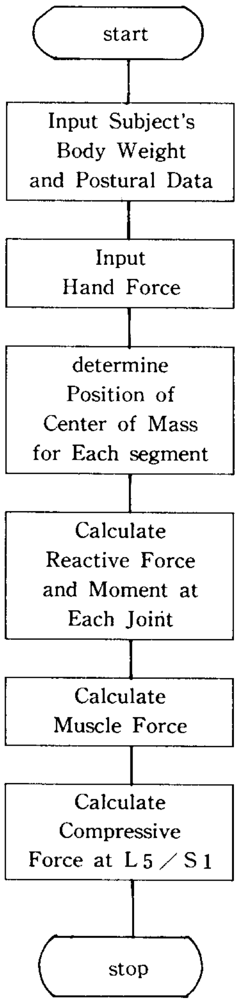


Figure 2. Flow Chart of the Revised Biomechanical Push / Pull Model

Apparatus

The apparatus used in the experiments was listed as follows :

(1) One Nikon camera with 35 mm lens.

(2) Five Beckman monopolar surface EMG electrodes.

(3) Two EMG preamplifiers.

(4) Two AC voltmeter measuring RMS values of EMG signals.

Table 1. Anthropometric Data of the Subjects

Subject Code	Sex	Age	Stature (cm)	Weight (kg)
S 1	Female	21	162.0	50.0
S 2	Female	20	169.3	59.1
S 3	Male	30	171.0	75.0
S 4	Male	24	176.5	62.3

Table 2. Link Lengths of the Subjects

Body Segments	Subjects			
	S 1	S 2	S 3	S 4
HA-WR	6.2	6.7	6.9	6.9
WR-EL	17.8	24.3	25.6	22.8
EL-SH	26.2	29.5	27.0	28.0
SH-HP	38.7	44.9	50.6	44.2
HP-KN	43.1	39.7	50.8	46.1
KN-AN	37.4	40.5	42.0	38.3
AN-FT	13.8	15.2	17.8	14.6
LS-SH	39.5	37.5	39.5	38.5

HA = Hand WR = Wrist EL = Elbow SH = Shoulder LS = L 5/S 1
HP = Hip KN = Knee AN = Ankle FT = Foot

(5) A cart simulator : a special structure designed for dynamic pushing and pulling experiments with vertically adjustable bar handles [14].

(6) A load cell measuring the horizontal and vertical forces at cart simulator handel.

(7) A carrier amplifier (Model 130-2 C).

(8) A Hewlett-Packard 2100 computer (HP 2100).

(9) An analog to digital converter-type MP 6812.

(10) A Kodak Carousel 650 M projector.

Five surface electrodes were placed on prepared sites of the subject's body. One set of electrodes were attached 5 cm apart above the erector spinae muscle located on the dorsal surface of the lower back near the L 2/L 3 area. Another set of electrodes were 5 cm apart above the rectus abdominis muscles 3 cm above the umbilicus. One electrode was attached to the right pinnae to serve as a gound (Figure 3). The electrodes were connected to preamplifiers attach'ed to the subject's waist. The preamplifiers were each connected to an AC voltmeter to generate an RMS value of the incoming EMG signal, which was further transferred to the HP 2100 digital (A/D) converter. The cart was fixed at proper places for isometric pushing and pulling experiment. The load cell at the bar handle as connected to the carrier amplifier, which, in turn, was connected to the digital computer via the A/D converter.

Each subject wore tight-fitting clothing, and reflective tapes were used to mark the major joints, indicated in Figure 1, with reference to palpable bony landmarks identified by Dempster [11]. Sagittal plane photographs were taken using the 35 mm camera and were hence projected via the Kodak Carousel 650 Mprojector onto 9″ x 12″ grid paper for magnified drawings of the postures.

