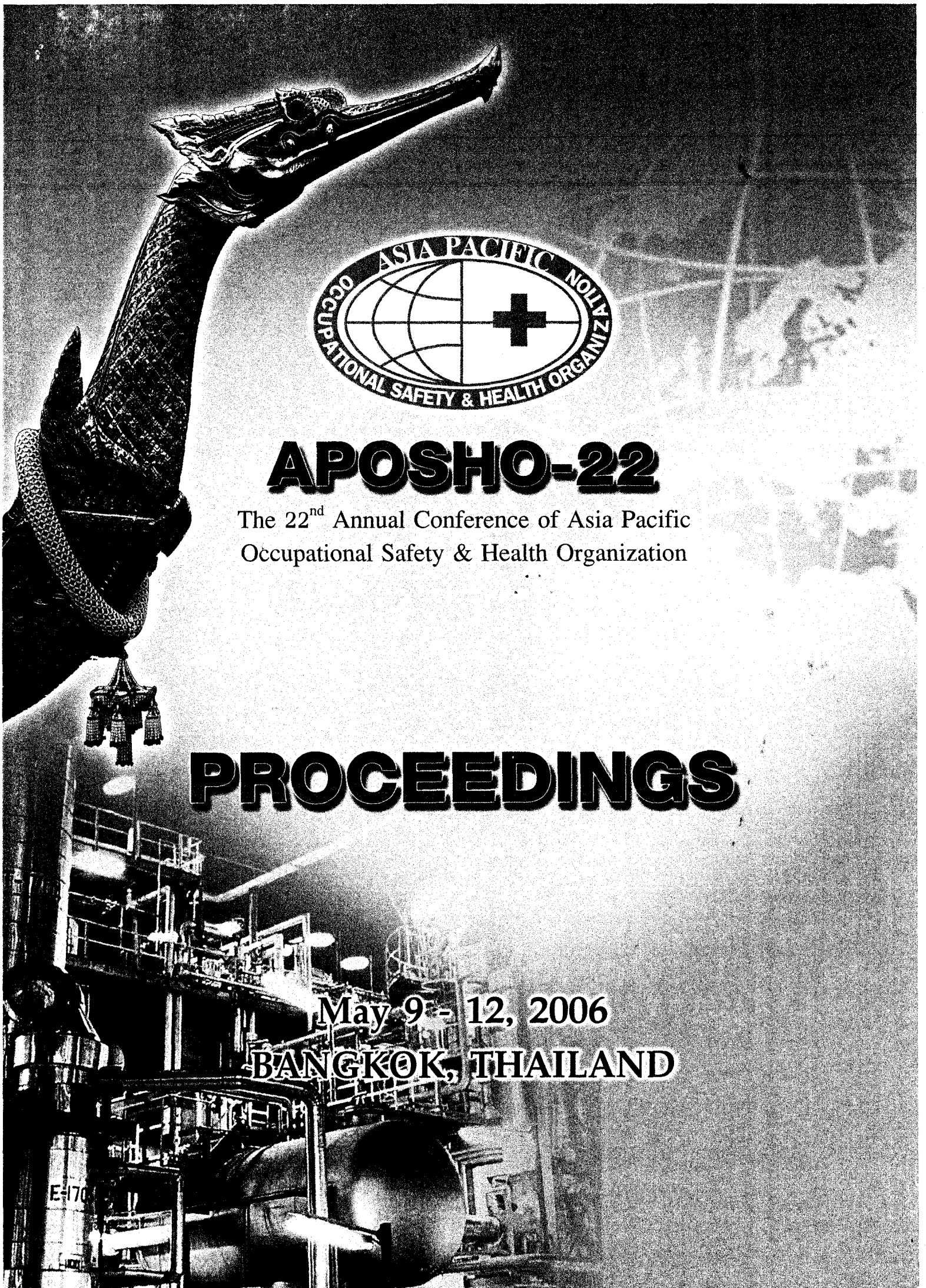

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A Study of Lower Back and Upper Extremity Muscle Activities in Push and Pull Tasks

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The objective of this study was to investigate lower back and upper extremity muscle activities and push and pull strength capabilities. Ten male industrial workers performed two-handed maximum push and pull exertions in 32 positions as combinations of force direction (push and pull), height (knuckle, elbow, shoulder, and head), and horizontal angle (0, 45, 90, and 120 degree deviated from sagittal plane). Muscle activities in erector spinae, middle deltoid, and trapezius during force exertions were recorded using surface electromyography (EMG). Push and pull strengths were measured using the isometric strength measuring system. The results showed that as height increased, the normalized EMG values for erector spinae, middle deltoid, and trapezius increased when pulling, but they decreased with an increase in height when pushing. The maximum strengths were 73.28 Newton (N) for push, and 75.24 N for pull. The knowledge of muscular effort and strength capabilities can provide a quantitative basis for a better design of industrial tasks and workstations.