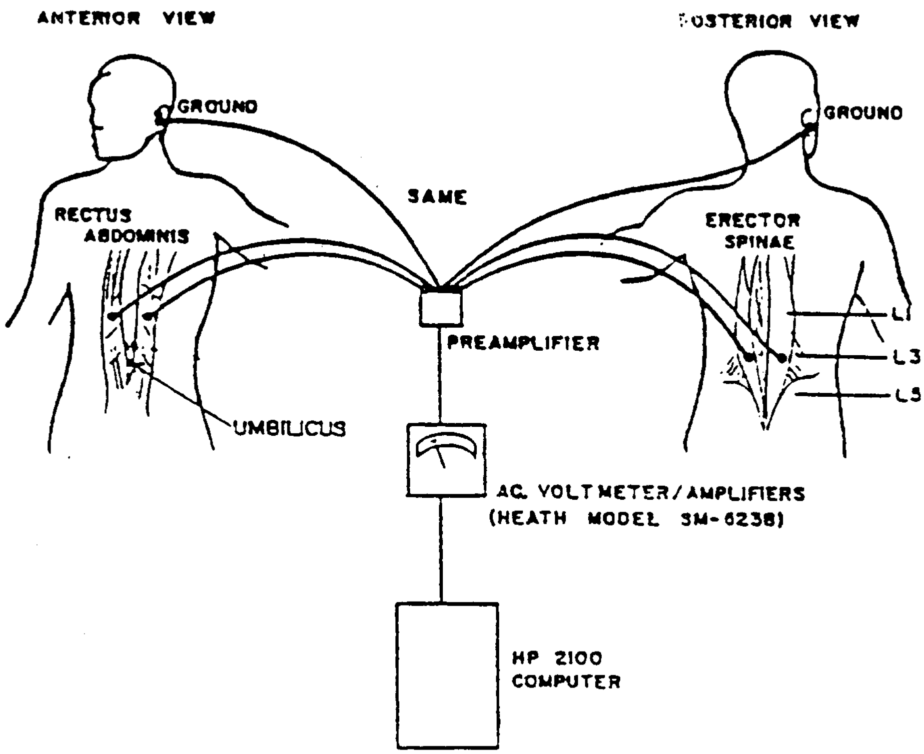


Figure 3. Positions of the Surface Electrodes on the Subjects

Procedure

Two sets of experiments were performed in this study. One set of experiments involved isometric hand pushing and pulling in a standing erect posture. Another set of experiments involoved isometric hand pushing and pulling in a free posture.

1. Isometric Hand Pushing and Pulling in a Standing Erect Posture

As shown in Figure 4, the subject stood straight while pushing or pulling a cart, the bar handle of which was set at the subject's shoulder height. Counter forces were transmitted to both thigh and pelvic area of the subject using a brace in order to generate the maximum exertion. The subject was asked to continuously increase the exertion up to the maximum force over the approximately three second period and to remain at the maximum exertion for another one second. A metronome was used to help the subject control the speed of increasing his or her exertion. Integrated EMGs (IEMGs) of both the erector spinae and the rectus abdominis were recorded along with the horizontal and vertical hand forces. These IEMG and hand force data were sampled at 10 millisecond intervals for four seconds using a data collection program compiled on the HP 2100 computer.

Five replications were carried out for pushing and pulling respectively and hence each subject was required to perform 10 tasks of standing erect pushing and pulling.