Keywords: push strength, pull strength, muscle activity, maximal voluntary contraction

1. Introduction

Many industrial jobs require manual activities such as lifting, pushing and pulling. These activities are sometimes performed in unfavorable positions. The knowledge of human strength capabilities can be used to design industrial tasks and workstations. Evidence indicates that manual activities may lead to musculoskeletal disorders and compensation costs [2]. The site of manual handling injury is often recognized to be the back (45%), and the upper limb (35%) [1]. According to Yate and Karwowski [3], there exists a link between local muscular strain during work and these disorders. The electromyogram (EMG) has been used to determine the muscular effort exerted during manual tasks. However, very little EMG data during push and pull tasks are available. The objective of this study was to measure lower back and upper extremity muscle activities and push and pull strength capabilities.

2. Method

2.1. Subjects

Ten male industrial workers participated in this study. These subjects had no history of injuries or musculoskeletal problems. Physical characteristics of the subjects are shown in table 1.

Table 1. Physical characteristics of the subjects.

Physical Characteristics	Average	SD
Age (years)	32.50	11.39
Weight (Kg.)	57.82	10.71
Height (cm.)	164.48	4.48
Arm Reach (cm.)	80.54	3.53
Chest Breadth (cm.)	31.82	3.05
Chest Width (cm.)	20.60	1.86
Biceps Circumferences (cm.)	27.81	3.23

2.2. Working conditions

Each subject exerted isometric strength in 32 different working conditions as combinations of force direction (push and pull), height (head, shoulder, elbow, and knuckle) and horizontal plane (0°, 45°, 90°, 120° deviated from sagittal plane). Sequence of measurement conditions was randomized among the subjects. All measurements were performed in standing posture with extended arms. Each subject was required to use both hands to exert strength.

2.3. The isometric strength measurement procedure

Before the experiment, the subjects had completed training of what body postures the subject should assume for each measurement condition. To measure strength, the subject applied his maximal exertion in the first two seconds without jerking and held it for another three seconds. A rest period of at least 2 minutes was provided between successive trials.

2.4. Measurement of muscle activity

Muscle groups selected in this study were erector spinae, middle deltoid, and trapezius. Muscle activity was recorded using surface electromyography. To elicit maximum muscle activity in the muscle groups, the subject performed the maximum isometric contraction for each of three muscle groups. The muscle activities recorded during the maximum isometric contraction were used to normalize the muscle activities produced during the isometric strength measurements in 32 working conditions.

To determine the muscular effort during isometric force exertions in different working conditions, measurement of muscle activity was performed. During the isometric strength exertion, the EMG signal and strength values were recorded for 5 seconds.

2.5. Data analysis

The EMG samples and strength values during steady state were averaged. The averaged EMG and strength values computed for each force exertion represented the EMG and strength measured. To obtain the normalized EMG values, the averaged EMG values were divided by the EMG values generated during the maximum isometric contraction. Thus, the normalized EMG values were presented as percentage of maximum voluntary contraction (MVC) of each muscle. Analysis of variance (ANOVA) was performed to determine the significant effect of exertion height and horizontal angle.

3. Results

The normalized EMG values during push and pull strength exertions in different working conditions were grouped to generate means and standard deviations. Table 2 and 3 provide the normalized EMG during push and pull exertions, respectively.

Table 2 shows that the normalized EMG in erector spinae, middle deltoid, and trapezius obviously decreased with an increase in height. For push strength exertion, the greatest normalized muscle activity in left erector spinae (41.00%MVC) was recorded at knuckle height and 90° horizontal angle. The highest normalized muscle activity in right erector spinae (33.95%MVC) was found at knuckle height and 45° horizontal angle, whereas that in middle deltoid (49.45%MVC) was found at knuckle height and 120° horizontal angle. The maximum normalized EMG in trapezius of 44.42%MVC was found at elbow height and 120° horizontal angle.

Table 2. Normalized EMG of muscle groups (%MVC) by working condition during push strength exertion.