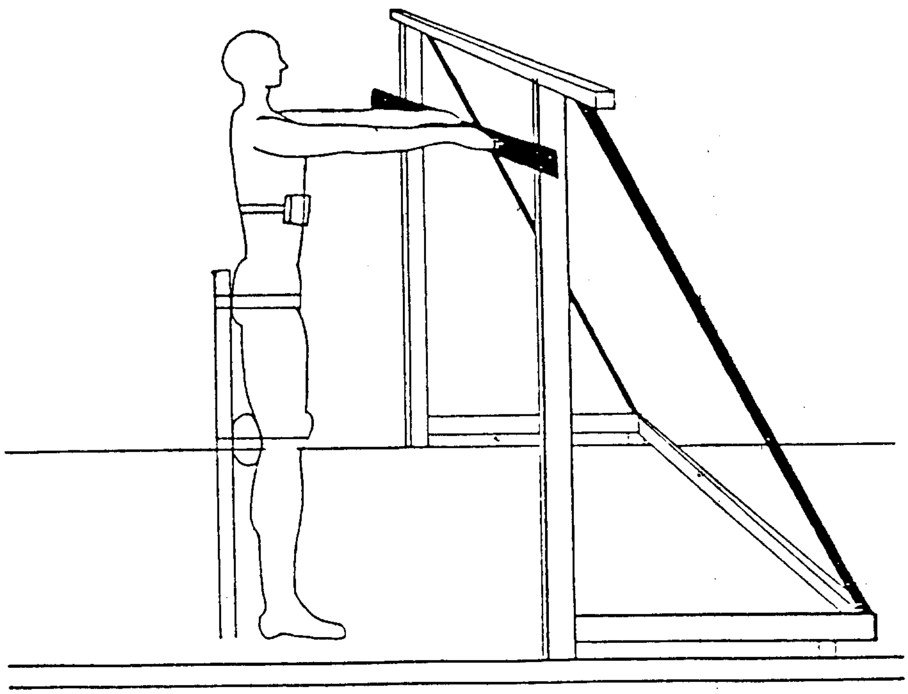


Figure 4. Isometric Hand Pushing and Pulling in a Standing Erect Posture

2. Isometric Hand Pushing and Pulling in a Free Posture

The subjects were allowed to try their preferred posture until they achieved what they believed would permit the greatest pushing and pulling force capability. Once they achieved what they believed to be their optimum posture, they were asked to continuously increase the exertion up to the maximum force over the three second period and to remain at the maximum exertion for another one second. IEMG and hand force data were also recorded every 10 milliseconds for four seconds using the data collection program. Three handle heights (66 cm, 109 cm and 152 cm) were used in this experiment on the basis of the post studies [9, 17].

The experimental design consisted of two factors : bar handle height (Low 66 cm ; Mid -109 cm, and High-152 cm) and force direction (push and pull). This 3 x 2 design resulted in 6 trial blocks, each of which was replicated 3 times. Hence, each subject was required to perform 18 tasks of pushing pulling in a free posture.

In both experiments, the order of pushing and pulling was randomized within each handle height. A three minute seated rest period was provided between tasks.

RESULTS AND DISCUSSION

Results of Isometric Hand Pushing and Pulling in a Standing Erect Posture

To validate the interactive role of the rectus abdominis and the erector spinae during isometric hand pushing and pulling, IEMG activities of both the muscle groups were examined in relation to the torques generated at the L 5/S 1 disc. Computation of these torques was based on biomechanical concepts. In the standing erect posture, it was assumed that no torques were produced due to body weight. As shown in Figure 5, the rectus abdominis muscles were much more active than the erector spinae during pushing, while opposite results were exhibited during pulling. These results supported the theoretical background of the revised biomechanical push/pull model.

The relationship beween the integrated EMG of active muscles and the tension by the same muscle group during isometric pushing and pulling in a standing erect posture was determined using the following regression model :

$$IEMG = b_0 + b_1 F_{mus} + b_2 X_{dir} + b_3 F_{mus}X_{dir} + e \quad (1)$$

where IEMG = integrated EMG of the erector spinae or the rectus abdominis (μv)

F_{mus} = musde force of the erector spinae or the rectus abdominis (kp)

$X_{dir} = 0$ if pushing

$= 1$ if pulling

Table 3 shows the results of the regression analysis, including the equations of the regression lines and coefficients of determination (r^2) for four subjects. Significantly different slopes and intercepts were found between pushing and pulling equations and variations among subjects were exhibited as well. Such variations may be explained by the fact that the IEMG amplitude varies depending on positions of the electrode[13]. However, the results exhibited a high correlation (r^2=.75 to .89) for each equation, This supported the validity of the use of IEMG as an indirect measurement of the tension exerted by the same muscle group. Such a linear relationship between the IEMG and muscle force agreed with the results from the past studies[3, 10].

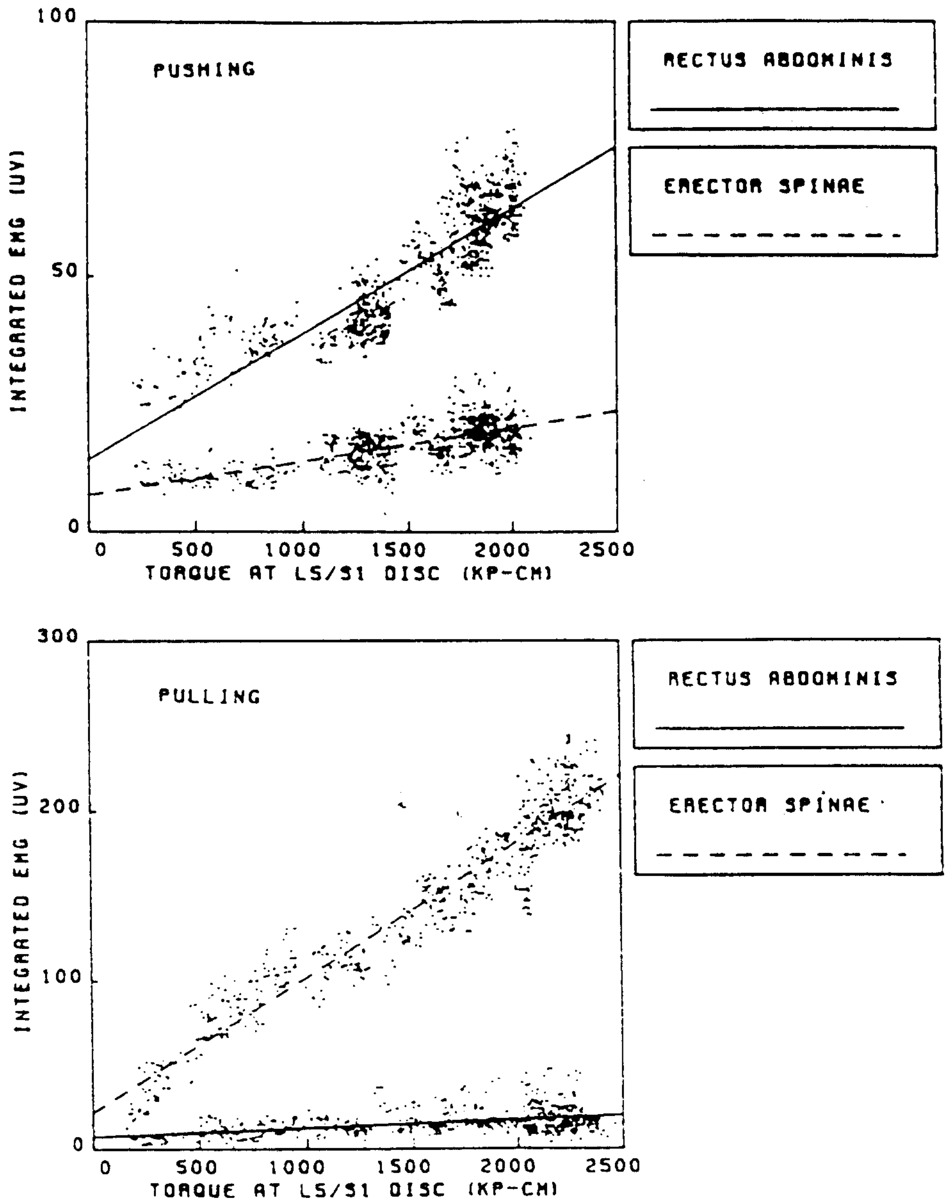


Figure 5. Regression Lines for the IEMG and Torques at the L5 / S1 Disc
During Isometric Pushing and Pulling in a Standing Erect Posture

Table 3. Least Square Error Regression Analysis of the IEMG and Muscle Force During Isometric Pushing and Pulling in a Standing Erect Posture

Subject Code	Equation	r^2
S 1	$IEMG = 19.64 + 0.23\,F_{mus} - 3.59\,X_{dir} - 0.11\,F_{mus}X_{dir}$	.87
S 2	$IEMG = 18.99 + 0.05\,F_{mus} + 4.39\,X_{dir} + 0.04\,F_{mus}X_{dir}$	.89
S 3	$IEMG = 8.78 + 0.13\,F_{mus} + 24.41\,X_{dir} + 0.19\,F_{mus}X_{dir}$	.75
S 4	$IEMG = 5.12 + 0.12\,F_{mus} + 6.99\,X_{dir} + 0.06\,F_{mus}X_{dir}$	.85

Unit : IEMG(μv) ; F_{mus}(kp)

$X_{dir}=0$ if pushing ; 1 if pulling

Results of Isometric Hand Pushing and Pulling in a Free Posture

IEMG activities and horizontal and vertical hand forces, recorded during the free -postured pushing and pulling experiments, were analyzed along with the corresponding postural data. The resulting postural data are graphically depicted in Figlure 6 for the various tasks. The horizontal distances from hand to front and rear ankles are also denoted in the figure.