Height	Horizontal Angle	Mean Normalized EMG of Muscle Groups (%MVC) and Standard Deviation			
		Left Erector Spinae	Right Erector Spinae	Middle Deltoid	Trapezius
Head	0	2.84±2.85	7.42±7.58	22.68±14.68	19.58±11.41
Head	45	2.83±3.17	8.24±8.30	18.96±9.27	21.33±17.21
Head	90	3.16±5.40	12.08±10.99	12.69±9.26	15.43±11.24
Head	120	1.22±1.45	13.35±8.37	9.69±5.64	22.79±13.41
shoulder	0	4.37±4.53	10.28±9.75	25.81±17.95	22.77±14.71
shoulder	45	4.73±4.39	8.17±5.51	27.75±16.95	24.94±17.56
shoulder	90	7.58±9.69	15.24±8.71	25.73±13.76	29.42±10.72
shoulder	120	5.48±4.91	15.82±8.97	22.12±13.22	28.26±12.88
Elbow	0	26.09±15.12	23.79±11.90	29.59±15.10	18.45±11.89
Elbow	45	30.01±13.66	21.80±7.66	32.65±15.23	26.08±11.87
Elbow	90	28.48±13.60	21.40±8.81	42.19±21.23	36.86±19.11
Elbow	120	34.95±13.40	20.85±7.64	44.16±13.88	44.42±16.78
Knuckle	0	29.82±10.10	31.92±11.33	30.53±16.23	22.21±23.67
Knuckle	45	39.96±10.37	33.95±11.24	45.20±15.70	30.45±12.80
Knuckle	90	41.00±11.23	28.76±11.18	48.20±8.50	38.33±11.11
Knuckle	120	38.55±9.30	27.74±12.54	49.45±18.00	36.22±18.41

The data in Table 3 revealed that as height increased, the normalized muscle activity in erector spinae, middle deltoid, and trapezius increased when pulling. For pull strength exertion, the greatest normalized EMG in left erector spinae (55.09%MVC) was recorded at head height and 90° horizontal angle, whereas that in right erector spinae (32.94%MVC) was found at shoulder height and 0° horizontal angle. The highest normalized muscle activity in middle deltoid (53.79%MVC) was found at head height and 0° horizontal angle. The maximum normalized EMG in trapezius of 42.81%MVC was recorded at head height and 120° horizontal angle.

Table 3. Normalized EMG of muscle groups (%MVC) by working condition during pull strength exertion.

Height	Horizontal Angle	Mean Normalized EMG of Muscle Groups (%MVC) and Standard Deviation			
		Left Erector Spinae	Right Erector Spinae	Middle Deltoid	Trapezius
Head	0	42.03±18.03	32.59±18.76	53.79±14.93	30.39±17.19
Head	45	53.30±17.55	25.43±14.53	39.36±14.60	26.59±12.33
Head	90	55.09±12.91	17.24±12.05	39.91±18.60	37.81±16.74
Head	120	54.55±17.20	13.17±7.33	41.11±18.51	42.81±15.42
shoulder	0	43.85±15.88	32.94±18.47	30.79±13.09	16.71±8.97
shoulder	45	48.01±14.48	20.58±9.69	24.17±12.35	15.59±9.68
shoulder	90	43.72±21.25	13.81±4.50	26.52±13.87	25.32±16.42
shoulder	120	50.14±22.72	15.82±10.86	31.27±18.13	33.27±17.76
Elbow	0	46.43±18.38	26.28±12.88	7.24±6.03	8.35±5.99
Elbow	45	29.14±12.10	15.03±6.48	5.73±7.34	6.92±4.95
Elbow	90	37.45±13.44	19.80±13.88	7.25±7.05	17.07±11.93
Elbow	120	35.43±10.76	15.07±7.20	15.39±13.76	28.37±13.17
Knuckle	0	17.17±9.95	16.78±8.33	8.00±5.72	10.87±7.73
Knuckle	45	19.10±7.86	23.95±8.22	5.61±4.45	8.78±6.95
Knuckle	90	21.40±6.49	26.65±9.19	4.78±3.34	11.13±7.68
Knuckle	120	20.08±14.18	22.62±12.19	9.87±13.85	15.84±9.89