The regression model (1), was also used in the analysis of pushing and pulling in a free posture. Table 4 shows the results of the least square error regression analysis of the IEMG and the muscle force of the rectus abdominis or the erector spinae for four subjects. The

Table 4. Least Square Error Regression Analysis of the IEMG and Muscle Force During Isometric Pushing and Pulling in a Free Posture

Subject Code	Han-dle Height (cm)	Equation	r^2
S 1	66	$IEMG = 9.71 + 0.041\,F_{mus} - 0.015\,F_{mus}X_{dir}$	.45
	109	$IEMG = 9.71 + 0.600\,F_{mus} - 0.143\,F_{mus}X_{dir}$	.55
	152	$IEMG = 13.56 + 1.442\,F_{mus} - 3.85\,X_{dir} - 1.186\,F_{mus}X_{dir}$	.46
S 2	66	$IEMG = 15.20 + 0.207\,F_{mus} - 0.026\,F_{mus}X_{dir}$	.32
	109	$IEMG = 15.20 + 0.247\,F_{mus} - 0.112\,F_{mus}X_{dir}$	.41
	152	$IEMG = 5.48 + 0.036\,F_{mus} - 9.72\,X_{dir} - 0.721\,F_{mus}X_{dir}$	.44
S 3	66	$IEMG = 16.54 + 0.185\,F_{mus} - 0.047\,F_{mus}X_{dir}$	.32
	109	$IEMG = 16.54 + 0.181\,F_{mus} - 0.061\,F_{mus}X_{dir}$	.49
	152	$IEMG = 16.54 + 0.241\,F_{mus} - 0.172\,F_{mus}X_{dir}$	.53
S 4	66	$IEMG = 4.86 + 0.377\,F_{mus} + 5.87\,X_{dir} + 0.226\,F_{mus}X_{dir}$	.62
	109	$IEMG = 4.86 + 0.254\,F_{mus} + 5.87\,X_{dir} + 0.157\,F_{mus}X_{dir}$	.17
	152	$IEMG = 4.86 + 0.454\,F_{mus} + 5.87\,X_{dir} + 0.119\,F_{mus}X_{dir}$	.48

Unit : IEMG(uv) ; F_{mus}(kp)

$X_{xir}=0$ if pushing ; 1 if pulling

results, though, did not show as high correlation as those of pushing and pulling in a standing erect posture. This may be due to the interaction of other muscle groups such as internal and external oblique muscles[4], or it may be due to the interactive effects of the hand force and trunk flexion[5].

It was noted that the equations varied among four subjects, and that different slopes were derived for three handle heights of pushing and pulling. Although slopes of pushing equations varied greatly between subjects, slopes of pulling equations exhibited a systematic change for three handle heights. The slope decreased as the handle height decreased. It should be noticed that during pulling at low handle heights, a large portion of EMG

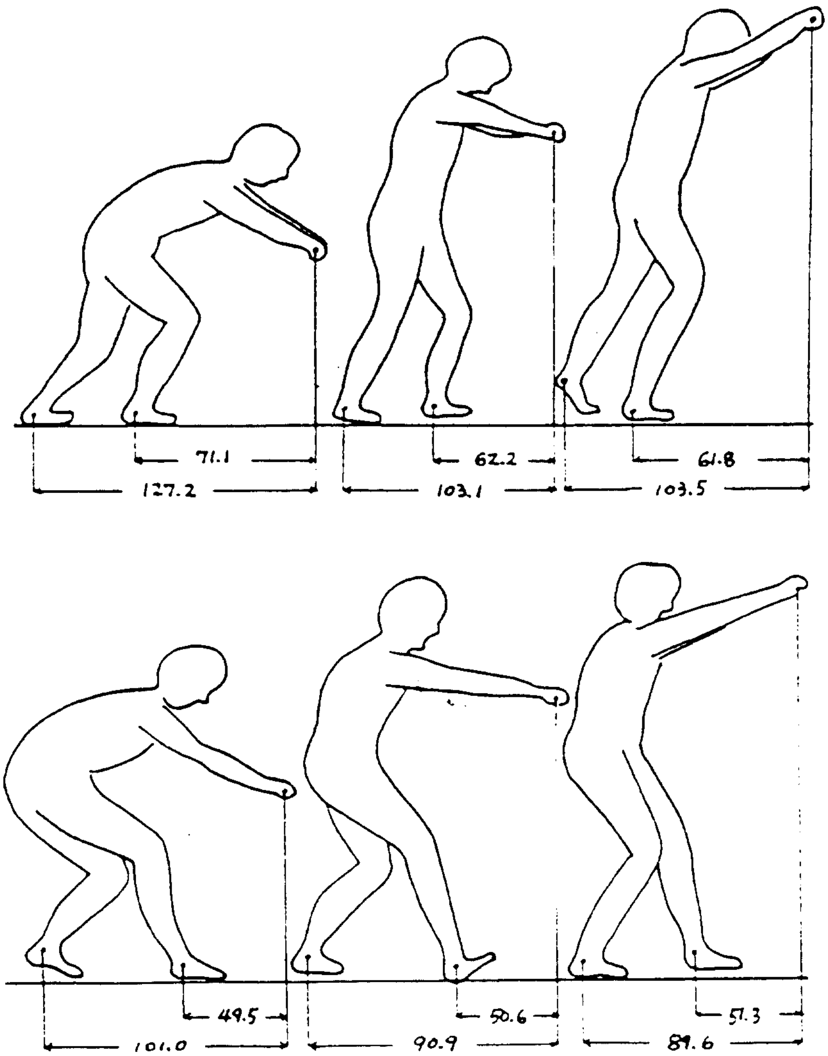


Figure 6. Mean Posture During Pushing and Pulling in a Free Posture

activities was derived by torso flexion, but at high handle heights, the effect of the force at the hand might be even greater. Hence, higher slopes found at the high handle height might imply that contribution of the external force to the EMG activities may be greater than that of torso flexion. This result was in accordance with the study of de Vries[20], in which it was shown with regard to the relation between IEMG and tension of a given muscle that the slope decreased according to the maximum force which can be exerted by the muscle.

Table 4. Least Square Error Regression Analysis of the IEMG and Muscle Force During Isometric Pushing and Pulling in a Free Posture

Subject Code	Handle Height (cm)	Equation	r^2
S1	66	$IEMG = 9.71 + 0.041F_{mus} - 0.015F_{mus}X_{dir}$	.45
	109	$IEMG = 9.71 + 0.600F_{mus} - 0.143F_{mus}X_{dir}$	.55
	152	$IEMG = 13.56 + 1.442F_{mus} - 3.85X_{dir} - 1.186F_{mus}X_{dir}$	.46
S2	66	$IEMG = 15.20 + 0.207F_{mus} - 0.026F_{mus}X_{dir}$	.32
	109	$IEMG = 15.20 + 0.247F_{mus} - 0.112F_{mus}X_{dir}$	.41
	152	$IEMG = 5.48 + 0.036F_{mus} - 9.72X_{dir} - 0.721F_{mus}X_{dir}$	.44

Unit: IEMG (uv); F_{mus} (kp)

X_{dir} = 0 if pushing ; 1 if pulling

Table 4. Least Square Error Regression Analysis of the IEMG and Muscle Force During Isometric Pushing and Pulling in a Free Posture (Cont'd)

Subject Code	Handle Height (cm)	Equation	r^2
S3	66	$IEMG = 16.54 + 0.185F_{mus} - 0.047F_{mus}X_{dir}$	.32
	109	$IEMG = 16.54 + 0.181F_{mus} - 0.061F_{mus}X_{dir}$	.49
	152	$IEMG = 16.54 + 0.241F_{mus} - 0.172F_{mus}X_{dir}$	.53
S4	66	$IEMG = 4.86 + 0.377F_{mus} + 5.87X_{dir} + 0.226F_{mus}X_{dir}$	.62
	109	$IEMG = 4.86 + 0.254F_{mus} + 5.87X_{dir} + 0.157F_{mus}X_{dir}$	.17
	152	$IEMG = 4.86 + 0.454F_{mus} + 5.87X_{dir} + 0.119F_{mus}X_{dir}$	.48

Unit: IEMG (uv); F_{mus} (kp)

X_{dir} = 0 if pushing ; 1 if pulling

During isometric pulling in a free posture, the maximum force was greastest at low handle heights and thus the slope decreased as the handle height decreased. The regression lines for the IEMG amplitude and muscle force during isometric pushing and pulling in a free posture for a typical subject are shown in Figure 7.