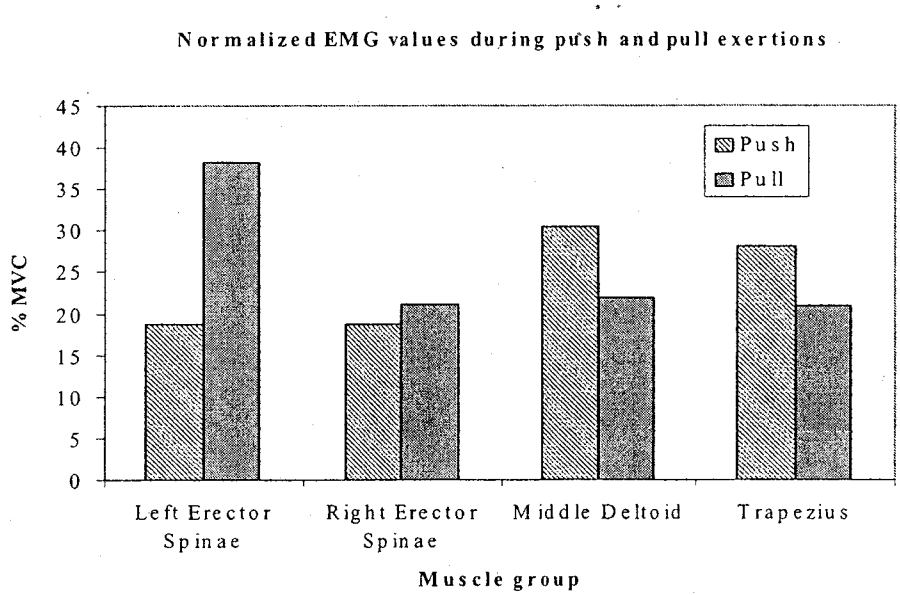

Figure 1. The normalized EMG values for four muscle groups during push and pull strength exertions.

Figure 1 shows a graphical picture of the mean normalized EMG values during push and pull strength exertions. On average, the normalized muscle activities in left and right erector spinae during pull strength exertion were greater than those during push strength exertion. However, the normalized EMG values for middle deltoid and trapezius during push strength exertion were higher than those during pull strength exertion. The analysis of variance conducted for the normalized EMG values in four muscle groups during push and pull

exertions is presented in Table 4 and 5, respectively. Height, horizontal angle, and two-way interaction significantly affected the normalized EMG values of some muscle groups.

Table 4. P-values in the analysis of variance for the normalized EMG values during push exertion.

Source of Variation	Degree Of Freedom	P Values			
		Left Erector Spinae	Right Erector Spinae	Middle Deltoid	Trapezius
Height	3	0.000**	0.000**	0.000**	0.000**
Horizontal Angle	3	0.051	0.784	0.120	0.000**
Subject	9	0.000**	0.000**	0.000**	0.000**
Height*Horizontal Angle	9	0.204	0.077	0.000**	0.010**
Error	135				
Total	159				

Note: * = significant at alpha = 0.05, ** = significant at alpha = 0.01

Table 5. P-values in the analysis of variance for the normalized EMG values during pull exertion.

Source of Variation	Degree Of Freedom	P Values			
		Left Erector Spinae	Right Erector Spinae	Middle Deltoid	Trapezius
Height	3	0.000**	0.457	0.000**	0.000**
Horizontal Angle	3	0.025*	0.000**	0.015*	0.000**
Subject	9	0.000**	0.000**	0.000**	0.000**
Height*Horizontal Angle	9	0.784	0.001**	0.285	0.218
Error	135				
Total	159				

Note: * = significant at alpha = 0.05, ** = significant at alpha = 0.01

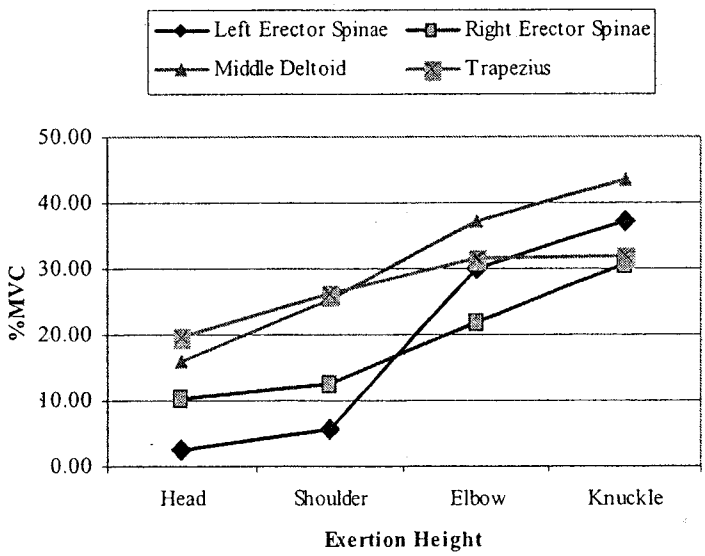

Figure 2. Mean normalized EMG values for four muscle groups when pushing at different exertion height.