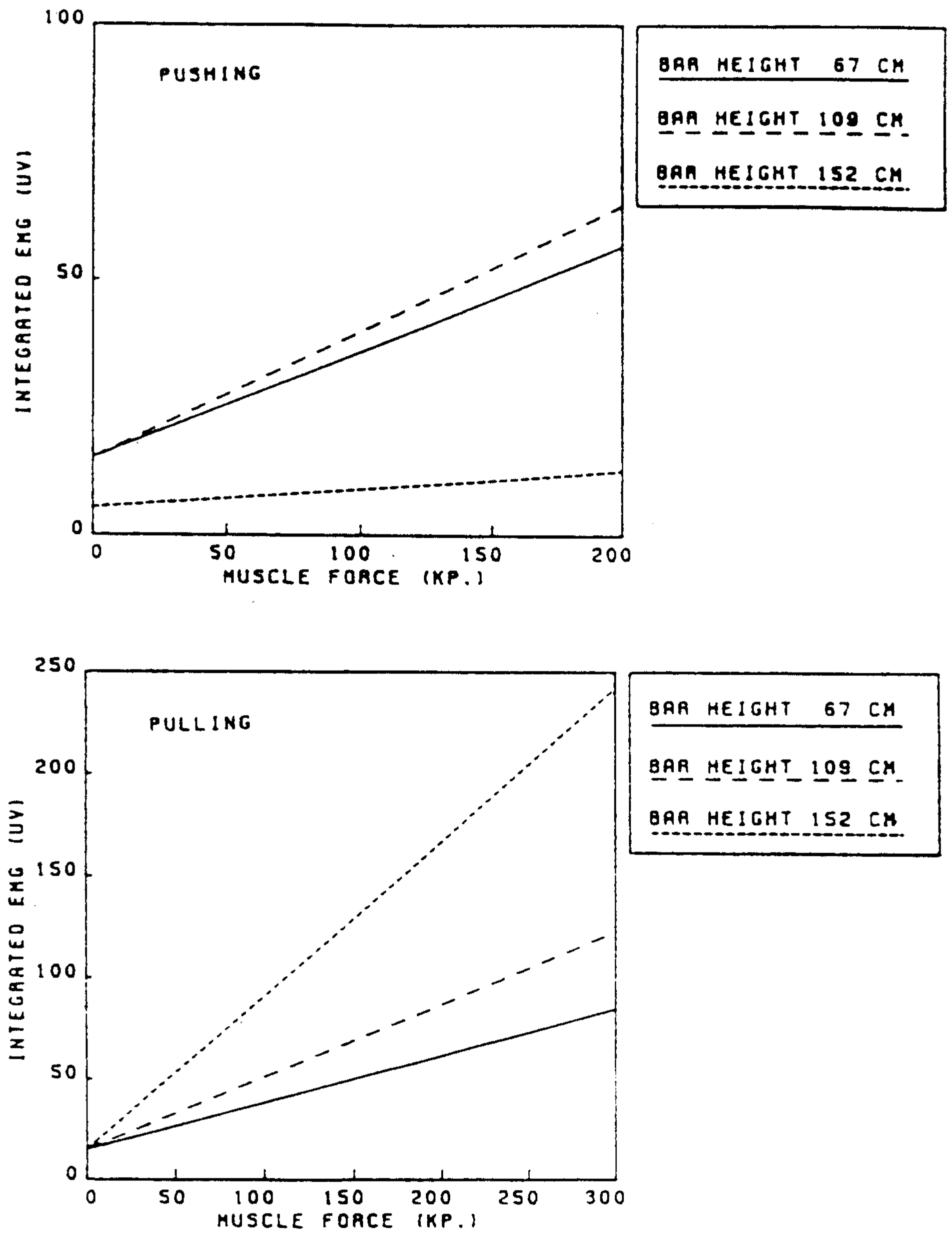


Figure 7. Regression Lines for the IEMG and Torques During Isometric **Pushing and Pulling in a Free Posture**

As shown in Table 5, different muscle groups of each subject were active during isometric pushing at three handle heights. It can be seen that the erector spinae muslces were always active during isometric pulling at three handle heights for all subjcts. Therefore, it was found during isometric pushing in a free posture that the erector spinae muslces also can be active depending on the body posture and the magnitude of the force at hand.

Table 5. Muscles Active During Isometric Hand Pushing in a Free Posture

Height Height	Muscle Active			
	S 1	S 2	S 3	S 4
Low (67 cm)	back	back	back	abdom
Mid (109 cm)	back	back	back	abdom
High (152 cm)	abdom	abdom	abdom	abdom

back = erector spinae muscles
abdom = rectus abdominis muscles

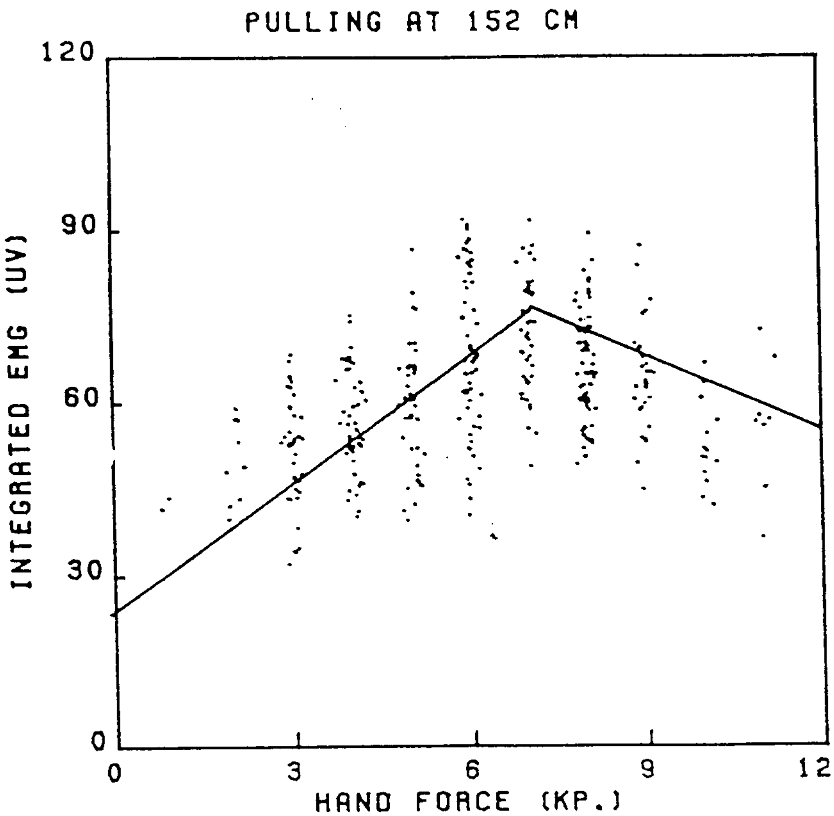


Figure 8. Plot of IEMG Amplitude to Horizontal Hand Force During **Isometric Pulling at the High Handle Height** (152 cm)

An interesting phenomenon was seen during isometric pulling at the high handle height. As shown in Figure 8 the IEMG amplitude increased as the hand force increased and the EMG amplitude began to derease as it reached the maximal exertion. Such a decrease in IEMG level was not seen at the mid and low handle heights. This prehaps due to the role of ligaments at the maximum exertion as observed when the trunk is at full flexion[12, 13].

CONCLUSION

The purpose of this study was to examine the effects of body posture on the pushing and pulling strengths and the L 5/S 1 compressive forces, and to validate the use of the IEMG as an indirect measurement of the tension exerted by a given muscle group during pushing and pulling. To accomplish this, isometric hand pushing and pulling experments in various posture were performed, and the IEMG and hand force data collected during the experiments were analyzed along with other measures computed from the revised biomechanical push/pull model. The findings from this study are as follows :

(1) During isometric pushing and pulling in a standing erect posture, the rectus abdominis and the erector spinae muscles were acting as an antagonistic pair with respect to the L 5/S 1 intervertebral joint. When a person pushed, the EMG activities of the rectus abdominis was responive to the force exerted at hand while the EMG activities of the erector spinae were almost silent(Figure 5). Opposite results were found when a person pulled. During isometric pushing in a free posture, however, the decision of which muscle being active seemed to be dependent upon both the body posture and the magnitude of the force exerted at hand.

(2) The regression analysis revealed that the IEMG and the muscle force of the rectus abdominis (or the erector spinae) during isometric pushing (or pulling) in a standing erect posture were linearly related with coefficients of determination fo .75 to .89.

(3) The relationships between the IEMG and the muscle force during isometric pushing and pulling in a free posture were not well correlated. This may be due to the interacion of the oblique muslces or due to the interactive effects of the hand force and torso flextion. It is proposed that the IEMG results should be carefully interpreted when tasks of pushing and pulling were performel in free postures.

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