Figure 2 reveals that for push exertion, the normalized EMG values increased with a decrease in exertion height in most cases. However, the normalized trapezius EMG value did not increase when altering exertion height from elbow to knuckle. As shown, left erector spinae gave the greatest increase in muscle activity as exertion height changed from head to knuckle. Figure 3 shows a slight change in muscle activity in four muscles as the horizontal angle changed. Right erector spinae and middle deltoid almost remained the same activity levels as the horizontal angle increased. It is obvious that the effect of exertion height on muscle activities in four muscles was greater than that of horizontal angle.

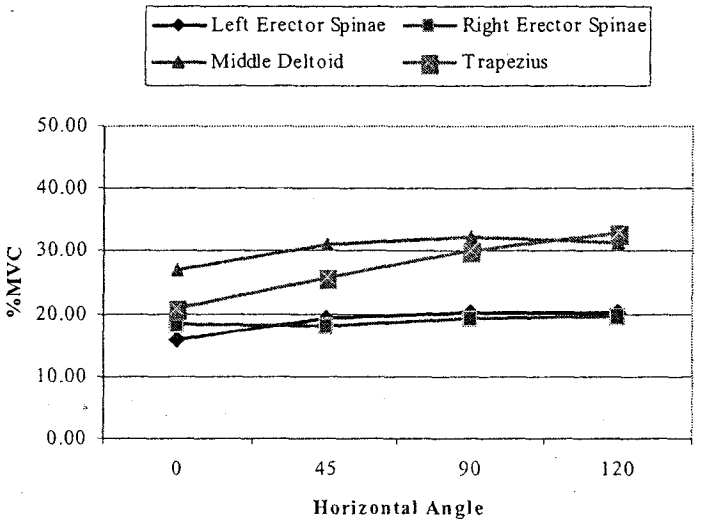

Figure 3. Mean normalized EMG values for four muscle groups when pushing at different horizontal angles.

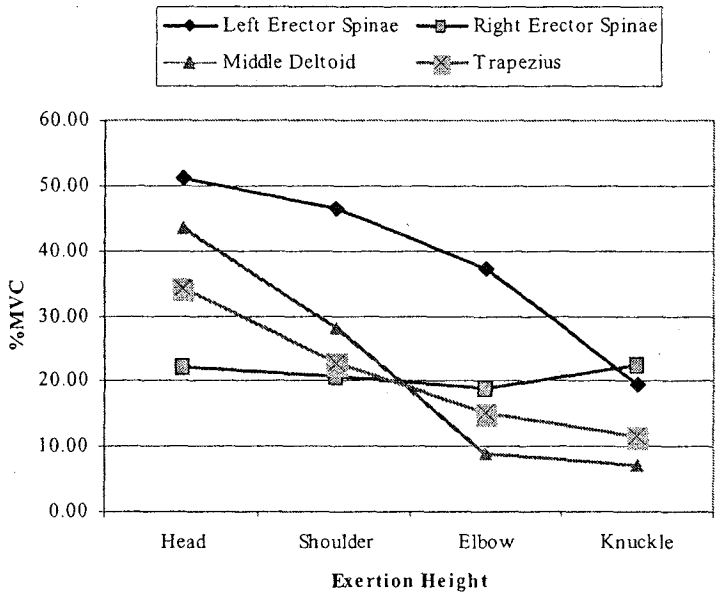

Figure 4. Mean normalized EMG values for four muscle groups when pulling at different exertion heights.

The effect of exertion height and horizontal angle on muscle activities for pull exertion is presented in Figure 4 and 5. The normalized EMG values for left erector spinae, middle deltoid, and trapezius decreased with decreasing in exertion height. For right erector spinae, the normalized EMG value slightly decreased when exertion height decreased from head to elbow, but it slightly increased when exertion height decreased from elbow to knuckle.

Although the effect of horizontal angle on the normalized EMG values for four muscle groups during pull exertion was significant (Table 5), it tended to influence the normalized EMG values for different muscle groups in the different manners (Figure 5). As the horizontal angle changed from 45° to 90° and 120°, the normalized EMG values increased in most cases. Nevertheless, the normalized EMG for right erector spinae slightly decreased as the horizontal angle increased from 90° to 120°.

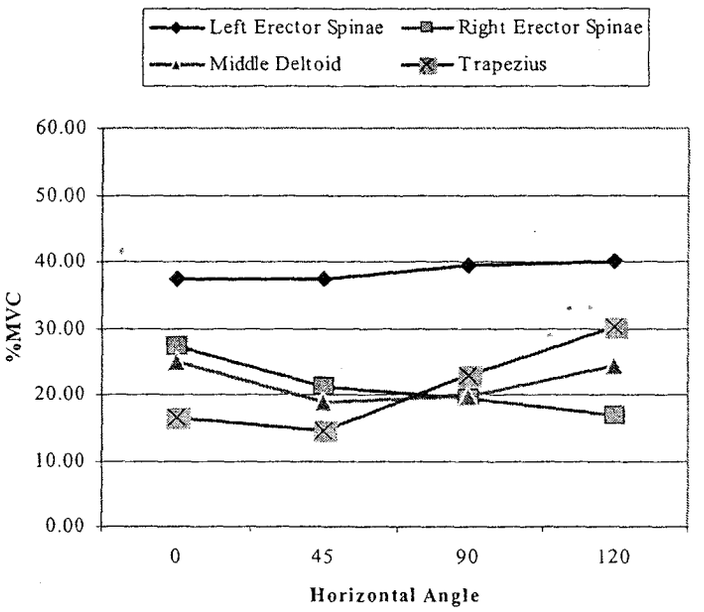

Figure 5. Mean normalized EMG values for four muscle groups when pulling at different horizontal angles.

The push and pull strengths are shown in Table 6. The greatest push strength was 73.28 Newton (N), which was found at elbow height and 90° horizontal angle. The maximum pull strength was 75.24 N, which was recorded at knuckle height and 0° horizontal angle. The lowest push strength was 13.20 N, which was found at head height and 120° horizontal angle. The minimum pull strengths was 36.30 N, which was recorded at elbow height and 120° horizontal angle. The analysis of variance performed for the push and pull strength values is presented in Table 7. Height and horizontal angle significantly affected the strength values.

4. Conclusions

The results of this study suggest that effect of exertion height and horizontal angle must be accounted for in the design of industrial tasks and workstations. Depending on type of force exertion, height and horizontal angle, the muscular effort for lower and upper back and shoulder muscles, as well as strength exertions, can vary greatly.

When pushing, more muscle activity occurs in the upper back and shoulder muscles than in the lower back. Conversely, when pulling, more muscular effort is employed in the lower

back muscle than in the upper back and shoulder. Pushing at knuckle and elbow height would be more stressful than pushing at shoulder and head height. Pulling task at shoulder height and above should be avoided to prevent lower back injury.

Table 6. Push and pull strengths by working conditions.

Height	Horizontal Angle	Isometric Strength (in Newton)	
		Push Strength	Pull Strength
Head	0	28.15±13.19	38.16±19.25
Head	45	31.39±14.36	55.03±26.02
Head	90	41.10±20.90	47.68±19.76
Head	120	13.20±7.54	39.83±27.71
Shoulder	0	24.33±12.50	40.02±19.13
Shoulder	45	48.36±16.31	46.89±20.26
Shoulder	90	53.37±11.86	43.56±34.94
Shoulder	120	41.10±21.20	37.28±23.95
Elbow	0	43.85±10.92	37.38±17.05
Elbow	45	70.63±18.04	47.28±16.28
Elbow	90	73.28±20.74	41.20±12.15
Elbow	120	72.99±20.94	36.30±11.95
Knuckle	0	67.30±34.05	75.24±28.30
Knuckle	45	69.45±35.33	72.79±27.27
Knuckle	90	68.18±26.08	66.12±27.50
Knuckle	120	63.96±34.15	62.78±22.27

Table 7. P-values in the analysis of variance for push and pull strengths.

Sources of Variation	Degree of Freedom	P Values	
		Push Strength	Pull Strength
Height	3	**0.002	**0.000
Horizontal angle	3	**0.007	*0.035
Subject	9	0.171	**0.000
Height*Horizontal angle	9	0.762	0.889
Error	135		
Total	159		

5. Acknowledgement

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6. References

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